E-Learning CAAD with VR and Landscape Architecture Rendering Functionality

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Abstract: *Possible applications of Virtual Reality (VR) in Digital Architecture (DA) and Landscape Architecture (LA) projects include collaborative design, Computer-Aided Design (CAD) cognition, as well as haptic rendering with e-learning functionality. Following the current trends in digital architecture, this paper aims to present VR technology as a medium for communication among members of CAD design teams, and as a tool which successfully be used for presentation purposes in landscape architecture projects. Also, the e-learning functionality embedded in digital architecture projects is demonstrated using haptic rendering functions. The proposed methodology is based on widely available off-the-shelf software tools which can be used by creative teams to support visual studio projects in architecture. Finally, a case study related to a small urban area in Thessaloniki, Greece is used to demonstrate the functionality of the proposed method.*

Keywords: *virtual reality, CAD, digital architecture, landscape architecture*

1. Introduction

Virtual Reality (VR) in Architectural sciences like Digital Architecture (DA) and Landscape Architecture (LA) has certain advantages as a presentation tool compared to other traditional solutions like 2D drawings, 3D models, images and video. Using the technology of VR, not only the present situation can be visualized, but also the future and/or the past of a study area can be imagined from different viewpoints.

The fact that there are no identical definitions of Virtual Reality in the literature, attributes the different conceptions researchers have been expressed during the last decades. Jaron Lanier seems to be the first who gave a precise definition of VR: "An interactive, three-dimensional environment generated by a computer in which a person is immersed" (Lanier et al., 1989). A more recent definition given by Manetta and Blade is more structural and gives more emphasis on moving capabilities (Navigation): "Virtual Reality: A computer system used to create an artificial world in which the user has the impression of being in that world and with the ability to navigate through the world and manipulate objects in the world" (Manetta & Blade, 1995). The underlying hypothesis is that the necessary prerequisite for a system to be considered as a virtual reality application is free, physical navigation by the user in a three-dimensional environment generated by a computer and also interaction between user and environment.

Apart from the search for satisfactory definitions, it is found that not all VR applications are necessarily associated with the use of expensive equipment such as gloves, Head-Mounted Displays (HMD) and body suits. These applications are called Desktop VR. On the other hand, fully immersive applications allow users to become integrated into a virtual world with almost all human senses activated but they have high cost of maintenance.

Paper contribution. In this paper, for the first time in literature, VR technologies with haptic rendering functionality are discussed for Computer-Aided Architectural Design (CAAD) and Landscape Architecture projects. The primary motive for this paper was the relatively limited knowledge on methodologies regarding the design process of virtual reality applications for use in CAAD and Landscape Architecture projects.

Paper organization. The rest of the paper is structured as follows: The Section 2 (VR in Digital Architecture and Landscape Architecture) is about important factors that should be considered in creating virtual environments. The Section 3 (VR: Haptic Rendering with e-Learning Functionality) discusses the educational benefits of applying effective methods for e-learning documentation with 3-D modelling. The Section 4 (VR in Landscape Architecture: Methodology) exposes step by step the methodology of designing and planning a virtual landscape architecture scene. The Section 5 (VR in Landscape Architecture: An Application Example) illustrates the applied methodology in an application example using specific 3D CAAD software in combination with the Virtual Reality Modeling Language (VRML). Finally in Section 6 (Conclusions) the conclusions as well as some future extensions are discussed.

2. VR in Digital Architecture and Landscape Architecture

From the designers’ point of view, certain advantages of VR are summarized below: 3D designs can be available over the Internet/Intranets and give direct feedback to the creation team, evaluation and critique procedures can occur from any point of view of the virtual scene and multiple readings of the outcome is possible and easy (Moloney & Armor, 2003).

Important factors in creating virtual environments are analyzed by Petric who distinguish five factors that compose a set of challenging features for a virtual scene: Immersion, Presence, Interactivity, Autonomy and Collaboration (Petrick et al., 2002). Other researchers like Lammeren, extend this list by adding more factors (Lammeren et al., 2002). What is stated here is that the new generation of Landscape Architects could consider seven factors as the most important: Immersion, Information Intensity, Interactivity, Navigation, Intelligence, Communication and Checking.

2.1. Immersion

Immersion has been defined by Witmer and Singer as ‘a psychological state characterized by perceiving oneself to be enveloped by, included in, and interacting with an environment’ (Witmer & Singer, 1998) determining the degree of immersion. An important feature related to Immersion is that multi-sensory interactions, i.e. visual, acoustic and kinetics are combined in such a way that the user actually feels he/she is there (Whitelock et al., 2000) offering him/her the chance of a pleasant and productive experience.

2.2. Information Intensity

This factor is very important because the increasing proximity allows participants to examine objects and important features in increasing detail (Lammeren et al., 2002). It seems to be true that Landscape Architects have a different perception of the so-called Level of Detail (LOD) when using 3D paper drawings than VR designers. In 2D drawings objects can be seen in scales previously stated and agreed by the design team, for example 1:30 for a house (Bourdakis, 2001). In VR the LOD is dynamically adjusted as the user navigates through the virtual scene.

Unfortunately, by increasing the requirements of LOD (higher information intensity) a number of demanding technical issues arises that is beyond the scope of this paper.

2.3. Interactivity

Based on the definition of Wikipedia (http://en.wikipedia.org), Interaction in VR can be seen as the mutual exchange of actions between users, objects and the environment that have an effect upon one another in the three dimensional space. Using the VR interface, architects and their clients can have a first-hand experience of the proposal. The VR interface is characterized by transparency, which means that conscious thinking about how to act is not required by the users. Moreover, the way to interact with the virtual environment is characterized by the feeling of presence and comes naturally to the users without spending time and energy to take formal instructions.

2.4. Navigation

Users can navigate through large and complicated virtual environments using an avatar (virtual body). Examples of large web enabled multi-user environments are the Secondlife (http://secondlife.com) and ActiveWorlds (www.activeworlds.com), although those particulars are not initially developed for scientific research or educational purposes. Navigation for users means participation and understanding of the virtual scene. Important issues involved in navigation are avatar’s response speed, motion speed in 3Dspace and the required accuracy of the above figures (Diot & Gautier, 1999).

2.5. Intelligence

The use of VRML to develop the basic structure of VR applications is similar to object-oriented programming. 3D objects are composed by geometry, methods and some user and/or system driven events that trigger the behaviour of objects. Those ‘intelligent’ objects or automations, seeing form the scope of Landscape Architecture, are referred to both static (automatic door opening triggered by the avatar proximity) and dynamic elements (seasonal falling of leaves, plat size, etc.).

Another practical use of system’s intelligence is related to collision detection and physical powers. Collision Detection in Landscape Architecture comes as a result of algorithms which check intersections of 3d objects (for example users cannot walk through trees and walls).

2.6. Communication Tool

In order to compose a basis for successful communication between researchers and clients, VR in Landscape Architecture tends to minimize the required communication during all phases of process (Kahkonen, 2003). Normally, the understanding of major key-points of a 2D drawing project requires that the designers must use the same notation (symbols and assumptions) (Maher et al., 1999). VR can offer a direct examination of the project without such conventional limitations, including geometry, texture, planting, lighting and acoustic conditions.

2.7. Checking

The fact that Landscape Architecture proposals can be checked against a wide range of criteria before they exist in real world is one of the major advantages (Petric et al., 2002). Collaborative design is made possible by Virtual Design Studios (VDS) (Brandford et al., 1994) and is the most modern fashion for practice and checking before the actual construction schedule put into practice (Oloufa, 1993) (Webster et al., 1996).

3. VR: Haptic Rendering with e-Learning Functionality

Nowadays, VR functionality can provide effective methods for e-learning documentation with 3-D modelling, thanks to the innovations of sensors, graphics cards, screens and the high processing power offered at relatively low prices (Kalay, 2006) (Westera, 2005). Taking into account that Landscape Architecture is related to numerous photogrammetric data acquisition and processing methods, haptic rendering, CAAD/multimedia data integration and projection methods (Vladoiu, 2004; Weber, 2004; Styliadis 2007), it is easily understood that the requirements of visualization are very demanding. VR, as a promising technology, provides low cost solutions for educational and professional activities in Landscape Architecture. New feasible methods for digital documentation of buildings and the surroundings have been available and the 'digital documentation with 3-d modelling functionality' is becoming a new term in IT approach of architecture related fields (Styliadis, 2007).

In the recent years, VR has become widely accepted as a pedagogically valuable way to supplement in-class instructions (face-to-face). Summarized benefits of what the VR functionality can do in CAAD education are listed below:

- Engage learners to be involved into problem solving (Problem Based Learning);
- Enhance spatial thinking, reasoning and content understanding through the use of 3d models and simulations of concept plans;
- Approach the problem solving through distant communication and collaboration;
- Learners can easily extend, manipulate and manage the knowledge base (learning modules);
- Allow educators to differentiate their instruction;
- Allow learners to follow their own personal learning style (Individualized learning);
- Offer a uniform way for learners to meet learning goals;
- Has a positive effect on time students usually spend in educational activities;
- Offer all of the above without any geographical or time restricts (e- learning funcionality).

Apart from the above, while working on real projects in design studios, learners become more proficient in the use of computer-aided design, geographic information systems, and video simulations (Dzitac et al., 2007). Also, experimentations with e-learning platforms for CAAD courses have shown encouraging results (Leao, et al., 2007). Many universities and institutions, which support architectural subjects with e-learning functionality, tend to emphasize Information and Communication Technologies (ICT) in their curriculum to provide their students with skills and professional advantages (Garba, 2004).

Examples of Virtual Reality Laboratories established by institutions to support courses and major projects can be retrieved by the over 10 year's long research of V. Bourdakis in various publications (Bourdakis, 2004; 2001; 1998; 1996; Bourdakis & Robson, 1996).

4. VR in Landscape Architecture: Methodology

Designing and planning a virtual Landscape Architecture scene is a complicated task, especially if it is taken into account the fact that the members of the design team can be spatially separated. The current project, as any other in this field, is not only a drafting piece of work. It deals with the standard Landscape Architecture methodology, the collection and management of digital and in-print material, database and VRML source code development. The study of 3-D scenery modeling and techniques based on digital images, object-oriented graphic databases of 3-D parametric models and geometric/topologic constraints is an active research area (Styliadis et. al., 2003; Styliadis, Vassilakopoulos, 2005). Other issues the creation team confront are the rendering of the scenes, the architectural complexity of the objects, the perspective representation and the insertion of three dimensional sound. Although there is no standard methodology widely accepted for developers to follow, some basic steps of the methodology followed by this project can be mentioned below.

4.1. Preparation

At the beginning, all the available resources (images, drawings, video, texts, interviews, GPS data and topographical maps) of the study area are overviewed in line with the scope of the project. Other important factors like existing physical resources, history and particular characteristics of the study area and the surroundings should be recorded. At the same time, certain urban planning limitations and financial information are taken into account

4.2. Software Tools

The set of software tools finally selected for the design phases of the virtual scene is the outcome of a short research over the Internet about the available software. Important factors for the selection of software tools were:

- The professional potentialities of the software;
- The drafting accuracy and the easiness of restoration;
- The learning time and effort normally needed by a moderate designer to be able to use the full power of the software;
- The existence of VRML/X3D exporter embodied into the CAAD software;
- The rendering quality (texture mapping support, lighting effectiveness, reach library of materials, rendering speed);
- The support of compatible file formats for input/output;
- The previous knowledge and experience of the creation team.

4.3. Information gathering and site analysis

First, all relevant information is selected, like city plans, maps, aerial photographs, video shootings, etc of the studying area and the surroundings. Also, information is selected regarding the culture, history and the aesthetic resources of the site. Because of the poor quality of the 2D drawings usually obtained from the municipalities, extra measurement sessions are imported into the team’s schedule. Measurements of street furniture, road widths and existing buildings, monuments, etc took place with conventional instruments. Diagrams about traffic flow, existing planting and space usages are created in 2D. The gathered information is analyzed in relation with the scope of the design, in order to obtain a complete view about the existing conditions of the study area and the achieving goals.

4.4. Concept planning

Concept planning is a process which is characterized by collaboration and creativity.

Solutions are provided through exchange of ideas among members of the creation team, clients and other participants. The solutions are evaluated in order to choose the most appropriate ones. Concept planning is not totally isolated from drafting processes; rather it is more like a circle process among those two phases.

4.5. Drafting Process – (Scene development and LOD Issues)

Every virtual landscape environment that is designed has one or more scenes. A scene can be a room, a park, a building, or a whole city. The shape, size, material, position and orientation of 3D objects is important considering architectural concepts like unity, rhythm, proportion and symmetry (Lammeren et al., 2002) and aesthetic consistency. By breaking down the whole scene into separate 3D components make possible to have the necessary flexibility of major alterations during all phases of the creation.

During drafting phase, CAD software found on the market is used to construct the imaginary or existing architectural elements. In case of existing buildings, feasible methods like 3D reconstructing from digital images using geometric constraints can be used to obtain the VRML solid (exterior only) model of the building (Heuvel, 2003). Today improvements in sensor technology allow the acquisition of high quality digital images (Kazakeviciute et al., 2005) for texture extracting and use in 3d Models.

As stated before, information Intensity deals with the level of detail (LOD) and this affects the quality of the presentation. Usually, a lot of rotations and translations can overload a computer system. To control the overload conditions, in order to keep the frame rate of the final display high, each 3d object with complicate geometry is represented in the scene with different LOD, depending on the avatar proximity. As an example, consider the trash can 3d model. Initially it is loaded into the scene as a simple box, since details cannot be viewed from long distances. By the user proximity (triggering proximity sensor), this object is replaced by the maximum LOD 3d object, showing the trash can in maximum detail (see fig.1).

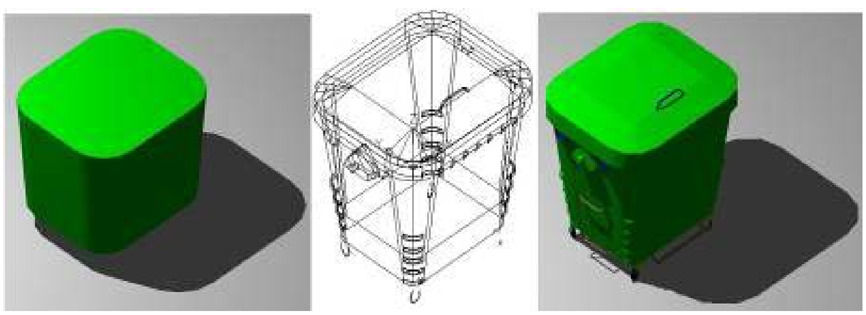


Fig. 1. Example of an object with 2 levels of detail: Simple geometry with minimum LOD (left), original object in wireframe (center), object with maximum LOD (right)

In some occasions (massive and complicated objects) various levels of detail are defined for given geometries. Browsers, or stand alone vrml players, automatically choose the appropriate LOD level based on a set of predefined distances between object and avatar. The simple algorithm which chooses the most appropriate LOD for a given object at any time during navigation is based on the formula (Web 3D Consortium, 2004):

$$LOD(l) = \begin{cases} LOD_o, if.l < R_o \\ LOD_{i+1}, if.R_i <= l < R_{i+1}, for -1 < i < n-1 \\ LOD_{n-1}, if.l >= R_{n-1} \end{cases}$$

where,

LOD(l): winner LOD

LOD_0, LOD_1, LOD_2, …, LOD_{n-1}: n values (object instances of various LOD)

R_0, R_1, R_2, …, R_{n-1}: ranges which partition the domain from 0 to infinity.

l: avatar's distance to object

4.6. Lighting

To maximize the quality of lighting effects, all experimentation with light sources is done on scenes without materials or colors other to white. This method of lighting adjustment, although it requires a lot of experimentation to reach the best results, was the most appropriate to offer uniform lighting effects to the overall scene.

Three types of light sources were used in this implementation, each one with different characteristics (as graphically explained in table 1).

DirectionalLight defines a light source with parallel rays that shines from a uniform direction. This is analogous to the Sun effect where everything is illuminated from the same direction. The DirectionalLight does not have a location (or it is located far away from virtual scene) and illuminates all object-nodes below (in the hierarchy of nodes). A graphical representation of DirectionalLight is shown on table1 (a).

PointLight on the other hand, has no vector in 3D space, but it has a specified location. The light rays of this source are spread equally in all directions and can affect all 3D objects. The only restrict is the value of Radius as shown in table1 (b). Given an object located inside the circle defined by Radius, the Intensity of light on that object is given by the formula (Web 3D Consortium, 2004):

$$I = \frac{1}{coefficientA + coefficientB * R + coefficientC * R^2}$$

Where coefficients A, B and C represent three levels of light attenuation.

SpotLight is described by a combination of PointLight characteristics (location, radius and attenuation coefficients) and DirectionalLight (direction). The light rays are affected by two more properties: CutOffAngle and BeamWidth which describe a cone that points to the source and the circular fade out near the edges (table1 (c)).

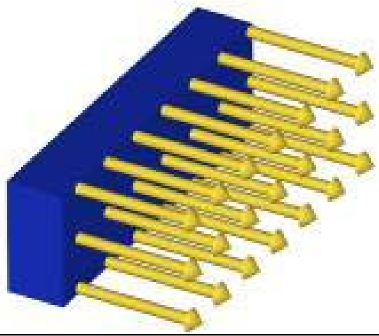
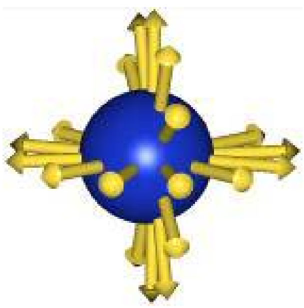
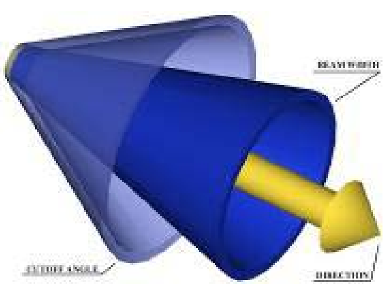
4.7. Materials-Appearance of objects

To control the surface appearance of objects, two different methods can be followed. By the first method, material nodes are used to specify the colour, light reflection and transparency (for example windows glasses). This method keeps the overall size (in MB) of the project low and this is its major advantage. A second way to give an object a particular complicate appearance is to attach an image file to that object. Shooting photographs of real elements like street furniture (lights, tiles, etc) was necessary in order to take the primary information about texture of surfaces.

4.8. Cameras

Camera objects are not visible, but can be reached through a right-click popup menu at any point of the display screen. The effective use of the cameras located at different entry positions during navigation, can offer to the user an interesting “transcending” experience like teleportation. This is about the ability given by the system designer to let the user move rapidly from one point to another, working in a similar way internal links (Anchors) do in HTML files.

Table 1 VRML light nodes used in the case study.

Light Type	VRML example	Fields
(a) DirectionalLight (Sun) 	DirectionalLight { on TRUE intensity 1 ambientIntensity 0 color 1 1 1 direction 0 -1 0 }	On: Set the light on or off Intensity: values in the range 0.0 to 1.0 (stronger light) AmbientIntensity: values in the range 0.0 and 1.0 (contribution to the overall lighting) Color: an RGB value of light color Direction: A vector to which light rays are parallel
(b)PointLight (bulb) 	PointLight { on TRUE intensity 1 ambientIntensity 0 color 1 1 1 location 0 0 0 attenuation 1 0 0 radius 10}	On:-as above- Intensity:-as above- AmbientIntensity:-as above- Color:-as above- Location: coordinates of the light source Attenuation: values zero or greater, specifies light looses reversely proportional to distance from the light source (default value 100). Radius: values zero or greater, specifies max distance of the light rays.
(c) SpotLight 	SpotLight { on TRUE intensity 1 ambientIntensity 0 color 1 1 1 location 0 0 0 direction 0 0 0 attenuation 1 0 0 radius 100 cutOffAngle 0.78 beamWidth 1.57 }	On:-as above- Intensity:-as above- AmbientIntensity: -as above- Color:-as above- Location: -as above- Direction: -as above- Attenuation: -as above- Radius: -as above- CutOffAngle & BeamWidth: angles which define the width of the beam and the fade out at the edges.

4.9. Lighting Effects

Lighting effects play an important role in the realism of the final projection and give a specific 'atmosphere' to the scene. A very popular effect is implemented by Fog node (non-visible). There are two major categories of Fog: Linear and Exponential which deals with how the fog's density increases with distance. Other properties of Fog node refer to Color which was set to white and VisibilityRange set to a large value in order to be inconspicuous.

4.10. Automations

Scripting language incorporated in VRML is used for the performance of certain automations. Although intelligence of VR systems can give impressive results by complicate behaviour of objects, in Landscape Architecture projects automations can be limited to simple actions such as opening and closing doors, object rotations, etc.

4.11. 3D Sound

VR worlds developed by VRML are audio enabled during navigation. This feature can be useful to developers to check certain acoustic characteristics of the studying area. Sound is attenuated according to the distance between a sound source and an avatar. The specified intensity (values from 0 to 1) is being heard between MinBack and MinFront as shown in fig.2. As the avatar is moving from the internal ellipsis to the external, specified by MaxBack and MaxFront, the intensity of sound is attenuated linearly to -20dB. Adjusting Min-Max borders, different kinds of sound nodes can be produced as shown in fig. 3.

This simple trick of linking one single AudioClip to many SoundNodes positioned at selected points of the scene saves a lot of system resources (memory). Also offers an impressive 3D sound experience to the users and thus maximize the Immersion factor stated earlier.

4.12. Presentation of the final scene

The final outcome consists of a group of wrl files (VRML file extension), images and sound files that all together include the geometry, intelligence (automations), links to different parts of the project as well as the multimedia content.

The final version of the project must be tested with various web browsers in combination with vrml plug-in players available on the Internet. Designers must be aware of the fact that the final result may vary from one software combination to another, probably because VRML files, actually ASCII text files, are interpreted and not compiled by the browsers.

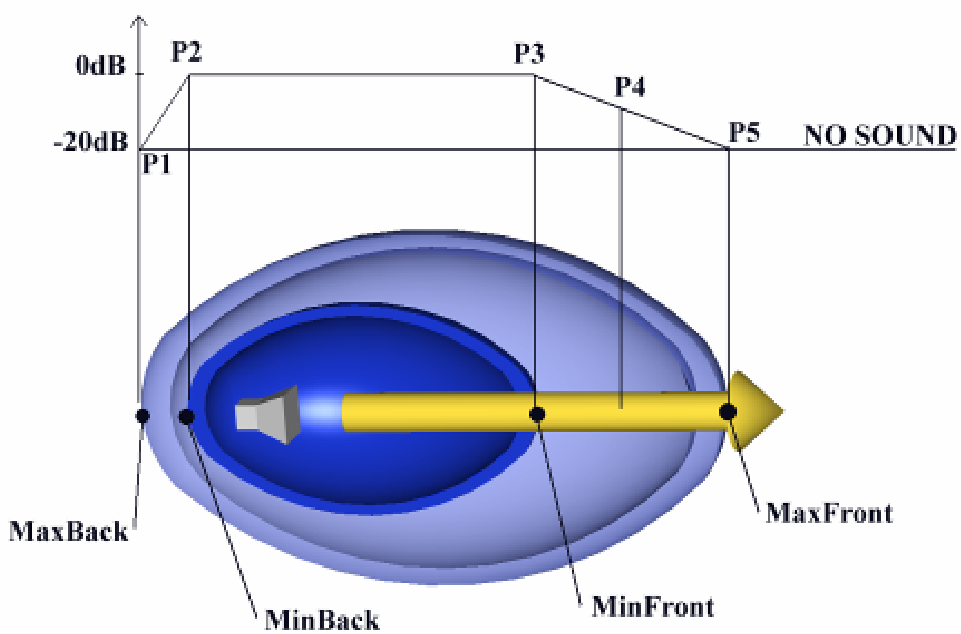


Fig. 2. Sound Node and volume levels (Web 3D Consortium, 2004).

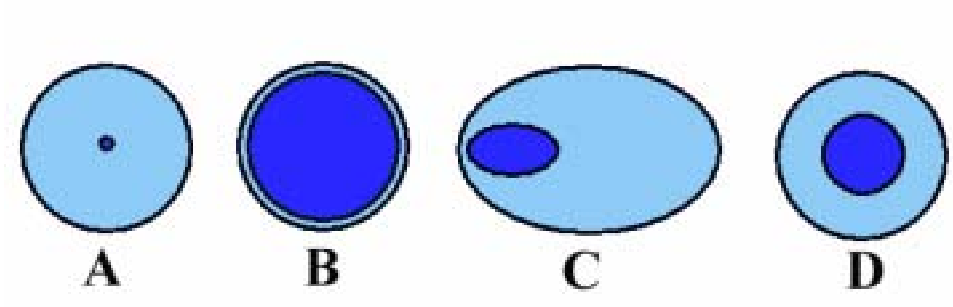


Fig. 3. Four kinds of sound nodes used for (A) birds, people talking, (B) wind, avatar walking, (C) speakers in the cafeteria or in the amphitheater, (D) car engines, traffic noise.

5. VR in Landscape Architecture: An Application Example

For the reader’s convenience, the study area of the application example is a 75x93 m^2 located in front of the historic port of Thessaloniki and currently is used as a parking area. The starting point of the design process is the 2D drafting of the basic concept of the area (see fig.4 & 5a,b) including planting, business and sport activities, existing elements and park furniture.

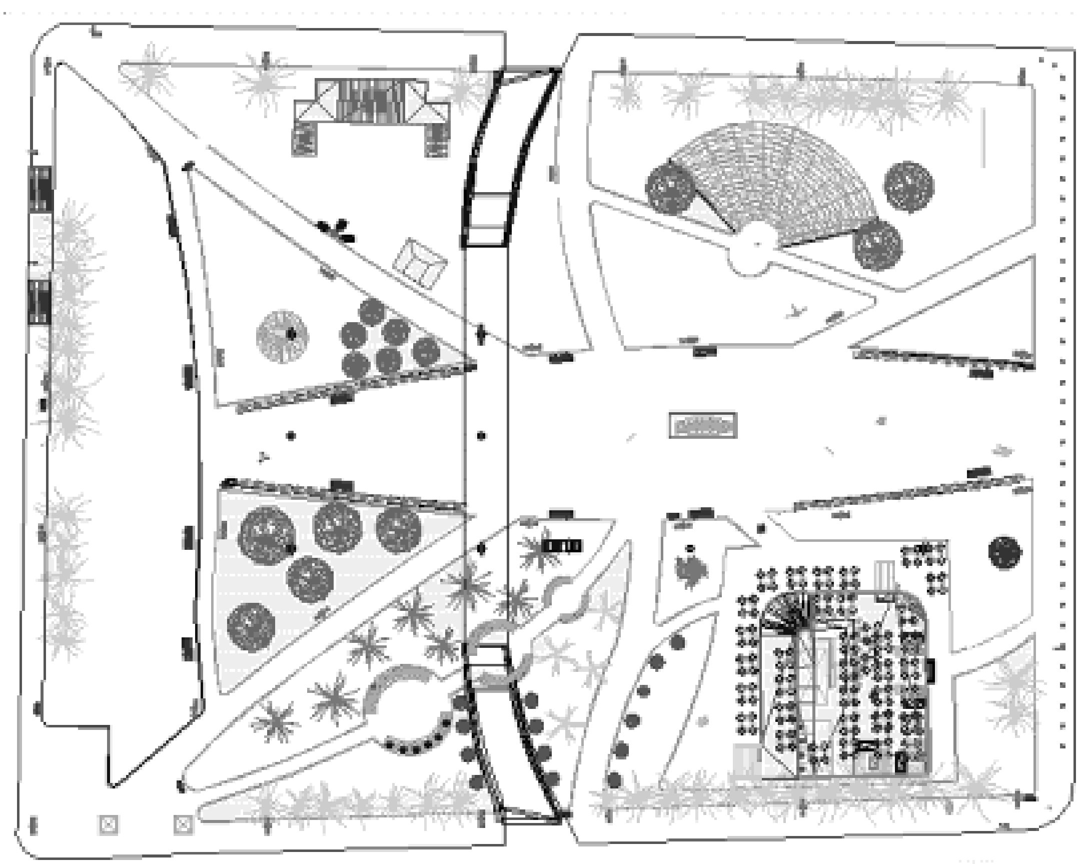


Fig. 4. A basic concept plan of the recreation area.

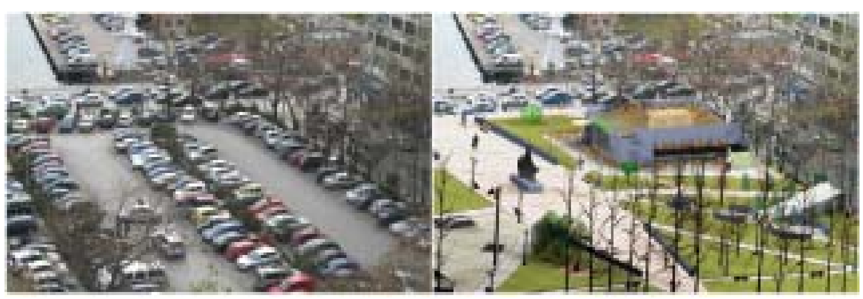
The case study presented below was mostly engineered using the 3D-Studio Max (Autodesk Inc) software package, while parts of it were drafted with AutoCAD 2006 (Autodesk Inc) and imported into the main scene as external files. The original 3D model was enriched with VRML scripting code and finally exported as a wrl file capable of reproduction in widely used browsers.

VRML plug-in players implement a Graphical User Interface (GUI) for navigation through the virtual scenes and for applying operations on the 3D objects. After having tested and evaluated several plug-in players for VRML, it was the Cortona (Parallel Graphics) which was finally selected as one of the most appropriate for the popular browsers Internet Explorer and Mozilla Firefox.

In addition to the starting viewpoint (camera), a set of additional cameras are imported into the scene. Camera nodes in VRML define exact positions from which to view a scene and some of their parameters can give effects like special effect lens (fish-eye). Another used effect was the linear fog to give to the overall scene a better depth of perception.

Because the output file sizes an exceeded the expected, the Win-gz (copyrighted by Bob Crispen) or similar compression utilities can be used to compress the original file with very satisfactory compression rates. The small file sizes keep the download time short even at a moderate bandwidth.

(a)



(b)

Fig. 5. (a) 3D model of the proposed concept plan (3d scene) (b) Study area (before-after).

Taking into consideration that the typical target audience of VR landscape architecture projects is composed by people with at least basic computer skills, a set of system variables was initially set. Those system variables include viewpoints (cameras), navigation adjustments, speed and collision detection regulations. Advance users can change those values at a later time (navigation/execution time).

After a few cycles of execution tests in web browsers, few more adjustments can be made to ensure the efficient interpretation. Four digits of precision are selected for projection of the geometry and 15-20 frames per second are considered satisfactory to achieve a realistic as well as a comfortable navigation, given the total size and complication of the scene.

6. Conclusions

VR functionality has been an area of increasing research especially in architecture related fields where visualization has a huge effect. VR is both an artistic and a scientific language that can be used during creation, presentation and checking processes. Also, it can be used as a tool to offer real prospect for learner participation in educational activities related to CAD and virtual studio projects.

The methodology presented in here, followed by an application example, illustrated how desktop VR technology can address the challenges to experiment with scenes in real visualized projects. More efficient user control and management of scene parameters is desirable for the future. In such a system students could locally modify values of variables in real time. The possibility to change 3d model appearance and behaviour on demand, or study the dynamic alteration of the whole scene over time/seasonal parameters is the fourth dimension in addition to the haptic rendering functionality. It will be possible for learners/designers to dynamically retrieve the geometry and texture of planting from a floral database. Given the time and GPS global position of the study area, the examination of lighting conditions (artificial lighting and sun) during morning, midday, afternoon and night could be possible at run time.

Fig. 6. (a) Human-scale exploration (walk) to study lighting conditions (here manually adjusted at design time).

New methods are invented to take advantage of the VR technology. In order to choose between competitive ideas, VR technology and haptic rendering functionality made possible to locate advantages and disadvantages, strong and weak points of the concept plans. Also it allowed a better understanding of the flow of movement in the area, from the pedestrian’s point of view. It would be difficult right now to get a clear answer if the proposed methodology results better urban and landscape implementations in real world than the conventional methods. All conclusions are relied on the assumption that 3d real time navigation is helpful for communication among experts and have a positive effect on public participation. To what degree those methods are effective remains a task for further research. Today, it could be stated that apart from the educational benefits of 3d visualized projects, VR functionality is to additionally support the decision making in Landscape Architecture planning by demonstrating major key-points of the concept.

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