INTERACTION MECHANISMS IN A COLLABORATIVE LARGE SCALE VIRTUAL ENVIRONMENT FOR PUBLIC CONSULTATION

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Abstract

This thesis extends research in Collaborative Virtual Environments (CVEs) by exploring their use in a purposeful interactive public application. Though often discussed, few such studies have been undertaken, since the widespread availability of 3D platforms is a recent phenomenon. The application selected is that of urban planning and review. The experiments use a virtual cityscape in which planning changes are presented to the public at large. Respondents inhabit the shared environment and can modify and comment upon proposed designs.

The significance of the work is the application of CVE technology to a task involving public interaction and feedback on a large scale. The thesis is that the ready accessibility of the 3D presentation, together with the communication stimulus of the environment, will facilitate useful engagement by the public in the planning processes. The research involves investigating the mechanisms of interaction and design commentary within this process.

This requires the building of a virtual environment, which involves technological challenges. First, we analyse the virtual environment itself and the way information can be organised into it. Then, we deal with management of the different possible interactions. Finally we implement a solution to visualise the environment using 3D graphics techniques.

Evaluation focuses first on performance of the system. Experiments are then undertaken on general public, first by providing an usability evaluation, and then by launching a simulation of a urban planning project, the results of which are analysed with supervision of professionals from the urban planning field. Next, a survey on general public in order to evaluate their feedback on the use of CVE technology in the urban planning consultation process.

Declaration

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institution of learning.

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Chapter 1

Introduction

The idea of Virtual Environments has been around for a long time. A significant part of the proposed novelty that VEs offer is the "natural" 3D interface which will be easier for untrained users to work with; the ability to share an environment with other users, and to experience and exchange information with them directly; and of course a natural vehicle for tasks that work with inherently three dimensional data. Evidence for the improved communication availed by VEs includes major commercial successes of large-screen projection-based VEs for communicating ideas in design review, and in sales and marketing. Firms such as Shell and BMW are using this kind of technology.

However, comparatively few applications have been built that involve large numbers of people in a concrete task amenable to external evaluation, and so it is hard to gauge how effective VEs really are for these purposes. Examples of work that goes some way to this goal are Diamond Park[WAB+97], ITW (Inhabiting The Web)[TS97], Inhabited TV[BGB+98], alphaworlds[Act], military simulations, and the work in multi-media art such as that of Knowbotic [Kno], and distributed computer games. However, there are no examples where VEs have been used as a natural forum for public concerns.

The fact that so few examples exist is largely due to the immaturity of the software technology, together with the cost of 3D hardware capable of working with non-trivial environments. In the last years however, such hardware has gone from costing tens of thousands of pounds, to less than two hundred. Serious applications that exploit the widespread availability of such capabilities have yet to mature.

The aim of this PhD thesis is to explore new forms of public interaction made possible by this increasing ubiquity of 3D interface technology.

The case we select as our exemplar study is that of public engagement with the process of government. Such public engagement in the processes of government is commonly reported as a key factor lacking in our socio-economic milieu. According to the hypothesis, Collaborative VEs offer the possibility of achieving such engagement more readily. As a computer science thesis, our focus is largely upon the technological issues in creating such a platform.

In this chapter, we first introduce to Virtual Reality, Virtual Environments and Collaborative Virtual Environments. Then, we define the key terms used in this thesis, talk about the urban planning public consultation process and traditional computer science use in urban planning. Finally, we give an overview of the thesis.

1.1 Virtual Reality

In this section, we discuss Virtual Reality (VR), giving a definition and reviewing its main applications.

1.1.1 A definition of VR

The term "Virtual Reality" was possibly first used by Jaron Lanier, one of the pioneers of the field, in 1989[KHS89]. As being used in different contexts, it is not easy to give a precise definition of VR. Aukstakalnis and Blatner gave a general definition of VR[AB92]:

"Virtual Reality is a way for humans to visualise, manipulate and interact with computers and extremely complex data."

VR is about the use of computer science technology to simulate an environment, with which people can interact. This field has grown in the last decades from the need of simplifying interactions between human beings and computer systems. There is also the idea of using VR to simulate a real (or potentially real) environment. VR research has developed into three directions:

1. First, there is a need to increase the visualisation realism of the simulation. The idea comes from the improved feeling of realism with the addition of a third

dimension to computer graphics. Therefore, research has emerged with the development of three-dimensional (3D) computer graphics, and followed 3D hardware and software development.

2. Second, there is a need to increase the feeling of immersion inside the simulation. For that, there has been research about new ways of interactions with the environment, with the use of advanced interaction devices. As examples of those, we can name devices which increase the visual input of the environment, as Head-Mounted Displays or 3D goggles. There are also devices which simulate the sense of touch, which are called haptic devices.

3. Finally, there is a need to increase the "behavioural" realism of the environment. Indeed, despite the visual realism and feeling of immersion, if the environment does not behave properly, the feeling of illusion can fall apart. Therefore, there has been research on the activity inside a VR simulation, so that it can behave properly.

1.1.2 Applications of VR

In the early decades, as the cost of hardware was extremely high, the first applications of VR have been limited to industry or research purpose. Then, in the last years, with the mass availability of 3D graphics hardware, applications for the general public have started to develop.

We have here a look at the main application domains of VR:

- Virtual prototyping: this application allows manufacturers to design and test a virtual prototype model without having to build a real one. The benefits of this approach are a reduction of costs, and the possibility to perform a high number of tests, which would take a large amount of time with a real model.

- Teleconference and teleoperation: This field requires the use of a high bandwidth on the network to transmit data. Unlike video streams, VR models can be used to reduce the volume of exchanged data. Hence, there has been work on the design of interaction metaphors.

- Data visualisation: VR can be used to visualise large or complex data sets allowing a better understanding and manipulation of the data. Examples of use of this domain include medical and scientific applications, such as weather simulation or chemistry.

- Vehicular simulation: VR is used a lot to simulate the handling of a specific vehicle, mostly for training purposes. For example, it can be a flight simulator designed for military or civilian pilots, or a space simulator to train astronauts.

- Entertaining: This public-oriented application domain has developed significantly in the last years. It includes video games, such as arcade games (this can be sometimes a simpler version of a vehicular simulation) or 3D computer and console games. It also includes virtual tours to reproduce environments such as museums.

- Urban planning and architecture: With the recent increase of 3D hardware efficiency it has become possible to visualise large scale environments, such as cities. Therefore, VR can be considered as a new tool for urban planners and architects. This is the application area we are interested in the thesis. We review in details research in this field in the next chapter.

1.2 Virtual Environments

Having introduced VR, we now focus on VEs. We also introduce to Collaborative Virtual Environments in this section.

1.2.1 An Introduction to VE

A VE is the environment within which a VR simulation is undertaken. VE research is only a part of VR research, as it focuses more on the software rather than hardware. That means it does not deal with the use of devices to enhance the feeling of immersion of people. Therefore, VE research is about visualisation of 3D environments and interaction which can be performed using standard devices, such as a mouse or a keyboard.

1.2.2 Collaborative Virtual Environments

The development of the Internet and computer network technology has inspired the idea of collaborative work using computer science, which is Computer Supported Collaborative Work (CSCW). Therefore, systems have been developed to support this idea in the last ten years, using available computer science technologies. Among them is the VE technology, which has been combined with CSCW to create the CVEs. Here are the main issues of Networked VEs for Cooperative work [BBF+95]: communication, spatial structure and embodiment. Some examples of CVE architectures are DIVE[CH93], AVIARI[WHH+93], MASSIVE[GB95], NPSNET[MZP+95], SPLINE[BWA96] and DEVA[PCMW00].

First, most of research on CVE has been about the technical challenges, such as networking performance and number of supported users. There was simply the idea of making a CVE work[GBF+01]. Then, application-oriented research could be engaged. We review in the next chapter general public applications of large scale CVE, as we study in the thesis the benefits a CVE can bring to large scale public consultation, and so target the general public as potential users.

1.3 Definition of Terms:

Having introduced VR and VEs, we now define some terms which are used in the thesis with particular meaning.

Architecture: In our context, architecture is about the design of the different parts of the city, as buildings, roads, crossroads or monuments. There are interesting books which provide an introduction to architecture[HC95][Tho99].

Urban planning: Urban planning deals with analysis and design of city data to plan its future development and evolution[CS79]. This gathers together different disciplines such as social sciences and architecture[PC97].

Urban design: according to Barnett[Bar82], urban design is the "process of giving physical design direction to urban growth, conservation and change". It makes the link between architecture and urban planning. It deals with a physical arrangement of the buildings, streets and other landmarks.

GIS: A Geographic Information System is a set of software tools used to manage geographical information, such as input, storage, analysis and display[Hux91][ABCK91].

CAD: Computer-Aided Design deals with the design of objects using a computer, in 2D or in 3D. It is the result of the evolution of traditional drafting with the use of the power brought by computers[Beh88].

VRML: The Virtual Reality Modelling Language is a 3D scene description language, used for "describing multi-participant interactive simulations – virtual worlds networked via the global Internet and hyper-linked with the World Wide Web"[VRM]. It has become the standard language for interactive simulation within the World Wide Web (WWW).

1.4 The Urban Planning Consultation Process

In this section, we introduce the urban planning consultation process. First, we talk about the idea of public consultation in urban planning, and then discuss about the current ways of consulting people.

1.4.1 The Idea of Public Consultation in Urban Planning

Public consultation has become an important task for promotion of urban planning projects, being instigated by different institutions. The idea of citizen participation has grown in the United States with the advocacy planning movement during the 1960's[Kur00]. It has then expanded during the last decades, being reshaped and redefined by politicians, planning professionals, developers, activists, and citizens.

The planning theorist, L.W. Milbrath, defined in 1965 the different behaviours that the public has in their concern and involvement in planning issues[Mil65]:

1. First, most of the citizens do not really care about planning decisions.
2. Second, there are people in the spectator level who can respond to a survey, vote, or take time to be at least a little informed of proposals.
3. Third, there are those in the transitional level who would attend public hearings or contact public officials.

4. Finally, there are people who are at the highest level of participation, who become part of decision-making bodies or are involved in community groups as tenant associations or political parties.

S. Arnstein, another theorist, developed a theory in 1969 called the "ladder of citizen participation"[Arn69]. She categorised how institutions use citizen participation methods based on motive and effectiveness. Figure 1.1 shows this ladder.

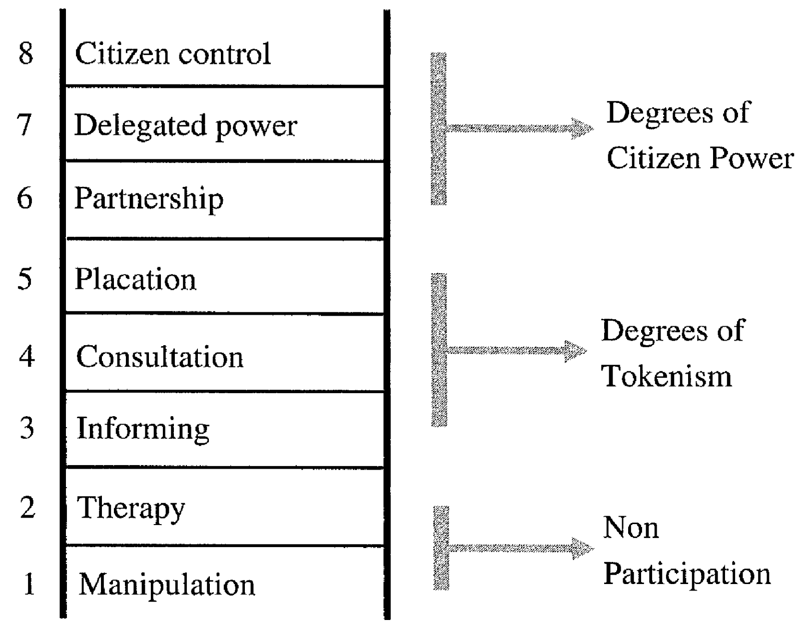


Figure 1.1: The ladder of citizen participation

- The bottom levels, which include manipulation and therapy, are the least effective. It is assumed here that an action has public support simply by the lack of opposition. So, there is no real effort to inform the public.
- The next levels involve forms of tokenism, as informing, consultation and placation. There are there some efforts to educate public of future actions. However the underlying power remains with the professional to make the decisions.
- Finally there are the levels which include partnership, delegated power, and citizen control. They are the most effective levels of participation, as there is exchange of power through negotiation and consensus building.

Now that we studied the idea of public participation, we have a look on how the actual consultation process is handled in the next section.

1.4.2 The Actual Consultation Process and its Limitations

We explore in this section the different ways public consultation is undertaken. We classify them by the medium which is used to show information to the public.

- First, information can be shown simply on static 2D medium, as paper or posters. People can see artistic pictures of the proposal area, or maps of the city, next to a text description.
- Then, information can be shown on a video. The video shows how the project area may look, using non real-time 3D rendering. A voice usually describes the view.
- Finally, a physical small scale model of the proposal area can be built to be shown to public. There is usually some text information next to the model to describe it.

A public consultation is usually presented as a hearing. The information is exposed in public buildings, such as city hall, and people can visit the exposition and leave feedback. The way they leave feedback is simple, as they just write their comments on a notebook. Sometimes they can engage in dialogue with planners or architects.

There are now a few projects which are delivered over the Internet[Kin02], such as the latest project for the district of "Les Halles" in Paris[Hal], where people can watch videos of four different proposals and vote for the one they prefer. But the process remains basically the same. The only main difference is that comments are transmitted over the Internet, instead of written on a notebook. However the availability of the proposals on the Internet is a factor of increasing public involvement.

These ways of consultations have some limitations in common:

- First, there is a lack of interactivity. All consultation techniques (static 2D medium, video or physical model) are passive. There is no way for users to navigate freely inside the environment, to pick his own perspective (this is obvious for static 2D medium and video information, and the physical model gives only a global overview of the project area), and there is no way to modify the environment.

- Then, there is a lack of feeling of immersion. Indeed, with a physical small scale model because of its scaling limitations, and without the ability to navigate freely inside the model with static 2D medium or video information, it is really difficult to feel immersed inside the environment, because of the lack of a feeling of "freedom".
- The comments are limited. As they are written on a notebook, they lack precision. It is indeed difficult to write a comment on a specific object or view without a clear reference. Finally, they are restricted to general comments. This is a direct consequence of the lack of interactivity; indeed, as it is impossible to get a specific local point of view, it is obviously impossible to comment from it.

These limitations lead to non exploitable results for planners and can explain the lack of interest to urban planning from people[APR00, Lau01, EA02]. The thesis investigates an alternate way to consult people, by using a VE to model the proposal area, in order to enhance the results of consultation, and so drawing public interest and really engage them in the planning process.

1.5 Traditional Computer Science Use in Urban Planning

In this section, we review the main computer science technologies traditionally used in urban planning, which are GIS and CAD. We consider them as traditional, as opposed to VE technology that we review in the next chapter. We then show the first example of a general public application, which is the computer game Sim City[Sim].

1.5.1 Involved Technologies

The first computer science technology which has been used for urban planning is a database. In the 1960's, Roger Tomlinson led the development of Canada Geographic Information System (CGIS)[Tom67], which is considered the first GIS software. The idea was then developed by research groups and institutions, with the development of numerous software. In the 1990's, with the growth of the World Wide Web, GIS became accessible through the Internet[Rin98], leading to the idea of decision support for urban planning[BD96]. GIS has been designed in 2D. However, with the development of 3D computer graphics, there have been extensions of GIS to 3D, with the use of VEs to represent data.

The other computer technology involved in urban planning is CAD. With the development of computer science, it has become possible to use computers for architectural design, using CAD software. First, CAD was in 2D, and was started to be used in architecture in the 1970's. With the emergence of 3D computer graphics, CAD became available in 3D. In the 1980's, software was developed to help architects to design 3D models, reaching mature status in the 1990's[Don02]. Therefore, it became possible to design 3D models of architectural models, such as buildings, bridges or monuments, which could then be used for physical simulations of the material (for example, study the impact of wind on a bridge), or to generate views of the future architectural item, such as images or non real-time multimedia presentations, which can be used for public consultation. We can now consider that most of the architects are familiar with this technology, although some of them are still reluctant to fully embrace design software. 3D CAD was not designed to be used for real-time rendering, because of hardware limitations. But with the development of 3D hardware computer graphics, CAD models can now be visualised in real-time. Therefore, there have been some examples of CAD models incorporated into VEs.

In summary, we can see that these two traditional computer science applications of urban planning have started to use VE technology, driving forward this field to this technology. We review in the next chapter research and application in this area.

1.5.2 A General Public Application: Sim City

The first example of an application allowing the general public to have a first approach to urban planning on computer is the video game Sim City[Sim]. Published in 1990, it allowed players to create and manage a city. Although there have been other large scale environment simulation games, such as economic or transport system simulations, Sim City remains the only example of city simulation game, and has been the public's first contact with computer-based urban planning. Obviously, the simulation has been extremely simplified and would not be applicable to real cities, but this is an interesting approach for gauging public interest in urban planning. Indeed, as the game was a major commercial success, we can be reasonably confident that people would be interested in participating to the urban planning process, using even more elaborate software.

There have been multiple sequels of Sim City or derived games which have been released, but we can see that there are no examples of one using a 3D real-time representation of the city. Rendering is restricted to 2D or isometric view, and so no free navigation is allowed on the model. This could be due to the immaturity of the 3D graphics software technology as discussed previously in this chapter, or to hardware limitations. The benefits of a 3D model can be argued as well, as extra navigation is not necessarily required to play this kind of games. But usability issues can be raised too. Indeed, there is the idea of the difficulty of interacting inside a large scale 3D city environment for people who are not necessary fully trained with 3D computer graphics, and computer games have to be user-friendly. These issues are raised by the thesis.

1.6 Thesis Overview

The thesis is divided into 11 chapters:

- Chapter 2 focuses on the related work in computer graphics. First, we review the different technologies related to 3D city rendering. Then, we study the use of a large scale CVE for the general public. And finally, we review applications of VEs to urban planning.
- Chapter 3 develops the idea of using VE technology, emphasising the motivation to apply the technology to this field.
- Chapter 4 focuses, in a general way, on a theoretical description of a VE for public consultation. This environment is composed of both a model and information about the model.
- In Chapter 5, we study the different interactions which can be executed inside this environment.
- From the theoretical description, Chapter 6 describes the design, following UML specifications, of a city environment for use in the urban planning field.

- In Chapter 7, we discuss the implementation of a cityscape prototype environment for experimental use, following the design described in Chapter 6. We focus on the visualisation of the environment. Results of a performance experiment are presented in this chapter.

- In Chapter 8, we describe the human computer interface, and how we implemented the different means of interacting with the environment.

- Chapter 9 discuss the usability study done on the completed prototype environment.

- In Chapter 10, we present the application-oriented experiment, which are the urban planning simulation and the survey on the general public.

- Finally, in Chapter 11 we conclude the thesis.

Chapter 2

Related Work

Having introduced to the different technologies related to the subject, we now review related work in 3D computer graphics.

We first focus on the different technologies involved in VEs, concerning the representation of city environments. We then review applications CVEs for general public use. Finally, we discuss the use of VEs in urban planning.

2.1 VE Technologies Involved with City Environments

Most public planning reviews concentrate upon small areas of a city, for example a park area, or redevelopment of a shopping centre, or Airport. Some situations require larger areas to be modelled, for example a motorway, rail route, or redevelopment of a waterfront area. Therefore, in reviewing technology literature, we can give emphasis to the more general issue of large-scale structures, typified by work on entire cityscapes.

2.1.1 CityScapes

Several VE research groups have studied the design of cityscapes, for a variety of purposes. Cityscape metaphors have been used to visualise abstract information, such as hierarchical graphs[KV97], and commonly appear in early VR literature as metaphors for navigating a variety of information.

Locally, at the University of Manchester, the Advanced Interfaces Group has developed one Cityscape, as part of the citizen-oriented Escape Project[PGW98]. That project focuses upon the cityscape as a metaphor for embedding other citizen oriented information spaces – a kind of 3D, shared, version of the world wide web. Escape is characterised by the terms "electronic landscape" and "the place where places meet". It does not concern itself directly with what happens within those shared landscapes. However, the graphics technology employed in the rendering of large scale cityscapes is impressive, and useful input to the thesis. Other rendering work related to computer games also pushes the important frontiers of rendering technology for large scale cityscapes, as shown in Section 2.1.4. Other projects include the City of London tourist application by Nottingham and SICS[SF99]. We review this project in Section 2.2.1.

UEA Norwich is also working in the area of building and rendering urban environments, in the areas of high-level parametric specification of buildings. For example, generating a building from the number of windows, door positions and roofing style[BJDA01]. A second line of UEA work is in level of detail optimisation in the rendering of urban landscapes, first by avoiding the "popping" effect through the gentle migration of external facets (such as windows) behind external faces as distance increases, and then by a component based approach to occlusion culling, for example rendering only a roof if that is the only part of the building that is visible[BWW$^+$01]. There are other works about occlusion culling on cityscape environments, as from Vienna University of Technology[WS99], M.I.T. and INRIA[DDTP00], and Tel-Aviv University[COFHZ98].

Some other projects deal with informative cityscape models, in order to populate them with autonomous virtual actors, such as humans and cars[TD00, FBT99]. Virtual agents can be useful to increase the realism of cityscape environments, as it gives to people a better idea of the scale of the environment. Populating a cityscape environment with virtual agents can be useful for urban planning, as it allows performing simulations, for example on crowd or traffic behaviour, in order to test a planning proposal.

2.1.2 Cityscapes in VRML

Many city models have been constructed using the VRML modelling language, and can readily be found on the Web[VCi]. Some of them are very accurate, as the city of Tokyo model made by Planet 9 studios[Pla], one of the leading VRML city design companies.

Though often constructed to a high degree of accuracy, these models are quite limited. First, sometimes they cover small parts of the city – this is a limitation of what can be viewed using a VRML-equipped browser at acceptable frame rates. Next, interaction is extremely limited, usually just passive navigation for a single user. The achievement of these models is the model itself, not what can be done with it. Finally, current VRML specifications are limited when dealing with large scale cityscapes[Bou97].

2.1.3 Image-based Rendering

A new branch of computer graphics research, that of image-based rendering, offers a possible solution to the rendering of large-scale structures such as cityscapes, in situations where the geometric complexity in a scene is too great to achieve interactive frame rates by conventional (polygonally based) means. In combination with existing approaches, the technology is likely to allow substantially more complex models to be accommodated with interactive performance.

Important work in this area applied to city environments includes that of the University of California at Berkeley[DTM96], M.I.T.[Coo98] and University of Oxford[LCZ99]. Computer games rely almost exclusively upon the basic (static) image-based technique of texture maps – essentially the use of photographs within the scene to give the illusion of geometric detail. We can get away with this if the components represented by a picture appear on a plane – such as the bricks of a wall – hence the common appearance of many computer games. Other research focuses upon a more dynamic approach, warping the picture to give the illusion of correct perspective shifts when the features of the image should lie at different distances from the viewer[PAC97]. They are hence more genuinely helpful in attaining visual realism. This technique, called bump-mapping is now integrated in the hardware of the Graphic Processing Units (GPUs)[Kil00] of 3D rendering graphic cards.

2.1.4 A Mature Application: City Models in Computer Games

Computer games have always been one main application of VE research, as one of their aims is to represent realistic enough environments to maximise players' immersion. With the development of 3D computer graphics, most of the games are now in 3D. In this section, we review the use of the different VE technology related to city environments we described in the last sections in computer games. We focus on games using large scale city environments, where it is possible to navigate freely. We do not talk here about massively multi-player games over the Internet, as they are reviewed in Section2.2.3.

First, we can consider racing games, as there are numerous examples of such games using city environments. However the size of these environments is often limited to the boundaries of the racing tracks. But there are examples of racing games, where entire cityscape environments were designed, to allow people to navigate freely inside these environments. A good example is Midtown Madness[Mid], developed by Angel Studios for Microsoft and released in 1999. It was the first racing game allowing free navigation inside a 3D city environment. The original game and its sequels used models of the cities of Chicago, San Francisco, London, Paris and Washington. Despite some places that are very well represented, these are simplified models of the cities, discarding some data, such as small streets, and so cannot be used in an urban planning application.

Then, we focus on games with more freedom of movement, as previous examples were limited to car navigation. There are games where players can roam through a large scale city environment in different ways. A good example is Grand Theft Auto III[GTA], developed by Rockstar Games and released in 2001. In this game, people can explore freely an imaginary city populated with humans and vehicles called "Liberty City", by walking or driving vehicles from a car to a helicopter. Other examples include Grand Theft Auto III sequels and the console game adaptation of the movie Spider-Man 2[Spi] released in 2004. In this game, players put on the costume of the hero, and navigate freely inside a realistic model of Manhattan, populated with virtual humans and vehicles. These games are interesting, as they develop the idea of freedom of navigation inside a city environment. However the city is only the place of action, and not a real actor of the game.

Finally, we consider games where the city is playing a more active role in the action. A good example is Republic: the Revolution, developed by Elixir Studios, including in the team the former researcher of the Advanced Interfaces Group A. Murta, for Eidos Interactive[Rep] and released in 2003. In this game, the player is a political leader, who must rise to power. Three city environments have been designed, in which virtual humans are used to simulate the population. It is possible to zoom smoothly from a global point of view of the city to a local point of view, to watch specific events. The city is an actor of the game, as players must observe the evolution of its inhabitants. However the city is not the centre object of the game, as it was in Sim City.

The commercial success of these games shows that we reached a certain software maturity in developing VE technology involved in 3D city environments. This also shows that usability of large scale cityscape VEs is quite good, as they are to be used by a large audience. However, as games are usually restricted to an audience of fairly young people who are used to new technologies, we cannot really talk here about general public. Furthermore, there is not the idea about interacting with the environment itself, as it is more used as a field for the action, and not as the object of the game. And we saw in Section 1.5.2 that the games placing the city environment as the object of the game, which are Sim City and its derived games, do not use a real-time 3D rendering with free navigation. The thesis explores the idea of using a 3D virtual city environment by the general public, where this environment is the object of the application.

2.2 Large Scale CVEs for General Public

As previous sections illustrate, graphics technologies for rendering substantial city-like models have been explored by a number of projects. What is not common however is for participants in such a VE to be able to have significant interactions with it, and each other. Fundamental to our idea is the user-level ability to modify the city, and to share the environment with fellow participants.

Related to this idea, we now review work and applications on large scale CVE emphasising on their application to public activities. We first focus on city environments. Then, we explore the idea of virtual communities, out from the urban planning context. Finally, we talk about a mature application, which is the one of massively multi-player online games.

2.2.1 Shared Cityscapes Environments for General Public

We review, in this section, examples of distributed cityscape environments, which were made available to the general public.

Nottingham University and SICS developed, from the COVEN project[NT96], a tourist helper application for London City[SFPS99] using the DIVE platform. Using a 16x10 km square around the centre of London, they developed a city visualisation map to allow people to select with selectable criteria tourist attractions, such as hotels, pubs or theatres, they are interested in. They can access data on these attractions, and then watch them on a 3D model. They also developed a simulation of a journey on the subway, with a crowd simulation of people following routes around the area inside the arrival station. They included also some facilities for group communication. The evaluation was mainly about the technical aspects of the application, by measuring acceptable frame-rate on SGI O2 and Onyx platforms, and by performing network trials. This is an interesting approach for a general public use of a shared city environment, as it includes the idea of a tourist helper application and the idea of communication between the users. Some of its features, such as the use of the map and a database to access object information could be used for potential urban planning applications.

The Glasgow Directory[EM01], which has been developed by the ABACUS group of Strathclyde University, is a shared VRML model of Glasgow, which can be visited by multiple users, who can engage conversation with each other. The model, whose size is 25 square kms, uses simple geometry without any texturing. There is also a map, which can be used by people to select buildings and roads, in order to access to information about them on a database. People are represented with avatars, and can engage conversation using a chat window. This application, which has been made available on the Internet, has proved to be useful for tourists. However, the lack of realism of this model limits its use for urban planning.

These two examples show the potential use of shared city VEs, on which people can access information and engage conversation with other users. The idea of accessing information from objects is an important feature for an urban planning application, as it is a way to access planning information. In the thesis, we study this kind of information, we can find in a large scale VE for public consultation.

2.2.2 Virtual Communities

An important class of CVEs is that of the virtual communities, interactive city-like VEs. A number of these use the Active World[Act] technology, such as Alpha World. These are interesting as they actively seek to build a community of users, albeit without the pretension to represent a real cityscape, or a serious interaction with an urban planning process. Nonetheless, they are perhaps on of the best examples of large-scale communities of VE users engaged in a shared city-like landscape.

Cornell University used the active world technology to build a 3D virtual museum shared environment. It is said[Cor02]: "We are confident that it is possible to present data within the virtual world dynamically and to allow visitors to contribute content to the space". Therefore, our idea to make users contribute to the model by adding information or propose new design ideas seems promising. However they experienced a "difficult learning curve". This means that an important part of the evaluation has to focus on usability experiments, assessing how people manage to interact with the environment, as we want an application that people will be able to use easily and quite quickly without experiencing a too difficult learning curve.

Having reviewed the idea of virtual communities, we focus in the next section on an application of them, which is the one of massively multi-player online role playing games.

2.2.3 Massively Multi-player Online Role Playing Games

In this section, we review a mature application of CVEs for a large audience use, which is the one of 3D Massively multi-player online role playing games (MMORPGs), as they deal with people immersion into large scale VEs. They come from the merging of text Internet role playing games and CVEs.

The idea of MMORPG comes from MUDs (Multi User Dungeons), which were text-based role playing games over the Internet developed in the 1980's, and mainly used in the 1990's with the introduction of the World Wide Web. These games were restricted to communities of enthusiastic players. In 1996 Meridian 59[Mer] was released, which was one the first commercial MMORPG available, and the first one using a 3D environment, allowing a maximum of 100 users to play on the same server. The first popular MMORPG is Ultima Online[UO], which was released in 1997, allowing 500 players to play simultaneously on the same server, but using a 2D environment with an isometric view. The first popular 3D MMORPG is Everquest[Eve], allowing 2000 users to play on the same server, and released in 1998, which can be considered as a threshold date history of MMORPGs. Following Everquest numerous MMORPGs were released, such as Dark Age of Camelot[Dar] and Anarchy Online[Ana] in 2001, Star Wars Galaxies[SWG] in 2003 and World of Warcraft[WoW] in 2004.

These games place the players inside a large scale 3D environment, in which they can engage in dialogue with other players and run some tasks, such as performing "missions" or visiting places, which can be performed individually or in groups. They have also a high level of interaction with the environment itself, as some games allow players to manage cities, by placing houses and other buildings, and players can build their own house and arrange its interior. These are basically the interactions of virtual communities, which are amplified by a better immersion of the players, as there is the idea of role playing.

First, these MMORPGs show that CVEs work at a large scale, as they were designed to work on standard Internet connections, despite some latencies problems, which can appear with a high number of players, and the disparities of the geographical location of the different players. Next, the success of these games to a wide audience states that the usability of these CVEs is good too. Here again, as in Section 2.1.4, we cannot qualify this audience as general public. Finally, MMORPGs shows that CVE technology has reached a certain maturity, and could potentially be the best platform for virtual communities[KJW].

By comparison to the idea of virtual city driven by the thesis, the environments of existing MMORPGs are mostly virgin environments including cities, which do not reach the complexity of real cities. Only the recent MMORPG The Matrix Online[Mat] developed by Mololith and released in 2005, uses a huge cityscape as an environment, and is a first example showing the software maturity of using a large scale city model in a CVE application designed for a large audience.

2.3 VEs and Urban Planning

We now focus on the application of VE technology for urban planning. First, we review projects using single-user city environments not connected to any database. Next, we study extensions to GIS by the use of VEs. Finally, we review interactive environments dedicated to the urban planning process.

2.3.1 Single-user Stand-alone City Models

In this section, we explore the use in the urban planning context of city models, we define as "stand-alone", meaning that they are not connected to any external database.

Virtual Edinburgh:

The ABACUS group designed a Virtual Edimburgh 3D model[EM01], accessing 3D data held electronically by the national mapping agency[Mav87]. Commissioned by the Old Town Renewal Trust, the model was used to help preserving and regenerating the old town. The model, which covers the entire old town, is of good visual quality, with the use of textures, which is suitable for public consultation. It has been used to show the visual impact of planning proposals, but has limited interaction, as it is not possible to perform real-time modifications or leave feedback on the system. It has not been made available over the Internet because it was too large. Therefore, it was not used for wide public participation, and only showed during some presentations.

Virtual Bath:

The CASA (Centre for Advanced Spatial Analysis) group from University College London and the University of Bath have developed a VRML model of Bath[BD97], represented in a square of 10 km x 10 km. It has been made available on the Internet, and then used to show to the public different alternatives of the city development. As Edinburgh model, the Bath model is realistic enough for public participation. However interaction is restricted to navigation inside the model, as no object modification, information visualisation and feedback recording features were made available.

Since the models we studied in this section are not linked to an external database, they do not include information visualisation. We review in the next section VEs from GIS data, which include the possibilities of information access.

2.3.2 VEs from GIS Data

In this section we now focus on city models linked to an external database, improving existing GIS software.

VGIS:

Georgia Institute of Technology developed an extension of GIS to a real time VE called VGIS, to be used for military visualisation and simulation[LKR+98]. In order to do this, they designed an algorithm[LKR+96] for real-time rendering of high-complexity geometrical surfaces, using level of detail reduction. VGIS was not first designed for urban planning use, but there has been some work[YMW+99] on adding features and improving functionalities of VGIS for a future possible use in collaborative planning. However, there is there no idea of public participation here.

Virtual London:

More overtly urban uses have included work by CASA of UCL, who has worked on the integration of 3D GIS data into cityscape presentations of the City of London[BDJ99, DSD97]. Their idea is to integrate 3D technology into GIS software, by expanding the ArcView software[Arc]. They have also developed a 3D plug-in via VRML to visualise the city in 3D over the Internet. The result is therefore a VRML cityscape generated from GIS software.

Though fascinating in its own right, this is essentially a 2D design, using the GIS software interface, offering only limited scope for interaction, or for direct 3D editing of the models. The ability to capture information directly from GIS databases is however intriguing. The model can be used for accessing information, using all the features of the GIS database. It is also designed to display environmental impact data, such as pollution, using simulations. However, it is not suitable for public consultation, as there is not the idea of leaving feedback, and because of the lack of realism of the model, as it uses non textured buildings and does not offer a large coverage of the city.

GOOVI-3D:

The Fraunhofer Institute of Computer Graphics in Germany has developed a VRML-based interface to GIS called GOOVI-3D[CJ98]. It allows people to access and interact with a GIS database over the Internet, distributed using CORBA. A model of Frankfurt has been developed, allowing navigation and information visualisation. It is also possible to select a specific object and access to its information as HTML documents. An interesting feature of this approach is the ability to perform GIS information queries and to visualise the results on the 3D model. However, like the Virtual London model, there are no forms of interaction other than navigation and information access. There is also no idea of leaving feedback, and the model does not offer a large coverage as well, and cannot therefore be fully used for public consultation, as for example to watch the impact of a proposal on the whole city.

KARMA-VI:

KARMA-IV[VMG+99], developed by the Delft University of Technology in the Netherlands, is a system which combines GIS, CAD and VE technologies, by using three representations of an urban environment:

- First, there is 2D map view called "plan view", offering 2D GIS functionalities. This view, which is used in the preliminary study phase of the urban planning process, allows people to display and analyse information, such as population or traffic.
- There is a second view, called "model view", which is a 3D map including simple 3D CAD objects. This view is used in the design and modelling phase, having a global point of view of the environment.
- Finally, there is the "world view", which is a full 3D view including complex CAD objects and textures. This view is used for the public consultation phase, presenting a realistic VE where people can navigate and so perform a visual analysis of the area.

The idea of using three different view is interesting. However the VE view is mainly limited to visualisation and does not provide many query interactions, and does not offer the possibility to record feedback. Furthermore the system is not available over the Internet, and so limits its use for public participation.

CommunityViz:

CommunityViz[Com] was developed from 1997 to 2001 by The Environmental Simulation Center[ESC] in New-York. This application, which is a decision support system which extends ArcView, is used for community planning. It has been used successfully in numerous projects (it is for example used for the task of redesigning the Manhattan area damaged by the September 11th incident), and is being used in urban planning, but also in other applications, such as community land-use planning or natural resource management. The system includes three components:

- First, there is the Scenario Constructor, working in 2D, which is used to build and analyse different planning scenarios.
- Then, there is the SiteBuilder3D, which allows modelling and exploration of the environment.
- Finally, there is the Policy Simulator, which can be used for 4D regional forecasting.

Although successful, and representing environments with good realism level, CommunityViz has some drawbacks. First, the environmental modifications offered by the SiteBuilder3D are only possible using the 2D GIS interface, and so not the VE one. Then, there is no possibility of deliverability over the Internet as it has not been implemented. Finally, there is no idea of public consultation in the application, as its use is restricted to planners.

GeoVR:

Developed by the University of Hong Kong, the GeoVR system[HL02] uses the idea of dynamic generation of a 3D model of a city from its GIS data. In order to do that, the client sends parameters values, corresponding to the information he wants to access, to a server, which generates the 3D model and deliver it as VRML model over the Internet. The only possible interactions are navigation and information visualisation. There is also no additional information available, on the contrary of HTML information provided by GOOVI-3D. Finally, there has been no use of this system on city data but rather on "virgin" geographic landscapes. However the idea of dynamic generation demonstrates the coupling of Internet GIS and VRML, and could become interesting for further use in urban planning.

SUCoD:

The University of Sheffield have developed the Sheffield Urban Contextual Databank (SUCoD)[Pen03], which allows people to access GIS data about different historical urban forms of Sheffield. The system can generate a VRML model of a selected area, enabling 3D visualisation and navigation. Having been made available on the Internet[SUC], this enables the public to access these resources. However, there are no other forms of interactivity, and therefore no idea of active public consultation.

2.3.3 Interactive Environments

In the two last sections, we reviewed models used for urban planning and geographic data visualisation, but which do not allow advanced interactions on the VE, such as environmental modifications. We explore in this section more interactive VEs.

CVDS:

CASA developed the Collaborative Virtual Design Studio (CVDS) system[DDSF98, BDJS00], using Active World[Act] technology to make it accessible over the Internet. The idea of this application is to allow people to communicate and perform synchronous real-time modifications of the environment. In order to do that, the system sets permissions to determine which user can perform the interaction. The idea of performing real-time modifications with the idea of collaboration is interesting. However, this system has limitations for real urban planning use because of the low complexity of the model (CVDS was designed to run on low-bandwidth networks). Furthermore, it is to be used by planners, and so does not include the idea of public participation.

Urban Simulator:

The Urban Simulation Team at the UCLA, lead by Professor W. Jepson, are developing a very accurate 3D model of Los Angeles, covering over 4,000 square miles and linked to the ArcView GIS software, and an urban simulator to interact with the model in real time[SJ99, JF98]. According to Jepson[JLF96], "As the model becomes more realistic and recognizable, the inclusion of nonprofessionals in the design / decision making process is facilitated. Ultimately, a potentially affected community could become involved by periodic viewing development of a design and providing professional planners and designers feedback based on reactions to the visualization." Such work supports the thesis that VEs are of genuine benefit to the urban planning process.

The aim of urban simulator is to explore different planning scenarios, over space and time, by navigating and performing environmental modifications. It is possible to query the GIS database and display the results on a 2D map or directly on the 3D model. It is also possible to make real-time object modifications. The system has been used in numerous urban planning projects, and in other areas, such as car navigation, tourism and historic reconstruction.

The accuracy of the model allows people to view planning proposals in a very realistic way. However, there has been no further development for a public consultation use, as there is no idea of feedback recording. Furthermore, because of the size of the Los Angeles model (it is projected to reach 1 terabyte in the last few years), it will be difficult to make the model accessible to a large audience over the Internet.

Collaborative Urban Planner:

T. Manoharan from Heriot-Watt University has worked on designing a prototype CVE to be used in the whole urban planning process, after having studied the general requirements of such a model by interviewing professionals from the urban planning field[Man03]. This is the most complete model regarding public participation, as it allows people to view information about the proposal, and is the only system that stores user comments.

However the public consultation features from this application remain basic, as it only follows these general requirements (for example recorded feedback is only of general nature, as comments do not exploit the spatiality of the environment). Furthermore, there has been no user-based experiment to test the application on general public. These experiments are necessary, as an application providing public consultation must have the approval from public. These experiments are challenging too, as navigating inside a 3D environment is not an easy task for the general public.

Therefore, keeping in mind these requirements, the thesis investigates in more details the consultation process, studying the benefits of using a CVE, by performing user experiments using a prototype model, to assess if the general public will be able to use such an application and leave positive feedback about the approach.

2.4 Summary

First, we have reviewed in this chapter VE technology involving 3D city model representation, and saw that these technologies have proved to produce fairly mature software, with the example of computer games.

Then, we reviewed the use of large scale CVE technology for general public, showing again software has reached maturity with massively multi-player computer games.

However these games, albeit accessible to a large audience, are not accessible to everybody. That is why we have to run usability tests on people not used to these games, as we target the general public.

We finally reviewed applications of VE technology for urban planning. This software is mainly reserved for professionals, providing none, few or basic public consultation features. Indeed, for most of the models there is the idea of showing to people the development of the city, but without other forms of interaction, such as model modifications and leaving feedback. There was only one model allowing people to record feedback on the system. Finally, the increase of public consultation on these models was mainly justified by:

- the availability on the Internet
- the possibility to visit different alternatives of a proposal
- the possibility to access to planning information

But no other forms of interaction, such as leaving precise feedback on the model or proposing environmental changes have been investigated. Furthermore, there is no example of an experiment on general public to study their use of such technology.

In conclusion, it seems interesting to investigate in more details the idea of using CVE technology for public consultation in the urban planning process, as related technology has reached some maturity, and research in this area has been very limited. Therefore, the thesis explores this idea, testing it with experiments on the general public. The next chapter develops the idea.

Chapter 3

Using CVE Technology for Urban Planning

Having reviewed the existing urban planning practices, and relevant VE technologies, we now consider the role of CVEs in the urban planning process.

After some suggestions about the potential use of CVEs in the process, we discuss the motivation to use our approach. Next, we briefly talk about how we might evaluate such an approach and explain a case study of how the new process would work. Finally, we show how our approach can improve the consultation process itself.

3.1 CVEs as Tools for Urban Planning

Urban designers work mostly with 2D design. There are good reasons for this. It would be presumptuous to assert that 3D tools should replace existing practices. In the public mind however, cities are three-dimensional edifices, so the public would expect a planning proposal to be presented in 3D, and find such a presentation easier to comprehend and work with. Further evidence here is the common use of physical models in public planning consultations. One difficulty in this process is that such models are often presented as clean architect models, "artist's impressions", whereas the existing situation is presented as unpleasant photographs of reality, with all that that entails (see the presentation of the Piccadilly scheme in Manchester as evidence of this). Obviously architects take an advantage of using clean models, as they can show their models from the best point of view. However, the gap between reality and these models can be also considered as a factor of the lack of interest to the process from the general public we discussed in Section 1.4.2, as the model they are consulted on is different from the final result. Therefore, reducing this gap is an option to consider to improve the consultation process. One advantage of the VE technique here, is that of a neutral presentation for both the existing, and the proposed situations. Alternatives can be presented side-by-side, or overlaid upon the same model under user control. Members of the public could then more readily compare their direct experience of reality with the VE model of the existing, and the VE model of the proposed. Therefore, it is necessary to make available the contrast between the existing and proposed within the same VE presentation.

Further to this is the idea of feedback and engagement from the public participants. A number of possibilities present themselves for exploration in the project. At a minimum level, members of the public would be able to offer comments – a kind of "graffiti" – on the proposals. This should allow interaction with other participants. More advanced would be interaction with the model to suggest design alternatives. This is more complex as it involves facilitating 3D editing with untrained operators, and the problems of maintaining multiple versions of the model in an environment that we aim to be shared. Beyond this there is the question of how all this information, the numerous feedback and modifications, are to be presented in a useful way to the designers, and how this fits into their work process. But all these are interesting problems to be addressed in the research.

Finally, there is the idea of increasing the number of participants in the process by delivering the VE available over the Internet. Indeed, when accessible on the Internet, people can be consulted on their own PCs by using their Internet connection to visit and interact with the city environment.

More detailed reasons of using VE technology for increasing public consultation are available on a study made in the UK[Bul01].

3.2 Motivation

Having reviewed the potentials of our approach, we now state reasons to use this idea for public participation in the urban planning process. First, we discuss the needs of the planners. Then, we focus of the growing importance of communication in our world driven by the Internet. Finally, we talk about the growing importance of 3D computer graphics in computer science.

3.2.1 Involving Urban Planners

In this section, we review preliminary interviews with people from the urban planning field we met in the beginning of the research.

First, there is a need of 3D software for planners. We gathered that there is a lack of 3D tools to assist them in their work, so they are constrained to use 2D design software. Obviously we reviewed in the last chapter some softwares using 3D VEs for urban planning, but most of them are in the experimental stage, and so are not often used by planners. Therefore, research in this field has to go on until really mature software can be produced.

Then, planners insisted on the limitations of public participation for now, which are the ones described in Section 1.4.2. In most of urban planning project, interactions with the public are often restricted to a look at a static model of the city area concerned with the project, and leaving some general feedback. So, the idea behind using a VE is that we can improve this feedback by including it to the model. Furthermore, the public can modify the model itself, which is impossible with a cardboard model. Breaking limitations of such participation mechanisms is possible through the use of a VE:

- First, the consultation is now dynamic, as the 3D cityscape can evolve in real-time, unlike a static model. Therefore, it becomes possible to present on the same model several alternatives of a project. Furthermore, modifications of the proposal can be carried out in real-time on the model, while observed by public.

- Then, using a 3D immersive environment, it is possible to associate information to a specific point of view, as next explained in Section 4.3.3. Static models only allow display of restricted to the limited available perspectives.

- Finally, a 3D model would obviously seem more realistic for people than a static model. Indeed, they can navigate within the environment with the same scale as human beings. Furthermore, using the latest rendering technologies, city models have become extremely realistic, as seen in Section 2.1.3.

3.2.2 A World of Communication

In this section, we focus on the development of the Internet, which has brought our world in the era of communication.

The Internet, which was created in the late 1960's was first used by computer experts, scientists, engineers and librarians, and matured in the 1970's with the development of the TCP/IP protocol. In the 1980's, the Internet became a lot easier to use for non technical persons, because of the standardisation of its protocols, but it remained limited for research, education, and government uses. It became available to the general public, with the development of the World Wide Web (WWW) and the growth of independent commercial networks. The 1990's and the early 2000's have seen the increase of Internet use for the general public. Now, more and more homes are equipped, with high-speed connections, and the Internet has entered into common language, and should be as common as phone or television in the next few years. More and more services are now available over the Internet, and others are to come.

One key principle of the Internet is the reduction of the boundaries of time and distance. It is indeed possible to access information and communicate with anybody from any part of the word instantaneously. From this comes the idea of communicating and accessing information from home computers, and not being forced to move and get the information. This can be an asset for the urban planning process, as people are often reluctant to go to hearings, because of distance or time constraints. The Internet is also known as a place for public forum, facilitating communication between people. There are different ways to communicate, which are email, discussion forums, or real-time communication such as IRC or instant messaging.

In conclusion, with the development and the democratisation of the Internet, which is known to be a means to bring people closer and to facilitate communication between them, it seems obvious that a method of public consultation made available over the Internet will increase public involvement. Indeed, R. Kingston, from the Leeds group, reviewed projects involving "e-participation" of citizens over the Internet, using 2D distributed GIS, which have proved to be a good alternative to traditional consultation[Kin02]. He suggested an "e-participation ladder", which is an analogy of the Arnstein ladder of citizen participation we discussed on in Chapter 1. Furthermore, experiences showed that the use of remote computer science technology has been proved to stimulate public participation in the urban planning process[MP00], by the use of computer-supported mediation systems, because of the increase of communication and information provided by information technology. However, Kingston stated that e-participation will only work if people from the public are willing to use these new tools. That is the reason why we need to get feedback from people during the evaluation stage of the thesis, asking them if their own participation would be increased by our approach.

3.2.3 The Emergence of 3D Computer Graphics

In the last years, 3D has been taking a growing share in computer graphics. The technology is now cheap and readily available, since what were really powerful GPUs a few years ago are now available on expensive home computers. There are examples of applications, which have evolved from 2D to 3D, such as computer games or CAD. We have seen in Chapter 2 that there are many 3D models of cities. The number of these models has dramatically increased these last years. We did review as well some extensions of current computer use practice, and new softwares using VEs in the urban planning field. So, designing a 3D city model for people consultation in urban planning seems to go in the right direction.

With this development of 3D computer graphics, real-time 3D environments can be considered for use in the architecture field. G. Schmitt et al. say[SWKvdM95]: "The improved evaluation and visualisation component of VR will lead to a wealth of new discoveries in architecture that could not occur otherwise." Therefore, VR, as a new tool for architects and designers[Sch93], has benefits, compared to traditional CAD design. Indeed, unlike CAD, a VE brings the feeling of immersion, can be multi-user oriented and favours interactions between the user and the environment. Therefore, as simulation becomes more realistic, the public should give more accurate feedback, since they really feel as if they were inside the environment.

In the general public side, CVEs are an evolution to text Internet for public use, as they include the main features, which are information access and communication. There have been examples, we reviewed in the last chapter, of use of large scale CVEs for general public, with the case of the MMORPGs, we reviewed in Section 2.2.3, showing a certain software maturity of using CVE technology for a wide targeted audience of users.

To conclude, the emergence of 3D computer graphics has made computer science applications migrate from 2D to 3D. Urban planning may take advantages on this evolution. Indeed, the use of real-time VE, made possible with the development of this technology, opens new horizons for use in architecture. Finally, we saw that applications using CVEs for general public has started to mature. All this make us confident in using CVE technology to improve public involvement in the urban planning process.

3.3 Evaluation

Having discussed motivation of using our approach, we now focus on how we could assess such an approach. The thesis has two aspects. One technological, the other application/user oriented.

Technological evaluation is largely objective, using performance metrics such as frame rates and scene complexity relative to that required of a cityscape. We propose to measure this to determine how well the system performs technically. This is useful, as this can then be separated from the performance of the application ideas themselves.

Application and user oriented experiments can be divided into three parts:

- First, we must evaluate the usability of the application, which means how people succeed in using it. This can be measured objectively by performing tests on people, asking them to perform tasks with the application[PRS+94]. These experiments have to first include a tutorial, as people need to learn how to use the application. As we want this application to be easily accessible, measurement of the tutorial tasks completion is a fair way to assess that.

- Second, we have to evaluate how well the overall system can be said to facilitate and improve the process of consultation in urban planning. Some objective measures can be obtained, such as the amount of interaction, number of messages left and feedback given and so forth. However, evidence for the effectiveness of the system is likely to be best elicited by an ethnographic approach, recording the interactions and commentary of participants. We could propose to show a particular design proposal. However, it would probably be infeasible to do this for a "real" proposal, given the effort involved in creating the model, and so we would use a simulated proposal in order to solicit input. Indeed, using a non-existent city, we would not have to deal with parameters as the accuracy of the model compared to the real city, as our goal is to only evaluate the interaction process. Furthermore, this would allow us to have a total control of the environment and so design the experiments we want. We would present the results of such input, together with any commentaries we could solicit from the professional planners involved in the exercise.

- Finally, we want some input from the people involved in the experiment, to investigate how they experienced the application. We have to prove that this approach has attracted interest from people. Indeed, it is no use to have an application which has proved to improve the process of consultation but has not support from people, as they would not use it in the future. Therefore, we need to ask people to evaluate the application, and give comments.

However, the core of the thesis concentrate upon the technological issues in facilitating such feedback and engagement of a large, shared, community of users; and upon the thesis that such environments are a practical proposition for public consultation, given the current technological state of the art.

3.4 Case Study

We now describe a public consultation process example during an urban planning process which would use our approach. Figure 3.1 shows how our model is used in this process.

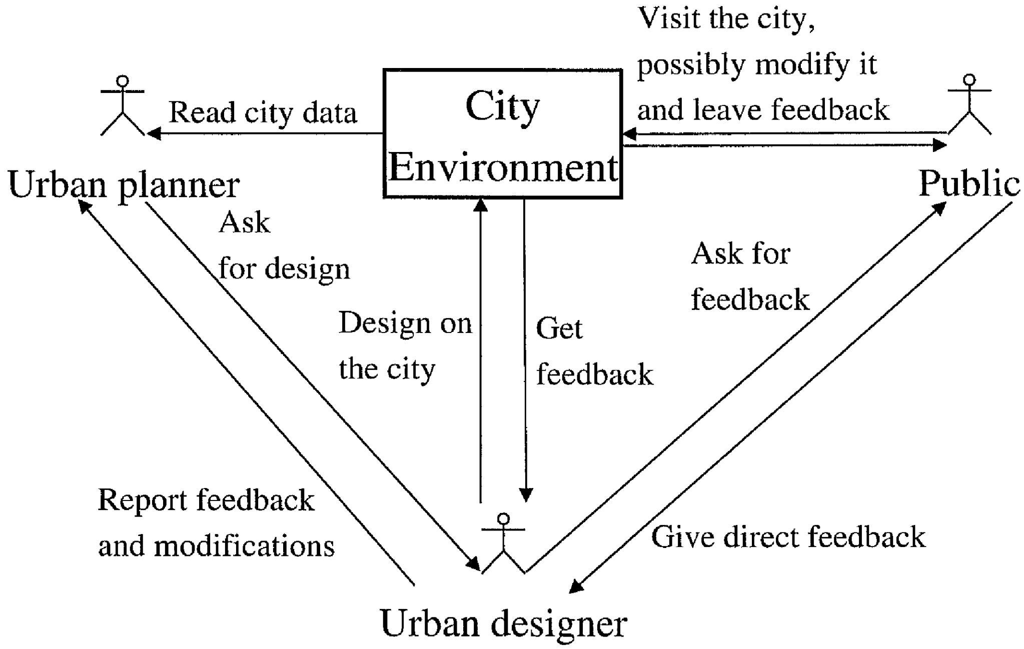


Figure 3.1: Case study

First, an urban planner observes city data, and decides that an area of the city needs to be redesigned. This observation can be done using GIS data from the city model. This is the stage of political decisions.

Then, he asks an urban designer to design this city area. The designer interacts with the city model, altering 3D models of the cityscape, according to the design directions he chose.

After that, the model is opened to public consultation. This is the stage of urban planning we are interested in for the thesis. The public can interact with the city, by modifying 3D objects, or simply by leaving feedback on the environment.

Then, the urban designer can collect this feedback by different ways:

- He can observe how the public modify the model.
- Or he can read the feedback they leave.
- Or simply, he can communicate with them during the consultation. The communication process can be mediated by human mediators.

After analysing this information he can alter the city design or report the feedback directly to the urban planner who can then make new decisions.

3.5 Improvements to the Consultation Process

In this section we discuss on the enhancements a city CVE bring to the traditional urban planning consultation processes. We discuss the process itself, and not the quality of the model. We develop some points which were mentioned in Section 3.2.1.

3.5.1 A Dynamic Consultation Process

As opposed to traditional consultations using small scale models, an illustration or a video, which would require the design of a new representation after every change[CR99], it is here possible to modify the model, even in real time, within the process. This is a more dynamic approach to consultation, as shown by Figure 3.2.

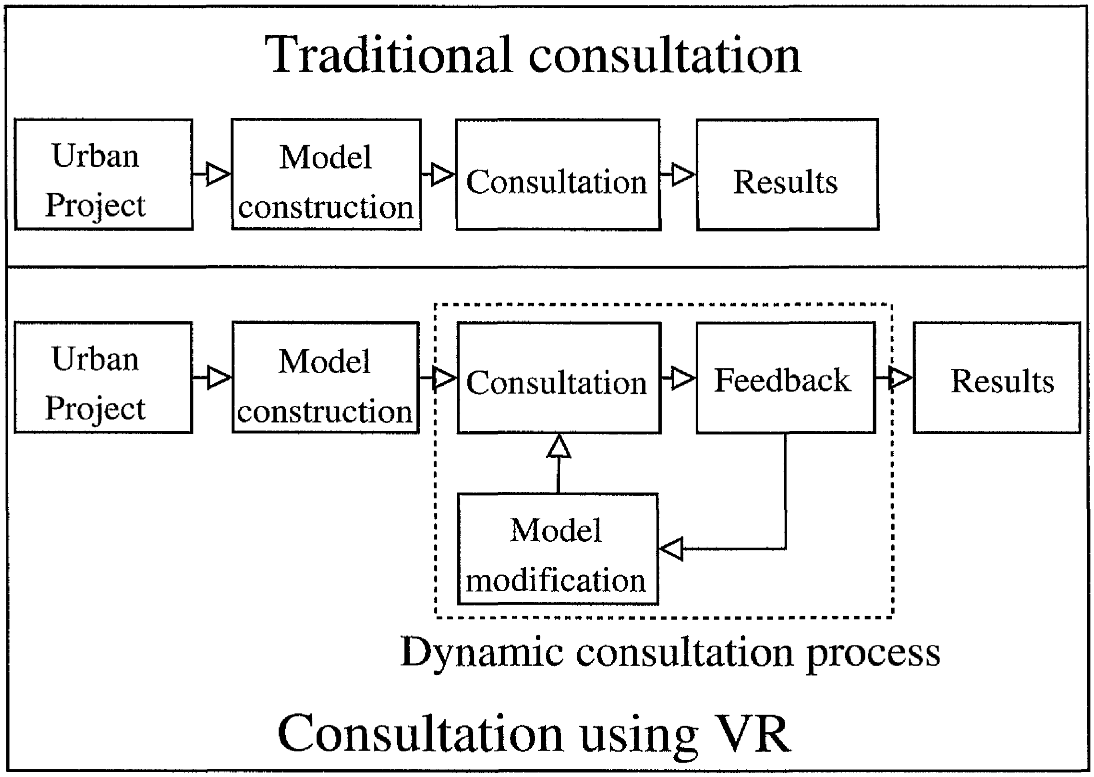


Figure 3.2: Consultation process becomes dynamic with VR

3.5.2 Including the Different Steps of the Process

As it is a complex task, the urban planning process is broken down into different stages. We can consider three main steps:

1. Design of the different planning proposals
2. Choice of a final proposal from the different alternatives developed
3. Refining of the chosen proposal

Using a VE, it is possible to set up different levels of detail, and so intervene in the early stages of urban planning. The first step uses a very low level of detail, as at this stage no precise decisions are made. People could be consulted at this step, entering the VE displaying a rough virtual "sketching" of the proposal. They could then leave their opinion concerning the proposal idea, and explain their needs. Precise feedback could be used to show some local concerns. However, modification changes are unlikely to be proposed at this step because of constraints rules in urban planning concerning large objects.

It is also possible with a VE to simultaneously present different alternatives of a proposal, and so to carry out public consultation in the second step. Indeed, people would visit the different proposals and vote for the one they prefer. They could argue their choice by leaving precise feedback on each proposal, and so planners would have a better understanding of their choices, and then select the proposal having the best feedback from them.

A VE can render very accurate city environments. Therefore, using a very high level of detail of the environment, people can be consulted during the last step. Because of the realism of the model, it would be possible to leave precise local feedback on the model, which could then be used to refine the model. The refining process could be dynamic and may be carried out in real time, as we saw in the last section. Furthermore the idea of model modification could be used for small objects, as there are less constraints on them compared to larger objects.

In conclusion, a VE environment would allow people consultation to be carried out in all the main steps of the urban planning process.

3.5.3 The Idea of a Continuous Participation

Like virtual communities and MMORPGs, we can adopt the idea of a persistent city environment. This would open new prospects:

- First, the environment could handle simultaneously multiple urban planning projects. People would enter the environment and then select the project they are interested in. A benefit of this idea is to simplify the use for both groups – planners and public – in a city concerned by multiple projects. Indeed, planners would work on the same model, and people from public would only have to interact with a single model for every project, without having to bother about which model to select. Furthermore, they could visit the different projects during the same session.

- Second, with the availability of a persistent model, it would be possible to use it for projects of different scale. Small scale planning proposals, such as the arrangement of a single street, are usually not subject to public consultation, because of the costs of designing a model, which would be enormous for a project of a small size. The use of a non persistent environment would raise the same kind of issues, such as the putting in place of the city model on the Internet would use resources. However with the use of a persistent environment planners would simply define a new project on the environment in real-time, and people could then be consulted instantaneously.

- Finally, a persistent environment would extend its use to other applications than consultation on urban planning proposals. Indeed, the model could be used as a 3D virtual "map" of the city, providing useful information on is objects, which would be useful for tourists for example. Using GIS data, the environment could be used to display daily information, such as pollution or traffic. It could be used as well as a mass transportation map. Finally, it could be used by people willing to buy a flat or a house to visit and get information on their future neighbourhood. Obviously, more applications could be conceivable.

3.6 Summary

After having suggested application strategies, by stating general principles about the approach to use CVE technology for public consultation in the urban planning process, we stated why we are confident in our approach. We then explained how we could evaluate the thesis. Evaluation is discussed in details in Chapter 9, with the description of experimentation work. Finally, after having showed a potential use of our approach on a use case, we showed how the consultation process itself could be improved using our idea.

Having enumerated the stakes of the thesis, we can now think about a theoretical model, which is described in the next chapter.

Chapter 4

A Virtual Environment for Public Consultation

In this chapter we describe a VE we think is suitable for large scale public consultation. We disregard here the city example, and so describe the environment in a general way.

The targeted environments are large-scale shared VEs accessible to many users. The environments we are studying here are model-based ones, on which people are consulted on design choices on an object (the city for example) which is represented by a model. The model itself is not the only component of the environment. Indeed, in a public consultation process, it is always shown with some information to guide the public (for example a key on a map or a small scale model of the city, or simply a text description).

We describe in this chapter this environment as it has to be in a theoretical way. But we first remind the prerequisites of such an environment.

4.1 Requirements of the Environment

We want to allow the application to be used by the general public from their home. So the application must be:

- Executable on most computers: That implies that it must run well on middle-performance range computers (standard CPU and 3D graphics card). So the complexity of the environment must take care of this requirement.

- Usable on the Internet: That means that the network distribution and bandwidth use of the application must be suitable for home Internet connections (DSL and modem Internet connections).

- User-friendly: Since general public is not necessarily used to 3D computer graphics, we have to ensure that people are able to easily use the application, which means navigate and access information from the model, with only a little training.

4.2 Composition of the Environment

As we said, this kind of environment has a dual nature. It contains a model and information. We describe in this section each of them.

4.2.1 The Model

The model represents the subject on which the consultation takes place. It is the cityscape representing the city for urban planning consultation processes. The model is subdivided into three layers. Figure 4.1 illustrates this subdivision.

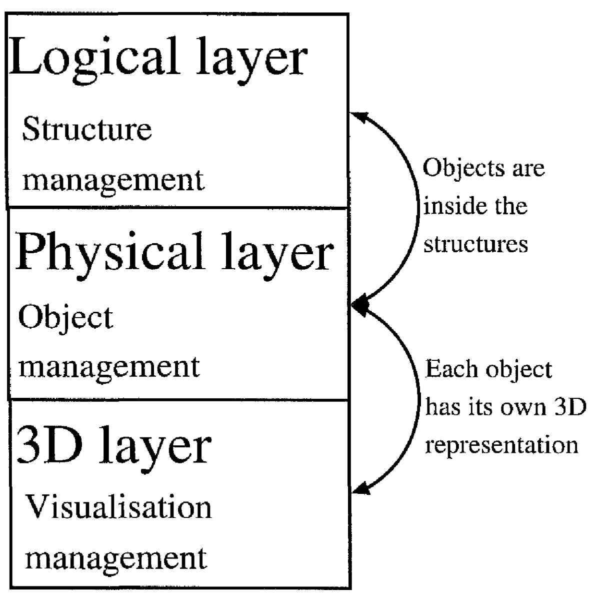


Figure 4.1: The model

The logical layer contains the data structures, providing a logical description of the model structure. These structures form a hierarchy, to subdivide the model into "areas". The physical layer deals with the description of the objects of model. Finally, the 3D layer contains the geometrical representations of the objects.

From the point of view of a city model, the logical layer subdivides the city into different areas, which can be considered as city districts for example. The objects can be pedestrian areas, buildings, roads or crossroads. The 3D layer contains the 3D representation of all the objects, and could hold smaller objects, called "3D landmarks", to be included on pedestrian area objects; these are called landmarks, as they would allow a better orientation inside cities. The logical and physical layer can be seen as GIS data, and the 3D layer can be seen as a 3D extension to GIS, as various work carried out we described in Section 2.3.2.

The logical and physical layers are independent from the 3D renderer that is to be used by the 3D layer. Therefore, it would be possible to use different 3D renderers easily. This feature can be useful to make use our model on a large range of computers.

We might question the usefulness of the logical layer. What is the interest in subdividing the model into "areas" ? The answer comes from urban planning. Indeed, as urban projects can be bounded to a specific area, the usefulness of the subdivision becomes obvious. Indeed, a consultation can be placed on an area of the logical layer of the model, and by separating this area from the others, it becomes possible to manage different interaction and display rules (for example, restricting interactions to the consultation area and use less complex 3D objects to display other areas).

4.2.2 Information

Information is very important in our study, as the goal of a consultation is an information exchange. We can subdivide the information into two classes. We have:

- **Model information**: This piece of information is brought by the designers of the environment. It is information related to the model.
- **Consultation information**: This piece of information is brought by the people who are consulted. This is the information obtained by the consultation.

For the cityscape example, model information is brought by urban planners. There can be a lot of information involved during an urban planning process. First, there is general information about a district of a city, such as its population, the number of school or history. Furthermore, there can be information about a specific object of the city, as some information about a building involved in an urban planning project (for example the date of achievement or the role of the new building). Consultation information is used to replace traditional comments from the public, usually written on a notebook.

4.3 Architecture of the Environment

In this section, we describe how information and the model are organised within the environment, by describing in details the relationships between them, as well as the organisation of information inside the space of the environment. Finally, using this description we classify information.

4.3.1 Relationships between the Model and Information

Here, we discuss how information is linked to the model. We decide to merge consultation and model information, as they are technically the same information. Indeed, a piece of information brought by the public could have been considered as a piece of model information if the comment was left by a designer.

Where is information about the environment located? It is obvious that some information is located on the model. For example, a description of an object can be considered as attached to this object. However, some pieces of information are not necessarily directly linked to objects of the model. For instance, a comment based on a particular view of the model (for example "from this view there is a lack of trees") cannot be linked to a specific object of the model.

Figure 4.2 shows pieces of information which are directly located on the model, and other pieces of information which are independent from it. We call the objects that contain these data "information/consultation boards". These objects can be considered just as information containers. We define them as objects which are not part of the model, but which can be linked to it (as next explained in Figure 4.3). They have two layers – the physical layer describing the object itself, and the 3D layer providing its representation, as well as its localisation in the 3D space. This localisation is a key element, as further explained in this chapter.

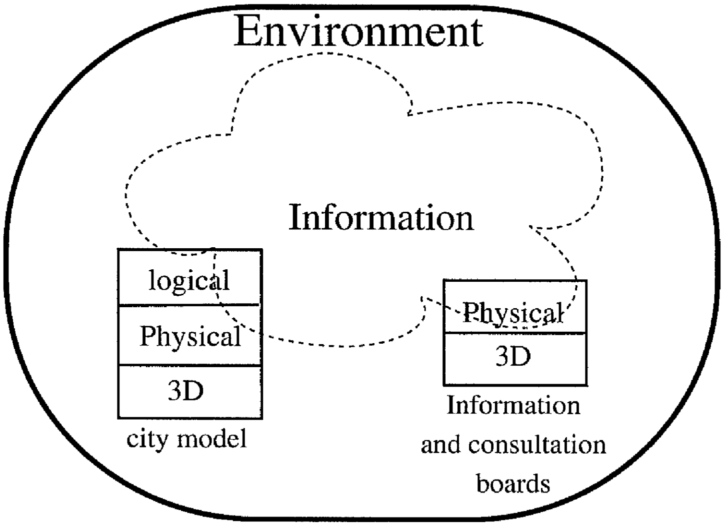


Figure 4.2: Information location on the environment

Looking now at a lower level, shown in Figure 4.3, we can now classify information.

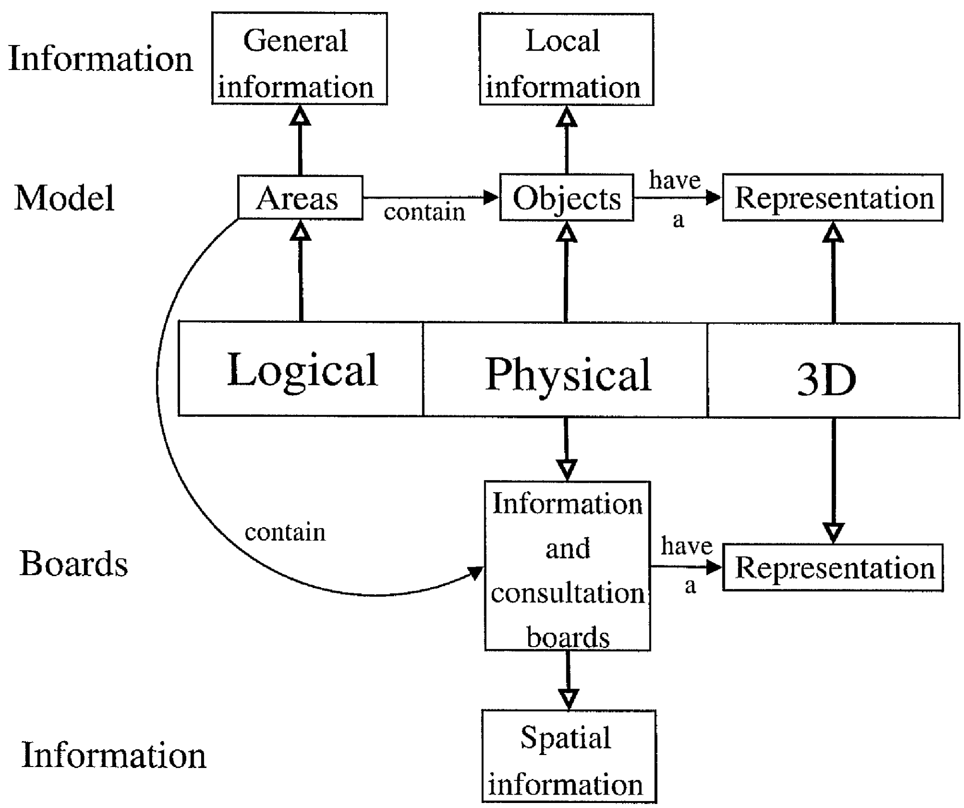


Figure 4.3: Information and model relationships

From this we can indeed notice three kinds of information:

First, a piece of information is linked to the logical layer of the model. We can classify this as "general" information, as it does not refer to the details of the model provided by the physical layer. We decide to name it **logical information**.

Then, a second piece of information is linked to the physical layer. We classify it as "local" information, as each piece of this information is related to a single object of the model. We name it **physical information.**

Finally, the last piece of information is linked to the boards we defined before. This piece of information can be considered as "spatial", as it is not directly related to the model, and depends mostly on the coordinates of these boards in the 3D space. Therefore, we name it **spatial information**.

Despite the fact that boards are independent from the model, we can notice a link between the boards and the areas. This link is indeed necessary, as we saw in Section 4.2 that a consultation depends on an area. So, each piece of information must be related to an area to be used during a consultation.

4.3.2 Localisation of Information

We defined three levels of information, which we named logical, physical and spatial information.

Logical and physical information are on model. Spatial information depends on a specific location in the 3D space, but this location is not directly linked to the model itself.

Physical and spatial information locations are local, opposite to logical information. That means that physical and spatial information have their own location in the 3D space (the object for physical data and coordinates for spatial data), and can only be accessed from their location.

What kind of data do they contain ?

Logical information is information about an area. For a city, this can be considered as general information about a district, without taking care of a specific object.

Physical information is information about a specific object of the model. For a city, this can be for example information about a building.

Spatial information depends on an area, but also on a location in the 3D environment. However, the information data can be cut off their geographic attributes. That means that a piece of spatial information can sometimes simply be considered as logical information. Though, spatial information does not generalise logical information, as a spatial piece of information is only available near its location. On the contrary, any piece of logical information is accessible anywhere on the area. This information is described in Section 4.3.3.

Figure 4.4 gives a summary of this section, showing the particularity of spatial information.

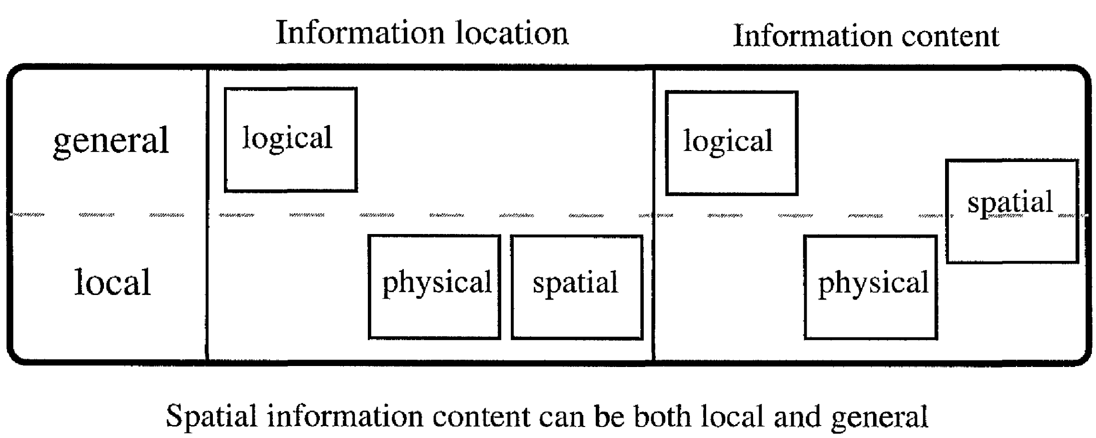


Figure 4.4: Information localization

4.3.3 A New Kind of Information

Spatial information would not be possible without expanding our environment to 3D. Therefore, we can see that VE technology allows the introduction of a new kind of information, and so enriches the environment.

This information can be varied. Let us see what it can be as model information.

First, this information can be general, as a piece of logical information. Therefore, we can see the boards carrying this piece of information as a way to dispatch a piece of the logical information of an area. This can be a good way to present information, as people can travel into the city, from an information point to another one.

But most important, this information can depend on its localisation. Here is the novel aspect of this information, as, on the contrary to a static models of the city, it becomes possible to have information about a group of objects based on their visualisation from a specific viewpoint. Figure 4.5 shows an example of spatial information on a cityscape. The information board can be focused around the group of buildings, describing it according to the view of them from itself. So with this visual stimuli, information may be assimilated in a better way.

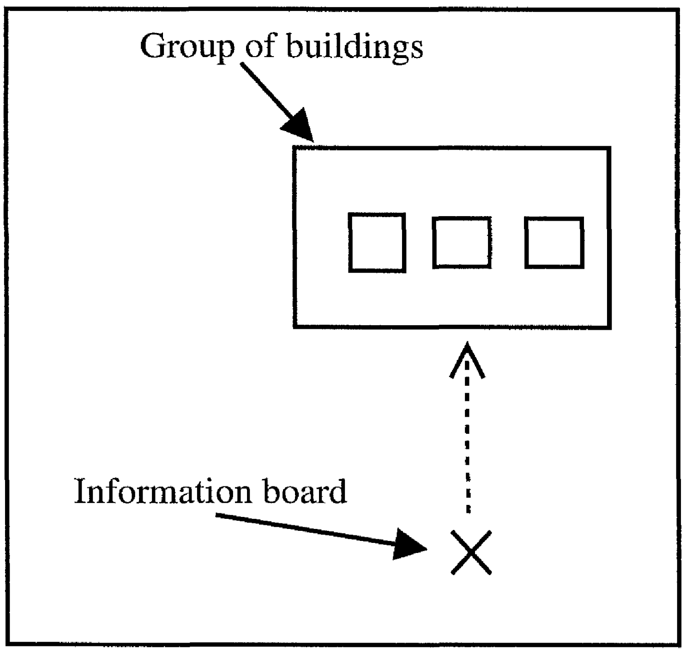


Figure 4.5: Spatial information example on the cityscape

But it is as consultation information that it has more benefits. Indeed, on the contrary to feedback from static models, comments are now local and so more precise. For example it is now possible to let a comment about a specific group of buildings, at visual range from the consultation board. If we look at Figure 4.5, using the information board as a consultation board it becomes possible to leave feedback according to the view of them (for example people can comment about the height of the buildings, which can be more easily assessed from this viewpoint).

Obviously, general comments (as part of logical information) can be left on any board.

In fact, specific boards can be chosen for general comments only. So consultation boards can be used to separate the classes of comments. At a lower levels, we could use these boards as parts of a general questionnaire, to make the comments quantifiable.

4.3.4 Generated Information

In this section, we observe logical information. Where does it come from? First, it can be independent of the physical objects of the data structure to which the information refers. For instance for an area, such information might simply be its name. We can call this information **ex nihilo logical information**. As consultation information it can be general comments on the urban project.

But logical information can also depend on the physical objects contained inside the data structure. As an example, it can be the number of objects of a specific type, or a mean of a numerical attribute of some objects (such as the average height of the buildings of a city area). Therefore, this piece of information is generated by the physical information of these objects. We call this **generated logical information**. As consultation information it can be a summary of the different comments on the objects of the area. If the comments are numerical, generated logical information can be the results of statistical functions on these values.

4.3.5 Summary of Information

Figure 4.6 summarise the different kind of information we defined.

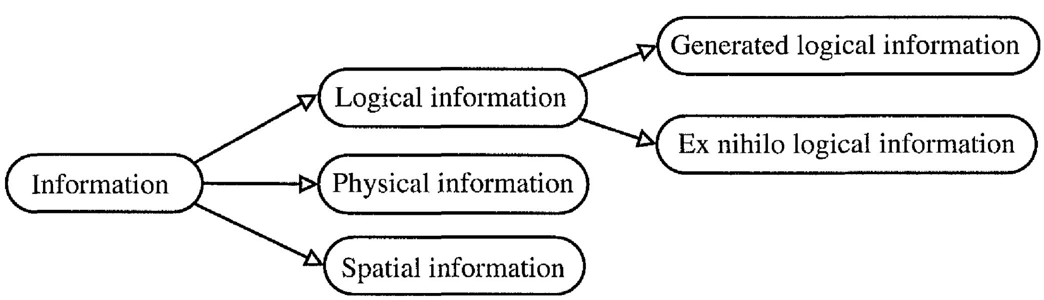


Figure 4.6: Information classification

4.4 Summary

We described in this chapter a theoretical model of a VE for public consultation. We detailed the different elements of this environment, and how they are linked together. So we saw that the environment contains a model and information which can be divided into different classes.

The next task is to think about how people visit and interact with this environment, dealing with its different components we described. Therefore, the next Chapter focuses on interaction inside the environment.

Chapter 5

Interaction within the Collaborative Environment

Having described the environment, we now study how people experience it.

First, we define who are the people we expect to visit the environment, by separating them into different groups. Then, we investigate the different possible interactions we can have between the users and the environment we defined before. And finally, we investigate how to manage these interactions between these people and the environment.

We do not discuss navigation in this chapter, as this depends on the choice of representation of the model. This issue is raised in Chapter 8. Therefore, this chapter focuses only on specific interactions related to public consultation. We do not discuss the way people carry out these interaction as well, in term of user interface, as this depends mostly on implementation choices. This is also addressed in Chapter 8.

5.1 Populating the Environment

We can subdivide the users, who may interact the environment, into three groups.

First, there are people managing the environment. They can be compared to the "root" user on a Unix-like system. Their role is to make sure the system is working properly. During a consultation they may ban users who disturb the consultation, or allow some people to do some specific interactions. We call them **managers**.

Next, we have the people modelling the environment. They correspond to programmers on a computer system, and are the urban designers of the virtual cityscape. Their role is to modify the environment. They can also access feedback from consultations. We name these users **designers**.

And finally, there are the people visiting the environment. They can be considered as program users on a computer system and are the public of an urban planning consultation. These users mainly access information from the environment and leave feedback. We call these users **visitors**.

Obviously there is a hierarchy between these three groups, and so a manager may model the environment, and designer can also just visit the environment. Figure 5.1 illustrate this hierarchy.

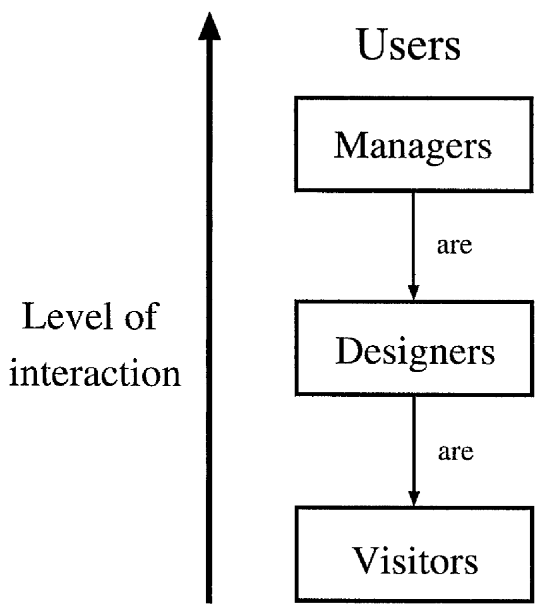


Figure 5.1: User groups hierarchy

We explore in the next sections the different kinds of interaction between the users we defined and the environment. First, we investigate interactions between people and the environment, then interactions between people themselves, and finally we discuss a way to manage these interactions.

5.2 User-environment Interactions

These interactions deal with the environment. So they can be related to the model or information. Other interactions deal with managing the ways the model is linked to information inside the environment. Therefore, we define three main types of interactions:

- Model-related
- Information-related
- Environment-related

We now describe each of them.

5.2.1 Model-related Interactions

These interactions are about modifying the model, which includes adding and removing parts of the model. We define two possible classes of interactions:

First, we have **active local interactions**. The model is modified, but only locally (not on the server). This allows visitors to modify the environment without affecting the other users' views of it.

And then, we define **active remote interactions**. The model is modified for everybody. This kind of interaction may not be allowed to visitors, as they affect the whole distributed environment.

5.2.2 Information-related Interactions

These interactions are about accessing and leaving information. They are critical, as they are deeply involved during the consultation. We define three possible interaction classes:

First, we consider **passive interactions**, which are about getting information from the environment. Information can be from the model or the consultation.

Then, we define **informative interactions**, which are about adding or modifying information on the model. These interactions are restricted to designers.

Finally, we have **consultation interactions**, which are about adding or modifying consultation information on the environment. These interactions are used by visitors when they leave feedback.

5.2.3 Environment-related Interactions

These interactions are about the management of the environment, such as adding or removing information and consultation boards. They are very similar to the model related active remote interactions. They are restricted to designers.

5.2.4 Summary of User-environment Interactions

Figure 5.2 summarises the different kind of information we defined.

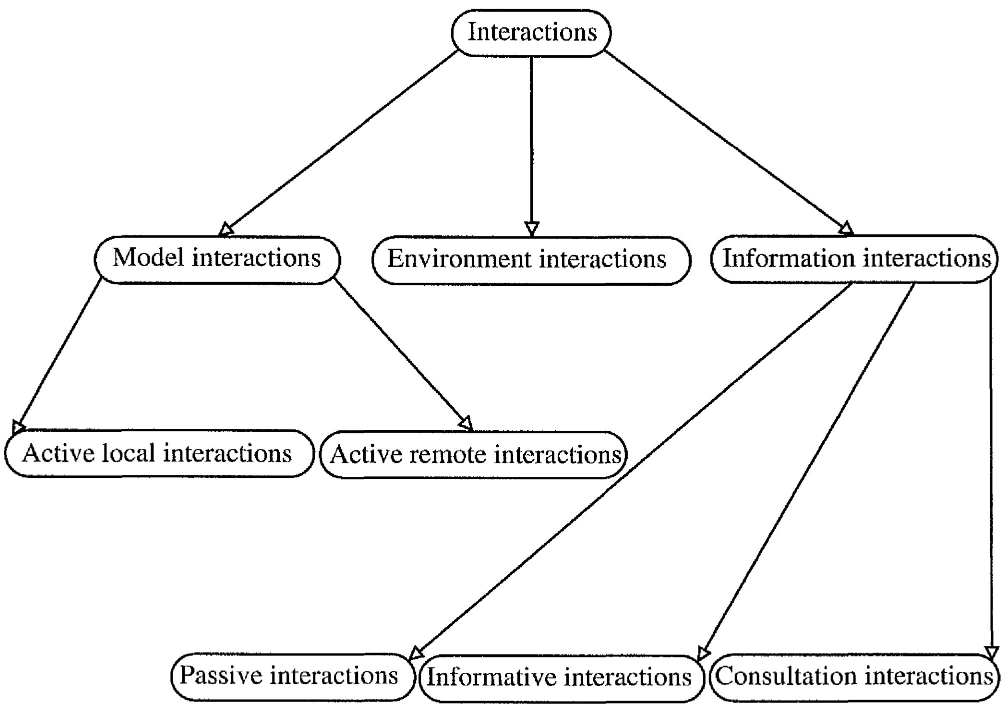


Figure 5.2: User-environment interactions classification

5.3 User-user Interactions

These interactions deal with communication between users, such as chat for example. Indeed, communication is a vital factor during a collaborative task. Consultation can be considered as a collaborative task, as a feedback from a group of individuals is not the sum of their respective feedback.

There are two ways communication can be achieved:

- First, communication can be private, concerning a group of two (or more) users. This can be useful when some people want to discuss about the feedback they want to give.
- Then, sometimes it can be useful to reach all the users by using broadcast messages. For example, a designer who made a modification on the model may want to inform all the participants.

5.4 Users and Interactions Management

Having all these different interactions and user types, it becomes necessary to manage these interactions according to the different kinds of users. Indeed, depending on the model, some users are allowed or not to do some interactions. Instead of using a static allocation, the idea is to apply Unix file-system features to the environment. We can thus see an interaction as an action (similar to shell commands on Unix) that some people (similar to Unix users) can perform on some objects (similar to files and programs).

During a consultation, the manager users interact with the other users, giving them "rights" on interactions, as would do the root user on a Unix system. So these interactions, which can be considered as meta-interactions, allow the interaction allocation to be real-time.

Why use flexibility? Consultations can vary from one to another. For example, we could imagine a first consultation, where public is only allowed to walk through the environment. Another consultation may involve some minor modifications of the environment in order to refine a proposal. So, a dynamic interaction allocation seems to be a good solution.

Then, why use real-time interaction allocation during a consultation? The idea is here to enhance the way consultations are made. Someone from the public could have at some point a design idea. A manager could hear him and allow him to express this idea (for example move an object) by giving him the appropriate right on some interactions. For urban planning, this idea seams interesting, as for now it is obviously impossible for someone from the public to modify the city model during a consultation.

Figure 5.3 summarises this section.

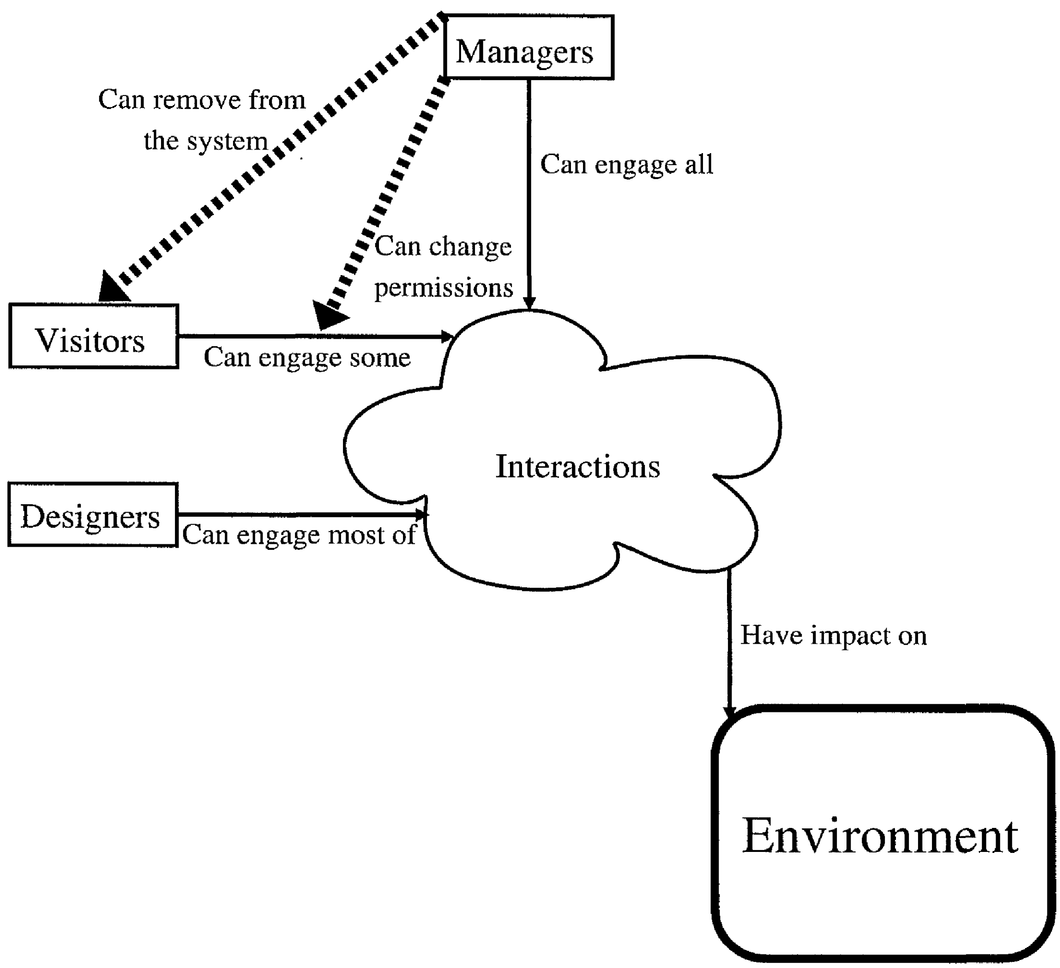


Figure 5.3: Users and interactions management

5.5 Summary

In this chapter, we studied how people would interact inside the environment. In order to do this, we first classified the different people who would visit this kind of environment. Then, we classified the possible interactions they can perform there. Finally, we talked about ways to manage these interactions, so their allocation can be flexible.

The continuation of the thesis focuses exclusively on urban planning, as it is the targeted application we selected. Therefore, the next Chapter focuses on the design a cityscape environment from the theoretical model we described in these two last chapters.

Chapter 6

Designing the Cityscape Environment

Having described the environment in a general way, we now focus on the specific cityscape environment. In this chapter, we describe the design of this environment. First, we discuss the design of the environment. Then, we focus on the design of interaction. And finally, we talk about the design of distribution.

6.1 Design of the Environment

In this section, we focus on the design of the environment itself, first on the city model, and then on information.

6.1.1 The City Model

The design of the city has been made object-oriented. Figure 6.1 shows a basic class diagram of the three layers of the model. Such kind of design has been used in various virtual cityscape development [TD00, FBT99].

The city contains an area tree, which define the logical layer of the data structure. Any area can contain city items, which can be pedestrian areas, buildings, crossroads or road segments. This is the physical layer. Then, all city items have an object to describe their 3D representation. This is the 3D layer. There is also the `Landmark_3D` class, standing for landmark objects which are on pedestrian areas.

We explain here some methods:

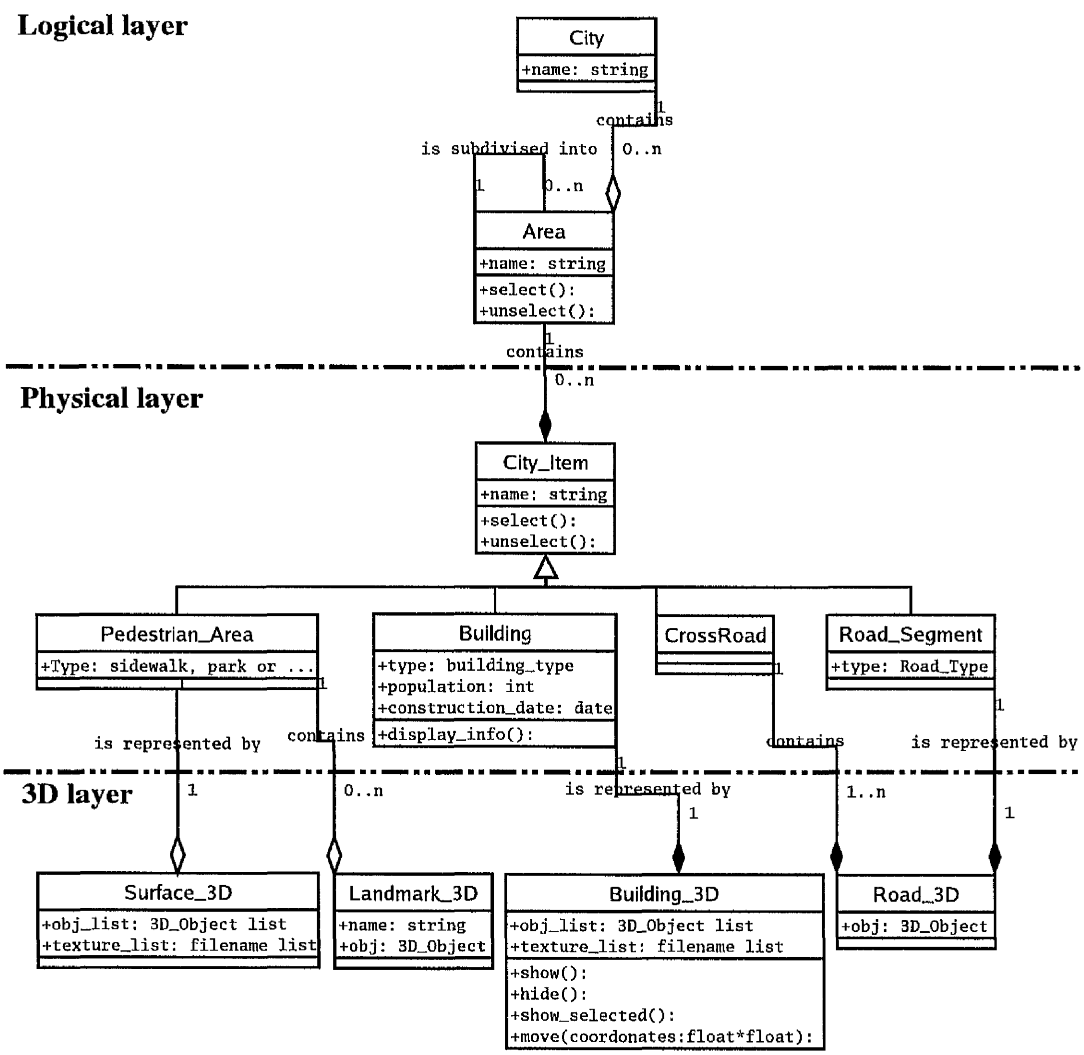


Figure 6.1: City model class diagram

- The `select()` and `unselect()` methods in class `Area` are used to set if areas are working areas, which means areas in which consultations are launched. Therefore, they are the areas in which users are able to interact with objects. The corresponding methods in class `City_Item` set if an object can be used for interaction.
- The `display_info()` method in class `Building` displays a piece of physical information about the building, such as the building type or its population.
- The `show()` and `hide()` methods in class `3D_Building` are be used to set if the object is to be displayed. This can be useful for slow computers to reduce complexity this way (buildings are large objects). The `show_selected()` method shows the building only if its physical corresponding object is selected.

6.1.2 Information

We investigate now how we design information, considering how we described it in Section 4.3. We decide to restrict information to text (this could be extended to other form of information, as sounds or video). So we can now classify information in a design way (Figure 6.2).

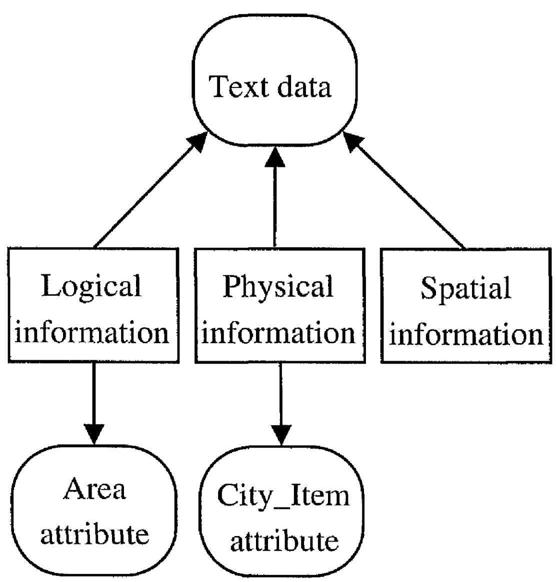


Figure 6.2: How information is represented

A part of information is therefore on attributes of objects from the model. We can consider them as part of the model, we described in the previous section. So we focus only on the "text data" structure from Figure 6.2.

Figure 6.3 shows the class designed for text data. It is an abstract class, from which inherit two classes, one for comment data and the other one for model information data.

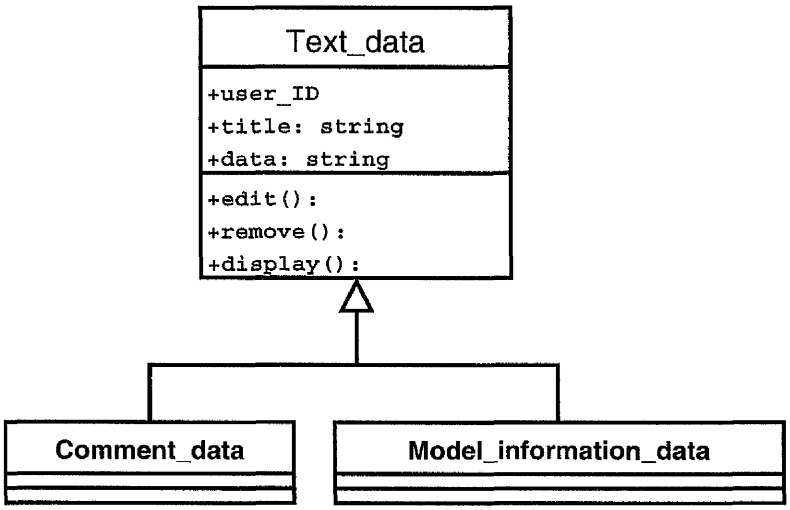


Figure 6.3: The `Text_data` class

Next we discuss how these pieces of information are linked to the model, first if information is on model and then if information is spatial.

On Model Information:

Figure 6.4 shows how this information is linked to the model. The class linked to `Area` describes logical information, and the one linked to `City_Item` describes physical information.

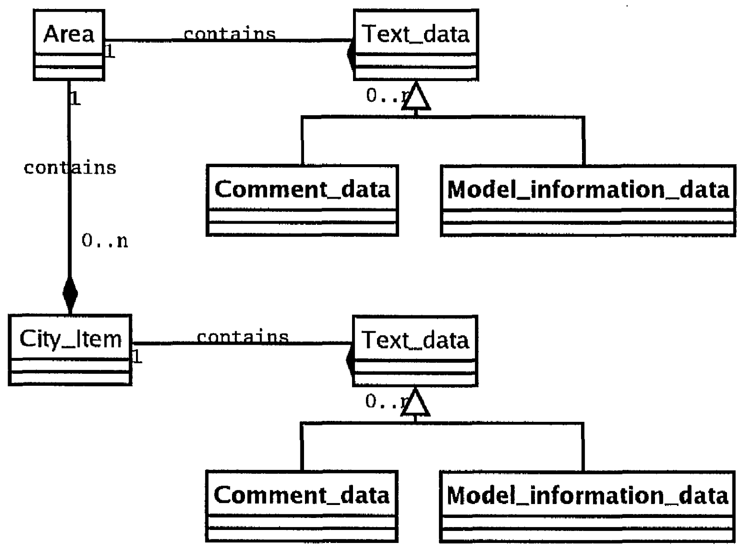


Figure 6.4: On model information design

Spatial Information:

To deal with spatial information, we define the `Information_Board` class (Figure 6.5), which contains this kind of information.

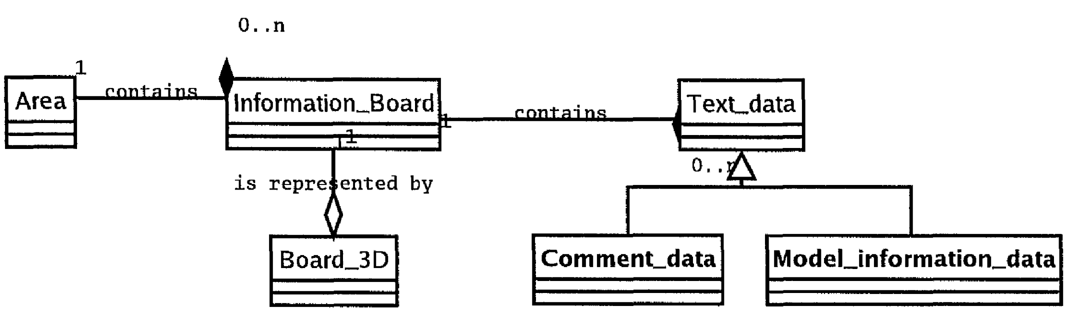


Figure 6.5: Spatial information design: the `Information_Board` class

6.1.3 Summary of Environment Design

Figure 6.6 summarises the design of the environment. We can make a parallel with Figure 4.2 on page 62 from Section 4.3.1.

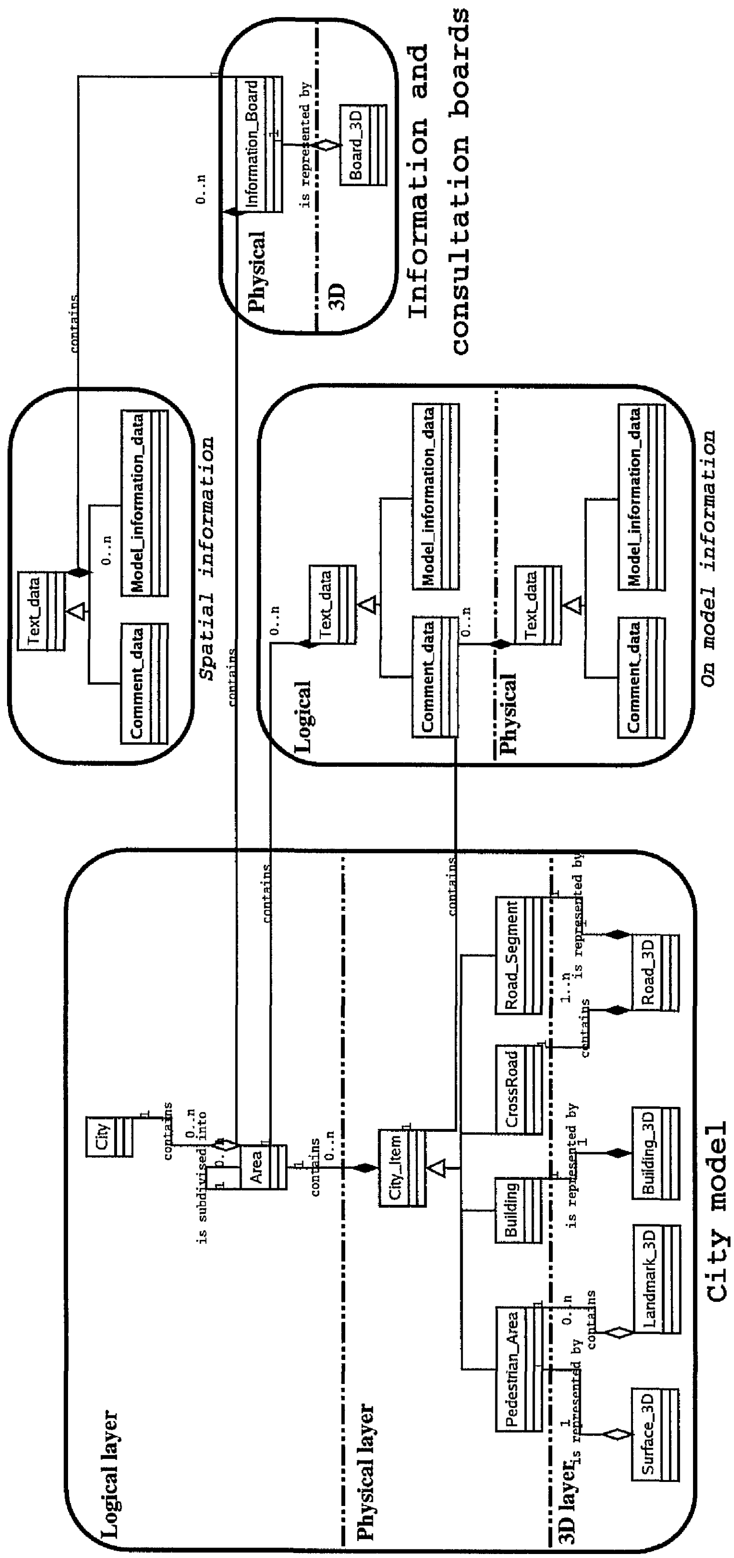


Figure 6.6: Design of the environment

6.2 Interaction Management

In thus section, we discuss user-environment interactions management. User-user interactions can be considered as messages going through the network interface, as designer in Section 6.3.

First, we must design the different users, we defined in Section 5.1, who inhabit the environment . In order to do this, we design the `User` class (Figure 6.7).

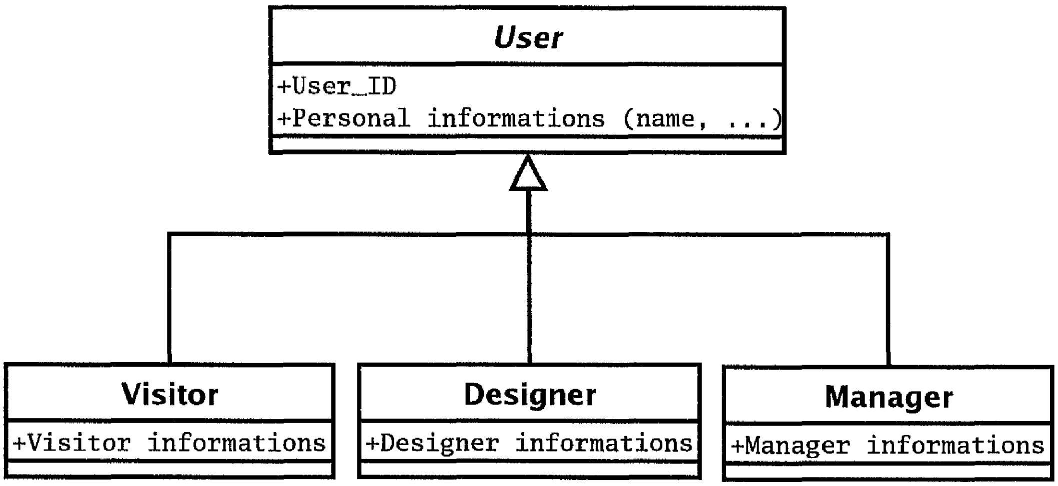


Figure 6.7: The users class definition

As shown, we use a virtual class from which inherit the three user classes. So, the attributes `Personal informations` are common to all users, such as their name. `User_ID` is a unique identifier to each user. It is used, for example, when someone leaves a comment or some information data (Figure 6.3 on page 78). So the ID allows to retrieve information about the user who wrote this piece of information. In order to do that, it is necessary to save on the server the users list, for these data to be persistent. Therefore, the first time a user connects, he is asked to enter his personal details, and then be given a User_ID. And the next times, he only has to enter this ID.

Each class of user has its own attributes. This can be useful for the `Visitor` class, as some personal information can be used to make an analysis of the feedback.

Then we define the `Interaction` class (Figure 6.8).

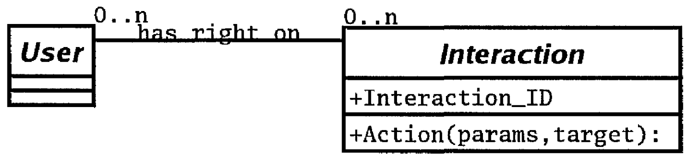


Figure 6.8: The `Interaction` class

The link between the User and Interaction classes represents the rights users have on some interactions, as described in Section 5.4. Managers manage interactions simply by adding and removing these links.

The `Interaction` class contains an identifier, `Interaction_ID`, which is used for network messages. Section 6.3 describe distribution design.

Basically, an interaction is a combination of an action and a target. The target is the object of the environment, which is involved in the interaction, and the action method is the piece of code corresponding to the interactions, with parameters if needed. The Interaction class is abstract. The "real" interaction classes inherit from it. Table 6.1 gives some examples of possible interaction classes.

Interaction	Action	Target	Parameters
Move a building	move	Building_3D	coordinates
Rotate a landmark object	rotate	Landmark_3D	angle
Add a comment to a board	add comment	Information_Board	comment_data
Read information on a board	read info	Information_Board	none
Get generated information	get generated info	Area	information type
Add a building	add building	Area	Building
talk to someone	talk	User	message

Table 6.1: Example of interaction classes

The "Get generated information" interaction deals with generated logical information seen in Section 4.3.4. There are different ways to get and display this information, as generated pieces of information can be very different from one to another (it can be for example the population of an area, or the function of each building of the area). Section 8.3 discuss how these different kinds of information are displayed.

Now that we defined the users and interactions, we focus on how a consultation itself is managed. In order to do that, we define the `Consultation` class (Figure 6.9).

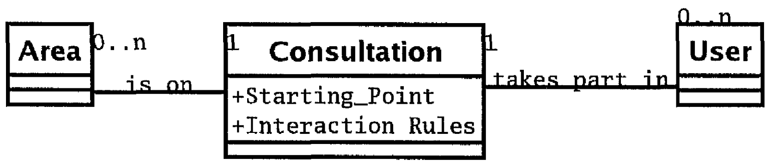


Figure 6.9: The `Consultation` class

When a user connects to the environment, he accesses the `Consultation` class, and so is aware of the concerned area of the consultation, the interactions rules and gets starting coordinates in the 3D space (`Starting_Point`). Reading the `Interaction Rules`, the user class can be linked to the interactions he has rights on, and then he can be transported to the starting coordinates, ready to participate to the consultation on the selected area.

With this design it becomes possible to handle multiple consultations on the same model. Indeed, using multiple instances of the consultation class, people can participate to different projects. These consultations do not interfere one with another, if we enforce that an area cannot be linked to more than one consultation, as stated by Figure 6.9, and that a consultation cannot be linked to a "son" of an area already linked to another consultation in the area tree. Therefore, no object in the city model can be linked to more than one consultation. The multiple consultation process can be useful for a large city, in which multiple projects are run.

6.3 Distribution

In this section we discuss on the design a possible network interface. We first focus on the chosen architecture, and then we talk about issues about the environment, which are raised by distribution, in design terms.

6.3.1 Distribution Architecture

We chose a client-server architecture. The reason for that, which is obvious, is that there must be a persistent place to store city data, as people connect to the environment only during a limited time. Furthermore, this seems to be a good architecture in terms of bandwidth use, as we want to connect low-bandwidth computers to a high-bandwidth server (there are fewer bandwidth restrictions for the server, as it can hosted by big companies or administrations, such as city councils). Besides, this architecture has proved to be effective on MMORPGs software we discussed in Section 2.2.3.

The city data are on a server, on which multiple clients can connect. As the environment is to be distributed, it is necessary to adapt our model. The idea is that clients build the city locally, from script data sent by the server. Then, the network is only used for updates (modification of a building, adding a 3D landmark,...). So, this way, the communication process does not use too much bandwidth. When a client modifies the city, it sends an update request to the server, which distributes it to the other clients. The idea is to send a script command, in order to minimise the use of the network. Figure 6.10 shows two examples of the network interface usage.

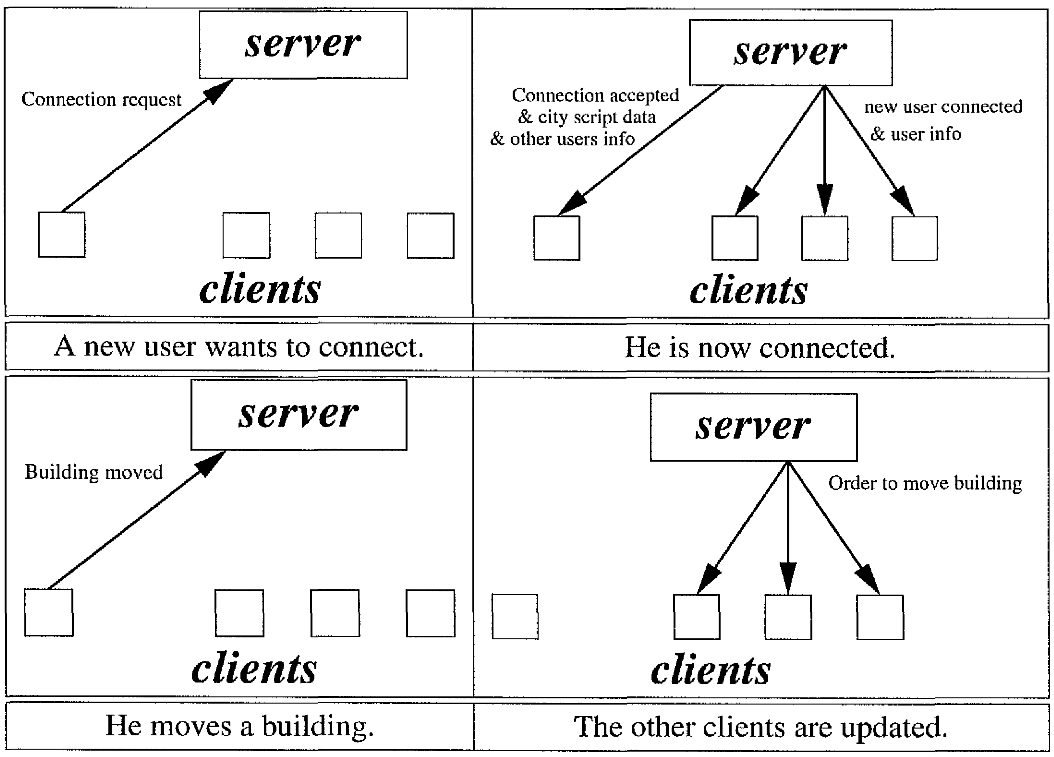


Figure 6.10: Network running examples

6.3.2 Objects Indexing

To use script remote messages, it is necessary to create an index of all the objects which can be modified to use in the network messages. Indeed, these objects need to have a unique identifier to be sent through the network, so the receiving computer knows which object is concerned. This Section raises the issues of objects indexing.

First, we have to set which objects are on the index. We must choose a minimum of objects, in order to minimise the use of the bandwidth. However, all the objects of the city model are concerned. Indeed, every object from the 3D layer can be modified (for example moved), as well as every object from the physical layer (for example a change on some attributes), as well as areas (for example adding new pieces of information or new objects). Even the "city" object is concerned; however this last one does not need to be indexed as it is unique. Still, some objects do not need to be indexed, as they refer to other objects. This is the case for `Surface_3D` and `Building_3D`, as they are linked to the corresponding objects of the physical layer. Therefore, they can be accessed by these objects. However `Landmark_3D` and `Road_3D` objects need to be indexed.

Finally, we have to design the index. The idea is to design a superclass of the indexed objects, called `Indexed_Object`. So `Area`, `City_Item`, `Road_3D` and `Landmark_3D` inherit from this class. Then we can use an index table to link these objects to their identifiers (an `Objects_Index` object). Figure 6.11 shows the design of the `Indexed_Object` class.

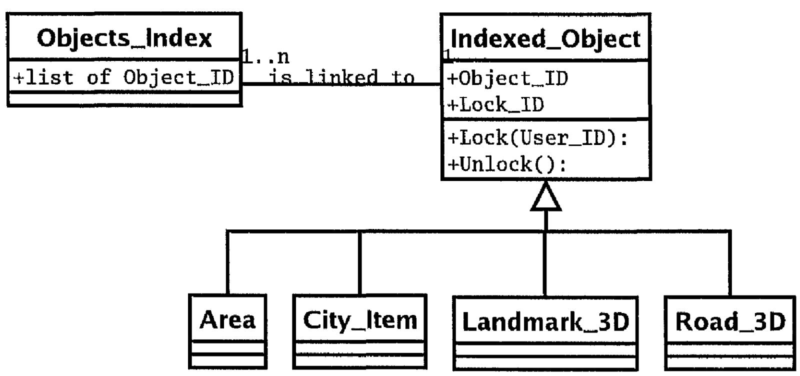


Figure 6.11: Objects indexation design

6.3.3 Locking Mechanism

Here, we discuss the issue raised when multiple users try to interact with the same object at the same time. If the interaction is passive, which means the object is not modified (for example accessing information), we can allow many users to perform the action at the same time. However if the object is modified, we must ensure that it is done by only one user. In order to do that, we need to implement a control mechanism.

The idea is to implement a locking mechanism, as in the DIVE platform[CH93]. So when a user wants to modify an object he has to lock it. This is the use of the `Lock` method of the `Indexed_Object` class from Figure 6.11. When the object is locked by the user (the `Lock_ID` attribute is a reference to the `User_ID` of this user), he can perform the interaction. After that the object can be unlocked.

There may be some abuses on objects locking. For example if someone locks an important object and takes his coffee break that would raise some difficulties for the whole consultation! To face this problem, we choose to restrict that a user can only lock one object and we allow the manager users can unlock any object. Other means can be considered, such as using an inactivity timer.

6.3.4 The Initial Stage

We describe in this section the initial stage, when a client connects to the server.

Each client is loading city script and then building the 3D city locally. But, what about the textures and 3D models? They need to be sent too (we could assume that each client has already a set of textures and 3D objects and that only they can be used, but that would highly limit the design). They can be sent the first time, and then be referenced on indexes, an index for the textures and another one for 3D models. So when the city is loaded, the client checks if the texture or corresponding 3D object of each item is in the index. If not, the file is loaded and added to the index, so it does not have to be loaded the next time. Figure 6.12 shows the process.

As we are dealing with large scale cityscapes, an other problem could occur, as most of the city amount of data is represented by texture and complex 3D models. So it would take a lot of time to load the whole city the first time. Still, a consultation focuses on a particular area. So the idea is to load only textures and 3D objects from this area, as objects of the other areas can be rendered by simple objects, as suggested in Section 4.2 on page 60.

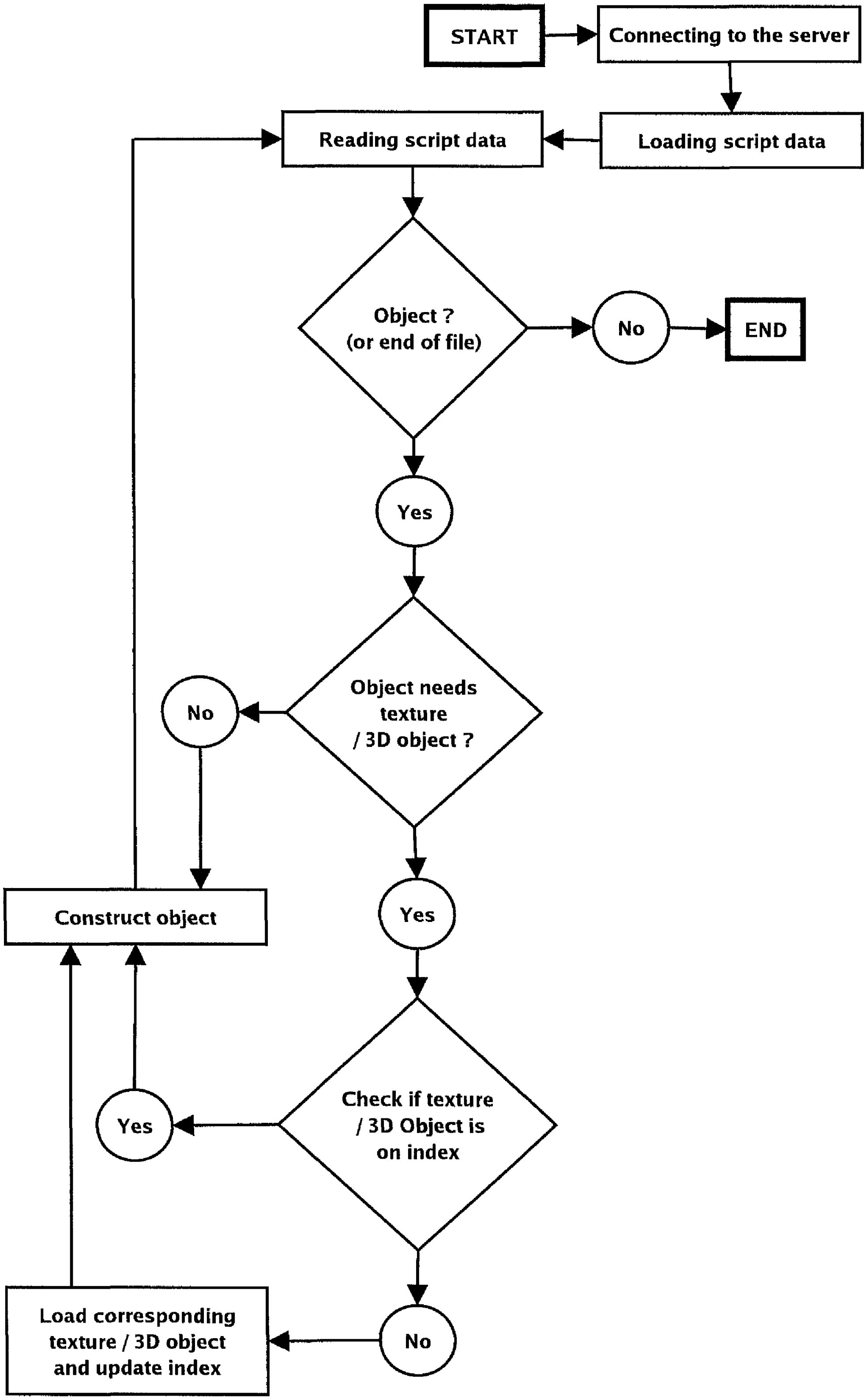


Figure 6.12: Initial stage process

6.4 Summary

We designed in this chapter a cityscape environment for public consultation, including the interactions management and distribution.

Having these design specifications, we can now think about implementing a prototype model, following them, for experimental use. Chapter 7 focuses on the implementation of this prototype.

Chapter 7

Implementation of the Cityscape Environment

In this chapter, we discuss the development of the cityscape environment used to run the experiments. After having described the specifications of this prototype environment, we first describe the development of cityscape model. We focus here only on the 3D layer, as development of the two other layers is simple, following design specifications. We then specify a language to describe the city data we implemented, which is used for data archiving. But first, we explain the implementation choices we made.

7.1 Choices of Implementation

In this section we explain the technical choices we make for the implementation of the prototype environment.

7.1.1 Cross-platform Ability

As the general philosophy of the application is its availability to numerous users, an important point is to make it work on multiple platforms. Therefore, we have to prove that the technology was easily implementable on different computer systems.

That is why we decided to work on a cross-platform implementation. We chose to implement the environment on both windows and Linux operating systems. Indeed, windows is the most used operating system by the general public, and Linux, which is highly supported by the scientific and academic communities, becomes more and more popular.

7.1.2 The 3D Language

The next choice is about the 3D computer graphics language. There is the possibility to use a high-level 3D graphics description language, such as VRML or use a low-level 3D graphics programming library such as OpenGL[Ope].

A high-level language has its advantages, as it is usually cross-platform. However, as we saw in Section 2.1.2, such languages have limitations with dealing with interaction with large scale VEs, and a library allow more flexibility for programming. Therefore, we decided to use a low-level programming library. We discuss the chosen library in Section 7.3.1.

7.1.3 Programming Language

The next step is to choose a programming language. We decided to use the C++ language to implement the environment. There are numerous reasons for this:

- First, we need a language with cross-platform ability. C++ has become a highly used standard, with many libraries and compilers available on most of the computer systems.
- Second, the C++ language is an object oriented language, which was required by our design.
- Third, C++ is a more efficient object oriented language compared to other languages such as Java.
- Finally, the C++ language is very used in computer graphics, and so offers many useful libraries to implement a VE.

7.2 Specifications of the Environment

In this section, we discuss the chosen interactions and information to implement in the prototype for experimental use. The way these interactions are performed and information is displayed is addressed in the next chapter.

7.2.1 Information

We describe here which kind of information we implemented, and on which form they are described. This follows the design specifications from Section 6.1.2. We separate model from consultation information.

Model Information:

Model information is brought by professionals. For each information type, we describe logical, physical and local information.

- First, we consider logical information. As we saw in Section 4.3.4, this information is divided into two kind of information, ex nihilo and generated logical information. We describe each of them:
  - Ex nihilo logical information is simply displayed as a single text description, as an implementation of the `Text_data` class from Figure 6.3 of Chapter 6 on page 78, about the selected area.
  - As generated logical information, we decided to use a panel of possible information. We selected the total population of the selected area, the medium height of the buildings of the area, the population of the buildings of the area, and the type of the buildings of the area (public building, residential building, office building or private building).
- Second, we have physical information, which is information about an item of the city. It is its attributes (for example the height if the object is a building), and possibly a text description.
- Finally, local information is displayed as a text description stored in the information boards.

Consultation Information:

Consultation information is contained inside the comments left by people during the consultation. Comment data are simply a text description with a reference to its creator, following design specification from Section 6.1.2. We now describe each kind of consultation information.

- First, there is general consultation information, which we name general comments. To reduce the complexity of use, we decided to include these comments to the consultation boards. Indeed, in Section4.3.2 we noticed that local information can be sometimes considered as general information. Therefore, a consultation board can be assigned to general comments. This way, people should be less confused.
- Then, physical consultation information can be considered as comments on the objects of the city. We stated that it is possible to comment on every object of the city.
- Finally, local consultation information is local comments located on consultation boards. We define two kinds of consultation boards:
  - On one hand, there are those who are placed by the designers of the environment. These boards are key points of the consultation, and are so placed on strategic places on the cityscape. Some of them can be associated to general comments, and others to local comments. We can qualify them as "public" consultation boards . These boards contain a list of comment from the different users who used them. They can be sometimes located at the same place as the information boards. In order again to reduce confusion and complexity we decided to merge these two boards, and call them simply **boards**. Therefore, these boards contain both a text description and comments from people.
  - On the other hand, the users can add their own consultation boards during the consultation. That allows them to comment from their own point of view, and so add more precise information than it would have been using public consultation boards. We simply call these boards **free comments**. Each of them only contains the comment of its creator.

7.2.2 Interactions

In this section we describe the different interaction we decided to implement for the prototype environment. The idea is to use a panel of possible interactions to study how people manage them. So, as the experiments are based on the consultation, we focus on the interactions required only for this task, as well as some environment modification interactions. We describe the implemented interactions, using the classification from Figure 5.2 on page 71:

- Model-related interactions:
  - Active interactions:
    - Move an object
    - Rotate an object
    - Change colour/texture of an object (not applicable to landmark objects)
- Information-related interactions:
  - Passive interactions:
    - Display ex nihilo logical information from an area
    - Display generated logical information from an area
    - Display physical information from an object
    - Display local information from a board
    - Display comments from an object
    - Display comments from a board
    - Display a free comment
  - Consultation interactions:
    - Comment on an object
    - Comment on a board
    - Leave a free comment

7.3 The 3D Layer

Having described the choices of implementation and stated the prototype VE, we now focus on the development itself. We had to develop a specific 3D layer to represent the city 3D objects as buildings, roads, crossroads and pedestrian areas.

7.3.1 The Maverik Library

We decided to use the Maverik[HCK$^+$01] library to represent our objects in 3D.

Maverik (MAnchester Virtual EnviRonment Interface), developed by the Advanced Interfaces Group at the University of Manchester, is a C toolkit for managing display and interaction in stand-alone single-user VE applications. it includes 3D objects creation and manipulation, navigation and interaction. It uses OpenGL[Ope] to render the 3D objects.

Therefore, the objects of the 3D layer are implemented using Maverik. In order to do that, the idea is to design objects containing Maverik 3D data structures describing the geometry of the city items. Indeed, as Maverik is a C and not a C++ toolkit, there are no Maverik objects, but only Maverik C structures.

7.3.2 The 3D Layer Classes

To fit Maverik functionalities, some changes need to be made to the class diagram. Figure 7.1 shows the new 3D layer class diagram.

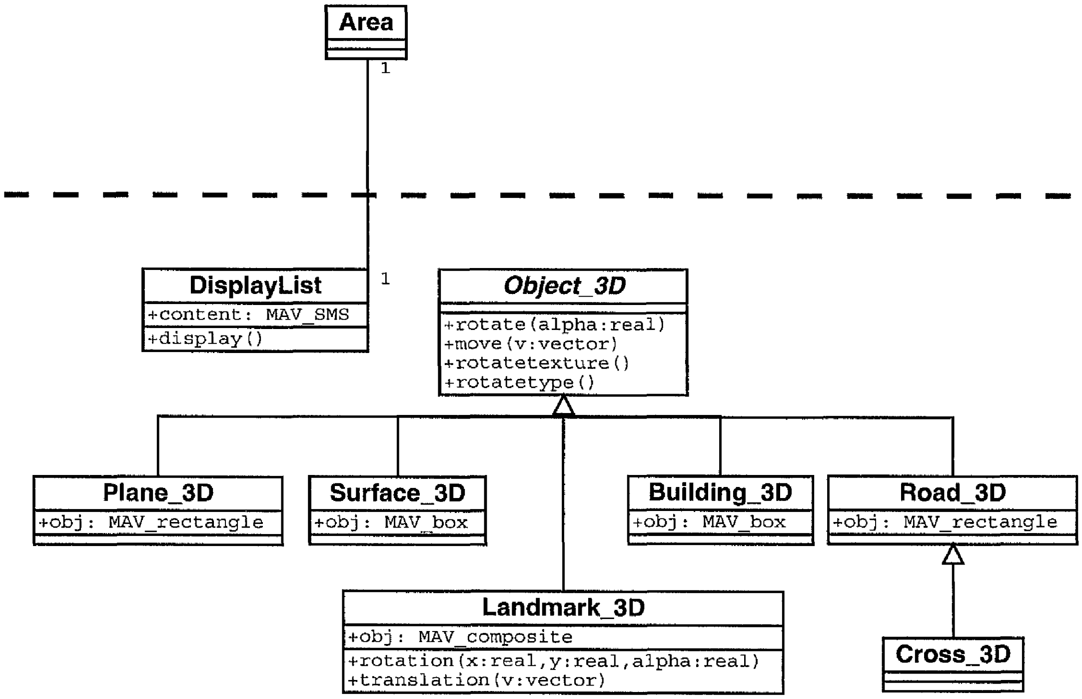


Figure 7.1: 3D Maverik Layer

The first change is the creation of an abstract super class called `Object_3D`. Each 3D object class inherits from this class.

The second change is the creation of another class called `DisplayList`, which is linked to the `Area` class. In fact, each `Area` object contains an instance of this class. It is used to display the 3D objects on screen. Indeed, it contains a list of the Maverik 3D objects to be displayed. The idea of having one display list for an Area is to allow easily different levels of detail to be used, as we want to distinguish the different areas. This can be useful to see well which objects belong to which area. So, when a 3D object is created, it is added to the list.

The third change is the creation of a `Plane_3D` class, representing the ground plane. It is not a part of the city model, but is required to render the ground.

The last change is the creation of a `Cross_3D` class. Previously, the idea was to use multiple 3D road segments to describe a crossroad. However using a dedicated object is more practical. Therefore, the link between `CrossRoad` and `Cross_3D` objects is now the same as for the road objects. We can also see that the `Cross_3D` class inherits from `Road_3D`. Indeed, for now we use the same Maverik 3D object to describe crossroads and the road segments. Another change is that `Road_3D` does not need to be indexed anymore, as it was stated in Section 6.3.2.

The `Object_3D` super class has `rotate()` and `move()` methods. These methods are used to rotate and move the corresponding Maverik 3D objects. They are called when the user wishes to move or rotate an object. Theses two methods are implemented differently according to the class, as there are some constraints:

- The class `Plane_3D` is fixed, so the two methods do nothing.
- The class `Surface_3D` is linked to a class containing `Landmark_3D` objects. So, when moving or rotating this object, the methods must call methods of these `Landmark_3D` objects to move with the surface. These methods are `rotation()` and `translation()`.
- The `Landmark_3D` objects are bounded inside their associated `Surface_3D` object and so cannot be moved beyond it.

Objects can be textured or coloured. The `rotatetype()` method is used to change the rendering mode between textured or coloured, and the `rotatetexture()` method is used to change the colour or texture of an object.

7.4 Visualisation

Having described the 3D layer, we now discuss the visualisation of the environment. We first focus on the level of detail, and then talk about how we decide to represent the boards.

7.4.1 Level of Detail

Detail level is an important part, as it must be balanced to fulfil two opposite aims, which are visual realism and performance. Indeed, they are opposite, as a better visual realism of an object is associated with a higher complexity of its 3D model, and so a decrease of performance. There are different factors we can use to play on the level of detail. We now describe each of them, with the choices we made on these factors for implementation.

1. First, we have to decide on the geometry of the objects. As the targeted application is urban planning, we do not need to use a too complex object geometry, as architects use usually simple clean models. Therefore, we decided to render buildings as simple textured or coloured rectangle objects. This is not a too bad approximation, as usually real buildings have this shape. Figure 7.2 shows the building geometry.

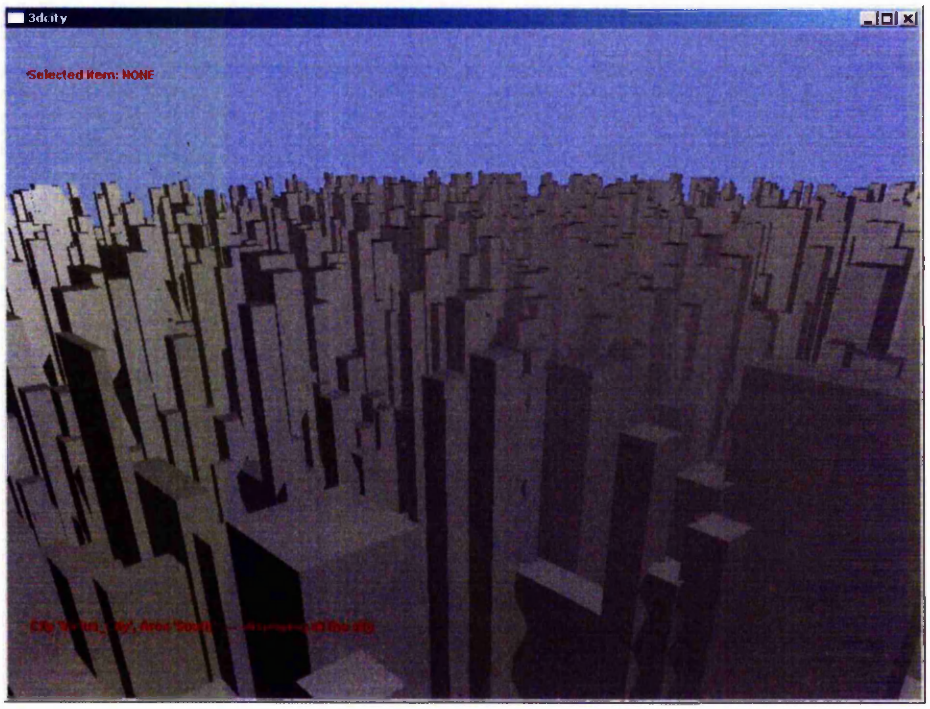
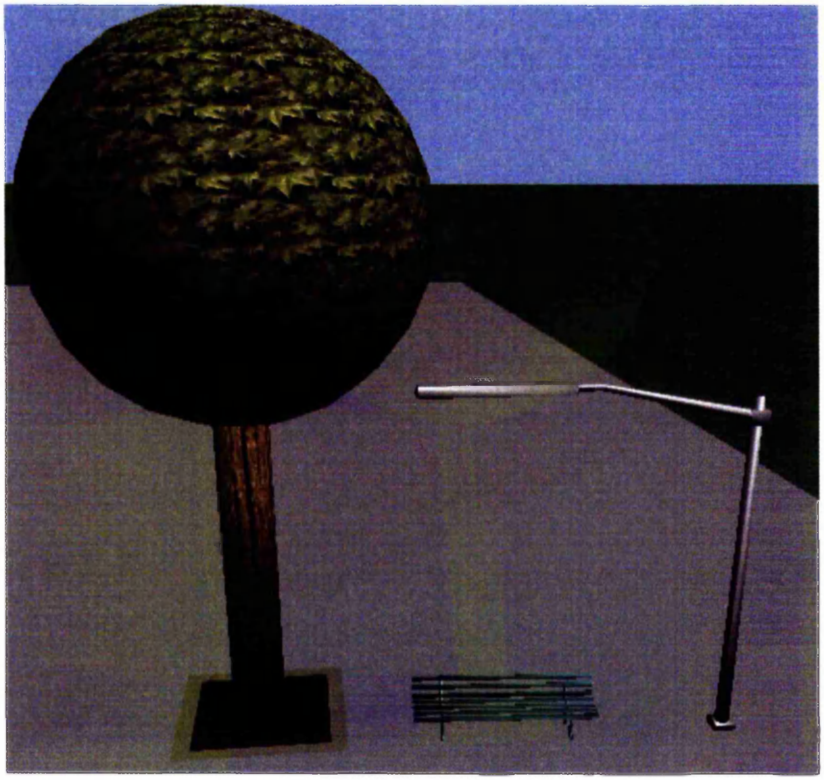


Figure 7.2: Buildings geometry

To render landmark objects we need a higher geometric complexity, as we want them to be realistic enough. We used AC3D[AC3] models to represent these objects, and selected the lowest possible complexity keeping these object realists. Figure 7.3 shows some of the objects.



The tree uses 181 surfaces, the bench 608, and the street light 212.

Figure 7.3: Some landmark objects.

2. The second factor is the use of different levels of detail to display different objects. As during a consultation only the area linked to the planning proposal is to be explored in details, we decided to use a low level of detail to render the other areas. Therefore, for these areas, we do not use texture on large objects and we do not display landmark objects. This helps reduce the complexity, and it becomes also easier this way to visually separate the consultation area from the other ones. Figure 7.4 shows the display of the consultation area surrounded by the other areas.

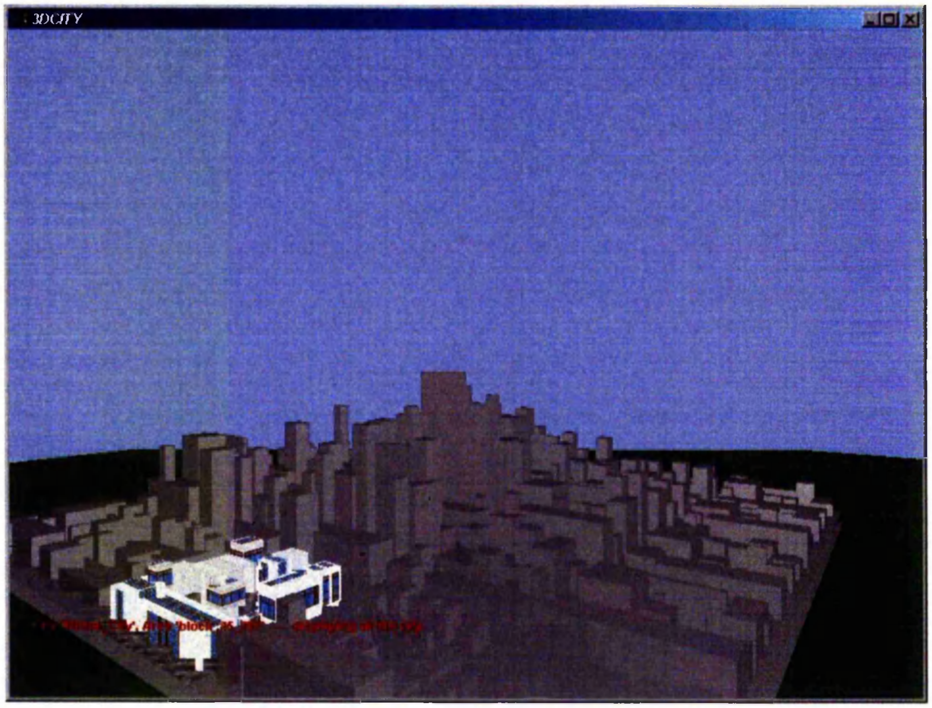


Figure 7.4: Use of different levels of detail

3. The third factor is the use of distance to change level of detail, by using a lower level of detail for distant objects. For large objects, we can use a "fog" to not render distant objects, and for landmark objects we can choose to not display them if they are distant enough. This is a good way to improve performance. However we did not use it. Indeed, concerning the consultation area, there is a need to display the area with full level of detail, so people will be able to watch the proposal from any point of view. Concerning the other areas, there is no need to hide small objects as we already use a lower level of detail on them, and large objects have to be always shown as we want users to be able to have a view of the whole city, so they can see the impact of an urban project from a global point of view.

4. The last factor is the use of 3D acceleration and possible optimisations to improve performance. First, there are 3D hardware acceleration and some optimisations which are directly supported by the used 3D language. As we use OpenGL, 3D acceleration and some optimisation, such as vision culling, which does not render objects out of the vision field, are directly supported. There

are then some optimisations we can use at the software level. We used backface culling, which chooses to not render inner surfaces. However we did not consider occlusion culling, which is frequently used to display large scale environment as cityscape as we saw in Chapter 2. Indeed, this optimisation is not effective for some views, especially above root height. Furthermore, it is not really suitable for real-time model modifications, as it needs a pre-processing task to analyse the environment. Obviously, as 3D computer graphics hardware technology and research progress, it will be possible to increase the level of detail in the future, using new optimisation techniques.

Having set up the level of detail, we could carry out a performance experiment in order to assess if the environment is suitable for use on standard computers. This experiment is described in the next section.

7.5 Performance Experiment

7.5.1 Description of the Experiment

The goal of this experiment was to ensure that the model is suitable for public consultation, in the sense that we do not want technical limits to affect people during consultation. We therefore had to see if the chosen model was suitable for standard computers, in term of display performance. The best way to test that was simply to measure the frame rate.

Frame rates were measured on two different computer systems. The first, a Pentium III 450Mhz / Geforce 2 GTS Linux machine, can now be considered as a low-performance range computer system. The other one was an Athlon XP 2000+ / Geforce 4 Ti4600 Windows XP machine, which can be considered as a middle-performance range computer system.

We divided the city into blocks (Figure 7.5 shows one of them) of 15 buildings. Each block contains also 3D landmarks.

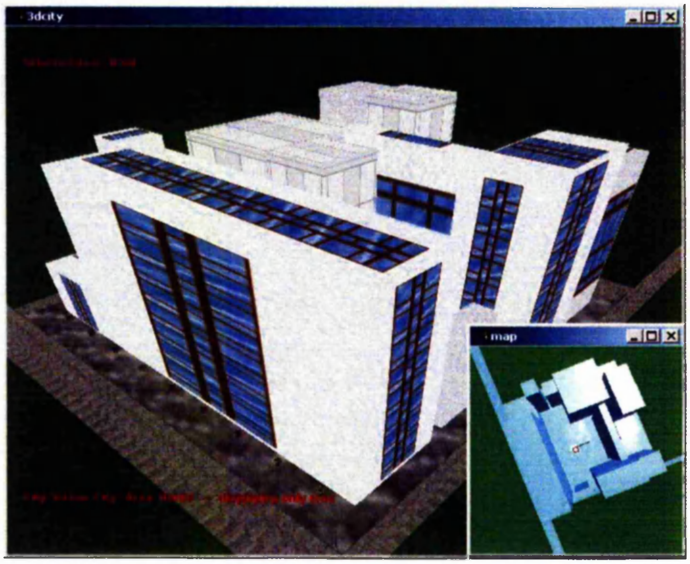


Figure 7.5: A city block

We selected a block to be the consultation area and varied the total number of blocks, without changing the size of the consultation area. Indeed, the consultation area are usually bounded to a reasonably small size, whatever the size of the city is. Areas of this size can be represented by a 3D model with a fair performance, as shown by the VRML models discussed in Section 2.1.2. Therefore, the challenge is here to be able to display the whole city environment.

The experiment consisted of an automated navigation inside the city near the consultation block, as people would navigate during a consultation. During this movement the frame rate was recorded.

7.5.2 Results

These results were published in a (peer reviewed) paper at the EGUK Theory and Practice of Computer Graphics Conference in 2004[GH04]. Figure 7.6 shows the results of the experiment, as a chart displaying the frame rate according to the number of blocks for the two computer systems.

The results are very encouraging, as if we consider a frame rate of 20 frames per second an acceptable threshold[JLF96], we can see that the low-performance range computer displays cities properly up to about 50 blocks, which represents 750 buildings. Using the same criteria, the medium-performance range computer was able to display cities up to 400 blocks, meaning 6000 buildings.

Therefore, technically, using the chosen level of detail, the city model is able to perform properly on standard computers. Indeed, we can consider that 750 buildings cover the size of fair big city, and 6000 buildings an important part of a megalopolis. So it is possible to render the whole city, or an important part of it if the city is a megalopolis, so people will be able to see the impact of planning projects on the whole urban environment.

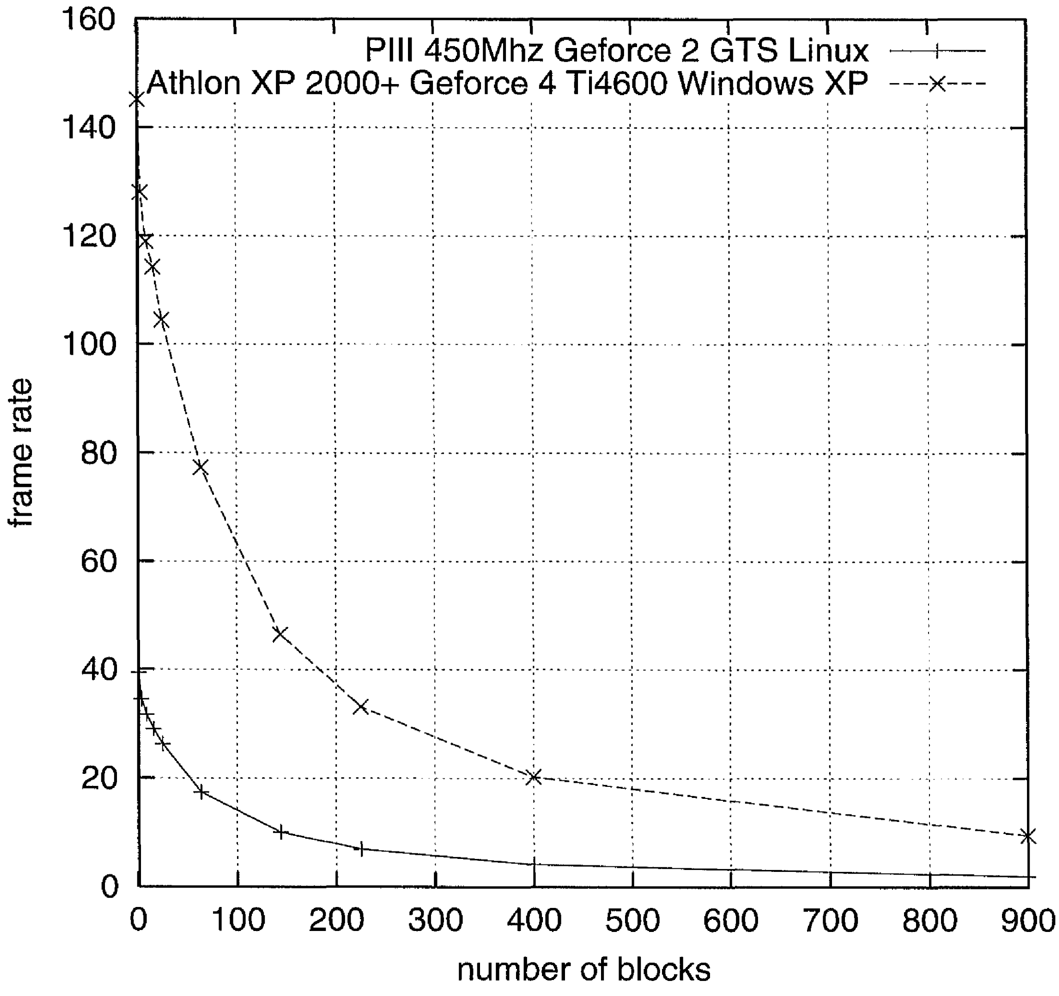


Figure 7.6: The frame rate experiment results

As the results were good enough, we could therefore go on with the implementation, refining the model using realistic textures and objects to improve the feeling of realism. Figure 7.7 shows the final result.

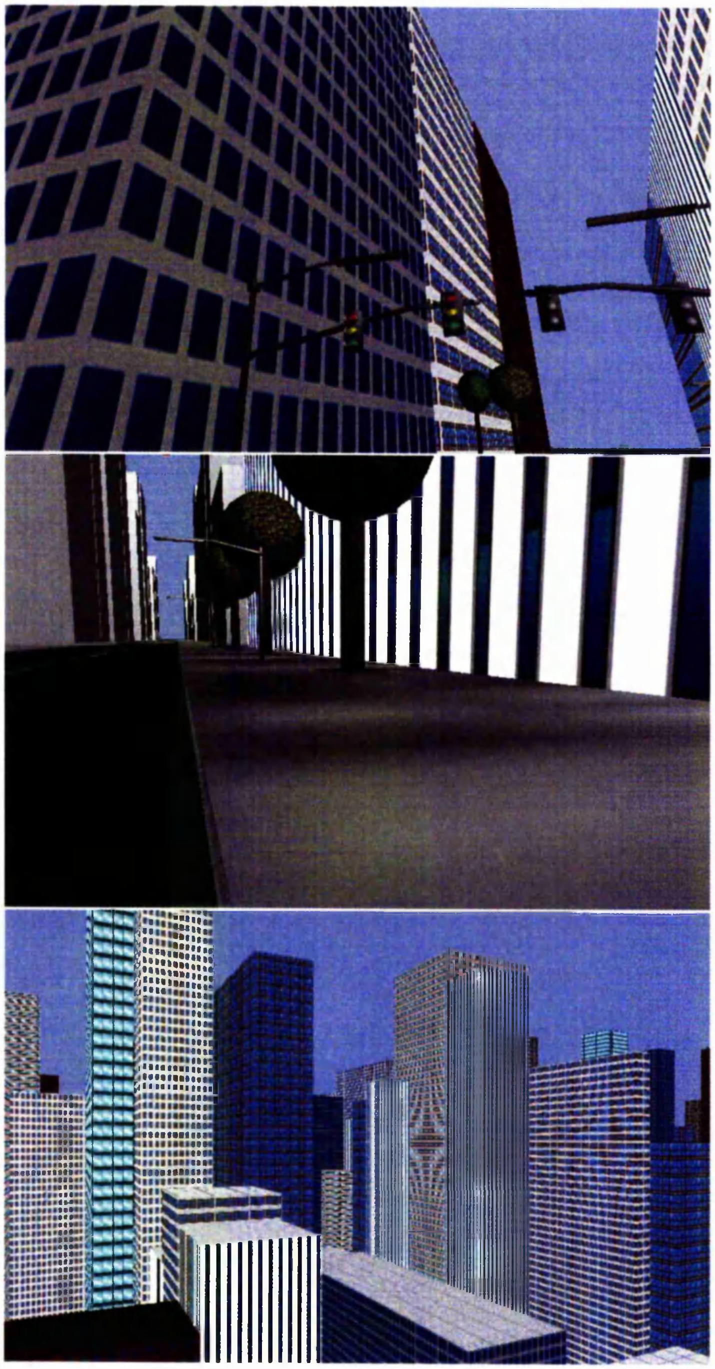


Figure 7.7: The final city model

7.6 Representation of the Boards

Having implemented the visualisation of the environment, we focus now on how to represent the boards. There are two possibilities to display them. First, we can use a physical object, as sign for example. Or we can a virtual object, as a board visual information is just coordinates of a viewpoint.

A good choice would be a virtual object, as a physical object can obstruct the view the board is showing. However a physical object is useful to find the location of a board. So a solution has been found somewhere in-between. The board is represented by a simple cube, representing a bounding box of the coordinates of its attached viewpoint. For better visibility of the environment, only its outline (bones) is shown. This single geometry form has been used, so people would identify easily the boards, distinguishing them from objects of the model. When a user is on the exact board coordinates the board is not be anymore displayed, so it does not disturb the view. Figure 7.8 shows this representation.

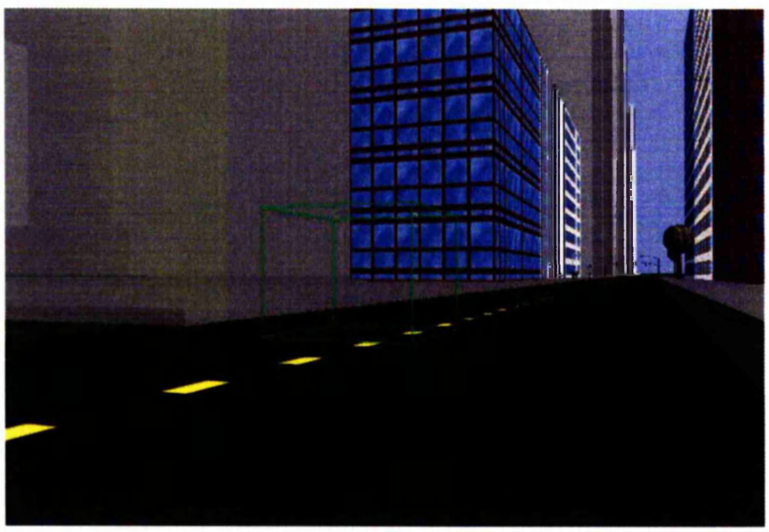


Figure 7.8: Representation of a board

Having decided on the board representation, next is the question on how to reach a board exact position. This issue is raised in Section 8.3.

7.7 A City Description Language

As we have implemented the environment data, we can now think about a language to describe it, to be used to load a city, and save city data after changes. We chose to use a simple text script language instead of a database, as it is sufficient for a prototype model.

Here is a formalised grammar of the city description language we used:

```
citydef         :  name descriptiondef '\n' consultationdef areasdef
                ;
consultationdef :  name viewpointcoords '\n'
                ;
areasdef        :   areadef | areasdef areadef
                ;
areadef         :  'A' name descriptiondef '\n' subareasdef
                | 'A' name descriptiondef '\n' cityitemsdef subareasdef
                | 'A' name descriptiondef '\n' cityitemsdef
                ;
subareasdef     :  subareadef | subareasdef subareadef
                ;
subareadef      :  'S' name name descriptiondef '\n' subareasdef
                | 'S' name name descriptiondef '\n' cityitemsdef subareasdef
                | 'S' name name descriptiondef '\n' cityitemsdef
                | 'S' name name descriptiondef '\n'
                ;
cityitemdef     :  pedestriandef commentsdef
                | buildingdef commentsdef
                | crossroaddef commentsdef
                | roadsegmentdef commentsdef
                | boarddef commentsdef
                | freecommentdef
                ;
pedestriandef   :  'P' name pedestriantype displaytype number
                   real real real real real descriptiondef '\n' landmarksdef
                ;
buildingdef     :  'B' name buildingtype number displaytype
                   number real real real real real real descriptiondef '\n'
```

```
                ;
crossroaddef    :  'C' name crossroadtype displaytype
                   number real real real real real descriptiondef '\n'
                ;
roadsegmentdef  :  'R' name roadtype displaytype
                   number real real real real real descriptiondef '\n'
landmarksdef    :  Epsilon | landkarksdef landmakrdef
                ;
landmakrdef     :  'L' number real real real descriptiondef '\n'
                ;
boarddef        :  'E' name viewpointcoords textdescription '\n'
                ;
freecommentdef  :  'F' number name number textdescription '\n'
                ;
commentsdef     :  Epsilon | commentdef commentsdef
                ;
commentdef      :  'U' number name textdescription
                ;
displaytype     :  COLOURED | TEXTURED
                ;
pedestriantype  :  SIDEWAY | SQUARE | PARK
                ;
buildingtype    :  RESIDENTIAL | PUBLIC | PRIVATE | OFFICE
                ;
crossroadtype   :  CROSS | T | ROUNDABOUT
                ;
roadtype        :  STREET | AVENUE | BOULEVARD
                ;
descriptiondef  :  textdescription | Epsilon
                ;
textdescription :  #[a-zA-Z0-9_\-\+\*,;:!.?  '\n']+#
                ;
name            :  \'[a-zA-Z0-9_\-]+\'
                ;
viewpointcoords :  real real real real real real real real real
                ;
```

```
number          :   [0-9]+
                ;
real            :   [0-9]*\.[0-9]+
                ;
```

Next, we define integer numbers to describe the different possibilities of "displaytype", "pedestriantype", "buildingtype", "crossroadtype" and "roadtype".

The "Epsilon" rules stand for void.

The "consultationdef" rule describes the consultation area by its name and the starting user location described by "viewpointcoords". The "commentsdef" rule describes the part of consultation information which is located on a physical object and boards. The "freecommentdef" rule describes the other part of consultation information, which is represented by the free comments.

The "descriptiondef" rule describes model logical and physical text information described in Section 7.2.1. Model local information is described in the "boarddef" rule.

On the objects descriptions, the "number" flags are parameters as index of the texture or colour of the 3D object representing the city item, and the "real" flags are parameters to build 3D objects, such as height, length or coordinates. For landmark objects, the first "number" flag is a reference to the object we want to use, such as for example a tree, a bench or a statue. In the "commentdef" and freecommentdef" rules, the first "number" flag is the ID of the user followed by his name. In "freecommentdef", the second "number" flag is used to count the free comments of each user.

An example of a city description file is available in Appendix A.

7.8 Summary

In this chapter, after justifying implementation choices, we defined the specification of a prototype city environment. We then implemented its content and visualisation. Next we performed a performance experiment, which showed that the model was technically suitable for standard computers. Finally we implemented a solution to store its data, by using a description language of the model.

Now we need to think how practically, in term of user interface, people can interact with the environment. Therefore, the next Chapter focuses on the implementation of the human computer interface.

Chapter 8

Human Computer Interface

Now that the model has been implemented, we focus on how people interact with the application. This is an important part, as the user-friendliness is part of the prerequisites (Section 4.1). We decide how they navigate and orientate themselves, access information, leave comments, and interact with the objects of the model. But we first have a look at the graphical user interface.

8.1 The Graphical User Interface

The Graphical user interface (GUI) is implemented with the QT library[QT]. QT is a C++ multi-platform library used to write high quality GUIs. We chose this library because of its popularity, the ability to interface it with Maverik, and the possibility to use this library on both Linux and windows operating systems.

Figure 8.1 shows a screenshot of the GUI. Each part of this window is tackled in the next sections.

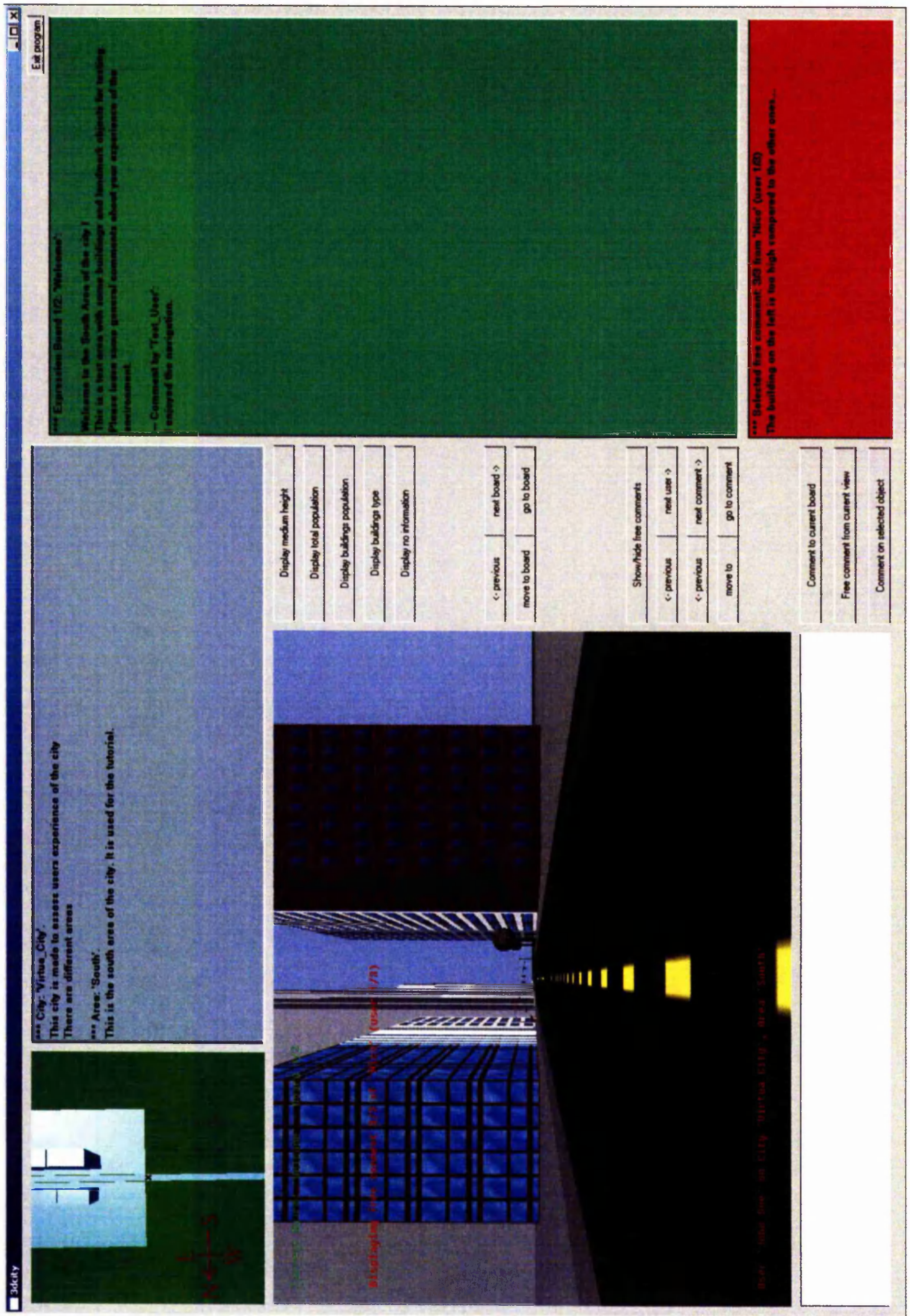


Figure 8.1: The GUI

8.2 Navigation and orientation

In this section, we describe how navigation inside the environment is implemented, as well as orientation. We had to consider the idea of orientation, as we are dealing with a large scale environment.

8.2.1 Navigation

The first interaction experienced in a VE is navigation. As one of the environment prerequisites is that the application must run on standard computers, it is obviously impossible to use VR-specific input devices, such as haptic devices or gloves, and so we are restricted to keyboard and mouse navigation.

We decided to use the mouse for navigation, as many VE applications and computer games have proved that it was an intuitive and quite easy to learn device to use for navigation. We did not implement any keyboard navigation by choice. Indeed, we wanted to separate keyboard from mouse inputs, in order to reduce the complexity of use of the application. Indeed, some people can be easily confused if they have to use both keyboard and mouse for navigation. Evidence of this can be the difficulty of some people to play some 3D computer games, as first person shooter action games where both mouse and keyboards are needed to navigate. It is for certain that for some users may navigate easily with the keyboard, and so we take a risk that some people could have some difficulties. Experiments will assess how users manage to navigate inside the environment, and therefore check if the idea was good or not.

We used the three mouse buttons, in order to maximise the degrees of freedom. The left mouse button is restricted to movements in the ground plane, the right mouse button allows to move up and down, and the centre mouse button allows to look around with two degrees of freedom (left/right and up/down).

We also implemented a collision detection on the objects. This was necessary, as we do not want the user to visit the inside of the objects, which are empty. Furthermore, this allows us to use the backface culling optimisation we talked about in Section 7.4.1. And finally, if someone collides with an object, this object will seem more "real" to him.

8.2.2 Orientation

Having implemented the navigation, we must be sure that users do not get lost, as we are dealing with a large scale environment. In order to do that, we developed a map windows of the city. Figure 8.2 shows the map window.

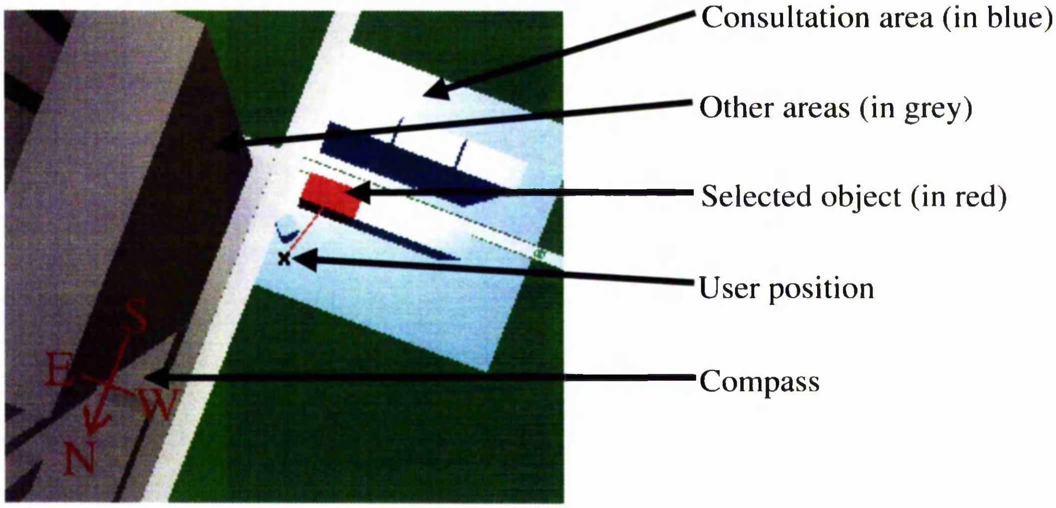


Figure 8.2: The city map window

The map provides useful orientation information to the user, as he can see his location, and use a compass to navigate. We also added a zoom function, so the user can have a local or a global view of the city on the map. It is also possible to navigate directly on the ground plane from the map window, and click on a point of the map to be transported directly there.

We enhanced orientation by using different colours, as shown by Figure 8.2. Therefore, we have a specific colour to separate the consultation area from the rest of the city. Within this area, we use another colour to show the selected object if required (we talk about the selection of objects in Section 8.5.1). So, using colours, it becomes possible to identify clearly the consultation area from the rest of the city, and within this area the selected object if needed.

We saw, in this section, that the map is useful to help orientate people inside the city. But it can be useful to display visual information too, as explained in the next section.

8.3 Information Access

In this section, we discuss how users get access to information. These are the passive interactions from Section 5.2 that we described in Section 7.2.2. We first consider model information. Consultation information is addressed separately at the end of this section.

8.3.1 Logical Information

This class of information is available everywhere. Indeed logical information is directly linked to an area, as well as a consultation. Therefore, this piece of information must be accessible from everywhere. We must differentiate now ex nihilo logical information from generated logical information.

Ex nihilo logical information is quite easy to represent, as it is just text data. So, the text is simply displayed on a text frame, as shown in Figure 8.3.

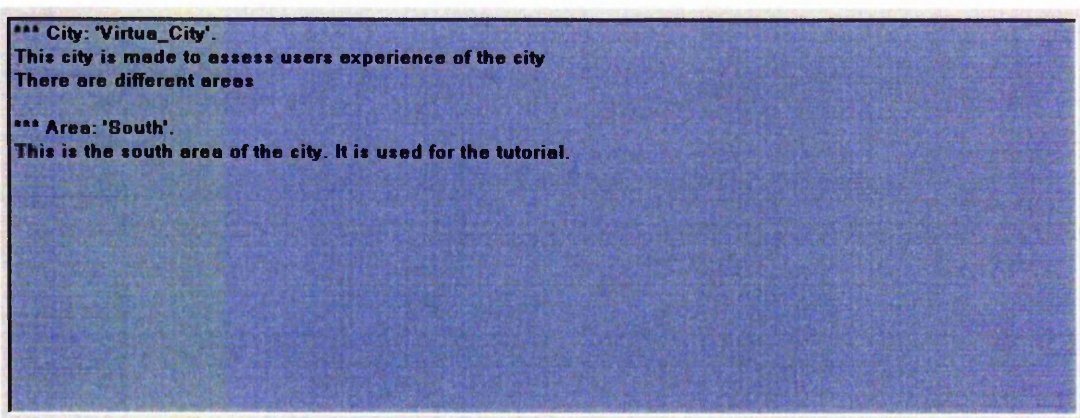


Figure 8.3: Ex nihilo logical text information frame

Generated logical information is trickier to display. First, we need to select how to trigger the display. This can be done by implementing queries as interactions objects (Figure 6.8), which generate and display the selected piece of information. We implemented the generated logical information queries, from the chosen piece of information we selected in Section 7.2, as icons on the GUI, as shown by Figure 8.4.

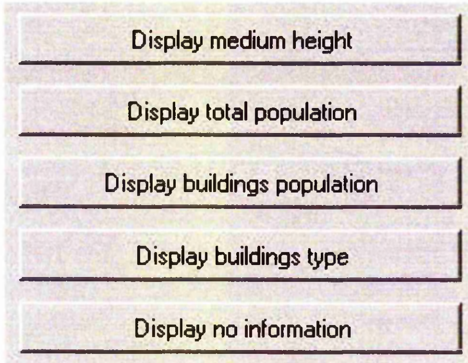


Figure 8.4: Generated logical information queries

Then, there are two possible ways to display this kind of information:

- First, the result can be a single value (for example the medium height of the buildings of the selected area), and so can be displayed as simple text information. We decided to display this text on the main view frame. Figure 8.5 shows an example of this.

Figure 8.5: Text display of generated logical information

- The results can also be the whole values of a set of objects (for example the height of each building of the area). A good way to represent this information is to use a colour code, with an appropriate legend, to represent this information by displaying, on both main and map view, the objects represented with these colours. The use of the map to display this kind of information appears obvious, as it gives a global view of the information, while at the same time it is possible to navigate in a local point of view on the main view. Figure 8.6 shows the visual results on the main window of the two queries we implemented on this kind of information. This visual information is also displayed on the map window, so it is possible to visualise it from two different points of view. The colours are based on the ones used in the game Sim City.

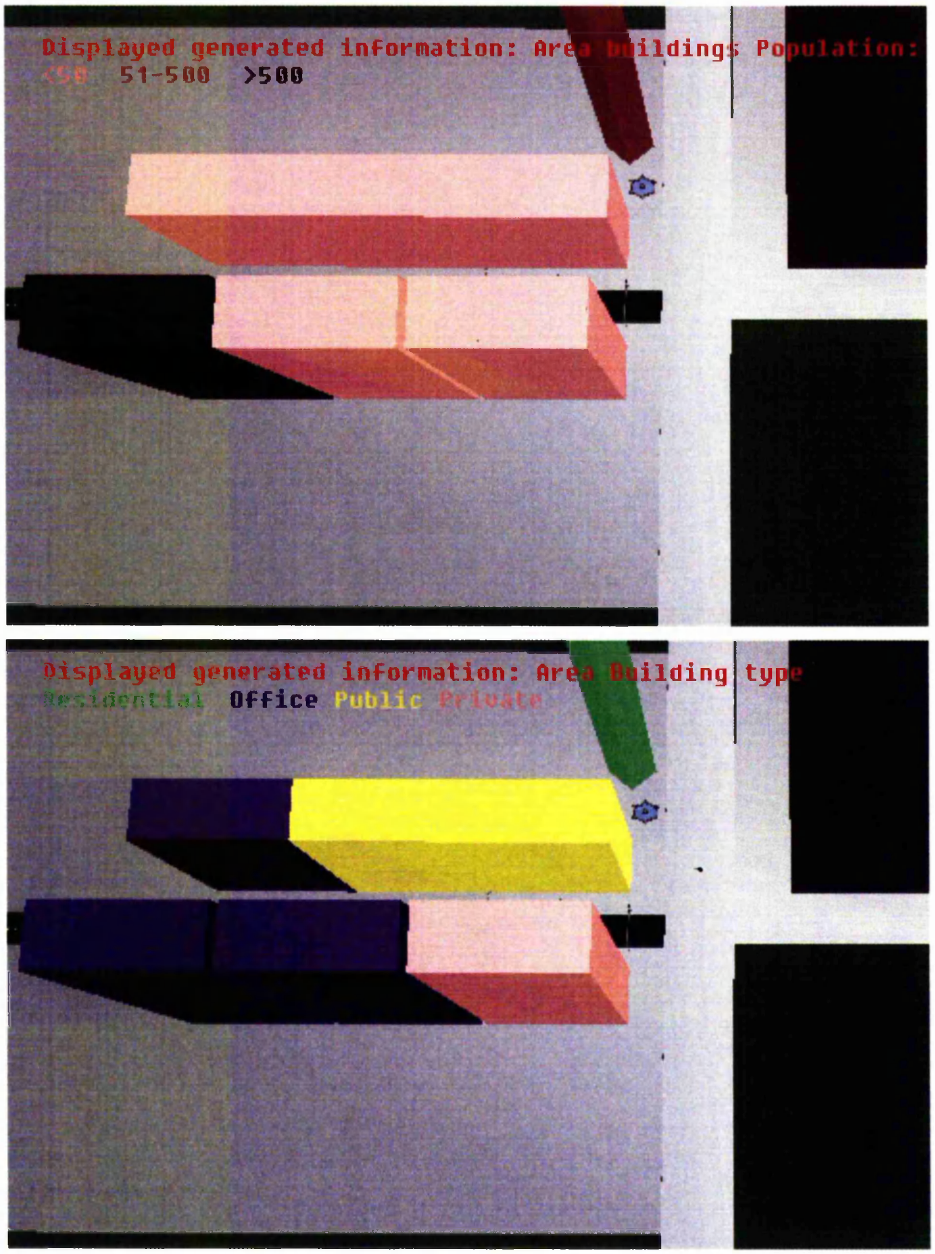


Figure 8.6: Display of "visual" generated logical information on the main view frame

8.3.2 Physical Information

This part of information is only available locally, on objects of the model. So users must be able to view the object to access information about it. Simply by selecting it (issues about selecting an object are addressed in Section 8.5.1), the user can access information about the object on the text frame used to display ex nihilo logical information. Figure 8.7 shows an example of such information display.

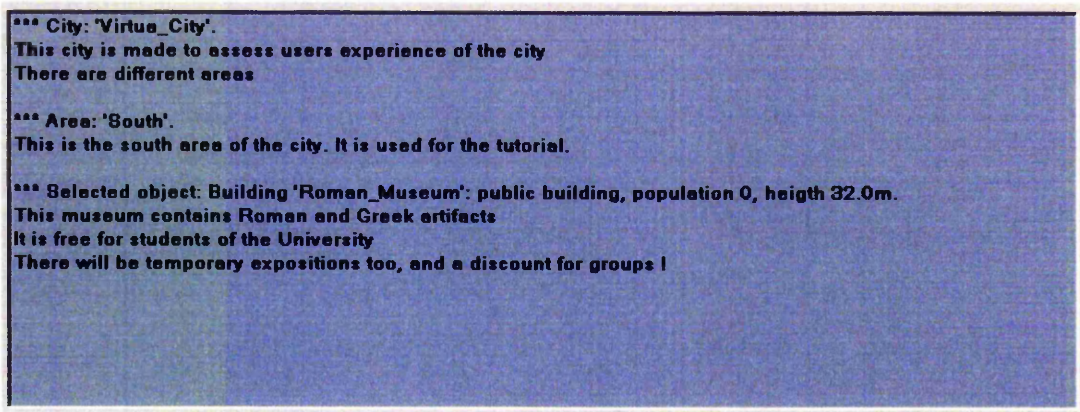


Figure 8.7: Display of physical information from an object

8.3.3 Spatial Information

This type of information is available on the boards. A board is not simply a set of coordinates on the 3D space, as it depends on the direction of view too. While it would be possible for people to reach the boards location by themselves quite easily (using for example an arrow to show the way), it is trickier to reach the correct view direction at the same time. Furthermore we need to be at an exact location. Therefore, we have to find a way to reach the boards easily. We implemented two different ways for that – an automatic smooth navigation and a direct transportation.

We used icons on the GUI, to first select a board, and then to reach it (Figure 8.8). "previous" and "next board" icons select the board, "move to board" starts the smooth navigation and "go to board" triggers the direct transportation.

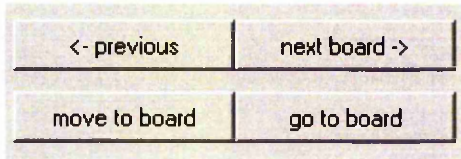


Figure 8.8: Board selection and navigation

The information contained inside the board is displayed on a specific text frame, as shown by Figure 8.9. The background colour of the frame changes, depending on if we are on the board coordinates or not.

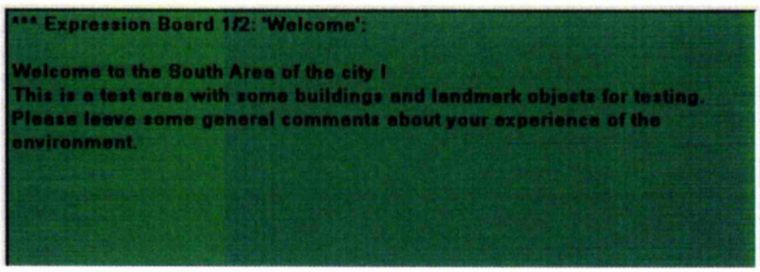


Figure 8.9: The board text information frame

8.3.4 Consultation Information

Now that we have tackled model information access, we now address consultation information. We saw from Section 7.2 that we have three types of comments, which are comments on an object, comment on a board and free comments. We explain how these comments are be displayed.

Comments on objects and boards can be easily displayed, on their respective text information frames (Figures 8.7 and 8.9). Therefore, when someone leave a comment on an object and a board, the comment text data are available at the same place as their associated model information, as shown by Figure 8.10.

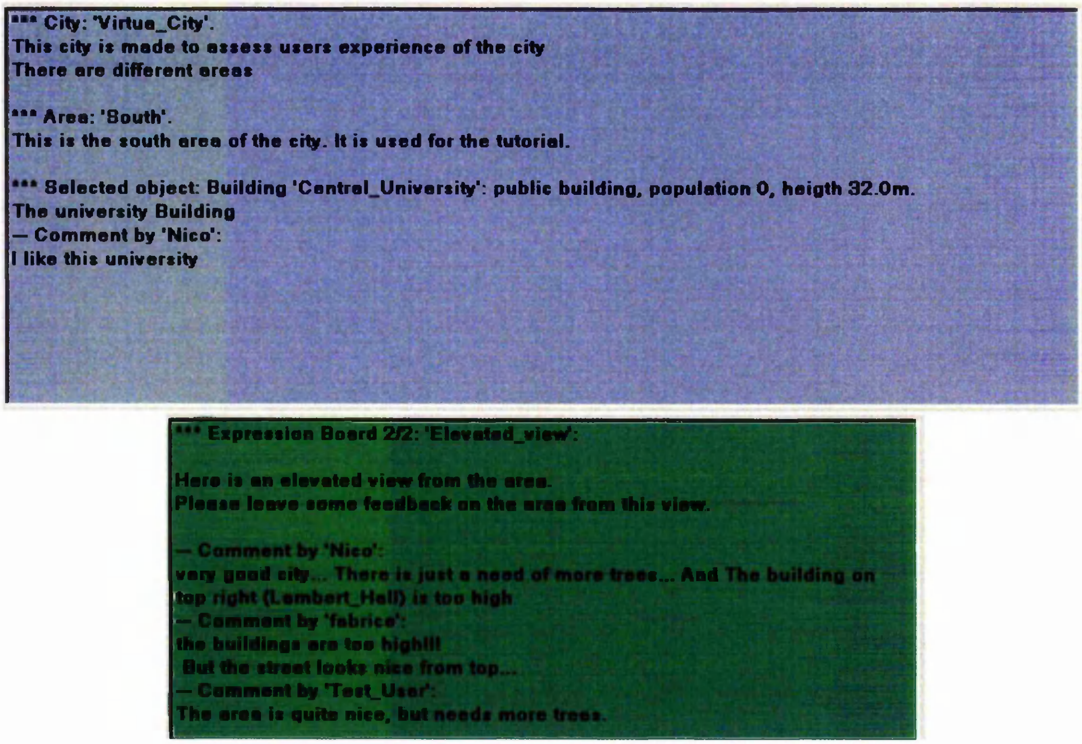


Figure 8.10: Objects and board comments display

Free comments can be considered to be simplified version of the boards, as they have the same characteristics. A free comment is a board which contains a single comment from someone. Therefore, we use the similar methods to display free comments, as the ones we used for the boards information. Figure 8.11 shows the part of the GUI relative to the free comments selection and navigation.

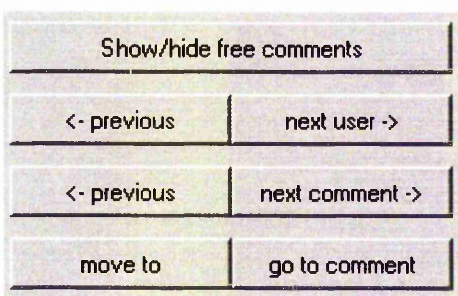


Figure 8.11: Free comment selection and navigation

The "Show/hide free comments" icon is used to select if we want to display free comments. It can be useful to mask this piece of information if it is not needed, in order to save the clarity of the GUI, or to not be influenced by other comments. To select a free comment, users must first select the user who wrote it, which is done using the "previous" and "next user" icons. Then, he can select his/her different free comments using the "previous" and "next comment" icons. The "move to" and "go to comment" icons trigger respectively the smooth navigation and direct transportation to the free comment location, the same way it is done for the boards.

As boards' text data, the free comment data are displayed on a text frame, as shown by Figure 8.12. As for the board text information frame, the background colour of the frame changes, depending on if we are on the comment coordinates or not.

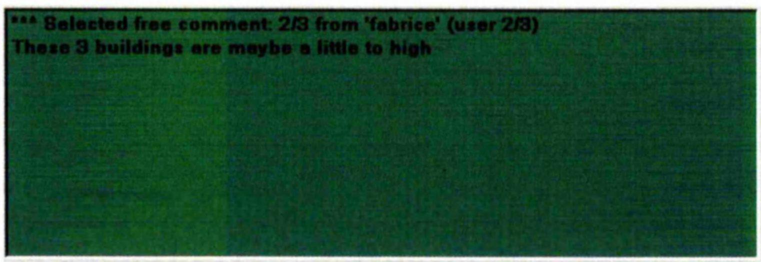


Figure 8.12: The free comment text information frame

Figure 8.13 shows the associated view of this comment, showing its meaning.

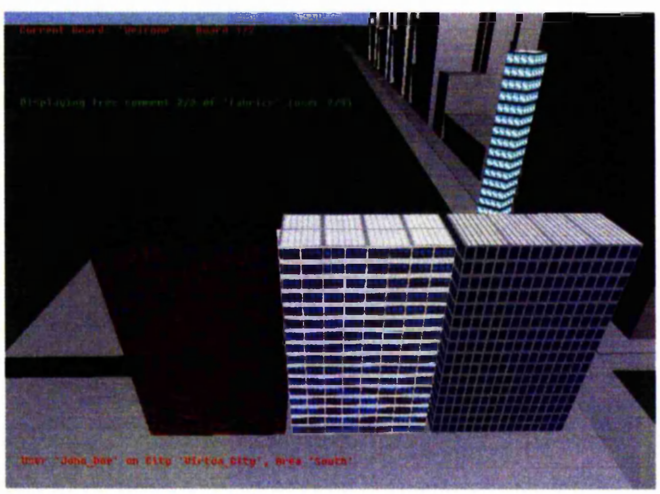


Figure 8.13: Attached view of the free comment

8.4 Consultation Interactions

Having described how people access information, we now talk about how they add information to the model, which is about the way they add comments. In this section we discuss about the three kind of comments we defined in Section 7.2.1, comments on objects, comments on boards and free comments. Figure 8.14 shows the comment text edit frame, next to three icons, one for each kind of comments.

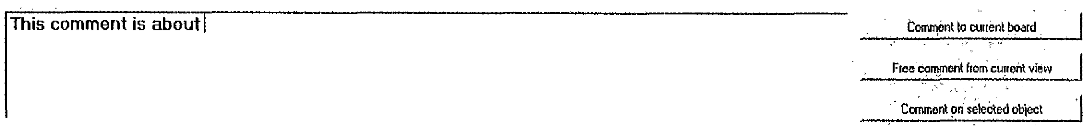


Figure 8.14: The comment text edit frame

We describe how to record these three comments:

- To comment on an object, the user must first choose the object on which he wants to comment, by selecting it (issues about selecting an object are addressed in Section 8.5.1). Next, he can write his comment on the text edit frame and click on the "comment on selected object" icon. And then, the information is added to the object.
- To comment on a board, the user must first select the board he wants to comment on, as we saw in Section 8.3.3. He can then write the comment on the text edit frame. The user must be on the board location to record his comment, so we are sure he comments from the board point of view. If this is the case, he can record the comment by clicking on "comment to current board" icon.
- Finally, to add a free comment from his point of view, the user just has to write his comment on the text edit frame and click on "free comment from current view" icon.

8.5 Interacting with Objects

In this section, we discuss how users interact with the objects. We talk about the way people select the objects, and then how they perform interactions, which are the active interactions described in Section 7.2.2, with them.

8.5.1 Object Selection

We introduced a process of object selection before being able to interact with any object of the city model. It is only possible to select one object at one time. The first reason for this is that it allows to clearly identify the object we are dealing with, and so reduces user confusion. It is also useful for a collaborative use as there is a need to lock an object before interacting with it, as we explained in Section 6.3.3.

To select an object, it is only needed to point to the object with the mouse and press a key, as no mouse button is available because being assigned to navigation, to select an object. Figure 8.15 shows a selected object. The object is transparent to separate it from the other ones. It is also displayed using the red colour on the map, as we saw in Section 8.2.2. There is as well a red line from the user position to the centre of the selected object, which can be useful to find the object if the user lost track of it.

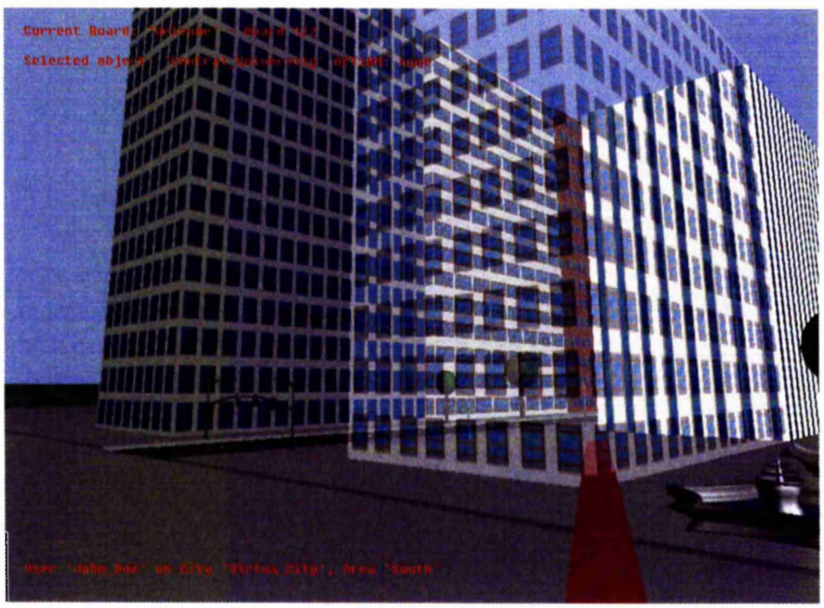


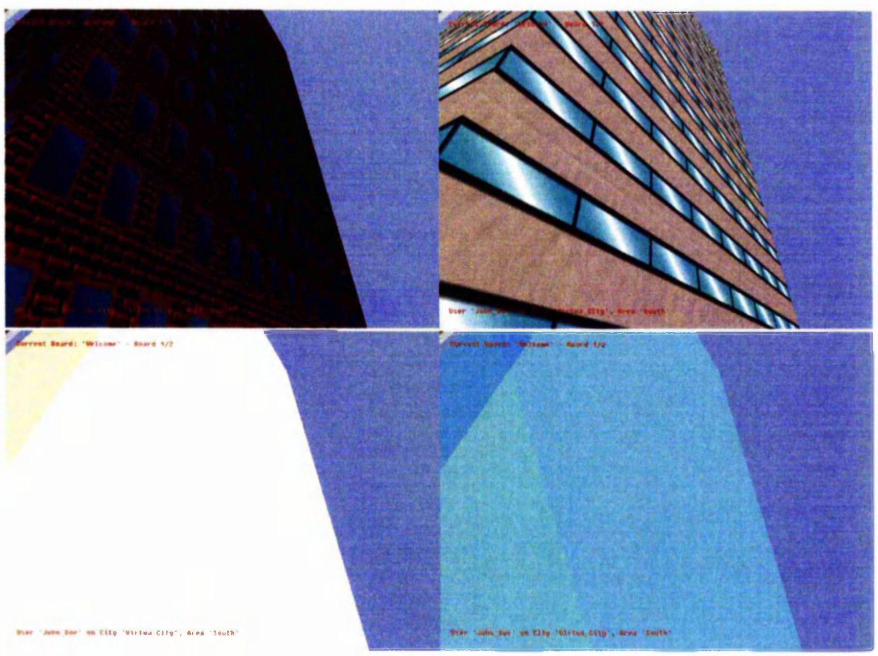
Figure 8.15: Selection of a building

Once the object is selected, information about it is displayed, as shown in Section 8.3.2, and active interactions with this object are possible. We describe these interactions in the next section.

8.5.2 Active Interactions

We describe, in this section, how the possible active interactions, defined in Section 7.2.2, are handled. These interactions are about objects manipulation.

First, the user can change texture or colour of some objects. In order to do that, he can at first choose if the object is displayed using a colour or a texture, and then change the texture (or colour), by choosing one from the available texture (or colour) for the type of the object (obviously, for example, the road textures are different from the building textures). These changes are made using a key input from the keyboard. A reason for this choice, instead of a graphic interface, was to not over clutter the GUI. Figure 8.16 shows an example of this interaction.



Here are 4 screenshots of a building with 2 different textures and 2 different colours.

Figure 8.16: Texture and colour change

Next, the user can move an object. In order to do so, he must first start the interaction by pointing to the selected object with the mouse and press a key on the keyboard. Then, the object follows the mouse pointer, and the user if he is navigating at the same time. Once the object is at the desired position, the movement can be stopped by pressing the same key. As seen in Section 7.3.2, there are some constraints, when moving objects:

- The movements are limited to the ground surface, so the law of gravity is always respected.
- The movements of landmark objects are limited to their associated pedestrian area plane.
- When moving a pedestrian area, its associated landmark objects move with it. Figure 8.17 shows an example of moving a pedestrian area.

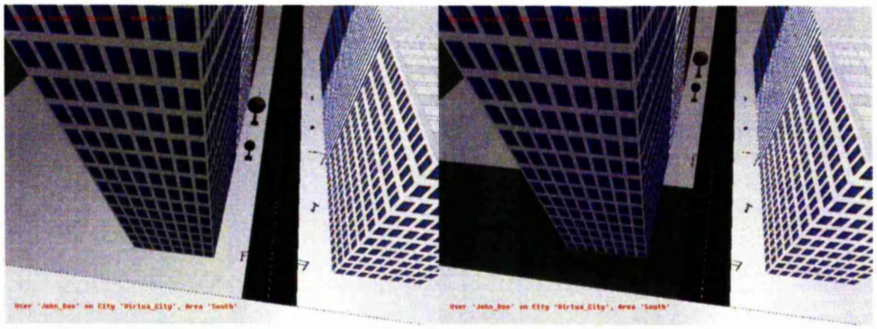


Figure 8.17: The sidewalk on the left has been moved forward

Finally, the user can rotate a building. This interaction is triggered exactly the same way as the movement interaction, using a keyboard input. The direction and speed of rotation is determined by the position of the mouse pointer on the 3D view window. Figure 8.18 shows an example of a rotating interaction .

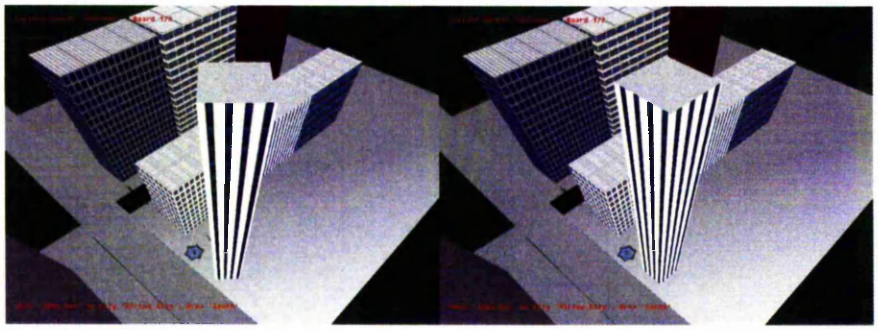


Figure 8.18: Rotating a building

8.6 Summary

In this chapter, we finished implementing the prototype application with its user interface. We implemented the ways people navigate inside the environment, access and add information, and interact with objects. We gathered all these feature inside a GUI.

Now that the prototype is implemented, we are now ready for experimentation. We discuss the experiments in the two next chapters.

Chapter 9

Usability Study

After having technically assessed the model, and before experimenting it in a public consultation context, subsequent experiments must assess how easily the users can access the information from the model, and perform interactions inside the VE. This chapter discusses these experiments.

9.1 Description of the experiment

People are selected with different experience in computer science and 3D computer graphics. They have to answer a questionnaire about their age, sex, background, and experience in computer science and 3D. The questionnaire form about their personal information is available in Appendix B.

As discussed in Section 3.3, a good way to measure this is to ask people to perform tasks in an environment, and measure how they manage to perform them. There can be different tasks, as navigation, accessing information, or environment modifications. Each task can be assessed independently. Doing this test with people, with different experience in 3D, can tell us how people, with none or little experience in 3D, deal with navigation and interactions. Usability evaluation of a VE application is a complex task[BGH02]. Thus, there are many possible ways to execute this kind of evaluation. Here are different factors for measuring how people manage to perform the tasks we select:

- The success of performing the task: This is the simplest way to measure how people manage to perform a task, but it is also the less precise.

- The time required to perform the task: Can time be a good parameter to measure difficulty? For some tasks it can. For example a mathematical exercise can be considered difficult if it takes time to be completed. However, if there is no limited time to perform a task, some people can take a lot of time and yet have no difficulties to perform a task. Let us say that they take their time. And we do not want here to assess how people manage performing interactions in a limited time, as the application does not require that. Furthermore, there is the problem of knowing the threshold values to decide on how well the task was performed. For these reasons, we do not use time as a factor for our measurements.

- The amount of help needed to perform the task: This is a good way to check the difficulty of a task. There are different degrees of help. First, the help can be minimal, such as an advice. On the opposite direction, there can be a large amount of help, such as a demo of the task to perform. Obviously, to use this factor, we need an external person who can provide help.

- The perception of difficulty. This can be assessed by asking the performer his personal impression about the task's difficulty. This can be also observed by an external person. It is a good way to measure the difficulty for a specific individual, as it is distinguished from the intrinsic difficulty of the task itself. This is a subjective measurement, as it comes from a perception. However, if we limit this to two choices, just telling if the task was difficult or not, we can estimate that the measurement is accurate after a small dialogue between the person involved and an external person observing him.

Therefore, for the evaluation, we use these factors, apart from the time, to establish different degrees. The author is the external person, providing help if needed, and engaging dialogue with people. The use of an external person can furthermore ensure that people know exactly, without any ambiguities, the tasks they are asked to perform.

These experiments are conducted in different environments, to assess the use of navigation and the different interactions. The first environment is used for a tutorial, followed by environments focused on different tasks asked to perform we call "trials".

9.1.1 Tutorial

First, the users must learn how to interact with the environment. In order to do so, they enter a simple environment, where they perform a tutorial. They are asked to use the different interaction we implemented. We divide them into 6 groups:

- Boards and assisted navigation: this is about the selection of the boards to access local information and navigation from board to board.
- Free navigation: this is about mouse navigation on the main view window.
- Use of the map: this is about reading the map, and using the mouse on it for navigation and zoom.
- Display of generated information: this is about accessing generated logical information.
- Interaction with objects: this is about object selection and active interactions with them.
- Comment interactions: this is about adding the three kind of comments and reading free comments.

People can stay in the tutorial environment as long as they want, to make sure they learn each interaction properly. Each group of interactions, considered as a single task, as these interactions are similar, are assessed with these different degrees:

- At the higher level, the user performed the task.
- The user needed some help (asked questions) to perform the task.
- The user needed a lot of help (asked for a demo) to perform the task.
- At the lower level, the user did not manage to perform the task.

Here, there is no idea of difficulty of performing a task. Indeed, the tutorial tasks are considered simple, as there is no other objective than just perform an interaction (for example move an object), and so there is no notion of difficulty. The only difficulty is to know how to perform the interaction, and so can be simply measured by the amount of help needed. The tutorial evaluation form is available in Appendix B.

9.1.2 Trials

After the tutorial, we assess people performance, using the application into different environments. Inside each of them, people are required to perform some tasks. Here are the different environments:

1. In the first environment, illustrated by Figure 9.1, people are asked to get the medium height of the area, find the most populated building and give the number of public buildings. This requires generated logical and local information access, as well as navigation to get to a practical point of view to visualise the information.

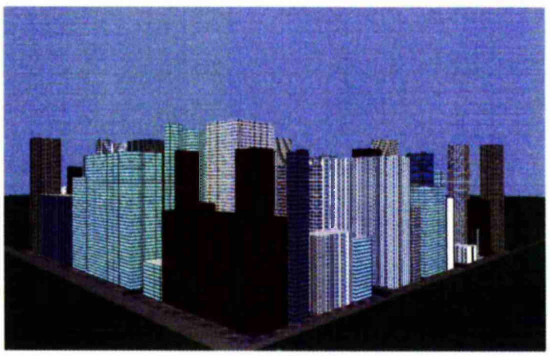


Figure 9.1: First trial environment - information visualization

2. The second environment is focused on consultation interactions. People are asked there to leave a free comment from an asked view, leave a comment on a chosen landmark object, access to a particular free comment and leave a comment on a board. Figure 9.2 shows this environment.

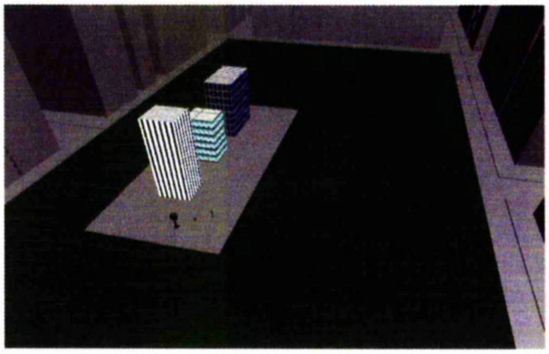


Figure 9.2: Second trial environment - consultation interactions

3. Finally, in the third environment, people interact with objects, performing active interactions. They are asked to move some buildings, move and rotate precisely an other building, move some landmark objects, rotate precisely an other landmark object, and change the texture/colour of two buildings. Figure 9.3 illustrates this environment.

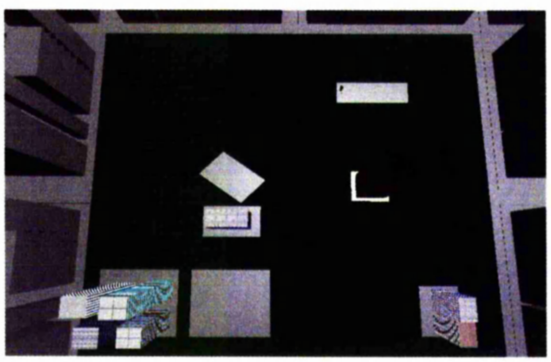


Figure 9.3: Third trial environment - environment modifications

Unlike tutorial tasks, each task is here assessed separately. Indeed, two task in the same environment are not necessary similar (for example, finding the most populated building is much more difficult than getting the medium height of the area). In order to valuate this experiment, we assess user task performance using these degrees:

- At the higher level, the user performed the task without difficulties.

- The user performs the task with some difficulties but without asking for help.
- The user needed some help (asked questions) to perform the task.
- The user needed a lot of help (asked for a demo) to perform the task.
- At the lower level, the user did not manage to perform the task.

Compared to the tutorial part, there is here the idea of difficulty of performing a task. Indeed, here the tasks have objectives (for example move an object to a specific location), and so we can measure if people have difficulties achieving these goals. The trial evaluation form is available in Appendix B.

9.2 Observation of the Results

9.2.1 People Involved in the Experiment

As shown in Appendix C, 46 people participated to the experiment. Each of them spent from 30 minutes to 1h15. The high difference of time for one person to another is explained by the various time needed to perform the different tasks. People were deliberately selected, from a city population, in order to get enough people with different experience in computer science, which is an important parameter to consider when proceeding with an usability experiment. A second parameter to consider in our case is the 3D experience, as the usability study concerns the use of a 3D software. Therefore, it was interesting to have people with different experience in this field. In order to do so, people were not directly according to their 3D experience, but we simply selected a large enough number of people with an advanced computer science experience, as usually people who have a 3D experience have already a fair computer science experience.

At first, Table 9.1 remains the meaning of the different levels of experience in these fields, as they were defined in Appendix B. There are six degrees of experience level in computer science, and five in 3D. Then, Table 9.2 shows the sample distribution.

Level of experience	Computer Science	3D
0	none	none
1	limited	casual game player
2	daily office automation	advanced game player
3	advanced office automation	very good
4	very good	expert
5	expert	

Table 9.1: Levels of experience in Computer Science and 3D

CS experience 3D experience	0	1	2	3	4	5	**TOTAL**
0	1	8	12	4	2	2	**29**
1	0	0	2	2	0	4	**8**
2	0	0	0	0	2	2	**4**
3	0	0	0	0	1	3	**4**
4	0	0	0	0	0	1	**1**
TOTAL	**1**	**8**	**14**	**6**	**5**	**12**	**46**

Table 9.2: Sample distribution

It can be noticed that only one person with no computer science experience was selected. Indeed, involving many inexperienced people with computer science would make it difficult to measure usability of the application, as this would involve as well usability issues about the use of input devices, such as the mouse. We would take a risk in measuring more the ability of a person to use these devices than the application itself. However this only person was selected by pure interest. He has an engineering background (but no computer science experience as he has been retired for some years), and so should have facilities people from a literary background may not have.

We can also notice that a lot of the people have an advanced experience in computer science. This can be explained by the choice of having a quite large proportion of people having experience in 3D, as explained in the beginning of this section. Furthermore, the selection of a high number of people with at least a daily office automation experience seems to be a fair anticipation of the future, as more and more people will get used to computers.

Despite the choice to have comparable classes size, because of the low sample size, some class sizes are too low. So we decide to regroup some classes:

- First, we merge people with none and limited computer science level, because there is only one person with no experience. We name the computer science experience of these people "none or limited".
- Then, we merge people with advanced office automation and very good level in computer science. A reason for this choice is that people had difficulties to distinguish these two classes, as they hesitated when filling the questionnaire. Furthermore, looking at Appendix C, the results of the people from these two classes seems to be close. We name the computer science experience of these people "advanced".
- Finally, we regroup people with at least an advanced game player level in 3D. Here again, the results of these classes seems to be close. We name the 3D experience of these people "advanced". This grouping seems fair, as we expect people with at least an advanced game player level to be able to use the program, whatever is exactly their level.

Table 9.3 shows the new list of experience levels, and Table 9.4 shows the new sample distribution based on these classes. For convenience we name now daily office automation computer science experience simply "medium" computer science experience.

Level of experience	Computer Science	3D
1	none or limited	none
2	medium (daily office automation)	casual
3	advanced	advanced
4	expert	

Table 9.3: New levels of experience in Computer Science and 3D

CS experience 3D experience	none or limited	medium	advanced	expert	**TOTAL**
none	9	12	6	2	**29**
casual	0	2	2	4	**8**
advanced	0	0	3	6	**9**
TOTAL	**9**	**14**	**11**	**12**	**46**

Table 9.4: New sample distribution

Having described the people involved in the experiments, we now observe the results of the usability evaluation. First results (with a lower sample number) were published in a (peer reviewed) paper at the Pacific Graphics conference in 2005[GH05]. We first focus on the tutorial results. Then, we present the trials results. Detailed results of each person are available in Appendix C.

9.2.2 Tutorial Results

First, we analyse the results of the tutorial. We wanted to know if people could use the different features of the application by themselves, reading the tutorial instructions, or if they did need help.

We can see from the results of Appendix C that almost everybody was able to perform the tutorial without any help. There are only six people who did require some help, but only a small amount, as they did not need any demonstration, on navigation and interaction with objects. We can see that five of them (subjects number 2, 11, 30, 38 and 43) have a limited level of experience in computer science and none in 3D, and are from the people who experienced the most difficulties to perform the trials. They are people who would surely need assistance to use this kind of application in the future. What is more surprising is the third person (number 1), who needed some help on navigation, but performed quite well in the trials. This can be explained by the fact that the quality of the tutorial can be improved (for example with the use of videos showing how each feature works, or simply by explaining each feature in more details), so everybody knows clearly how the application works. Indeed, any help feature can be tested by a usability evaluation, and then be adapted to the needs of the users.

Despite that, the results of the tutorial were fairly good, as 40 of the 46 people (87%)

did manage it well. This means that the different features of the user interface are quite easy to understand, which is encouraging for the following of the experiment.

9.2.3 Trials

After having observed the tutorial results, we now consider the trials. We saw, in the last section, that people could manage to know how to use the different parts of the software quite easily. Now we assess how they used them, by measuring their performance on the different trials. We can see that there are numerous tasks. In order to simplify our analysis, we gather them into three categories, each of them involving one main feature of the application, which are the use of the user interface, navigation inside the 3D environment, and objects manipulation. Table 9.5 shows the association of the different tasks to these categories.

Category	Associated tasks
Navigation	- getting the most populated building - getting the number of public buildings (first environment) - leaving a free comment from a specific view (second environment)
Objects manipulation	All the tasks from the third environment except changing colour and texture of two buildings
Use of the user interface	All the remaining tasks

Table 9.5: Gathering of the trial tasks into three categories

We assess the three of them separately in this section. Each category contains three or more tasks. We only consider the score of the worse result of the category, as we consider that a category of tasks is mastered only if each task is, since users of the application have to know how to use all the features. If, for example, someone knows how to write a free comment, but not how to navigate to the view he would like to leave feedback from, he will not be able to write any free comment. That is why we only measure for each category the marking of least properly task people performed. The used marking has been defined in Section 9.1.2.

Use of the User Interface:

We examine here the use of the user interface, disregarding interactions related to the 3D environment. This involves the use of the different icons and keys provided by the interface, which does not require any knowledge in 3D computer graphics.

We notice from Appendix C that everybody did use well the user interface well, except five people.

These five individuals include subjects number 2, 11, 38 and 42, who experienced difficulties in using the user interface, but succeeded without any help, showing that they could anyway use the user interface by themselves. We notice that these are the people who required some help during the tutorial, but not for the same tasks, suggesting that they may just have forgotten the use of user interface features. This can be improved with the development of a help feature in the application, reminding the use of each icon and key.

Finally, there was only one person who required some help, the subject number 14, who has no experience in computer science. Surprisingly, this person did not have any difficulties with the tutorial. Therefore, subject to improvements, as suggested in Section 9.2.2, the tutorial is potentially accessible to everybody, regardless of their experience in computer science. However, lack of experience in computer science disorientates people, when they have to use the application by themselves without any provided help. That is why an help feature will be necessary for a final version of the application.

Looking at the tasks results in details in Appendix C, we notice that most of the difficulties came from the third task of the second environment, which is the access to a particular free comment (see Appendix B), and so related to the set of icons used to view free comments. It is indeed a complicated part of the GUI, and so could be improved. A possible solution would be the use of a browsable list of the available comments, allowing to select directly a chosen comment instead of having to click different times on different icons.

To summarise this observation, pointing out that the only people who did require some help is the only person with the least experience in computer science, and that the two only people who required some help have a casual computer science experience, it seems that a daily office automation level of computer science is sufficient to be able to use well the user interface.

Navigation inside the 3D Environment:

We now focus on the navigation trials. Unlike use of the user interface trials, results are more scattered here. Therefore, we watch them according to people experience in computer science and 3D, in order to see if we can observe a link. Tables 9.6, 9.7, 9.8 and 9.9 show for each result of the task the distribution of people according to their experience.

CS experience 3D experience	none or limited	medium	advanced	expert	**TOTAL**
none	1	0	0	0	**1**
casual	0	0	0	0	**0**
advanced	0	0	0	0	**0**
TOTAL	**1**	**0**	**0**	**0**	**1**

Table 9.6: People who required a demo to perform the navigation tasks

CS experience 3D experience	none or limited	medium	advanced	expert	**TOTAL**
none	8	1	0	0	**9**
casual	0	1	0	0	**1**
advanced	0	0	0	0	**0**
TOTAL	**8**	**2**	**0**	**0**	**10**

Table 9.7: People who required some help to perform the navigation tasks

CS experience 3D experience	none or limited	medium	advanced	expert	**TOTAL**
none	0	4	5	0	**9**
casual	0	0	1	1	**2**
advanced	0	0	0	0	**0**
TOTAL	**0**	**4**	**6**	**1**	**11**

Table 9.8: People who had some difficulties to perform the navigation tasks

CS experience 3D experience	none or limited	medium	advanced	expert	TOTAL
none	0	7	1	2	**10**
casual	0	1	1	3	**5**
advanced	0	0	3	6	**9**
TOTAL	**0**	**8**	**5**	**11**	**24**

Table 9.9: People who performed well the navigation tasks

First, we can notice that everybody could perform the task. There is no failure case. Then, it seems that the computer science level is a deciding factor, as all users with a limited or no computer science experience could not perform the tasks without some help, and only two of the 37 people with at least a daily office automation level required help. The 3D level seems to be less decisive, as no such trivial pattern can be found.

Therefore, it seems that a daily office automation level is usually sufficient to be able to perform the navigation tasks without requiring any help.

Objects Manipulation:

Having observed the results of both use of the user interface and navigation inside the 3D environment, remain the results of the objects manipulation trials. As navigation ones, the results are there scattered too. Therefore, we perform the same observation. The results are shown on Tables 9.10, 9.11 and 9.12.

CS experience 3D experience	none or limited	medium	advanced	expert	TOTAL
none	8	1	0	0	**9**
casual	0	1	0	0	**1**
advanced	0	0	0	0	**0**
TOTAL	**8**	**2**	**0**	**0**	**10**

Table 9.10: People who required some help to perform the objects manipulation tasks

CS experience / 3D experience	none or limited	medium	advanced	expert	**TOTAL**
none	0	4	5	0	**9**
casual	0	0	1	1	**2**
advanced	0	0	0	0	**0**
TOTAL	**0**	**4**	**6**	**1**	**11**

Table 9.11: People who had some difficulties to perform the objects manipulation tasks

CS experience / 3D experience	none or limited	medium	advanced	expert	**TOTAL**
none	0	7	1	2	**10**
casual	0	1	1	3	**5**
advanced	0	0	3	6	**9**
TOTAL	**0**	**8**	**5**	**11**	**24**

Table 9.12: People who performed well the objects manipulation tasks

The results are comparable to the navigation results, and even slightly better. Therefore, the observation is here the same, and so it seems that a daily office automation level of computer science seems usually sufficient to be able to perform objects manipulation without requiring any help.

Summary:

Having noticed that the results each task category are comparable, we decide to regroup them, considering the score of the worse task. Therefore, we measure the ability to use the whole program. Tables 9.13, 9.14, 9.15 and 9.16 show the result.

CS experience 3D experience	none or limited	medium	advanced	expert	**TOTAL**
none	1	0	0	0	**1**
casual	0	0	0	0	**0**
advanced	0	0	0	0	**0**
TOTAL	**1**	**0**	**0**	**0**	**1**

Table 9.13: People who required a demo to use the program

CS experience 3D experience	none or limited	medium	advanced	expert	**TOTAL**
none	8	1	0	0	**9**
casual	0	1	0	0	**1**
advanced	0	0	0	0	**0**
TOTAL	**8**	**2**	**0**	**0**	**10**

Table 9.14: People who required some help to use the program

CS experience 3D experience	none or limited	medium	advanced	expert	**TOTAL**
none	0	8	5	0	**13**
casual	0	0	1	1	**2**
advanced	0	0	0	1	**1**
TOTAL	**0**	**8**	**6**	**2**	**16**

Table 9.15: People who had some difficulties to use the program

CS experience 3D experience	none or limited	medium	advanced	expert	**TOTAL**
none	0	3	1	2	**6**
casual	0	1	1	3	**5**
advanced	0	0	3	5	**8**
TOTAL	**0**	**4**	**5**	**10**	**19**

Table 9.16: People who managed to use the program well

Here again the observation is the same, and so it seems that a daily office automation level of computer science is usually sufficient to be able to use the program without requiring any help.

This assumption is well illustrated by Tables 9.17 and 9.18.

CS experience 3D experience	none or limited	medium	advanced	expert	**TOTAL**
none	9	1	0	0	**10**
casual	0	1	0	0	**1**
advanced	0	0	0	0	**0**
TOTAL	**9**	**2**	**0**	**0**	**11**

Table 9.17: People who required help to use the program

CS experience 3D experience	none or limited	medium	advanced	expert	**TOTAL**
none or limited	0	11	6	2	**19**
casual	0	1	2	4	**7**
advanced	0	0	3	6	**9**
TOTAL	**0**	**12**	**11**	**12**	**35**

Table 9.18: People who used the program without any help

9.3 Statistical Analysis

Having observed the data, and made assumptions, we now proceed to a statistical analysis, in order to see if we can prove them. First we proceed to dependence tests in order to determine significant variables. Then, we estimate confidence intervals, in order to project our results on a much larger population.

9.3.1 Variables Dependence Study

We now observe the different variables of the study.

First are the variables extracted from the participants information:

- **User ID (abbreviated as UID):** this is the "User number" field from Appendix C. This is so the chronological order of the participant in the experiment.
- **Sex:** this is the simply the sex of the participant.
- **Age:** this is the age of the participant.
- **Edu. Science Level (abbreviated as ESL):** this is the level of science in the education background of the participant. This is related to the "Background" field from Appendix C. A literary background is considered as a low science education level, an economical background as medium, and a scientific/technical background as high.
- **CS Experience (abbreviated as CSE):** this is the computer science experience of the participant, described in Table 9.3.
- **3D Experience (abbreviated as 3DE):** this is the 3D experience of the participant, described in Table 9.3.

Then, we define two variables which seem interesting to study, according to the observation in the previous Section. So we define:

- **CS Medium Level (abbreviated as CSM):** this variable says if the participant has at least a medium (daily office automation) experience in computer science. This variable is interesting to study, as we observed that a daily office automation level seems to be enough for someone to be able to use the program without any help.

- **Has 3D experience (abbreviated as H3D):** this variable tells if the participant has any experience in 3D. Obviously, a participant is considered having experience in 3D when his experience is at least casual.

Finally, here are the variables describing the result of the experience:

- **Program Use Mark (abbreviated as PUM):** this is the global result of the usability study, defined in Section 9.1.2 on page 137.
- **Program Use Success (abbreviated as ESL):** this variable tells if the participant was able to use the program without any help.

Correlation Study:

A first way to examine the link between variables is to calculate correlation coefficients[WW90]. For two numerical variables $X = (x_1, x_2, ..., x_n)$ and $Y = (y_1, y_2, ..., y_n)$, the correlation coefficient is defined by the formula:

$r = \frac{cov(X,Y)}{\sigma_X \sigma_Y}$

where

$cov(X,Y) = \frac{1}{n}\sum (x_i - \overline{x})(y_i - \bar{y})$ is the covariance of X and Y.

$\sigma_X = \sqrt{\frac{\sum (x_i - \overline{x})^2}{n}}$ is the standard deviation of X.

$\overline{x} = \frac{1}{n}\sum x_i$ is the mean of X.

The correlation coefficient is bounded by -1 et 1, and measures the linear correlation between 2 variables. A value near 1 shows a positive correlation ($Y \simeq aX$ where a is positive), and a value near -1 shows a negative correlation. A value near 0 shows a non correlation. The correlation coefficient is used to characterise the dependence between two variables, when their distribution are gaussian, meaning that they are following the Normal Law, which is the case where the sample size is big enough. In this case, two variables are independent if and only if they are not correlated.

In order to calculate the correlation coefficients on our set, we have to digitize some variables :

- Sex: We choose arbitrary 1 for male, and 2 for female.

- Edu. Science Level: We choose 1 for low, 2 for medium and 3 for high.
- CS Experience and 3D Experience: we use the level of experience defined in Table 9.3.
- CS Medium Level: we choose 0 for people with an experience below daily office automation, and 1 else.
- Has 3D Experience: we choose 0 for people without experience, and 1 else.
- Program Use Mark: we use the same marking as defined on the trials user evaluation form from Appendix B. So we use:
  - 1 for people who required a demo.
  - 2 for people who required some help.
  - 3 for people who managed to use the program with difficulties.
  - 4 for people who managed to use the program well.

We can now calculate the coefficients. Table 9.19 shows the values.

	UID	Sex	Age	ESL	CSE	*CSM*	3DE	*H3D*	**PUM**	**PUS**
User ID	1.00									
Sex	-0.05	1.00								
Age	0.11	0.00	1.00							
Edu. Science Level	-0.02	-0.60	-0.23	1.00						
CS Experience	-0.25	-0.52	-0.54	0.68	1.00					
CS Medium Level	*-0.09*	*-0.23*	*-0.66*	*0.37*	*0.71*	*1.00*				
3D Experience	-0.16	-0.46	-0.40	0.53	0.65	*0.35*	1.00			
Has 3D experience	*-0.18*	*-0.40*	*-0.43*	*0.45*	*0.66*	*0.38*	*0.96*	*1.00*		
Program Use Mark	**-0.08**	**-0.37**	**-0.67**	**0.53**	**0.76**	***0.75***	**0.52**	***0.51***	**1.00**	
Program Use Success	**0.00**	**-0.33**	**-0.65**	**0.47**	**0.71**	***0.88***	**0.33**	***0.32***	**0.84**	**1.00**

Table 9.19: Correlation matrix of the variables

In our case, the sample size is not big enough to guarantee that they follow normal distributions. So, the calculated values can only be used as an indication. Furthermore, during the digitalization of the variables, choices had to be made, which could affect the meaning of the variables. Therefore, we cannot establish strong conclusions, but only assumptions (however stronger that the ones of the previous section as they are extracted from a calculation and not just observation).

We can first see that *User ID* is not correlated with any other variable related to participants information, suggesting that people were selected in a relatively random order. Furthermore, there is no correlation with the variables describing the result of the experience, suggesting that the results are not influenced by time.

We now observe the correlations of *Program Use Mark* and *Program Use Success* with the other variables. We can see that the higher correlations are obtained with *CS Medium Level*, and then with *CS Experience*. These correlations are positive, suggesting that the ability to use the program increases when the computer science experience increases. The strongest correlation between *Program Use Success* and *CS Medium Level* suggests that a daily office automation level seems enough to use the program without help, confirming the data observation. We can observe a lower, but still relatively strong correlation between the results variables and people age, suggesting that the more older the participant is, the more difficulties he has to use the program. Now, *Age* is correlated with *CS Medium Level*, and we can observe from Appendix C that people with a low or no computer science experience are older than people with more experience, which corresponds to a known fact observed on populations, as younger generations are more used with computers than older ones. So, the correlation between the age and the experiment result variables could result from the correlation between computer science experience and the results variables.

On the contrary, there is a small correlation between *3D Experience* and *Program Use Success*, suggesting that the ability to use the program without help does not depend on the 3D experience of the user. Furthermore, the small correlation between *Has 3D Experience* and *Program Use Success* suggests that the ability to use the program without help does not depends even on the fact that the participant has an experience in 3D.

As a conclusion, the most significant variable seems to be the computer science experience. We will now try to prove the link between this variable and the result of the experience. We will also check the link with the 3D experience, as it is an important variable to consider in a usability study about a 3D program.

Statistical Tests:

We study the link of computer science and 3D experience with the experiment results, which are not numerical variables. In order to prove the link between such variables, we use statistical tests. For qualitative variables, the most usual test is the **chi-square**

test of independence[WW90]. Let us use it to study the link between *CS Medium Level* and *Program Use Success*.

First, we display the table of observed repartitions of the sample according to the two variables we study. This table is called contingency table. On this table we display for each row and column the sum of its values. This value is called marginal total. Table 9.20 shows the result for *CS Medium Level* and *Program Use Success*.

Program Use Success CS experience	failure	success	**TOTAL**
none or limited	9	0	**9**
medium or more	2	35	**37**
TOTAL	**11**	**35**	**46**

Table 9.20: Observed repartitions

Then, we consider the null hypothesis stating that the variables are independent, meaning that there is no relationship between row and column repartitions. we calculate the table of theoretical repartitions supposing this hypothesis. In this case, the rows and column repartitions are independent. Therefore, the probability to be on a row R and column C is equal to the product of the probabilities to be on the row R and on the column C. Thus, the theoretical repartition of a row and a column is equal to the product of the row and column marginal totals divided by the sample size. Table 9.21 shows the theoretical repartitions for our example.

Program Use Success CS experience	failure	success	**TOTAL**
none or limited	2.15	6.85	**9**
medium or more	8.85	28.15	**37**
TOTAL	**11**	**35**	**46**

Table 9.21: Theoretical repartitions

Then, in order to measure the difference between the two tables, we use the chi-square distance. For each repartition, with a observed value Obs, and a theoretical value Th, we calculate the value $\frac{(Obs-Th)^2}{Th}$. The chi-square value is equal to the sum of these values. Table 9.22 shows the result of chi-square calculation for our example.

Program Use Success / CS experience	failure	success	**TOTAL**
none or limited	21.79	6.85	**28.64**
medium or more	5.30	1.67	**6.97**
TOTAL	**27.09**	**8.51**	**35.60**

Table 9.22: Chi-square calculation

So, chi-square is equal to 35.60.

We next calculate the number of degrees of freedom. It is equal to (R-1)(C-1) where R is the number of rows and C is the number of columns. In this example, R=2 and C=2, so the number of degrees of freedom is equal to one. Then a chi-square table can be used to determine, with a given number of degrees of freedom, the p-value linked to the calculated chi-square value. Considering an error margin of 5%, if the p-value is inferior to 0.05, we reject the null hypothesis, and so prove a link between the two variables.

For our example, using such a table[WW90], we can see that the p-value is inferior to 0.001. So the chi-square test demonstrates a link between *CS Medium Level* and *Program Use Success*.

However, there are constraints when using this test. First, the sample must be large enough, as as this tests uses an approximation. This is the case here, as samples with size greater than 40 are considered valid. Then, it is recommended to not have too low theoretical repartitions. There are discussions on which threshold value must be used, between 1 and 5[WW90]. Therefore, as we have here a value of 2.15, there are some risks that the result of this test may not be totally right. We could observe the same problem for other tests to perform on our data. Now, we do not want to have any ambiguity on the results. So we decide to use an other test.

An alternative test to chi-square, when sample size or theoretical repartitions are too low, is the **Fisher's exact test**[AB94]. Opposite to chi-square, this test is considered to be exact, as no approximation has to be made. Indeed, this test considers all the possible tables when marginal totals are fixed. As the computation of all the tables can become very complex when the numbers of rows and columns are too high, the practical use of this test is limited to 2x2 tables.

We consider the table shown by Figure 9.4.

a	b
c	d

Figure 9.4: A 2x2 table

The probability to have these values inside the table, considering that the marginal totals are fixed is described by the hypergeometric law. So we have:

$P(a,b,c,d) = \frac{(a+b)!(c+d)!(b+c)!(b+d)!}{(a+b+c+d)!a!b!c!d!}$

The principle of the test is to calculate the probability for each possible table. The p-value used to establish if the independence hypothesis must be rejected is the sum of the probabilities of all more extreme or similar tables compared with the observed, which are the table with a probability inferior or equal to the observed table probability. Considering an error margin of 5%, if the p-value is inferior to 0.05, we reject the independence hypothesis, and so prove a link between the two variables. It can be noticed that when the sample sizes grows, the chi-square probability tends toward this p-value.

The advantage of this test is that it can be used on our sample without any size restriction because it is an exact test. The drawback is that it is very complicated to calculate by hand, because of the number of possible combinations. However, numerous software allow to calculate the p-value. For our study we use the MedCalc software[Med].

We now apply this test to the previous example, from Table 9.20. The calculated p-value is 0.00000005, which is lower than 0.05, showing a dependence between *CS Medium Level* and *Program Use Success*. So we prove that the ability to use the program without any help depends on if the user has at least a daily office automation level in computer science.

In a more restrictive way, wen now compare successively each computer science experience class, from lower to higher.

First, we compare people with no or a limited experience with people with a medium experience. Table 9.23 shows the observed repartition. The calculated p-value is

0.000067, which is lower than 0.05, showing a dependence between the two variables. This link can be considered as positive (if the success grows when the computer science experience grows), or negative (if the success grows when the computer science lowers). As all subjects with no or a limited computer science experience have a failure result, this link cannot be negative, and is therefore positive.

Program Use Success CS experience	failure	success	**TOTAL**
none or limited	9	0	**9**
medium	2	12	**14**
TOTAL	**11**	**12**	**23**

Table 9.23: Observed repartitions for none to medium computer science experience

We next confront people with medium and advanced experience, as shown by Table 9.24. The calculated p-value is 0.486667, meaning that we cannot reject the independence hypothesis.

Program Use Success CS experience	failure	success	**TOTAL**
medium	2	12	**14**
advanced	0	11	**11**
TOTAL	**2**	**23**	**25**

Table 9.24: Observed repartitions for medium to advanced computer science experience

Finally, we consider people with advanced and expert experience, as shown by Table 9.25. The calculated p-value is 1, meaning that we also cannot reject the independence hypothesis.

Program Use Success CS experience	failure	success	**TOTAL**
advanced	0	11	**11**
expert	0	12	**12**
TOTAL	**0**	**23**	**23**

Table 9.25: Observed repartitions for advanced to expert computer science experience

As a conclusion, we could prove a positive link between *Program Success Use* and the computer science experience for people having no or a limited computer science experience, or a daily office automation level. So, the daily office automation level class is a threshold class, from which the ability to use the program without any help changes significantly in a positive direction. We can observe that this goes in the same direction as the assumption we made previously, stating that daily office automation level was sufficient to be able to use the program without any help. We could not find any link for people having at least a daily office automation level. But we did not prove that there was no link where we could not find any. However, the fact that every subject with at least an advanced computer science level succeeded in using the program without any help seems to confirm the observation we just made.

Now, we examine the influence of the 3D experience of the subjects on their results. First we study the link between *Has 3D Experience* and *Program Use Success*, whose repartitions are shown by Table 9.26. The calculated p-value is 0.035559, which is lower than 0.05, showing a dependence between the two variables.

Program Use Success 3D experience	failure	success	**TOTAL**
has none	10	19	**29**
has	1	16	**17**
TOTAL	**11**	**35**	**46**

Table 9.26: Observed repartitions for none to medium computer science experience

However, it seems logical to assume that the fact to have a 3D experience is linked to computer science experience, as it can be observed that people mastering 3D software can usually already master office automation software. Let us see if we can prove this link. Table 9.27 shows the repartitions of the sample according to the variables *Has 3D Experience* and *Medium CS Experience*. The calculated p-value is 0.016919, which is lower than 0.05, showing a dependence between the two variables.

CS experience 3D experience	none or limited	medium or more	**TOTAL**
has none	9	12	**29**
has	0	17	**17**
TOTAL	**9**	**37**	**46**

Table 9.27: Observed repartitions comparing 3D and Computer Science experience

Therefore, the relationship we established between *Has 3D Experience* and *Program Use Success* could be explained by this link. Indeed, we can observe that all subject who have no or a limited experience in computer science had no experience in 3D and have all failed. In the other side, people with an advanced experience in 3D had at least an advanced level in computer science and have all succeeded. So, in order to not compare these two extreme repartitions, a better (and more restrictive) test would be to compare successively each 3D experience class, from lower to higher, as it was done for computer science experience.

We first confront people with none and casual experience in 3D, as shown by Table 9.28. The calculated p-value is 0.390895, meaning that we cannot reject the independence hypothesis.

Program Use Success 3D experience	failure	success	**TOTAL**
none	10	19	**29**
casual	1	7	**8**
TOTAL	**11**	**26**	**37**

Table 9.28: Observed repartitions for none to casual 3D experience

Finally, we consider people with casual and advanced 3D experience, as shown by Table 9.29. The calculated p-value is 0.470588, meaning that we also cannot reject the independence hypothesis.

Program Use Success 3D experience	failure	success	**TOTAL**
casual	1	7	**8**
advanced	0	9	**9**
TOTAL	**1**	**16**	**17**

Table 9.29: Observed repartitions for casual to advanced 3D experience

As a conclusion, opposite to computer science experience, we could not find a threshold 3D experience threshold class, from which the ability to use the program without any help changes significantly.

Furthermore, if we consider people with at least an advanced computer science experience (20 subjects), they have a various experience in 3D, as 7 have no experience, 5 a casual experience and 8 an advanced experience. As they all succeeded using the program without help, we can say that the 3D experience was not significant when the computer science experience is at least advanced.

For these reasons, we can consider computer science experience as the most significant variable to describe the ability to use the program without help than 3D experience. Therefore, we only consider this single variable in the analysis. We have shown for our sample that there is a threshold experience class, the one of daily office automation level, from which the ability to use the program without any help increases significantly. However this concerns the sample only, and we need now to see how the results would be if we project them on a larger population. This is done in the next section.

9.3.2 Confidence Intervals Estimation

We now estimate what would be the result of the experiment on a larger population. As we established in the previous section that the most significant variable to study was computer science experience, we use the different computer experience levels to select population groups, on which we will make the projections. As we cannot guarantee that our sample is a representative cross-section of a city population, because people were selected according to their computer science experience in order to have enough participants in each class, we have to limit projections on each computer science experience class.

Let us consider a class, on which we measured on a sample of size n a variable with two possible modalities (for example *Program Use Success*). Therefore, for each participant, the result can be considered as a failure or a success. We name f the success frequency of the sample, which is equal to the number of subjects who succeeded, we name m, divided by n. We want to estimate the probability, we name p, of success for a larger population. To make such an estimation in statistics, we determine, considering an error margin of α, a confidence interval $[pmin; pmax]$ containing p with a probability of $1 - \alpha$[WW90].

We define for a participant a random variable X, which is equal to 0 if failure, and 1 if success. X is defined by the Bernoulli law of parameter p, meaning that P(X=1)=p and P(X=0)=1-p. Therefore, the variable $Y = \sum_{i=1}^{n} X_i$ is described by a binomial law of parameter n and p. So, we have:

$$P(Y = k) = C_n^k p^k (1 - p)^{n-k}$$

English statisticians C.J. Clopper et E..S Pearson demonstrated[CP34] that we can use as lower and upper limits of the interval the single solutions of the following equations:

$$\sum_{k=m}^{n} C_n^k pmin^k (1 - pmin)^{n-k} = \alpha/2$$

$$\sum_{k=0}^{m} C_n^k pmax^k (1 - pmax)^{n-k} = \alpha/2$$

This interval is called the **Clopper-Pearson interval**. It is considered as exact, meaning that to calculate it, no approximation needs to be made, and it can therefore be applied to samples of any size. As for Fisher exact test, the drawback is the complexity of calculation. However, statistic tables or programs can be used to calculate the Clopper-Pearson interval. This interval is also considered as conservative compared to other methods, meaning that it is larger. However, we have to use this method, because of the small size of the sample.

Therefore, we use the Clopper-Pearson interval, with an error margin of 0.05, to estimate for the different computer science experience classes the usability of the program on a large population. The program MYSTAT, a free DOS statistical package for students developed from the SYSTAT software[Sys], has been used to compute the values. Table 9.30 shows the computed intervals.

Computer science experience	Success cause	m	n	f	**Confidence interval**
limited	could use the program with a little help	8	8	1.00	**[0.63;1.00]**
medium	could use the program with at worse a little help	14	14	1.00	**[0.77;1.00]**
medium	could use the program without any help	12	14	0.86	**[0.57;0.98]**
advanced	could use the program without any help	11	11	1.00	**[0.72;1.00]**
expert	could use the program without any help	12	12	1.00	**[0.74;1.00]**
expert	could use the program without difficulties	10	12	0.83	**[0.52;0.98]**

Table 9.30: Clopper-Pearson intervals

Therefore, with 95% of certitude, we can guarantee that, considering a city population:

- At least 63% of people with a limited experience in computer science will be able to use the program the first time with a little help.
- At least 77% of people with a daily office automation experience in computer science will be able to use the program the first time with at worse a little help.
- Between 57% and 98% of people with a daily office automation experience in computer science will be able to use the program the first time without any help.
- At least 72% of people with an advanced experience in computer science will be able to use the program the first time without any help.

- At least 74% of people with an expert experience in computer science will be able to use the program the first time without any help.
- Between 52% and 98% of people with an expert experience in computer science will be able to use the program the first time without any difficulty.

We can talk about a first time use of the program, as all the participant of the experiment had no experience with the program before.

Therefore, we anticipated that at least almost 60 percent of people with simply a daily office automation experience in computer science will be able to use the program without any help the first time, and at least three quarters of them will be able to use it with at worse a little help. Concerning people with a more advanced experience in computer science, we established that at least three quarters of them will be able to use the program without any help the first time. Furthermore, at least half of people with an expert level in computer science will manage to use the program without any difficulties the first time. Finally, even people with a limited experience will have access to the technology, as at least almost two thirds of them will be able to use the program with only a little help the first time.

These results are encouraging, considering the relative small size of sample and the fact that the Clopper-Pearson interval is more conservative compared to other methods.

9.4 Conclusion on Usability

From the usability experiment results, we determined on the sample that the computer science experience of people was more significant than their 3D experience to determine the usability results, showing that the fact to have at least a daily office automation level was a threshold computer science experience level to determine if people could use the program without any help. This was confirmed when we projected the results on a large population, as we guaranteed that a majority (at least 57%) of people having a daily office automation level in computer science would be able to use the program the first time without any help. Results were also encouraging for people with a higher level, and even with a lower level, as a majority of them would be able to use the program the first time with only a limited help.

To conclude, a second objective of enhancing public consultation using VE technology has been achieved, as we were able, in term of usability, to make the technology accessible to a fair large audience. What we need to do next is to proceed to application-oriented experiments, to establish if the idea of the thesis of using a VE can improve the quality of the consultation, and if it gets support from the general public and professionals.

Chapter 10

Application-based Experiments

Having performed the usability study, the next step is to make experiments on an application context, which is the one of public consultation in the urban planning process. Therefore, this chapter describes these experiments. They have two main goals.

First, we have to judge the potential of the VE to improve quality of the consultation process. In order to do so, an urban planning simulation has been done on a part of people who participated to the usability study. The result of the simulation could then be analysed, with the help of urban planning field professionals.

But the main goal of these experiments is to get feedback from people about the use of a VE for public consultation. Indeed, as we want to prove that VE technology is accessible to the general public in the urban planning consultation task, it was necessary to assess usability. The results were encouraging, but they can be ruined if the feedback from people is bad. Indeed, with a low support from the public, this way of consultation would not really be used. Therefore, getting opinion from people is absolutely necessary. In order to do so, a general public survey was achieved in order to get feedback from a randomly sample of citizens.

10.1 Urban Planning Simulation Experiment

This first experiment was performed on the first people who performed the usability study. After having assessed their usability, the object of the experiment was to confront them with a real application of the program, engaging a consultation process and leave feedback on the model. Furthermore they could leave feedback about the program itself.

However, as stated in the previous chapter, the sample was not randomly selected, and therefore cannot really be considered as a representative sample of a targeted city population. Therefore, a more 'neutral' experiment needed to be done, which is the general public survey. However, we asked for feedback anyway, in order to design the survey more effectively, learning lessons from endured difficulties, and reading results to anticipate next ones.

10.1.1 Description of the Experiment

Let us first have an overview of the experiment, describing how it is conducted:

- First, people perform the usability evaluation discussed in the previous chapter.
- Then, people enter the simulation, where they experience free navigation and interaction inside a city environment, acting as citizen on a consultation scenario. The results of this experiment are the comments they leave on the environment.
- Next, we ask them to give some feedback about their experience of the environment, so they can assess themselves our approach as a way to consult people in the urban planning process.
- Finally, after having performed these experiments, we ask urban planning field professionals to assess our approach. In order to do so, after having presented to them the application, they enter the urban planning scenario city and read the comments left by the people. Then, they answer a questionnaire about their analysis of these comments and their opinion on our approach.

Figure 10.1 shows the whole experimental process. Next, we describe in more details each stage.

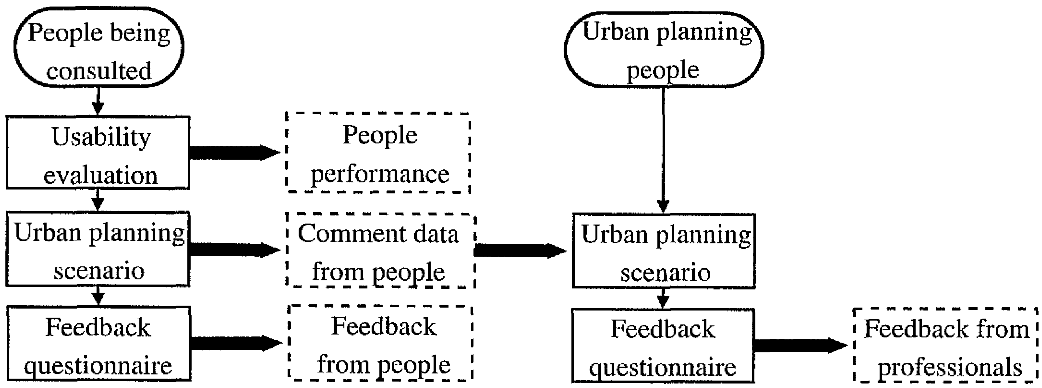


Figure 10.1: Summary of the urban planning simulation experiment

Urban Planning Scenario:

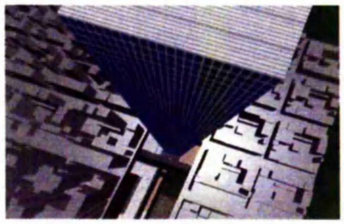
At first, we simulate a case of public consultation, making people visit the environment and leave feedback as comments. As discussed in Section 3.3, we use an non-existent city. Using this "virtual" city allows us to have better control of what we want to represent, and to anticipate public response. For example, we include to the consultation area a building with an enormous height, and so expect public to criticise that. Another reason is that evaluation of the thesis concerning the model realism is not about the representation accuracy of an existing city model (Chapter 2 already shows some very accurate models), but more about the feeling of immersion inside the environment. And so a 'neutral' representation of the model prevents feedback to be about the accuracy of a specific city environment people already know.

We ask people to play a role, telling them some of their preferences:

- They live near the concerned area.
- They want a day nursery (public building) and a cinema (private building).
- They want trees on every street.
- They do not want any hazardous decoration (statues) on the area.

Using these criteria, as well as general common sense, we can design on the area some test cases to check if people notice them. We designed 6 of them, as shown by Figure 10.2.

A high security prison



A very high building

A street without trees

Some cow statues

A day nursery

No cinema

Figure 10.2: Test cases of the urban planning simulation area

Using these test cases allows us to assess in a first way the application, checking if people can have access to information from the environment, by checking if they notice them. The corresponding evaluation form is available in Appendix B.

A second way to assess the application is to look at the results of the consultation themselves, the consultation data. This assesses the quality of people participation, and therefore the potential of the thesis approach as an alternative proposal to traditional people consultation. In order to do so, we check the results from the boards (as they are placed in strategic places), but also free comments and comments on objects, and check their relevance. For this task, we involve urban planning professionals, who read these data, and discuss them on a provided questionnaire (available in Appendix B).

Feedback from Users and Professionals:

The final task is to get feedback from the people, about their experience of the application.

We first engage a discussion with people who performed the experiment, asking them to answer a questionnaire (available in Appendix B). We ask them:

- to enumerate the positive aspects of this approach

- to enumerate the negative aspects of this approach
- to mark this approach as a way to be consulted (from 0 to 10), knowing that the software they tested is a prototype
- to tell if this way of consultation would increase their level of involvement in the urban planning process
- to give any other comments, such as ideas to improve the application

Then, we engage an other discussion with professionals from the urban planning field. They are asked to answer an other questionnaire, similar to the first one (again available in Appendix B), by asking them:

- to enumerate the positive aspects of this approach
- to enumerate the negative aspects of this approach
- to mark this approach (from 0 to 10)
- to tell if they would recommend this approach to be used for consulting people in urban planning
- to give any other comments, such as ideas to improve the application

10.1.2 Results

The user-oriented experiments involved the first 25 persons from the 46 participants who performed the usability experiment. The time of the experiments (without counting the usability study) was from 30 minutes to 1h15 for a person. The high difference of time for one person to another is explained by the various time to perform the simulation, and also the large amount of discussion with some of them. Detailed results for each participant are shown in Appendix C.

Assessment of the Application:

We observe now how people could manage to use the program, examining how they could access to information. First it can be noticed that during the experiment everybody did visit all the boards, and therefore had access to general and spatial information.

Now, we examine the test cases we placed on the city environment. Table 10.1 provides, for each test case, the number of people who did noticed it.

Test case	Number of people	Percentage
The prison	25	100%
The very high building	16	64%
The street without trees	25	100%
The cow statues	22	88%
The day nursery	25	100%
The lack of cinema	24	96%

Table 10.1: People who detected the test cases

We first observe how people did access to physical information. This is measured by the detection of the prison, the day nursery, the lack of cinema.We can notice that everybody did notice the prison and the day nursery. We can also see that only one person did not "notice" the lack of cinema, because he did not check all the private buildings. However we can consider this person as a particular case, as it is the one with no experience in computer science who needed a demonstration in the navigation tasks, and therefore would have needed important external assistance to properly use the application. Therefore, we can observe that the application allowed people to access physical information well, as soon as they have a minimum experience in computer science.

Then we observe information related to the 3D environment itself. This concerns the detection of the street without trees, the cow statues, and the very high building. Looking now at and the street without trees. First, we observe that all the participants detected the street without trees, which is an encouraging result. Then, we notice that all of them but three did notice the cow statues. These three people did require help in the navigation trials, and so would need some assistance in using the application. Therefore, we can say that the items were detected, as soon as people could use the program feature without help. This is confirmed by a Fisher's exact test made on the sample, whose repartitions are shown by Table 10.2: the p-value is equal to 0.008696, showing a positive link between the ability to use the program without any help and the ability to find the cow statues.

Program Use Success Did find cow statues	failure	success	**TOTAL**
no	3	0	**3**
yes	3	19	**22**
TOTAL	**6**	**19**	**25**

Table 10.2: Observed repartitions for cow statues use case

Finally, the least detected test case was the very high building. This could be explained that the fact that more advanced navigation was required to be able to view the height of the building (it was carefully hidden from any board associated view). However, some people who succeeded well the navigation trials did not see the building. Furthermore, if we make a Fisher's exact test, where repartitions are shown by Table 10.3, we compute a p-value of 0.142451, and cannot therefore show a significant link between usability experiment results and the ability to find the very high building.

Program Use Success Did find the very high building	failure	success	**TOTAL**
no	4	5	**9**
yes	2	14	**16**
TOTAL	**6**	**19**	**25**

Table 10.3: Observed repartitions for very high building use case

However, this observation can be explained by the fact that most of the participants who did not notice the building did not really check buildings size, as we did not ask them to do so (they stated this after the experiment). Indeed, if people would have been asked to do so, they would have take time to look at each building size, and therefore have greater chances to notice the very high building, and the results would have been better. Furthermore, we can also expect that people would have been more curious about the environment in a real urban planning process, as being this time really concerned about the project, and would have also greater chances to notice the building size. However, as building size is an important part of a consultation, a way must be found to allow people to have easily a good overview of the urban project. A possible solution is simply the use of more boards, as every board was visited during the experiment.

Therefore, we can say that from our sample, people were usually able to have access to information related to the 3D model, as soon as they did manage to use the program without any help during the usability experiment. There were some people who did not notice the high building but had however good usability results. However this could be explained by other factors than usability, and could also be corrected.

To conclude, we can say that people had access to information with a good success. A part of the people who did not notice a piece of the information are from the group of people who would needed some assistance during the usability study, showing a link between these results and the ones from the usability study. As the usability study results were encouraging, we can expect that there a fair large audience would notice most of the information. Besides, the detection of more items could be made easier by the use of more boards, so people would have access to more "strategic" views. Finally, the bad detection of the high building could be explained by the lack of interest of people to check this, which would be different compared to a real urban planning project.We can therefore validate the application as a possible way of public consultation. We observe next the potentials of our approach as a way to improve public consultation, by analysing the comments left by people during the simulation.

Analysis of Comments from People:

We now examine the consultation data left by people during the experiment. This assesses the quality of the consultation generated by the simulation, and therefore the potential of the prototype as a better public consultation application compared to the traditional process. With supervision of three professionals from the urban planning field, an architect, an urban planner particularly interested in the public consultation process, and a decision-maker - a town councillor and member of board of a public society for large scale cooperative urban planning, we reviewed data from each of the three types of comments. Each professional was interviewed separately.

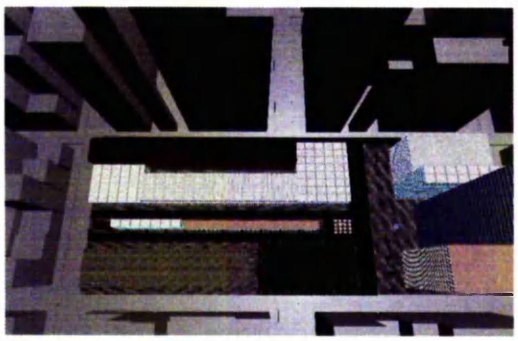
First, we have a look on the comments on boards. We provided four boards inside the environment, as shown by Figure 10.3. We review each board.

1. The first board, which shows a general view of the project, is used for general comments. According to all the professionals, these comments were comparable to comments we can find in hearings.

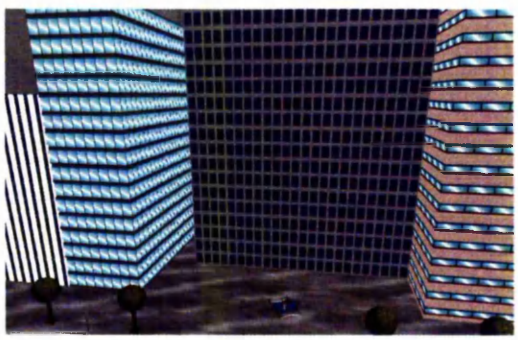
2. The second board focuses on a square surrounded by office buildings. It only includes a fountain and two benches, and so people were asked to write suggestion about its arrangement. Patterns were noticed between the different comments by the three professionals, as for example number of people asked for more trees and places to sit.

3. On the third board, the professionals observed again the same kind of patterns as on the second board, people asking mostly about equipment which could be included to the park.

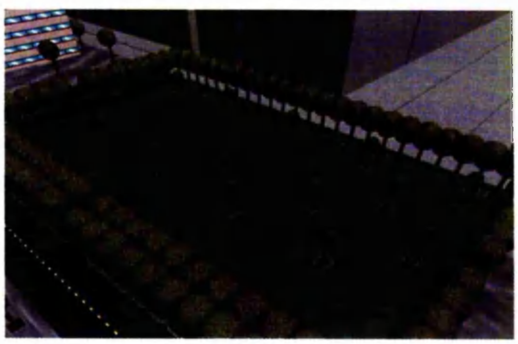
4. Finally, the fourth board, which is about a residential area of luxury flats, presented again a pattern according to professionals, as people complained about the too massive aspect of the buildings for a luxury flats standard.



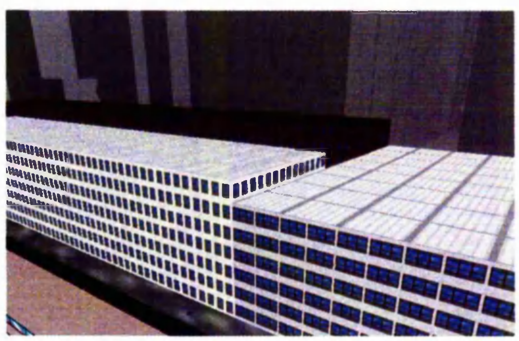
Board 1 - General view



Board 2 - Business centre



Board 3 - The park



Board 4 - Luxury flats

Figure 10.3: The four boards of the project

As a conclusion, the use of boards to gather comments was able to show some patterns in the different comments, which have been noticed by all the urban planning field professionals, as they are interpretable, unlike comments recorded in traditional consultation processes, which are mostly scattered. However, because of the small size of the sample we cannot guarantee that the same patterns would be automatically found on a larger population. Anyway, we still showed a potential of our approach, which was already quite appreciated by the professionals we interviewed.

Observing next comments on objects, we were able to find the same idea of patterns. The best example is the prison, which received a bad feedback, because of both its proximity to the day nursery and its location on an area near the place people were supposed to live. All the professionals found these comments useful, because of the patterns again, and the idea of precision of these comments, as it is possible to comment on any object, including very small ones.

Finally, we consider free comments. They were mainly on visual details, such as the street without trees, the very high building or the cow statues. The three professionals appreciated the idea of freedom, which stimulates people imagination according to the decision-maker. They also liked the idea of precision of these comments, as some of them were very pertinent according to them.

As a summary, this analysis of the consultation simulation experiment highlighted the potential of this work for improving the quality of public feedback, and therefore the quality of the public participation process, as we had encouraging results on our sample. However, in order to turn this potential into proved improvements, a larger scale experiment have to be done. This is discussed in Section 11.3.1.

Feedback from Participants:

After having made people participate to the different experiments, we invited them to answer a feedback questionnaire, available in Appendix B, in order to assess their motivation on using such a software in the future. Synthetic results of this questionnaire, for each person involved, are available in Appendix C. We do not include to this analysis the other comments and suggestion they left, as they are used for proposing future work directions in Section 11.3.

We first asked them to enumerate the positive and negative aspects of the approach of using a VE for public participation, from their experience with the prototype they used during the experiments. Table 10.4 shows the recurring responses, given by three or more people.

Positive aspects	Number of people	Percentage
Possibility to record comments	24	96%
Interactive	23	92%
User-friendly	18	72%
The three kinds of comments	14	56%
Realism	8	32%
Information display	5	20%

Negative aspects	Number of people	Percentage
Confusion with the three kinds of comments	11	44%
Navigation is a little difficult	10	40%

Table 10.4: Summary of positive and negative aspects

- We included to the people who quoted in the positive aspects the possibility to record comments people who quoted the three kinds of comments. Indeed, we can assume that the people who left a good feedback about the possibility to use the three kind of comments would have left a good feedback about the possibility to record comments as well.
- “Interactive” represents the idea of interactivity driven by the use of a VE, which involve navigation and possibilities of interaction with the different objects included in the VE.

The first aspect people appreciated is the possibility to record comments, as all of them but one quoted this as a positive point. This is explainable, as the possibility to record comment is the key feature of a consultation process.

The second most appreciated feature is interactivity, which has been quoted by 23 people (92%). This is a good evaluation result of our approach, as interactivity is the main asset of a VE compared to static media used in the traditional consultation processes.

Then, a large proportion of the people (18 people - 72%) quoted the user-friendly side of the application, which could have been anticipated by the results of the usability experiment, where most of the users were able to use the software without any help. This is a good result, for an evaluation of the idea to increase public involvement by proposing such an application, as the user-friendliness was a requirement of the model.

The idea of having three kinds of comments was quite appreciated, as it was quoted by more than half of the people (14 people - 56%). However 44% of them (11 people) were confused about where to use which comment. Work will so have to be carried out to clarify the process, as discussed in Section 11.3.2.

Finally, some people appreciated the realism of the environment and the possibility of information visualisation. The "realism" score is a little disappointing. This can be explained by the current level of detail of the prototype. Ways to increase realism are suggested in Section 11.3.2.

Looking now at the negative side, there are two main points, which include the confusion with the three kinds of comments we already talked about. The second point is about little difficulties experienced with navigation, being quoted by 10 persons (40%). This was to expect by observing usability experiment results, as six persons required some help for the navigation tasks. However we talk there only about "little" difficulties, which do not question the ability of most of users to be able to navigate by themselves, without any external help.

People were then asked to mark, out of ten, the idea of using a VE for public consultation compared to traditional consultation processes (people not aware about traditional consultation process were told about it), considering the experience they had with the prototype environment.

The results are encouraging, as the marks are from 7 to 10, with a mean of 8.24 and standard deviation of 0.91. Therefore, the approach got a good support from people.

Then, Table 10.5 displays the average mark of people according to their level of involvement in urban planning. They show that people who are not actively involved are at least as enthusiastic as people who are involved, which is a good result, as people with a low involvement are the targeted people for increasing public participation.

Level of involvement in urban planning	Average mark
low (0 and 1)	8.32
high (2 and 3)	8.00

Table 10.5: People mark according to their level of involvement

Finally we asked people if the availability of such a system would increase their participation to the process. Everybody except one answered yes. Therefore, this approach has good potential to improve public participation.

In conclusion, we can say that our approach has a good support for the people who experienced the prototype, as they appreciated user-friendliness and its specific features, such has interactivity, and considered it as a good approach for public consultation, which would increase their involvement. This will have to be confirmed by the general public survey results.

Discussion with Urban Planning Field Professionals:

As previously said in this section on page 162, we asked urban planning field professionals to supervise the analysis of the results of the urban planning simulation. From this analysis, professionals appreciated the three kinds of comments, as they could provide feedback with better quality than the ones traditional processes provide. Following this, there were discussions with them to get some feedback about our approach. A questionnaire, shown in Appendix B, was used to direct the interviews.

From a positive point of view, all the professionals appreciated the idea of 3D visualisation, as no traditional process provides this feature. All of them also liked the idea of interactivity of the environment, and especially the free navigation inside the environment, allowing a more precise and imaginative visit of the project according to the decision-maker, resulting in more pertinent comments which is not possible with a traditional hearing according to all of them. The three professionals appreciated also the use of the three kind of comments, offering more freedom and precision to the participants. The urban planner appreciated the realism of the environment, and the architect the use of the map. Finally, the urban planner insisted on the potentiality of this approach to enable people to visualise different alternatives of a project.

From a negative point of view, there were from the urban planner and the decision-maker reservations about the possibility for the general public to carry out environment modifications . Indeed, urban planning is governed by rules with many constraints, and understanding how these rules work is a very challenging tasks, which requires the reading of enormous documents.

Yet, the approach is still applicable to the other forms of interaction, and professionals, who gave an average mark of 7.67 out of 10 to the idea, would recommend the approach as a new way of public consultation, subject to improvements of the application, from the actual prototype model to a final application.

Finally, they gave some advices on how to improve the present software, which are included to future work directions in Section 11.3.2.

10.1.3 Discussion on Results

Having first observed that people could use well the program during the urban planning consultation simulation, confirming the usability study results, we could validate the application as a possible way of public consultation. Having next analysed the results of the simulation with the help of urban planning field professionals, we shown a potential of our approach to better the consultation process, permitting people to write more exploitable and precise comments. However, a ground experiment will need to be performed in order to confirm this potential, as suggested next in Section 11.3.1. However, professionals appreciated the approach, and would recommend the application of the idea to the urban planning consultation process.

The feedback from people who participated to the simulation showed a good support of our approach. However, this support was expressed by people who performed two experiments before, and therefore had already knowledge of the application. Now, the challenge is to have support from people who did not experiment of the program, in order to know if they would use it, and not if they appreciated its use. Indeed, if an idea has proved to have a good potential, but do not have support from people because they are not willing to try it, although people who tried it left a good feedback, it can be ruined. Furthermore, the experiment was not performed on randomly selected people, and therefore not really on a representative sample. Thus, a more 'neutral' experiment must be done, from a randomly selected population. That is why a survey on the general public has been done, in order to see if it confirms the present results. The next section discusses this experiment.

10.2 General Public Survey

10.2.1 Description of the Experiment

Having determined the potential of our approach to the urban planning consultation process, we now have to establish if it gets support from the potential users. In order to do so, a survey on a general public audience has to be conducted. Two options are available:

- First, we can envisage an on street survey, where people from the street or a public space are asked successively to see a presentation of the program, try it, and then answer a questionnaire.
- Second is the idea of performing a presentation to a group of people, offering the possibility for each participant to try the program and then asking them to answer the questionnaire.

The second solution was selected, because of the risk to only get really motivated people with the first one. Indeed, it is already difficult to have people answer to short surveys on street, as they often claim that they do not have available time. Therefore, people answering to these surveys are in a way already motivated people. So, performing our survey, which is longer than usual surveys, as it requires the demonstration of the program and a test of it before answering to questions, could attract even more motivated people, and therefore distort our results. In other hand, proceeding with a presentation, on a weekend, offers the possibility to make people come in family groups, and can attract people not necessarily motivated, if for example food and drinks are provided to participants.

Therefore, it was decided to organise an event on a weekend. Invitations were issued within the neighbourhood, using letterboxes or forwarded through different associations, asking people to come with their families, and promising food and drink for participants.

The experiment was planned as followed:

- First, an 15-minute interactive presentation of the prototype program is given to the audience.

- Then people are invited to try the program by themselves. Meanwhile, other participants can discuss around a buffet.
- Finally, as soon as a participant has tested the program, he is asked to answer a questionnaire.

The city model used for both presentation and interactive demonstration is the one used for the urban planning simulation experiment, so people can experience the program in an application context, and as well observe the comments from the simulation experiment.

The questionnaire is shown in Appendix B.

- Previously, we ask people some personal information. First, similar to last experiment, people are asked about their age, their level in computer science, their background, and their level of participation in the urban planning process. We also ask people if they have an Internet connection and if yes with which speed, in order to know if they are eligible for the use of this kind of program at home.
- Then, people are asked to answer to questions about the different features of the prototype. Multiple-choice questions are used, in order to ease the analysis of the results. Part of these questions have been chosen according to the feedback from the previous experiment, selecting the most and least appreciated features of the program. For each feature, four answer choices are proposed to the participants, as shown by Table 10.6.

Positive answers	Description
very good	the feature was well appreciated
good enough	the feature was fairly appreciated

Negative answers	Description
not so good	the feature was not really appreciated
not good	the feature was not appreciated

Table 10.6: Possible answers of questions

- Finally, we ask people if they would use such a program if it was available for public consultation in the urban planning process. If yes, they are asked to specify how - at home alone (without any help), at home with some help, or at city hall.

It can be observed that the marking question from the previous experiment questionnaire has been removed. Indeed, during the previous experiment, people expressed difficulties to mark the whole program. So it was decided to ease the 'marking' process by asking participants to mark independently its different features with multiple-choice questions.

10.2.2 Results

The event was organized on a Saturday late morning, at which 26 people participated. A 15-minute presentation and demonstration of the program was given using a video projector, in front of 26 people. Then people could try the program, discuss it around a buffet, and then complete the multiple-choice questionnaire.

24 questionnaires could be analysed (2 were incomplete), from people who all experienced using the program. Their results are shown in Appendix D. Here is the information about these participants:

- Their ages were from 24 to 80 years, with a mean of 44 years. Observing the detailed results from Appendix D, we can see that we can fairly separate the participants into two age classes:
  - People with age from 24 to 33 years, considered as the younger class (13 people)
  - People with age from 53 to 80 years, considered as the older class (11 people)

  (there was no people with an age between 33 and 53 years).
- 12 were male and 12 female.
- 5 people had no or limited experience in computer science, 13 a daily office automation level, and 6 a more advanced level.

- A high proportion of them had the Internet at home, as 17 people had a high-speed connection and 4 a slow-speed connection.
- Their background was diverse: 9 of them have a literary education, 7 of them a scientific education, and 8 people a mixed education between these two fields.
- Their level of participation in the urban planning process was also diverse: 6 people had a high level of involvement, 10 a casual level, and 8 a limited or no level.

Gathering a representative sample of the population is really challenging, as we cannot select randomly participants and force them to participate to the survey. Therefore the sample cannot really be considered as randomly selected from the population, as only people willing to participate to the experiment came, and had so already at least a little interest (although there were food and drinks in order to attract people, and some people came with family members who may not have come by themselves).

But if we consider the population of people usually willing to participate to the experiment, and therefore at least usually a little interested to the process, we can estimate that our sample was some how randomly chosen from this population, as there was no other criteria choice. This is by reinforced the fact that most of the participants characteristics are diverse. This estimation seems fair, as a non negligible proportion of the sample is composed of people with a high participation level in urban planning. However most of them have at most a casual involvement, but we could expect to have a larger proportion of them from the whole population of a city.

Therefore, for the following analysis, we consider that the sample represents this population of people having usually at least a little interest in the urban planning process.

Observation of the Results:

We first observe the results of the first ten questions about the different features of the program. Table 10.7 shows them.

Feature	good	good enough	not so good	not good
interactivity	15	9	0	0
user-friendliness	8	15	1	0
realism	7	14	3	0
navigation intuitiveness	6	8	9	1
use of boards	15	6	3	0
general information display	16	7	1	0
objects information display	19	4	1	0
map use	15	7	1	1
possibility to record comments	20	4	0	0
three kinds of comments clarity	7	9	7	1

Table 10.7: Feedback from the prototype: number of people who marked the features

Having a look on these results, we can observe that they are similar to the results of the previous experiment, as the participants marked highly, starting from the best respectively, the possibility to record comments, the information display, the interactivity, the user friendliness, and realism. The use of boards was also well marked. The only two negatively-rated features are the navigation and clarity of the three kinds of comments, corresponding to the two negative aspects of the previous experiment shown in Table 10.4. However they still have both a positive mark from a majority of people (almost 60% for both of them), and only at maximum one people marked a feature as 'not good'.

If we confront the navigation feature results with the participants experience in computer science, it can be observed that almost everybody with a limited level gave a negative mark (4 out of 5 people), opposite to both people with daily office automation level and higher experience, whose proportion of negative feedback was about one third. Table 10.8 shows the observed repartitions. However a Fisher's exact test on this table does not establish a significant link with an error margin of 5%, as the computed p-value is 0.122000. However, the small size of the sample of people with none or limited computer science experience makes it difficult to measure a link. Furthermore, the p-value is still low, and we can consider that there is a significant link with an error margin of 12.2%. Therefore, we can fairly estimate that there is a link, and so that the marking of this feature may depend on the fact that people have or not at least a daily office automation level in computer science, confirming the usability study results, as people with a no or a limited computer science experience did require help to navigate inside the environment. But looking in details at the results from Appendix D, a better criteria seems to be the age, which is illustrated by Table 10.9. This is confirmed by the computed p-value is 0.095302, still superior to 0.05, but low enough to consider the fair estimation of a link with an error margin of 10%.

Feedback about navigation intuitiveness Computer science experience	negative	positive	**TOTAL**
none or limited	4	1	**5**
at least daily office automation	6	13	**19**
TOTAL	**10**	**14**	**24**

Table 10.8: Observed repartitions for feedback about navigation confronted with computer science experience

Feedback about navigation intuitiveness Participant age	negative	positive	**TOTAL**
younger class	3	10	**13**
older class	7	4	**11**
TOTAL	**10**	**14**	**24**

Table 10.9: Observed repartitions for feedback about navigation confronted with age

Similar behaviour seems to be observed, considering computer science experience, when we examine how people answered to the clarity of the three kinds of comments, as shown by Table 10.10. However, the computed p-value of the Fisher's exact test on this table is equal to 0.288538, and therefore too high here to estimate that there can be a link. So, we cannot say that the feedback about the clarity of comments depends on the computer science experience of the participants. Confronting this question answer with people age, as illustrated by Figure 10.11, does not neither permit to establish a significant link, as the p-value is equal to 0.390452.

Feedback about clarity of comments Computer Science experience	negative	positive	**TOTAL**
none or limited	3	2	**5**
at least daily office automation	5	14	**19**
TOTAL	**8**	**16**	**24**

Table 10.10: Observed repartitions for feedback about clarity of comments confronted with computer science experience experience

Feedback about clarity of comments Participant age	negative	positive	**TOTAL**
younger class	3	10	**13**
older class	5	6	**11**
TOTAL	**8**	**16**	**24**

Table 10.11: Observed repartitions for feedback about clarity of comments confronted with age

As a conclusion, the results on the sample are promising, as every feature had a majority of good approval, confirming the results of the previous experiment. Thus, the approach received good input from people who had no previous experience with the program. However to confirm this, it was required to ask them if they would use the program, and if so with which level of confidence. This is the aim of the last question of the survey, whose results are shown in Table 10.12.

Would use such a program	Number of people
at home alone	13
at home with help	4
at city hall	4
no	3

Table 10.12: Number of people who would or not use such a program

Observing Table 10.12, we first notice that everyone, except three people, would use the program in an urban planning public consultation scenario, which is very promising, especially since a majority of people are confident enough to consider using it without help. The computer science experience seems to be a factor of the answer, as two from the three people not willing to use the program have a few or no computer science experience, and 5 out of the 6 people with an advanced computer science level consider using the program alone. The age of participants seems to be a factor as well: the people willing to use the program at home alone have an average age of 35 years, the ones willing to use it at home with help 47 years, the ones willing to use it at city hall 51 years, and the ones not willing to use it 72 years. Finally, participants level of involvement in urban planning seems to be also a factor, as the three people not considering using the program have a limited or no participation to the urban planning process. We proceed now with Fisher's exact tests, in order to confirm these observations considering the usual error margin of 5%.

First, people could have answered that they would not use the program at home because they do not have an Internet connection. So we confront the result with Internet availability of participants, as shown on Table 10.13. The computed p-value is equal to 0.193676, showing no significant link. This could be explained by the fact that one of the three people who do not have an Internet connection would use anyway the program at home. Maybe this participant considers having in the future an Internet connection, or she estimated that a use at 'home' includes the use of the program at family members homes.

Would use the program at home Have access to the Internet	no	yes	**TOTAL**
no	2	1	**3**
yes	5	16	**21**
TOTAL	**7**	**17**	**24**

Table 10.13: Observed repartitions confronting results with Internet availability

If we consider high-speed Internet availability instead of Internet availability, we observe the repartitions shown by Table 10.14, and the computer p-value is equal to 0.133555. So there is no significant link, but there may have a link because of the relatively low value of the p-value. However, because of the uncertainty of the meaning of 'home', it is risky to consider a link.

Would use the program at home Internet availability	no	yes	**TOTAL**
no or low-speed	4	3	**7**
high-speed	3	14	**21**
TOTAL	**7**	**17**	**24**

Table 10.14: Observed repartitions confronting results with high-speed Internet availability

Now, we study the link with the computer science experience. We would like to see if we can anticipate the usability study results. In order to do so, we want to know if the fact that people are willing to use the program at home without any help or not depends on their computer science experience, using the threshold experience of daily office automation. The computer p-value is equal to 0.142081, showing no significant link. Here again there may have a link because of the relatively low value of the p-value, but it is risky to consider this link, as people could have answered this question not considering usability issues (for example someone could prefer to use the program at city hall, because he prefers to have a human contact with the urban planning field professionals).

Would use the program at home without any help Computer Science experience	no	yes	**TOTAL**
none or limited	4	1	**5**
at least daily office automation	7	12	**19**
TOTAL	**11**	**13**	**24**

Table 10.15: Observed repartitions confronting results with computer science experience

Then we confront the result with people level of participation in urban planning, as shown by Table 10.16. We can see that as soon as their level of involvement is casual, people would use the program. This is confirmed by a Fisher's exact test performed on Table 10.17, as the p-value is equal to 0.027668.

Would use the program Level of involvement	no	yes	**TOTAL**
none or limited	3	5	**8**
casual	0	10	**10**
high	0	6	**6**
TOTAL	**3**	**21**	**24**

Table 10.16: Observed repartitions confronting results with people different levels of involvement in urban planning

Would use the program Level of involvement	no	yes	**TOTAL**
none or limited	3	5	**8**
at least casual	0	16	**16**
TOTAL	**3**	**21**	**24**

Table 10.17: Observed repartitions confronting results with people level of involvement in urban planning

Finally, we consider people age. We confront the results of the two age classes we defined previously, as shown by Table 10.18. First, observing if participants would use the program or not, the computed p-value is equal to 0.081522, not showing a significant link, but still a good chance to have a link. Then, observing if participants would use the program at home or not, the computed p-value is equal to 0.023265, showing a significant link. Finally, when we observe if participants would use the program at home without any help or not, the computed p-value is equal to 0.037727, establishing again a significant link.

Would use the program Participant age	no	yes	**TOTAL**
younger class	0	13	**13**
older class	3	8	**11**
TOTAL	**3**	**21**	**24**

Would use the program at home Participant age	no	yes	**TOTAL**
younger class	1	12	**13**
older class	6	5	**11**
TOTAL	**7**	**17**	**24**

Would use the program at home without any help Participant age	no	yes	**TOTAL**
younger class	3	10	**13**
older class	8	3	**11**
TOTAL	**11**	**13**	**24**

Table 10.18: Observed repartitions confronting results with participants age

Therefore, the age is also a significant variable. There is a very high proportion (92%) of people from the younger class willing to use the program at home. On the contrary, there is a majority (55%) of people from the older class not willing to use the program at home. Anyway a majority (73%) of them are willing to use the program. We observe also that a high majority (77%) of people from the younger class would consider using the program without any help.

For a conclusion, these results on our sample are promising, as most of the people would use such a program, including every people with at least a casual involvement level in urban planning. Concerning the confidence to use the program at home without any help, it is high for people from the younger class, but low for people from the older class. However, a majority of people from the older class would anyway use the program.

Confidence Intervals Estimation:

The encouraging results we discussed concern the sample only, and must be projected on a larger population to be confirmed. Therefore, we now estimate confidence intervals. As the sample size is small, we use again Clopper-Pearson intervals, as we did in Section 9.3.2, considering the standard error margin of 5%. We mainly project from the whole sample, but perform some projections from selected parts of the sample, following links that were established previously by Fisher's exact tests.

First, we project people feedback on the different features of the program, as shown by Table 10.19

People from the sample	Success cause: gave a good feedback on	m	n	f	**Confidence interval**
all	possibility to record comments	24	24	1.00	**[0.86;1.00]**
all	interactivity	24	24	1.00	**[0.86;1.00]**
all	general information display	23	24	0.96	**[0.79;0.99]**
all	objects information display	23	24	0.96	**[0.79;0.99]**
all	user-friendliness	23	24	0.96	**[0.79;0.99]**
all	map use	22	24	0.92	**[0.73;0.99]**
all	realism	21	24	0.88	**[0.68;0.97]**
all	use of boards	21	24	0.88	**[0.68;0.97]**
all	navigation intuitiveness	14	24	0.58	**[0.37;0.78]**
younger class	navigation intuitiveness	10	13	0.77	**[0.46;0.95]**
all	three kinds of comments clarity	16	24	0.67	**[0.45;0.84]**

Table 10.19: Clopper-Pearson intervals for people feedback about the features

Therefore, with 95% of certitude, we can guarantee that, considering a targeted city population usually willing to participate to the survey:

- At least 86% of people would appreciate the interactivity of the program, and the possibility to record comments.
- Between 79% and 99% of people would appreciate the information display features, as well as the user friendliness of the program.

- Between 73% and 99% of people would appreciate the map feature.
- Between 68% and 97% of people would appreciate the feeling of realism of the environment, and the use of boards.

This shows that the main features of the program would be appreciated by a large majority of people, which is a very encouraging result.

We can also guarantee that:

- Between 37% and 78% of people would appreciate the navigation intuitiveness of the environment. This shows that navigating inside the 3D environment is still considered by people as a hard task, despite the encouraging results of the usability experiment. However the confidence interval is still centered on a majority of people. People with a younger age are more confident, as Between 46% and 95% of them would appreciate the feature.
- Between 45% and 84% of people would find the distinction between the three kinds of comments clear. This shows that improvements will have to be made to enhance this clarity, as suggested next in Section 11.3.3. This is important, as the possibility to record comment is a highly appreciated feature, and the key interaction of a consultation software. However, there is still at minimum almost a majority of people who would find this distinction clear, which remains encouraging.

Finally, we estimate if a larger population would use such a program for urban planning consultation, and how. Table 10.20 shows the computer Clopper-Pearson confidence intervals.

People from the sample	Success cause:	m	n	f	**Confidence interval**
all	would use such a program	21	24	1.00	**[0.68;0.97]**
involvement level at least casual	would use such a program	16	16	1.00	**[0.79;1.00]**
all	would use such a program at home	17	24	0.71	**[0.49;0.87]**
younger class	would use such a program at home	12	13	0.92	**[0.64;0.99]**
all	would use such a program at home alone	13	24	0.54	**[0.33;0.74]**
younger class	would use such a program at home alone	10	13	0.77	**[0.46;0.95]**

Table 10.20: Clopper-Pearson intervals for potential use of such a program

We can see that despite the relatively bad feedback about the 3D navigation intuitiveness, people would anyway use such a program, as we estimated that more that two thirds of them would use the program. This is very encouraging. This minimum proportion increases to almost 80% for people with at least a casual level of involvement in urban planning.

A majority (from 49% to 87%) of people would use the program at home. Considering people with a younger age, the proportion is higher (from 64% to 99%). However, people would use it at home without any help will less confidence, as only 33% to 74% of them would do so. Again, the proportion is higher for people with a younger age, as almost at minimum a majority of them (from 46% to 95%) would consider using the program without any help. These results are still encouraging, as all these proportions are centered on a majority of people.

10.2.3 Discussion on Results

To conclude the analysis, we can say that the thesis approach received good feedback from a sample of a targeted population of people usually willing to participate to the survey we made, showing a potential of use in the urban planning process to increase participants involvement. These results were then projected on a larger population.

First, people would appreciate the different features of the prototype. The least appreciated feature would be the navigation intuitiveness, especially for older people. Nevertheless, younger people would like more this feature, which is an encouraging anticipation of the future. Finally, there would be reservations about the clarity of the distinction between the different comments types, pointing out required improvements on the prototype.

Finally, and more important, a large majority of people would use such a program in the urban planning consultation context, especially for people with at least a casual level of participation in the urban planning process. However, a smaller proportion, particularly when considering older people, would be ready to use the program at home without any help, despite the promising usability results we had. But is it a bad result? Indeed, public consultation is essentially a connecting activity, and can therefore benefit from the communication stimuli brought by the reunion of people groups. So, the fact that people are not willing to use the program alone at home, but rather with family members, relatives, or in a public place is not really a concern. Indeed, considering the promising usability study results, and the fact that a majority of people from the younger class would consider using the program without any help, we can fairly expect that there would be someone providing the required help inside a family (or relatives) circle. Therefore, the result to retain is simply the proportion of people willing to use the program. As this result is encouraging, we are confident that the use of a VE will in the future increase people participation in the planning consultation process.

However, we observed that the sample from this experiment cannot really be considered as a representative cross-section of a city population, as it rather represents people usually at least a little interested in the urban planning process. We can therefore expect that results would, maybe, be a little less promising on an entire city population. This is why a large full scale ground experiment, we discuss in Section 11.3.1, must be done, concerning the whole population of a city, in order to confirm the potential we have enlightened.

Chapter 11

Conclusion and Future Work

Having presented the experimental results in the previous chapters, we can now conclude the thesis. We first present the achievements of the thesis, and discuss on the limitations of current implementation. We then provide directions for future work. And finally, we give our last words.

11.1 Achievements

11.1.1 A Theoretical CVE for Public Consultation

We first presented in the thesis a theoretical idea of a VE dedicated to public consultation. The idea of having different types of information was developed, with in particular the concept of spatial information, which depends on a view point coordinate inside the 3D space. We then described the possible interactions inside the environment, and a way to manage them in a context of a collaborative use.

11.1.2 A Working Cityscape Prototype Environment

A city environment was then designed from the theoretical model, for use in the urban planning public consultation process. Next, for experimentation purpose, we implemented a prototype from these specifications, which works on both Linux and Windows operating systems. A performance experiment assessed that it was able to render large scale city environments on standard computers, making technology accessible to general public from a technical point of view.

Therefore, unlike small scale models of traditional participation and a large proportion of available VRML models, it is possible to have both a local and a global point of view of the city. Hence, this allows to see the details of a planning project, but also its impact on a large area.

11.1.3 Usability Experiments on General Public

We then performed a usability experiment on people selected with different experiences in computer science. This was an interesting experiment to run, as there have been examples of usability experiments on VEs, but none were run in the context of urban planning public consultation process.

Most of the people were able to use the software without any external help, showing that a daily office automation level was usually enough to be able to interact with the 3D environment. Projecting these results on a larger population, we proved that we can make the technology easy to use for a fairly large audience.

11.1.4 An Urban Planning Consultation Simulation

Having verified that VE technology was accessible to the general public, from a technical and usability point of view, a simulation of an urban planning consultation was launched. Its goal was to assess the application itself, as an alternative with high potentials to traditional public consultation processes. As for the usability experiment, this was again the first example of such a simulation.

Assessed by urban planning professionals, who gave a positive feedback on our approach, its results showed that the approach proposed by the thesis was a viable alternative, but also that it had a potential to improve the way public participation is handled, by providing better feedback to planners.

11.1.5 A Survey on the General Public

Having shown the potential of using a VE to improve public consultation, we performed a survey on an audience from the general public. It shown a good feedback on the different features of the prototype.

Projecting these results on a larger population, we estimated that a large majority of people would use this kind of program if it was available for the urban planning consultation process.

11.2 Limitations of Current Implementation

Having reviewed achievements, we now focus on the limitations of present implementation of the application so far.

The main weakness of our model is that it is only a prototype, and so has restrictions. We can therefore think about improvements of the application, regarding the user interface, realism of the model, the medium used to display information, and the ways information is handled. We discuss possible improvements in Section 11.3.2.

Next, the current prototype does not support networked distribution. We did not require it for the usability experiments and the urban planning project simulation we performed. We wanted to study the interactions related to public consultation, which is the possibility to visualise the environment in different ways, to leave feedback in different places. Having reviewed previous research, and in particular in Section 2.2.3 mature software regarding large scale CVE distribution technology for a wide audience use, we are confident in the fact that providing distribution to our environment is not challenging. The only difficulty could be the large size of the city environment. However, reducing level of detail on areas which are not concerned by the urban planning project allows us to use low data size to describe these areas, using the city description language defined in Section 7.7, as standard geometry without textures is used. This leaves the consultation area, whose size is always limited, as urban planning projects area are usually bounded to a relatively small size whatever the size the city is. So, using methods to minimise the bandwidth use, as suggested in Section 6.3, we have a high confidence that it will be possible to deliver such a model over the Internet.

Then, the software was not related to a real city model. Indeed, research focused on the study of interactions inside the environment rather than representing an accurate model. It would be useful to integrate a model of a real city, integrating GIS data, and building (or use) a 3D model of the city, in order to provide a ground experiment on the environment. This idea is discussed in Section 11.3.1.

Finally, the use of the three kinds of comments, which got support from professionals, was confusing for some people, meaning that there will need to be research on the ways to simplify the process for users. We talk about that in Section 11.3.3.

11.3 Future Work

Having reviewed the current limitations, we now provide future work directions in this section. We first discuss a ground experimentation stage of the VE, next enhancements of the application, then new research directions, and finally an extension to other applications.

11.3.1 Next Experimentation Stage

Now that lab experiments showed that our prototype has proved to have potential for enhancing public consultation in urban planning processes, the next logical step would be to confirm this potential, with the development of a full application, and its use for full scale ground experiments, with the collaboration of a city council, on a selected urban planning project. This would involve the development of a distributed version of the application, and as well the integration of data from a real city.

Therefore, using a distributed environment, people would be able to be consulted from their homes, and engage dialogue with each other, using the specifications provided in Section 6.3. People would access the environment via the Internet, or could have access to computers in public places. For people who would require external assistance, there could be someone demonstrating the application and assisting them, which would be for example simply someone from their family or friends circle, or someone employed by the city council.

People would first see different alternatives of the proposal, voting for the one they prefer, by giving feedback on the models. Then they would visit the chosen proposal in more details, providing planners with comments and possibly proposed environmental changes, so the proposal can be refined until a final proposal is adopted.

11.3.2 Enhancement of the Application

As the application we implemented was only a prototype, there are many ways to improve it. We discuss some of them in this section, which seemed important to us, as in particular some which have been suggested by people during the experiment.

First, the application may enrich the way to display information. We only used text information, but it is possible to enhance that by using multimedia extensions, as sound, image and video, as previous work proves that[Man03]. Furthermore, the use of audio has proved to improve user communication inside a CVE[SFPS99].

Next, there can be work on the GUI and navigation to improve user friendliness. Navigation has proved to be intuitive enough according to the user performance experiments, however we saw that most of users not trained with 3D had still some difficulties with the mouse navigation. Some people complained about the lack of clarity of the GUI, and so there will need work on improving that. An important point is the development of a help feature, as suggested by some people. This could include help keys or icons to remind commands, indicators on the 3D view to show information, such as altitude or inclinations angle, and the use of a specific mouse "arrows" during navigation to show which navigation mode is activated.

Then, the realism of the model can be improved, as only a few people quoted the realism of the model as a positive point of the approach. A first idea is to add more objects, as virtual humans, so there is a better scaling impression. The complexity of the model can be also increased, by using more detailed objects, such as CAD models. This future realism improvement is made possible by the constant observed increase of 3D computer graphics hardware performance. We can therefore apply the idea of a continuous improvement of the complexity of rendering, following this evolution. This is where the idea of having a separated the 3D layer takes sense, as an update would only concern this layer and not change the rest of the code.

Finally, we can think about using a temporal model. First, it will be able to show the evolution of the city from before to after the building concerning an urban project. Furthermore, a temporal model will be necessary to combine modification changes and comments. Indeed, our experiments separated these two interaction processes, as we restricted environment changes to the usability evaluation. Using them jointly raises the question of information coherence, as a comment left on an area which is modified afterwards has then an obsolete meaning. Therefore, using a temporal model, it will be possible to access the model state when the comment was written.

11.3.3 New Research Directions

First, we noticed that a part of people during the experiments got confused with the three different kinds of comments. A good solution for solving that would be to have a transparent interface for the user, who would just have to click on a single icon to record a comment. In the other side an intelligent system would handle the different comments, sorting them between the different categories. This system could be built using algorithm from Artificial Intelligence research.

In another direction, we could think about navigation helpers, which would help people experiencing difficulties with the application to reach wanted view. For example someone willing to have a global point of view of three buildings could tell the system "I want to see a top view of these 3 buildings", and the system would transport him to this view. There has been some research in this area[BL99].

Finally, there can be the idea of incorporating the technology to mobile computing, as there has been an idea of development of a 3D cityscape on mobile phones[RV01], made possible with the development of mobile 3D hardware. Public consultation features could be added to this kind of environment, so people could participate to the consultation process easily from anywhere.

11.3.4 Toward New Applications

Other applications that urban planning for the city model can be considered. Section 3.5.3 reviewed some potential applications. The tourism application seems to be the one of the more promising.

Indeed, considering this application, the city model would be separated into different touristic areas. People would first select the area they are interested in. This area would stand for the consultation area, represented with a higher level of detail. People would be able to visit this area, and access information. Logical information would be a description of the area, with for example historical details, as shown on tour guides. Physical information would provide information on important places or monuments (for example the description and the opening times of a museum). Finally, spatial information would show the main touristic views of the area. Furthermore, consultation information could be used as information brought from tourists who visited the area, providing feedback and some advices. Tourism professionals could also have access to this feedback, in order to improve the visit of future tourists. Therefore, the tourism application would use the same interactions as the urban planning consultation application.

11.4 Final Words

The thesis hypothesis stated that CVE technology could enhance large scale public participation. We selected the case of public consultation in the urban planning process. Having described in the thesis how a CVE could be oriented toward large scale public consultation, we implemented a virtual 3D cityscape environment prototype. We first established that the environment is suitable for public use in terms or performance.

We then experimented on the way people manage to visit the environment, accessing, adding information and using interactions, as we described in the theoretical model. For this purpose, an usability experiment were performed, which proved that we could make the technology accessible to a large audience.

After that, we wanted to verify that public use of VE technology at a large scale improved the public participation. In order to do this, we performed a simulation of an urban planning consultation, which proved that the way data are acceded and created gives a potential to VE as a new tool for urban planning public consultation.

Finally, having obtained support from professionals, we organised a general public survey, which shown a good support from the public community, and a potential of increasing people participation, as a large proportion of people would use such a program if it was available for public consultation.

Therefore, we are confident that the idea driven by the thesis may be applied one day as an efficient way for large scale public participation in urban planning projects. Now, this potential must be turned into a demonstrated improvement of the consultation process, by organising a full scale ground experiment on the entire population of a city, around a real project, with the support of a city council.

Appendix A

An example of a city description file

```
Virtua_City #This city is made to assess users experience of the city
There are different areas#
South 1.000 0.000 0.019 -116.837 0.350 0.073 -0.000 1.000 0.000
A South #This is the south area of the city.  It is used for the tutorial.#
E Welcome 1 1.000 0.000 0.019 -116.837 0.350 0.073 -0.000 1.000 0.000 #Welcome to the
South Area of the city !
This is a test area with some buildings and landmark objects for testing.
Please leave some general comments about your experience of the environment.#
U 3 Test_User #I enjoyed the navigation.#
E Elevated_view 2 0.000 -0.953 -0.304 -44.726 103.230 9.971 0.001 0.304 -0.953 #Here
is an elevated view from the area.
Please leave some feedback on the area from this view.#
U 1 Nico #very good city...  There is just a need of more trees...  And The building
on top right (Lambert_Hall) is too high#
U 2 fabrice #the buildings are too high!!!
But the street looks nice from top...#
U 3 Test_User #The area is quite nice, but needs more trees.#
F 1 Nico 1 -0.805 -0.000 -0.593 -14.834 0.350 -17.422 -0.000 1.000 -0.000 #I don't
think the cow makes a beautiful statue next to the fountain...#
F 1 Nico 2 -0.989 0.000 -0.145 -9.737 0.350 -0.113 0.000 1.000 0.000 #The street
is nice#
F 1 Nico 3 -0.679 -0.572 -0.459 7.984 56.810 2.247 -0.474 0.820 -0.320 #The building
on the left is too high compared to the other ones...#
F 2 fabrice 1 0.997 0.000 0.073 -93.646 0.350 -0.460 0.000 1.000 0.000 #I like the
```

```
road colour#
F 2 fabrice 2 0.016 -0.505 -0.863 -56.066 67.670 65.909 0.009 0.863 -0.505 #These 3
buildings are maybe a little to high#
F 2 fabrice 3 -0.462 0.049 -0.886 -3.639 45.440 2.422 0.022 0.999 0.044 #This building
is definitively too high !!!#
F 3 Test_User 1 0.552 0.325 0.768 -42.414 0.350 0.974 -0.189 0.946 -0.263 #Well..
This is the only tree of the street...  There should be more...#
B Central_University 3 0 0 25.000 20.000 10.000 4 -30.000 12.000 0.000 #The university
Building#
U 1 Nico #I like this university#
B Roman_Museum 3 0 0 25.000 20.000 10.000 7 -50.000 12.000 0.000 #This museum contains
Roman and Greek artifacts
It is free for students of the University
There will be temporary expositions too, and a discount for groups !#
U 2 fabrice #Only Greek or Roman ?#
B Chinese_Restaurant 5 0 0 40.000 20.000 10.000 5 -30.000 -12.000 0.000
B French_Restaurant 4 0 0 40.000 20.000 10.000 9 -51.000 -12.000 0.000
B Hilton_Hotel 4 750 0 40.000 20.000 10.000 10 -72.000 -12.000 0.000
R Oxford_Road 2 0 500.000 5.000 0 -265.000 0.000 90.000
U 1 Nico #will there be a bus stop on this road ?#
P sideway1 1 1 100.000 50.000 4 -65.000 28.000 0.000 #Grand Place#
U 1 Nico #we need more trees !!!!!!#
L 3 -20.000 2.000 90.000
L 9 -30.000 5.000 90.000
L 5 -40.000 5.000 90.000
L 1 -50.000 5.000 90.000
L 6 -60.000 5.000 0.000
L 4 -18.000 22.000 90.000 #The Fountain on Grand Place#
L 10 -23.000 22.000 0.000 #the wonderful cow statue !!!!#
U 3 Test_User #wow !
This is a beautiful cow !!!#
U 2 fabrice #A cow statue ?  Is it really serious ?#
L 8 -28.000 22.000 0.000
P sideway2 1 1 100.000 50.000 4 -65.000 -28.000 0.000
L 3 -20.000 -2.000 -90.000
L 7 -40.000 -5.000 0.000
```

```
L 8 -50.000 -5.000 0.000

L 6 -60.000 -5.000 0.000

B Lambert_Hall 2 300 0 60.000 5.000 5.000 6 -20.000 30.000 45.000

B Odeon_Theater 4 0 0 25.000 20.000 10.000 8 -70.000 12.000 0.000

A North

S NorthEast North

R Oxford_Street 1 0 500.000 5.000 0 245.000 0.000 90.000

R Broadway 3 0 1000.000 10.000 0 -10.000 502.500 0.000

S NorthWest North

R Broadway 3 0 1000.000 10.000 0 -10.000 -502.500 0.000

C cross 1 0 5.000 10.000 0 -10.000 0.000 0.000

U 1 Nico #Nice cross !#
```

Appendix B

Experiments forms

B.1 Personal information questionnaire

Person number (questionnaire is anonymous): ___________

Age: _____ Sex:_____ Background: ____________________________

(Literary / social sciences, Economy / business, or Scientific / technical)

Experience in computer science: ___
(0 none, 1 limited, 2 daily office automation - knows how to use simple softwares as word processor, 3 advanced office automation - knows how to use more complex softwares and may knows how to install software, 4 very good experience - knows how to use advanced softwares and may manage an operating system, 5 expert - have programming skills)

Experience in 3D Computer Graphics: ___
(0 none, 1 casual game player - mostly plays from time to time some video games, 2 advanced game player - plays often to 3D games player and/or can have a little experience with some 3D softwares, 3 very good experience - have a good experience with some 3D softwares, 4 expert - have work or high academic experience with 3D)

Level of involvement in urban planning projects: ___ *
(0 none or very limited, 1 casual - can answer to surveys , 2 high level of involvement - goes to hearings, 3 very high level - is part of decision-making bodies or is involved in community groups)

: This has not been asked to people who participated only to the usability experiment

B.2 User evaluation forms

B.2.1 Tutorial

For each part: 0 not succeeded, 1 succeeded with a lot of help (demonstration needed), 2 succeeded with a little help (question(s) asked), 3 succeeded without help

Have succeeded in doing the tutorial part 1 (boards): ___

Have succeeded in doing the tutorial part 2 (navigation): ___

Have succeeded in doing the tutorial part 3 (map): ___

Have succeeded in doing the tutorial part 4 (information): ___

Have succeeded in doing the tutorial part 5 (interaction): ___

Have succeeded in doing the tutorial part 5 (comments): ___

B.2.2 Trials

For each trial: 0 not succeeded, 1 succeeded with a lot of help (demonstration needed), 2 succeeded with a little help (question(s) asked), 3 succeeded without help but some difficulties, 4 succeeded without difficulties

B.2.2.1 Information visualisation

Got medium height of the buildings of the area: ___

Found the most populated building: ___

Gave the number of public buildings: ___

B.2.2.2 Consultation interactions

Left a free comment from an asked view: ___

Left a comment on a chosen landmark object: ___

Acceded to a particular free comment: ___

Left a comment on a board of the area: ___

B.2.2.3 Environment modifications

Moved buildings from a sideway to another one: ___

Moved and rotated a building to an exact location: ___

Moved landmark objects from an end to another of a sideway: ___

Rotated a bench so it faces a building: ___

Changed colour and texture of two buildings: ___

B.3 Urban planning consultation simulation form

Have the user noticed the prison ? ___ (yes or no)

Have the user noticed the very high building ? ___ (yes or no)

Have the user noticed the lack of trees on the particular street ? ___ (yes or no)

Have the user noticed the cow statues ? ___ (yes or no)

Have the user noticed the day nursery ? ___ (yes or no)

Have the user noticed that there was not a cinema ? ___ (yes or no)

B.4 User feedback questionnaire

Positive aspects of the idea:

Negative aspects of the idea:

Mark this process as a good way to be consulted for urban projects ___ (from 0 to 10)

Will this way of consultation help you to get more involved in the urban planning process ? ___ (yes or no)

B.5 Urban planning people questionnaire

Occupation in urban planning field: ________________

Are the results of this virtual consultation interesting for you ? And Why ?

Positive aspects of the idea:

____

____

____

Negative aspects of the idea:

____

____

____

____

____

____

____

____

____

Mark this process as a good way to consult people for urban projects ___ (from 0 to 10)

Would you recommend/use this as a new way to consult public ? ___ (yes or no)

B.6 General public survey questionnaire

Person number (questionnaire is anonymous): __________

Age: _____ Sex:_____

Background:

☐ *literary* ☐ *mixed between literary and scientific* ☐ *scientific*

Experience in computer science:

☐ *none or limited* ☐ *daily office automation* ☐ *advanced*

Do you have the Internet at home?

☐ *no* ☐ *yes with a low-speed connection* ☐ *yes with a high-speed connection*

Level of involvement in urban planning projects:
☐ *none or very limited* ☐ *casual* ☐ *high*

(very limited: is not really interested, casual: can answer to surveys , high: go at least to hearings)

1. How do you consider the interactivity of the program?

☐ *good* ☐ *good enough* ☐ *not so good* ☐ *not good*

2. How do you consider the user-friendliness of the program?

☐ *good* ☐ *good enough* ☐ *not so good* ☐ *not good*

3. How do you consider the realism of the program (considering the feeling of being 'inside' the city, compared to the view of a small scale model or a map)?

☐ *good* ☐ *good enough* ☐ *not so good* ☐ *not good*

4. How do you consider the intuitiveness of navigation inside the 3D city?

☐ *good* ☐ *good enough* ☐ *not so good* ☐ *not good*

5. How do you consider the use of the boards to display information?

☐ *good* ☐ *good enough* ☐ *not so good* ☐ *not good*

6. How do you consider the general information display (building types, population, ...)?

☐ *good* ☐ *good enough* ☐ *not so good* ☐ *not good*

7. How do you consider the information about an object (for example a building)?

☐ *good* ☐ *good enough* ☐ *not so good* ☐ *not good*

8. How do you consider the usefulness of the map?

☐ *good* ☐ *good enough* ☐ *not so good* ☐ *not good*

9. How do you consider the possibility to record comments?

☐ *good* ☐ *good enough* ☐ *not so good* ☐ *not good*

10. How do you consider the clarity of the three kinds of comments?

☐ *good* ☐ *good enough* ☐ *not so good* ☐ *not good*

11. Would you use such software if it was available for public consultation in your city?

☐ *yes, at home alone (without any help)*

☐ *yes, at home, but with help from someone else*

☐ *yes, but at city hall*

☐ *no*

Appendix C

Results of user-oriented experiments

In this appendix we give detailed results of the user-oriented experiments, which are the usability study and the urban planning simulation, providing for each person the results from the forms of Appendix B.

Results are provided on tables for each user. Here is the used table, for people who participated to both usability and urban planning simulation experiments (25 first users):

User number	Age	Sex	Background	CS	3D	Inv	Tutorial

Trials	Consultation simulation	Mark	Improve involvement ?

Positive aspects

Negative aspects

Other comments and suggestions

- "User number" is the chronological order of the person in the experiment.
- "Background" gives the background of the person this way: "Sci" for Scientific/Technical, "Lit" for Literary/social sciences or art, and "Eco" for economy.
- "CS", "3D" and "Inv" stands respectively for experience in computer science experience, experience in 3D Computer Graphics and level of involvement in urban planning projects from the personal information questionnaire.
- "Tutorial" gives the tutorial evaluation marks (from 0 to 3) in the same order as given in Appendix B.

- "Trials" gives the trial evaluation marks (from 0 to 4) in the same order as given in Appendix B.
- "Consultation simulation" gives the results of the urban planning consultation simulation forms in the same order as given in Appendix B.
- "Mark" stand for "Mark this process as a good way to be consulted for urban projects" from the user feedback questionnaire.
- "Improve involvement ?" stands for "Will this way of consultation help you to get more involved in the urban planning process ?" from the user feedback questionnaire.
- For "Positive aspects" and "Negative aspects", we regrouped people answers when it was possible (for example "user-friendly", "possibility to record comments", ...)

For people who participated only to the usability experiment (users 26 to 46), the table is simply:

User number	Age	Sex	Background	CS	3D	Tutorial

Trials

Here are the results:

01	26	F	Eco	2	0	0	3	2	3	3	3	3

4	3	4	4	4	4	4	4	4	4	4	4	Y	N	Y	Y	Y	Y	8	Y

Realism, three kinds of comments, use of board to help to navigate

May be difficult to use for people not getting used with computers

Cannot replace totally paper documents

02	59	F	Lit	1	0	1	3	2	2	3	2	3

4	2	3	2	3	3	4	4	3	2	3	3	Y	Y	Y	N	Y	Y	7	Y

User-friendly, interactive, three kinds of comments, information display

Navigation a little difficult, confusion with the three kinds of comments

- Need of a human presence for dialogue
- Need to implement a way to cancel an object modification

03	24	F	Lit	2	1	1	3	3	3	3	3	3

4	3	2	4	4	4	4	4	3	4	4	4	Y	N	Y	Y	Y	Y	9	Y

Realism, interactive, information display, three kinds of comments, user-friendly

Navigation a little difficult

- Very enthusiastic, and really wants this to be used

04	28	M	Sci	5	2	2	3	3	3	3	3	3

4	4	4	4	4	4	4	4	4	4	4	4	Y	Y	Y	Y	Y	Y	10	Y

User-friendly, three kinds of comments, realism

(none)

- Improve collisions handling and precision of objects modification
- Implement a way to select multiple objects
- Improve the geometry of the buildings

05	25	F	Lit	3	0	1	3	3	3	3	3	3

4	3	4	4	4	4	4	4	4	3	4	4	Y	N	Y	Y	Y	Y	10	Y

Interactive, possibility to record comments, user-friendly

Navigation a little difficult, confusion with the three kinds of comments

- Would be useful to have a summary of all information of an area
- Would be useful to have an help option for navigation

06	26	F	Sci	5	1	1	3	3	3	3	3	3

4	3	4	3	4	4	4	4	4	4	4	4	Y	Y	Y	Y	Y	Y	8	Y

Interactive, user-friendly, possibility to record comments, three kinds of comments

Confusion with the three kinds of comments, navigation a little difficult

- Will have to deal with comments coherence after objects modifications
- Implement a way to distinguish easily new from old buildings

07	32	M	Sci	5	3	1	3	3	3	3	3	3

4	4	4	4	4	4	4	4	4	4	3	4	Y	Y	Y	Y	Y	Y	8	Y

Interactive, user-friendly, possibility to record comments, three kinds of comments

(none)

- Implement a way to reach automatically a pedestrian view
- Improve level of detail and use objects as humans and cars

08	26	M	Sci	5	2	1	3	3	3	3	3	3

4	4	4	4	4	4	4	4	4	4	4	4	Y	Y	Y	Y	Y	Y	7	Y

User-friendly, information display, interactive, possibility to record comments

User interface a little dense

- Improve collisions handling
- The application could be used outside the urban planning context

09	27	M	Sci	5	4	1	3	3	3	3	3	3

4	4	4	4	4	4	4	4	4	4	4	4	Y	Y	Y	Y	Y	Y	8	Y

Interactive, possibility to record comments, three kinds of comments, user-friendly, possibility to read comments from other people

(none)

- Implement a way to combine a free comment and a comment on an object
- Improve text visibility
- Add more different objects to improve visual realism

10	57	M	Sci	4	0	1	3	3	3	3	3	3

4	4	3	4	4	4	4	4	3	4	4	4	Y	Y	Y	Y	Y	Y	9	Y

User-friendly, information display, interactive, the map, possibility to record comments

Confusion with the three kinds of comments, navigation a little difficult

- Must simplify the way to record comments (one single icon)
- Would be useful to have a summary of the comments at the end

11	55	F	Lit	1	0	1	3	3	3	3	2	3

4	2	2	3	4	3	4	3	3	2	4	4	Y	Y	Y	Y	Y	Y	8	Y

User-friendly, possibility to record comments, interactive

Confusion with the three kinds of comments, navigation a little difficult

- Will need help features and assisted training

12	28	M	Sci	5	1	1	3	3	3	3	3	3

4	4	4	4	4	4	4	4	4	4	4	4	Y	Y	Y	Y	Y	Y	8	Y

Realism, user-friendly, possibility to record comments, interactive

Confusion with the three kinds of comments, map navigation

- Implement help features, as visual signs, for navigation and orientation
- Must simplify the way to record comments (one single icon)
- The application could be used to enhance the telephone directory

13	27	F	Eco	3	0	1	3	3	3	3	3	3

4	3	3	4	4	4	4	4	4	3	4	4	Y	N	Y	Y	Y	Y	8	Y

Interactive, user-friendly, information display

Confusion with the three kinds of comments, navigation a little difficult

- Improve text visibility
- Implement an help feature

14	73	M	Sci	0	0	3	3	3	3	3	3	3

4	2	2	1	4	2	4	4	4	4	4	4	Y	N	Y	N	Y	N	7	Y

Interactive, three kinds of comments, possibility to record comments

Navigation difficult

(none)

15	30	F	Lit	1	0	1	3	3	3	3	3	3

4	2	4	3	4	4	4	3	3	3	4	4	Y	N	Y	Y	Y	Y	8	Y

Interactive, possibility to record comments, three kinds of comments

Navigation a little difficult

(none)

16	30	M	Lit	3	1	3	3	3	3	3	3	3

4	4	4	3	4	4	4	4	4	3	4	4	Y	Y	Y	Y	Y	Y	8	Y

Interactive, user-friendly, realism, possibility to record comments, three kind of comments

People not getting used with computer science may need direct assistance, User interface a little dense

- Improve visibility of icons

17	28	M	Sci	4	0	1	3	3	3	3	3	3

4	4	4	4	4	4	4	4	4	4	4	4	Y	Y	Y	Y	Y	Y	9	Y

User-friendly, possibility to record comments, three kind of comments, interactive

(none)

(none)

18	26	F	Lit	2	0	1	3	3	3	3	3	3

4	4	4	4	4	4	4	4	4	4	4	4	Y	Y	Y	Y	Y	Y	9	Y

Realism, interactive, user-friendly, possibility to record comments, three kinds of comments

(none)

(none)

19	28	M	Lit	2	0	1	3	3	3	3	3	3

4	4	4	4	4	4	4	4	4	4	3	4	Y	N	Y	Y	Y	Y	9	Y

Realism, interactive, possibility to record comments, three kinds of comments

Navigation a little difficult

(none)

20	39	M	Eco	2	0	3	3	3	3	3	3	3

4	4	4	4	4	4	4	4	4	3	4	4	Y	Y	Y	Y	Y	Y	8	Y

Interactive, possibility to record comments, the map

Confusion with the three kinds of comments

- Must simplify the way to record comments (one single icon)
- Implement an help feature
- Improve the red line position when an object is selected
- The selected object must be automatically unselected after some inactivity time
- It would be useful to use many boards to have many targeted view

21	58	F	Lit	2	0	1	3	3	3	3	3	3

4	2	3	3	4	4	4	4	4	4	4	4	Y	N	Y	N	Y	Y	7	N

Interactive, possibility to record comments

Navigation a little difficult, confusion with the three kinds of comments

- Using virtual humans will be necessary to improve realism

22	45	M	Sci	5	1	3	3	3	3	3	3	3

4	4	4	4	4	4	4	4	4	4	4	4	Y	Y	Y	Y	Y	Y	7	Y

Interactive, possibility to record comments, three kinds of comments

(none)

- It would be more logical to click on the comment icon before editing it

23	22	M	Sci	5	3	1	3	3	3	3	3	3

4	4	4	4	4	4	4	4	4	4	4	4	Y	Y	Y	Y	Y	Y	8	Y

Possibility to record comments, interactive, user-friendly

Confusion with the three kinds of comments

- Improve clearness of user interface

24	38	M	Sci	4	3	3	3	3	3	3	3	3

4	4	4	4	4	4	4	4	4	4	4	4	Y	N	Y	Y	Y	Y	8	Y

Interactive, possibility to record comments, user-friendly

(none)

- Implement the possibility to modify own comments
- It would be better to use icons instead of keyboard for some interactions

25	27	M	Sci	5	0	1	3	3	3	3	3	3

4	4	4	4	4	4	4	4	4	4	4	4	Y	Y	Y	Y	Y	Y	10	Y

User-friendly, possibility to record comments, realism, interactive, the tutorial

Confusion with the three kinds of comments

- Must simplify the way to record comments (one single icon)
- Implement the possibility to visit the inside of buildings
- Implement a night mode, where city lights could be tested

26	63	M	Eco	3	0	3	3	3	3	3	3

4	3	3	3	4	4	4	4	4	4	4	4

27	19	F	Lit	2	0	3	3	3	3	3	3

4	4	4	4	4	4	4	4	4	3	4	4

28	25	M	Lit	3	1	3	3	3	3	3	3

4	4	4	4	4	4	4	4	4	4	4	4

29	27	M	Sci	5	0	3	3	3	3	3	3

4	4	4	4	4	4	4	4	4	4	4	4

30	63	F	Lit	1	0	3	2	3	3	3	3

4	2	3	2	4	4	4	4	4	4	4	4

31	24	F	Eco	2	1	3	3	3	3	3	3

4	4	4	4	4	4	4	4	4	4	4	4

32	26	M	Sci	4	2	3	3	3	3	3	3

4	4	4	4	4	4	4	4	4	4	4	4

33	58	M	Eco	2	0	3	3	3	3	3	3
4	3	3	3	4	4	4	4	3	3	4	4

34	25	F	Eco	2	0	3	3	3	3	3	3
4	4	4	4	4	4	4	4	4	3	4	4

35	26	F	Eco	2	0	3	3	3	3	3	3
4	4	4	4	4	4	4	4	4	4	4	4

36	28	M	Sci	5	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4	4	4	4	4

37	42	F	Lit	2	0	3	3	3	3	3	3
4	3	3	4	4	4	4	4	4	3	4	4

38	68	F	Lit	1	0	3	2	3	3	2	3
4	2	2	2	3	3	4	3	2	2	2	3

39	55	M	Eco	1	0	3	3	3	3	3	3
4	2	3	3	4	4	4	4	3	3	4	4

40	36	F	Eco	2	0	3	3	3	3	3	3

4	4	4	4	4	4	4	4	4	4	4	4

41	29	M	Sci	5	1	3	3	3	3	3	3

4	4	4	4	4	4	4	4	4	4	4	4

42	52	F	Lit	1	0	3	3	3	3	3	3

4	2	3	3	4	3	4	4	4	3	4	4

43	54	M	Eco	1	0	3	3	3	3	2	3

4	2	3	2	4	4	4	3	3	2	4	4

44	26	M	Sci	4	2	3	3	3	3	3	3

4	4	4	4	4	4	4	4	4	4	4	4

45	24	F	Eco	3	0	3	3	3	3	3	3

4	3	4	4	4	4	4	4	4	4	4	4

46	36	M	Eco	2	0	3	3	3	3	3	3

4	3	4	3	4	4	4	4	4	4	4	4

Appendix D

Results of the general public survey

In this appendix we give detailed results of the general public experiments, providing for each participant the results from the forms of Appendix B.

Results are provided on tables for each user. Here is the used table:

User number	Age	Sex	Background	CS	Internet	Inv

Questions 1-10	Question 11

- "User number" is the chronological order of questionnaire reception.
- "Background" gives the background of the person this way: "Sci" for Scientific, "Lit" for Literary, and "Mix" for mixed.
- "CS" stands for the experience in computer science: 1 for none or limited, 2 for daily office automation, and 3 for advanced.
- "Internet" stands for the Internet connection of the participant: "No" for none, "LS" for low-speed, and "HS" for high-speed.
- "Inv" stands for level of involvement in urban planning projects: 1 for none or very limited, 2 for casual, and 3 for high.
- "Questions 1-10" provides the results of questions 1 to 10: 1 for not good, 2 for not so good, 3 for good enough, and 4 for good.
- "Question 11" provides the result of question 11: "Alone" for yes at home alone, "With Help" for yes at home but with help, "City Hall" for yes but at city hall, and "No" for no.

Here are the results:

01	57	M	1	Mix	LS	2

3	3	3	2	2	3	3	3	3	2	City Hall

02	80	M	1	Sci	No	1

3	3	3	2	3	2	3	4	3	1	No

03	25	F	2	Lit	HS	2

4	3	3	3	4	4	4	3	4	4	Alone

04	60	F	2	Lit	HS	2

4	3	2	2	4	4	4	3	4	3	City Hall

05	24	F	2	Mix	HS	2

3	3	3	3	4	4	4	3	4	3	Alone

06	77	F	1	Sci	No	3

3	3	3	2	4	4	4	4	4	4	With Help

07	59	M	2	Mix	HS	3

3	4	3	3	4	4	4	4	4	3	Alone

08	27	F	2	Lit	HS	2

4	3	3	3	4	3	3	4	4	3	With Help

09	64	M	1	Lit	HS	3

4	3	4	4	4	3	4	4	4	3	Alone

10	53	F	2	Mix	LS	2

3	3	4	2	3	4	4	4	4	2	With Help

11	79	F	1	Lit	No	1

3	2	2	1	2	3	2	1	4	1	No

12	58	M	2	Mix	HS	3

4	3	3	3	4	4	4	4	4	3	Alone

13	28	M	3	Mix	HS	1

3	3	3	3	4	4	4	4	4	3	Alone

14	27	F	2	Mix	HS	1

4	4	4	3	3	4	4	2	4	2	Alone

15	59	F	2	Lit	HS	3

4	4	4	4	4	4	4	4	4	4	City Hall

16	28	F	3	Sci	HS	2

4	3	3	2	4	3	4	3	4	4	Alone

17	33	M	3	Sci	HS	2

4	3	2	3	3	3	4	4	4	2	Alone

18	29	M	2	Lit	HS	1

4	3	3	2	2	3	3	4	4	3	With Help

19	29	M	3	Sci	HS	2

4	4	4	4	4	4	4	3	4	4	Alone

20	58	M	2	Sci	LS	1

3	4	4	2	4	4	4	4	4	2	No

21	28	M	3	Sci	LS	2

4	4	3	4	3	4	4	4	3	2	Alone

22	24	F	2	Lit	HS	3

4	4	4	4	4	4	4	4	4	4	Alone

23	27	F	3	Lit	HS	1

4	3	3	2	3	4	4	4	4	3	City Hall

24	24	M	2	Mix	HS	1

4	4	3	4	4	4	4	4	3	4	Alone

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