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A Virtual Reality Environment Supporting the Design and Evaluation of Interior Spaces

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Abstract

Interior space design is a collaborative process for deriving different proposals on the content and structure of any type of interior space. This process is partially supported by mainstream CAD systems which are not designed for that particular task but for general engineering- or architectural-design development. Although, several add-on modules have been developed for supporting mainly arctitectural design, still, significant effort is required in order to employ a CAD system due to their increased requiremenets and slow learning curve. However, if end-users (e.g., consumers) are to be directly involved in the process, new environments that emphasize on usability and intuitive interactions have to be introduced. VR technology can help in this direction as it provides the theories and tools to construct and manipulate 3D spaces using a 'real-world' metaphor. Desktop virtual environments can serve as a means to implement design applications for the end-users. In this paper we propose a methodology for designing and implementing virtual reality applications to support the process of interior space design focusing on usability for non-expert users. We present a prototype implementation of the proposed methodology and an informal user-centered evaluation of the environment.

Keywords: Virtual Reality, Virtual Environments, Interior Design

1 Introduction

Interior space design is a process, which involves the collaboration between clients and designers in order to conclude to a proposal about the content of any type of interior space. It involves decisions about style, form, content, furniture arrangements, etc. according to design principles and client preferences. Experiments have shown that designers using a three-dimensional (3D) environment spend less time synthesizing design concepts compared to traditional processes, such as sketching, as they can easily manipulate parts of the design and instantly evaluate the concept (Maher et al, 2006). Therefore, interior space design can benefit from the advanced visualization and interaction capabilities offered by Virtual Reality (Whyte et al, 2000) through the development of usable tools for developing and evaluating concepts in 3D.

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Immersive virtual reality interfaces are still not a commonplace for everyday users, mainly due to expensiveness of respective hardware and the related problems caused by long exposure to immersive environments, such as cyber sickness. However, desktop virtual environments, i.e. virtual reality applications that use common PC hardware (keyboard, mouse and monitor) are starting to demonstrate their great potential as a new medium for human computer interaction. Although not fully immersed, users interacting with desktop virtual environments demonstrate the effect of psychological immersion and can have a limited virtual reality experience in their home computers. Desktop Virtual Reality applications and especially Web-based ones can provide an affordable and accessible solution to real-time interactive interior space design.

There have been a number of approaches for designing interior spaces in 3D over the Web, such as (Lin et al, 2006; Varlamis el al, 2000) but in most of the cases the applications distinguish between the design phase which is a 2D interactive process of constructing the interior space and arranging furniture on the floor plan, and the visualization / evaluation phase which is a 3D representation of the concept. This use of two different representations permits the designer from instantly observing his/her concept whilst re-designing the space and slows down the design process. Furthermore, traditional CAD software is not designed for that particular task while it requires special skills and high-end hardware and can, therefore, be used mainly by professionals. Its use may complicate the collaboration between client and designer, as the latter cannot actively participate in the process of furniture arrangement in the 3D environment.

In this paper we propose a methodology for designing and implementing desktop virtual reality applications to support interior space design. The proposed methodology is based on an integrated environment, in which the design and evaluation of the interior space takes place. It takes into account the usability guidelines concerning 3D user interfaces and virtual reality applications, offers a variety of navigation modes, facilitates selection and manipulation of objects in 3D and provides multiple levels of user assistance. It follows a decentralized architecture, which is aiming towards reusability, extensibility and transferability.

The rest of the paper is structured as follows: Section 2 presents the related work in 3D environments for interior space design; Section 3 presents the proposed methodology for designing and implementing Desktop VR Applications for Interior Space Design; Section 4 presents in detail a prototype implementation of the proposed methodology and Section 5 presents an evaluation of the implemented environment. In the final section, the paper states the conclusions and future work.

2 Three-Dimensional Environments for Interior Space Design

The advances of computer graphics technology in the last 20 years have led to a shift in the process of interior space design from traditional conceptual sketches and drawings to the use of dedicated software environments for designing in 3D. The latter offer significant advantages to the designers, as they allow instant manipulation of the interior space elements and realistic preview of the concept, thus speeding up the evaluation and refinement activities that are found to be necessary in any conceptual design process (Potts and Catledge, 1996). Furthermore, the use of realistic 3D representations for visualizing interior design concepts facilitates the communication between designers and clients, as the latter get a richer picture of the final arrangement compared to looking at paper drawings. There are a number of professional applications for architectural and interior space design. Lok (2004) presents the most popular packages used by interior designers and a survey on the extent to which these packages have successfully replaced the drawing process in the phase of conceptual design.

Immersive virtual environments using projected VR or head-up displays have also been used for visualizing and/or manipulating interior space concepts as they can increase the sense of presence and provide a natural and intuitive object manipulation interface. A multi-user interior design application that can use VR platforms of various configurations is presented in (Korpipaa

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et al., 2000). Their paper emphasizes on a network protocol and a graphics engine that allows the same virtual space to be used by two or more remote systems using different hardware configurations.

Drettakis et al. (Drettakis et al., 2007) introduce a user-centered design approach for the development of virtual environments for architecture and urban planning. Their approach is applied to the requirements analysis, design and evaluation of an immersive VR application for redesigning a realistic environment by placing, arranging and manipulating elements.

Anderson et al. (Anderson el al., 2003) present an environment for conceptual design in architecture. They have designed and implemented an immersive virtual environment that emulates aspects of a typical designer's work area using a 'kiosk' toolbox. The design environment allows the insertion and placement of images, videos and 3D objects on any surface in order to establish a larger contextual environment and to allow designers to work in more than one scale simultaneously. Immersive VR technology has also been used for the participatory design of work environments (Davies, 2004). A number of prototypes using a VR development tool and a projected environment have been developed and tested during the design of a university campus.

An interesting alternative to immersive VR for interior design are tangible interfaces, which let users directly manipulate physical objects and observe the transformations on the respective virtual elements in an augmented environment. Seichter and Kvan (2004) introduce and evaluate three experimental tangible interfaces in a collaborative design setting.

Immersive and tangible interfaces may be promising means of interaction, but the technologies are still not mature enough to be used by everyday users in their homes. The recent advances in processing power and real-time rendering technology allow realistic interactive 3D environments to run in home computers, thus giving rise to Desktop VR applications that can be used as an alternative. Furthermore, 3D technologies for the World Wide Web have enabled virtual environments to be integrated in Web pages having a multitude of advantages, such as to be cross-platform, to be accessible to any user, to update their content or functionality from a remote source, to use other web technologies, etc.

The paper presented in (Varlamis et al., 2000) describes the design and implementation of a desktop 3D environment for visualizing interior spaces. The application lets users interactively design a room and place furniture and electric appliances inside it. It is aiming to support e-commerce by letting users preview products inside their environment before buying them. The implementation is a Web-based environment that uses a 2D interface for the interactive design of the room and the furniture placement and dynamically generates a 3D environment, from which users can preview their design concept.

Another Web-based application for multi-user interior design is presented in (Lin et al., 2006). Users collaborate inside the common environment to load and modify built-in 3D scenes and to interactively place 3D furniture models inside them. Communication is supported with instant messaging. The integrated environment offers multiple viewpoints and the interface to manipulate objects in the 3D space by applying geometric transformations on the scene elements.

The methodology presented in this paper is aiming to the design and implementation of virtual environments for interior design. Although there is already a number of similar applications, as outlined above, the current paper is giving emphasis to the support of the early stages of conceptual design (Austin el al., 2001), where the application should facilitate rapid rearrangement of furniture and alteration of style and decoration. Additionally, given that clients should also participate in the process of interior design and in some cases they may be the designers themselves, the proposed methodology is focusing on usability for non-expert users. The proposed environment is a Desktop VR Web-based environment, in which the interactions

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have been designed to support the various stages of interior design and to be usable and intuitive to new users.

3 Design Methodology

The proposed approach follows the principles of user-centered design and evaluation methodology for virtual environments presented in (Gabbard, 1999), and it is implemented in the context of Web-based desktop environments for the support of interior design. The methodology followed is outlined below:

1. User-task analysis: identification and description of potential user tasks in the process of mapping an existing environment in the virtual space and creating and modifying design concepts.
2. Specification of the virtual environment: based on the tasks identified, the virtual environment is specified in terms of content, representation and behavior.
3. User interface design: support of the user interactions, i.e. navigation, object selection and manipulation and system control, based on user tasks and usability guidelines for 3D environments.
4. System design: definition of the technologies, the software components and the databases that will be part of the implemented application.

The application of each individual step is presented in the following paragraphs.

3.1 User Task Analysis

The people involved in the interior design application are both designers and clients. Therefore, the potential users of an application that supports this process range from professional interior designers to inexperienced end-users. By studying designers and end-users requirements, we have identified three possible scenarios of using a VR interior-design environment:

1. A team of professional designers is asked to design and decorate an interior space, e.g. a plane, a conference centre, a hotel, etc.
2. A small team of professional designers is asked to decorate an apartment. Through an iterative process, where clients express their requirements and designers respond with alternative concepts, a final decoration-concept is derived.
3. An existing environment is redecorated by non-professional designers, e.g., by the owners of an installation. Several different concepts are tested until a satisfactory solution is derived.

The first case is already being supported by professional software, such as CAD applications with specialized add-ons, which provide sophisticated tools to professional designers to proceed to a detailed design of an interior environment. The proposed methodology is aiming to support the last two scenarios which include significant end-user involvement as well. Following are the main user tasks that have been identified for the process of interior design:

- *Construction and modification of the environment*: users construct a model of an existing apartment or room, usually based on a floor plan. They insert and modify elements such as walls, doors and windows to define the environment.
- *Definition of design requirements*: users define the requirements on which the interior design process will be based. They may include existing guidelines (e.g. design or safety principles) or define their own.
- *Formation of concepts*: users preview furniture and decoration elements from categorized libraries, select and insert them in the environment. They try out different concepts by rearranging objects inside rooms.
- *Concept refinement*: users refine a concept by adding details to the environment and making minor modifications to improve the aesthetics and ergonomics of the interior space.

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- *Evaluation*: users evaluate a proposed concept by observing the interior space from a first-person perspective, trying out various viewpoints and performing walkthroughs.

The tasks described above are used to specify the design requirements of the virtual environment and the user interactions.

3.2. Virtual Environment

Most 3D modeling applications present multiple viewpoints of the same environment simultaneously. On the other hand, a number of environments for interior space design let users construct the interior space on a floor plan and use 3D representation only for visualization and walkthroughs (Varlamis et al, 2000). The authors of this paper claim that both approaches are not fully appropriate for the inexperienced user, especially in the early stages of conceptual design, where not much detail is required. On the contrary, multiple viewpoints may frustrate the new user and slow down his/her tasks, whilst the use of different representations for interactive arrangement and walkthrough obstructs the instant evaluation of new concepts and will possibly lead to a constant switch between these two modes during their concept development. The proposed application is based on an integrated virtual environment, in which construction, object manipulation and user navigation can take place simultaneously. This approach requires the design of 3D user interactions and visualizations for all stages of constructing and manipulating an interior space and its elements.

One of the most important tasks in an interior design environment is the selection and transformation of the objects in the environment. The application should allow instant selection and arrangement in 3D to facilitate quick formation of concepts and to be used by inexperienced users in an intuitive way. On the other hand, a more detailed design of the interior space or the refinement of a concept requires tools for accurate scaling, positioning and alignment of objects. Following the paradigm of 3D modeling applications, the environment should support direct manipulation in 3D, as well as the ability to modify the values of the geometric properties and relations of the elements, e.g. position, size, distance from a given point, etc.

As far as the degree of realism in representation is concerned, the visualization of the environment should be as realistic as possible, in order to enhance the user's sense of presence whilst navigating inside the environment and observing the context. On the other hand, the environment must run at acceptable frame rates during the agent's navigation and interaction with the content. Therefore, common techniques such as the use of textures and levels of detail should be used in order to preserve realism without increasing the computational cost of rendering the environment. Collision detection is also a desirable feature in order to prevent the user from specifying impossible furniture arrangements, but this feature should be optional as it may slow down the user's task of trying new concepts or modifying existing ones.

Finally, all objects that are part of the interior design environment should be fully specified in terms of their properties and interactivity allowing for their dynamic manipulation. In the case that structural elements were represented as passive objects that could be arbitrarily transformed, a first time user would require a lot of effort to design a feasible environment.

Furthermore, the modeling of the ambient environment space requires operators that may even modify the geometry of existing objects in the environment, e.g. in the case of inserting a window on a wall. Therefore, the application should distinguish between different classes of elements, as their expected behavior varies and their relation to the environment poses several constraints. Additionally, users should have the ability to specify certain design requirements using rules that involve specific classes and properties, e.g. corridor width, distance from wall, etc. The predetermined functionality and semantics of various classes of objects in the environments will allow the development of tools that facilitate specialized user tasks concerning the selection and arrangement of elements whilst forming new concepts.

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3.3. User Interface

Following the specification of the virtual environment, the user interface is designed so as to support usable and intuitive user interactions. The basic interactions in virtual environments are user navigation, object selection and manipulation and system control (Bowman et al, 2001).

Concerning user navigation, the process of designing the interior space and arranging elements inside it can be better supported by an exocentric view of the environment, which will provide a global visualization of the scene, its elements and their relations. On the other hand, better understanding and evaluation of a concept is achieved with a first-person navigation that will present a more realistic aspect of the interior space. Therefore, the virtual environment should allow for both viewpoints, which can be supported by a number of well-known navigation techniques. During the process of modifying an existing scene and arranging elements, the user may have to observe the environment from different viewpoints to gain better understanding of the 3D structure and to interact with increased accuracy. To avoid continuous switches between navigation and object selection and manipulation, the environment should provide the means for instant change of viewpoint during any interaction task without having to explicitly select it from the system interface.

Users should be able to quickly select and manipulate the elements of the environment as the process of modeling an interior space and arranging objects involves the continuous application of geometric transformations on them. The most simple and intuitive selection technique in desktop 3D environments is to click on the projected geometry of an object. The system should provide visual feedback on the selected item and on the operations available at that moment using visual interaction components. Furthermore, given the variations in the behavior of different classes of objects, the environment should also support object-specific constrained-based manipulations to facilitate specialized tasks, e.g. grouping and alignment of furniture, arrangement of decoration elements on a wall, etc.

3.4. System Properties

The interior design environment is an application that involves both clients and designers, who may work on the same concept, may wish to share concepts and ideas, etc. To fulfill these and similar needs, a client-server architecture is preferable, as it can support remote sharing of working or complete concepts to be accessed by stakeholders. Furthermore, a decentralized architecture will allow users to preview and import furniture on demand and designers to manage and update the content. Thus, the environment can be better supported by a database on the server side that may include prototype interior spaces, sample concepts, furniture models, related information pages, color palettes, textures, etc. and will be managed by the design team and, optionally, by the users of the application. On the client side, users interacting with the application may browse the remote database, import content into the environment and store their concepts locally or on the remote server.

4. Prototype Implementation

Following the proposed methodology, the authors have designed and implemented a Web-based Desktop VR application for interior design. The application environment supports the interactive modeling of a room or apartment and the insertion and arrangement of furniture inside the environment. Its basic functionality is outlined in the following paragraphs.

The environment initiates with the presentation of the ground plane, on which users can map an existing sketch or ground plan of the interior space they wish to model. The construction of an apartment is processed by directly inserting walls through the specification of their end points on the 3D environment. The application automatically joins adjacent walls and forms corners. Users can refine the model either by directly adjusting the end points in 3D or by selecting a wall and altering property values such as width, length and height. Furthermore, users can

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modify the appearance of each surface by selecting colors and textures from existing libraries provided by the application or by specifying / uploading their own materials. Doors and windows can be inserted on existing walls and their position and size can be controlled using interactive 3D components. The appearance of the door and window frames can be modified by selecting a prototype from the respective library and letting the program dynamically construct the actual frame model that applies to the selected window / door dimensions. Finally, users can insert lights in the environment and interactively adjust their intensity, position and color.
Furniture items are selected from categorized libraries and can be previewed in 3D. Based on their category, they can be placed on the ground, on another object or on a wall. Once entered into the environment users can directly select and manipulate them. The application provides additional functionality for constrained-based interactions to support specific user tasks. It offers tools to group and ungroup furniture, to align their position or orientation and to snap them on a selected wall. Furthermore, furniture arrangement is enhanced with an additional tool that measures the distance between items, between an item and a wall or between two arbitrary endpoints. An embedded collision detection algorithm can check the integrity of the design concept.

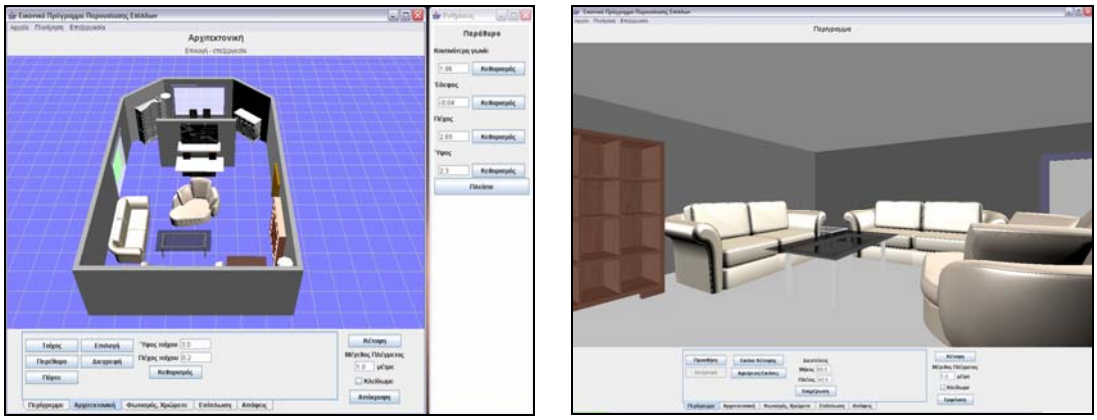

Figure 1: Screenshots of the environment in examine mode (left) and first person navigation (right).

The application supports both exocentric and egocentric visualizations. Users may examine a scene from outside using rotate, zoom and pan functions. Alternatively, they may navigate inside the interior space using first-person walking or map-based navigation. The application can also store actual viewpoints with descriptions in a list, in order to be used for later reference, e.g. whilst presenting a design concept to a client. Figure 1 presents two screenshots of the application that depict the same interior space from egocentric and exocentric viewpoint.
The environment has been implemented as a Java applet and is using the Java3D API for the scene rendering and user interaction. Furniture items have been modeled in VRML and are imported in the environment using the java3d-vrml97 loader (http://j3d-vrml97.dev.java.net/). Web-based technology has been preferred to a standalone solution, because it provides the required functionality to import models from external sources, to communicate with servers using TCP/IP, to present content-related information in HTML pages and to operate in various platforms. VRML has been chosen as a 3D file format for representing furniture items and other objects of the environment because it is a 3D graphics standard for the WWW, it can be easily imported in a Java3D application and there are a number of utilities available that can convert models from popular file formats to VRML.

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5 Evaluation

In order to provide insight on the usability of the interior design environments utilized by the proposed methodology, a user evaluation has been conducted, using the aforementioned implemented system. A group of 11 users participated in the evaluation process. There were four male and seven female users aged between 28 and 45. All of them were familiar with computers but had little or no experience in using 3D environments and CAD applications. The users attended a short introduction to the program and its functionality and then had to complete a specific scenario that was given to them in handouts. The scenario consisted of the following tasks: a) modeling of a room, b) addition of doors and windows, c) furniture placement, d) lighting and e) navigation. While the users executed the scenario, their actions were simultaneously recorded by a video camera and by an application for capturing mouse and keyboard input. As a result, their entire interaction with the program could be repeated and observed more carefully afterwards, and the time spent in each individual task could be accurately measured. The completion time ranged from 8.34 min to 19.28 min with the mean time being 14.32 min, indicating that there were significant variations in user performance.

Upon completion, the users had to fill in a questionnaire, in which they rated each of the main functions of the program concerning their usability using a 7-point Likert scale. The mean ratings were the following: architecture design: 5.09, furniture selection and arrangement: 5.0, lights and material: 5.27, navigation: 6.09.

Following discussions with the participants and analysis of their written comments indicated that most users would prefer the environment to provide more visual cues and assistance whilst they were interacting with the objects. Furthermore, the fact that some furniture items caused slight delays during their manipulation due to the increased polygon count irritated users and the discussions that followed suggested that fast response times are more important than visual quality. Despite these difficulties, participants were satisfied with the environment in total and most of them found it a helpful assistant to interior design. Concerning the ratings of the individual functions of the program, the results show an increased satisfaction from the navigation in the environment. This is mostly due to the fact that inexperienced users were able to efficiently navigate in the interior space using the map-based navigation.

6 Conclusions and Future Work

This paper presented a methodology for designing and implementing virtual environments to support the design and evaluation of interior spaces. Desktop virtual reality technology has been used as a medium to generate realistic visualizations of the environment in real-time and to let users formulate and refine their design concepts directly in 3D. The proposed methodology emphasizes in the usability of the environment especially for inexperienced users and aims to increase user performance in the process of modeling an interior environment, selecting furniture and decoration elements, and trying out various arrangements. The paper also presented a prototype implementation of the proposed methodology. The results of an initial user evaluation indicated that the environment can be easily used by non-expert users, although there were significant differences in performance. Also, the discussion with the participants suggested that an enhancement of the environment in terms of visual feedback and user assistance would improve the results.

Additional evaluations are planned for the near future with more complex scenarios and with the participation of both professional designers and non-experienced end-users, in order to improve the usability and efficiency of the environment. Furthermore, we are planning to enhance the environment with new features that would further support the design process, such as multi-user capabilities for synchronous collaboration between clients and designers, and new interactive components, such as sketch on surfaces or posting of annotations to visualize design requirements and abstract concepts.

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