CASE DIGITALO – A RANGE OF VIRTUAL AND AUGMENTED REALITY SOLUTIONS IN CONSTRUCTION APPLICATION

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ABSTRACT: We describe a range of Virtual and Augmented Reality (VR/AR) solutions applied during the planning and construction of VTT's new head offices, the Digitalo ("Digital House") in Espoo, Finland. During the building phase as well as in later evaluations 2003-2006, the various approaches used for Digitalo's visualisation included: radiosity rendering by still images; immersive virtual reality visualisation; mobile outdoors augmenting; augmented scale model; augmented web camera; 3D landscapes; and interior design by means of virtual and augmented reality. We employed various display devices ranging from HMD video glasses to CAVE screens, and from PDA's to varying kinds of PC solutions. Some of our solutions, for example the augmented web camera and scale model systems, have not been previously presented and they appear here for the first time. Also, we describe the current status of the applied methods, as well as directions for future research. Altogether, we believe this case study to be among the most comprehensive ones in the world to include such a wide variety VR/AR techniques applied in a single building project.

KEYWORDS: virtual reality, augmented reality, CAVE, HMD, web cameras, mobile computing, feature detection, markers, tracking, tangible user interfaces.

1 INTRODUCTION

Architecture and construction is generally recognised as one of the most applicable fields for Virtual and Augmented Reality (VR/AR) technology. The planning of new buildings involves important decision making on expensive matters, as well as communication and collaboration between various interest groups, which all in different ways signify the importance of having the future plans realistically presented to the stakeholders.

In the early 2000's it was decided that VTT would start building its new head offices Digitalo (i.e. "Digital House") on the neighboring parking lot site. As VTT's Virtual and Augmented Reality teams would also be moving into the building, it was natural to start applying the VR/AR methods for the 3D visualisation of Digitalo's architectural plans.

Different VR/AR visualisations were applied as presentations for the Digitalo planning committee, as well as for wider audiences such as the future occupants of the building. Some of the visualisations (LumePortti applications, ARonPDA and ARWebCam) were commissioned by Digitalo's proprietor Senate Properties, while others were developed during the construction work in projects jointly funded by various construction related Finnish companies and TEKES (Finnish Funding Agency for Technology and Innovation).

Figure 1. Still image visualisation of Digitalo.

As starting point, the 3D Studio Max model of the building was created by the architect visualisation company Adactive Ltd., which also created the first still image visualisations of the building (see Figure 1). Next, the model was transported to VTT's proprietary CAVE system *"LumePortti"* (i.e. "VirtualGate") for immersive VR visualisation, using data gloves and space mouse for navigation and other user interaction. LumePortti walk through visualisations were also shown real time on auditorium projector screens, allowing wider audiences get familiar to and comment about their new offices.

Also before the construction started in 2003, we developed a mobile PDA augmenting system *"ARonPDA"* to display the virtual Digitalo building outdoors at the actual construction site. The system was based on marker detection and a client/server architecture, with a laptop PC handling the tracking and 3D graphics, and the PDA displaying the augmented view video streamed from the server. The primary use of the augmented mobile visualisations was for demonstrations to the Digitalo planning committee.

Further during year 2003, just when the construction work was starting, we implemented an augmented web camera *"ARWebCam"*, enabling anyone using the Internet to see the virtual Digitalo augmented in the web camera's real time view of the construction site. Using the PTZ camera and clipping planes enabled by the system, people could also get to see close up views of their future office spaces.

Getting closer to the completion of Digitalo in 2005, we implemented an augmented scale model system *"ARScaleModel"* for viewing the virtual building on a conference table with data glasses. As a collaborative multi-user solution, the system enables people to interact with the virtual model each from their own view point, with a variety of interaction methods and functionality available.

Digitalo visualisations embedded in 3D geographic maps were performed with our *"3DTerrain"* system, also including other buildings and vegetation of the surrounding Otaniemi campus area. Final decisions of Digitalo's furniture and decoration were done using LumePortti visualisations of a detailed room model. Further interior design experiments were conducted with our *"ARInteriors"* system, augmenting virtual furniture into digital camera images of the existing environment.

Today, we are operating mobile AR with powerful tablet PCs capable to do all the processing without any servers, while tracking is done markerless with our proprietary feature detection algorithms (*"ARMobile"*). For outdoors visualisation we are now using GPS positioning and geographic map information from Google Earth for the model's placement, making the operation of the mobile AR system almost automatic, whenever and where-ever (*"AROnSite"*). Our most recent research involves implementing mobile augmenting also on camera phones (*"ARPhone"*).

The organisation of the paper is as follows. First we briefly explain how our work relates to previous work and alterative solutions implemented. The next three sections contain discussions of the application of 3D CAD modeling and still image visualisation; Virtual Reality; and Augmented Reality respectively. The Augmented Reality section is further organised in subchapters, each devoted to a separate application. Digitalo's embedding in 3D maps, as well as furnishing by VR/AR visualisation, is briefly discussed in two separate sections Some general remarks are finally provided in sections Discussion and Future Work; and Conclusions.

2 RELATED WORK

Considering the broad range of technology addressed, a comprehensive review on related work is beyond the scope of this case study article. Instead, the following sections include references to related work that corresponds most closely to our work. More detailed treatment of related work can be found in the articles by the authors of this paper, cf. References. Among other literature, we recommend e.g. the review articles by Azuma (1997) and Azuma et al. (2001) for a good introduction to Augmented Reality.

In the domain of Virtual Reality visualisation, different types of large screen stereoscopic systems have been used for architectural visualisation. An overview of VR technology utilisation in UK and USA based construction industry is presented by Whyte (2003). CAVE-like systems (Cruz-Neira 1993) represent the most immersive type of projector systems as they form a multi wall room with up to six sided systems, in which users see imagery surrounding them. When head tracking is included, a quite convincing feeling can be achieved of a space that exists only as CAD models before actually building it. These systems have evolved from expensive custom hardware to relatively inexpensive off-the-shelf PC based systems, which is the case also with our LumePortti system (Rönkkö 2004).

The first to implement client/server AR solutions with a PDA device were Geiger et al. (2001). In our implementation (Pasman and Woodward 2003), one of the main differences was that we used video coding rather than JPEG images. Also, the applications (close range vs. outdoors) were very different from each other (see Pasman et al. 2004). Outdoors AR in general has been implemented by various research groups, most often by other means than markers, e.g. beacons, sky line silhouette, 3D GIS information etc. & hybrid solutions; see e.g. (Behringer 1999, Azuma et al. 2006, Reitmayr and Drummond 2006). Today, we too are operating outdoors AR without markers, instead employing GPS, Google Earth map information and feature based motion tracking for the camera position registration (Honkamaa et al. 2007). Our special goal in this development is to keep the hardware as simple as possible (i.e. things you can expect to find in an ordinary camera phone), and to avoid any additional components such as gyroscope, compass, altimeter etc.

Our implementation of the augmented web camera in 2003 was probably the first of its kind to have been applied in a real construction project. Previously also MacIntyre (1999) had done experimental work with augmented web cameras. The augmented telescope (Fraunhofer 2005) bears some resemblance to our system, in the sense that the augmenting is based on interpreting PTZ parameters of a camera (telescope) on a fixed podium. For further reading, see e.g. (Columbia University 2007) for a range of outdoors AR applications, and (Klinker 2001) and for an in-depth discussion of calibration and other associated issues.

The most ambitious effort in the field of collaborative augmented scale models to date is presented with the ARTHUR system (Broll et al. 2004). Our ARScaleModel system takes a more lightweight approach, inspired by the

City Planning system by Kato et al. (2003). Compared with Kato's work, we include lot of similar features such as moving of lights, adding and transforming of components, virtual reality mode etc. Among the main differences, we perform the interaction by tangible and eye cursors vs. Kato's "magic cup", our VR mode relies just on visual tracking vs. gyrometer, while we also provide support for multiple users, pre-recorded walk throughs and hyperlinks.

In principle our ARScaleModel solution also enables collaboration over the Internet. Similar work in this direction is now commercially available by the company Metaio (2007). Metaio also develops still image augmenting software similar to our ARInteriors solution (Siltanen and Woodward 2006); the development of these two systems has been independent of each other, with the first prototype of ARInteriors demonstrated already 2003.

3 CAD MODELING AND STILL IMAGE VISUALISATION

Adactive Ltd. produces high quality 3D visualisations to help communication during design process. For Adactive, the case Digitalo was a pioneer project in the sense that the commission included both production of a 3D model suitable for real time applications and production of 3D still images. Keeping these somewhat contradictory needs in mind and knowing from previous projects that architectural design is in constant change until final drawings are produced, we decided to make all the 3D modeling with the AutoCAD program. The same program was used in the production of 2D architectural drawings. The ability to use the architects drawings as external reference drawings in our AutoCAD 3D model files, and furthermore, the ability to use these AutoCAD 3D models as linked files in 3D Studio Max provided a very flexible modeling pipeline and gave us the possibility to react quickly to design changes. Linking instead of importing the CAD geometry into 3D Studio Max gave us the ability to update geometry changes without the need of re-defining lights, material settings etc.

All 3D modeling was done using basic 3D objects in AutoCAD. Solid geometry and surface modeling was combined to produce as few polygons as possible without sacrificing the level of detail too much. The model of the building was divided into logical parts (wings, floor levels etc.) which were then referenced as AutoCAD blocks (instances) to minimise the amount of modeling needed. Material and texture settings were applied to the 3D model in 3D Studio Max. At this point, 3D still images were produced using radiosity rendering (Figure 2).

In order to make the real time 3D model spatially and visually more interesting and realistic we decided to bake the radiosity calculation solution into surface textures. Texture baking in 3D Studio Max takes the colors (or light intensities) stored in vertices during radiosity meshing and stores the combination of vertex colors and textures into new textures. At the same time, it also simplifies the radiosity mesh back to the original geometry. As the production pipeline defined by VTT required exporting to VRML format where only one texture channel was available, only diffuse textures containing all color and light information were used. This resulted in some problems with texture sizes. Even though the 3D model was divided into parts the limitations of texture sizes are visible in some parts of the model. This could have been avoided if multiple texture channels would have been available and multitexturing could have been used to store color information into tiling texture files and light information into separate light maps.

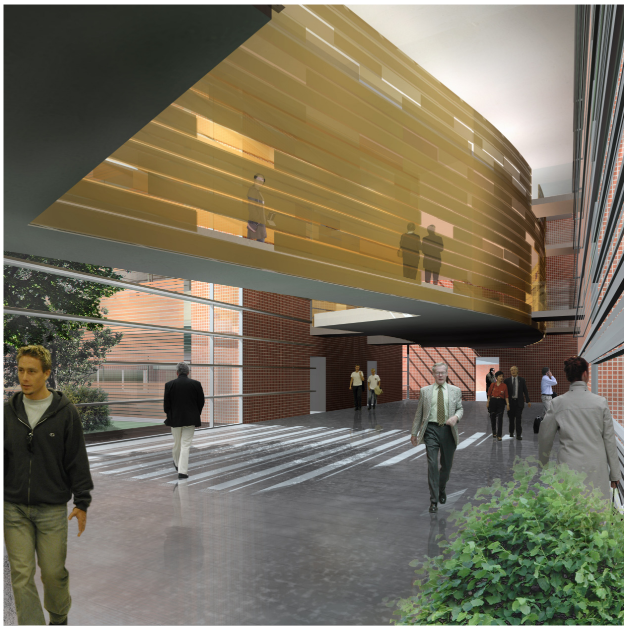


Figure 2. Radiosity rendering of Digitalo interior.

4 VIRTUAL REALITY VISUALISATION

LumePortti (Rönkkö 2004) is VTT's scalable virtual-environment platform which we had developed already to quite a mature level at the time of application with Digitalo in 2003. LumePortti runs on ordinary Windows PCs equipped with graphics cards suitable for 3D game play. The LumePortti platform supports various input technologies, including position and orientation tracking, data-glove input with basic gesture recognition, six degrees-of-freedom space mouse input and speech recognition. Feedback to the user is provided via stereoscopic real-time graphics, and audio. The system utilises passive stereo, that is, two projectors project the image for each wall. The image is separated for each eye by using polarisation filters in front of the projector lenses and by polarisation glasses for the users. In the case of Digitalo we used two rear-projection screens in an L-shape with two projectors each. Thus, four PCs were used to drive the graphics to the projectors; additionally the hardware included one input computer with an InterSense 600 ultrasonic/infrared tracker connected to it for head tracking, and one master PC to control the whole application.

LumePortti utilises in-house developed VR software to produce the visuals as well as to receive user input. The system also allows the usage of game engines as plug and play modules for the visualisation purpose. In this application we used the Cipher (2007) game engine in the implementation of the rendering component of our virtual reality system. The system consisted of rendering clients and a master that controlled user input module as well the rendering clients. Cipher provided basic exporters for 3D Studio Max geometry, material and lighting data. However, we extended the graphics content production pipeline with our own 3DS Max scripts so that we were able to get texture baked radiosity textures more easily for the final architecture presentation. Cipher itself supports features like real-time hard edged shadows and skeletally animated characters that were used to make the presentation of the architecture livelier as well as to give some additional visual feedback of relative sizes of spaces.

A video is available at (VTT Demos 2007) showing a navigation sequence inside the virtual Digitalo. Figure 3 below shows a snapshot of the video. Live presentations were exhibited to the designer and architect audience involved, as well as to a relatively large number of the future users of the building. The audience was able to try interactively navigating within the building with the space mouse, as well as view guided walk-throughs in larger auditoriums. The audience felt that the visualisations gave good insight what the building would be like. The future users of the building were very interested in commenting the building on the basis of the presentation. Some architects, on the other hand, also expressed views that they can visualise their plans in their head without such a visualisation. Overall, it is important to note that when trying to reach high visual realism, the dynamic range of display devices is not on par with what we can observe in reality.

Figure 3. LumePortti visualisation of Digitalo interior.

Currently, we have updated our system setup to two separate systems. One is a mobile setup “MobiTrix” using a rear projected foldable canvas and a miniPC with a gaming graphics card, together with two small projectors for stereoscopic viewing experience. This mobile system is commercially available today from the company SenseTrix (2007). The other system is a permanent meeting room installation at Digitalo with three vertical screens, as well as floor or roof projection to complement the vertical screens. The system incorporates VR viewing options directly to a meeting room and it provides also possibilities to observe 3D models and 2D project data simultaneously on separate back projected screens.

5 AUGMENTED REALITY VISUALISATIONS

5.1 *Hardware issues*

Altogether, our Augmented Reality development has been based solely on off-the shelf hardware devices. With the mobile PDA based system in 2003 we used the Compaq iPAQ H3800, equipped with FlyJacket iCAM camera and a D-Link WLAN Card, together with an ordinary 1,8 GHz laptop PC as the server. Today, the client-server solution has less importance, as hand-held tablet PCs are capable to take care of all the processing (incl. tracking, 3D graphics etc.) stand-alone. Our currently preferred choice for a hand held PC is the Sony Vaio VGN UX 90S tablet PC which runs with Windows XP and Vista, and it has an integrated camera and wireless network access (WiFi, Bluetooth).

Note however, that managing complex 3D building models on hand-held PCs requires typically some preparations, for example it may be useful to remove the internal parts of the building before application in outdoors visualisation. Also, a particular problem in outdoors augmented visualisation is presented by the reflections on the mobile device’s screen, at worst the users sees just the mirror image of his/her face when trying to view the augmented building. Actually, the previous model Sony Vaio VGN-U8G had a brighter screen than UX 90S, so we still use it for outdoors augmented visualisation especially in bright daylight. Also an external display device, e.g. video glasses, can be attached to the Sony via Sony Spare Port Replicator or via a small adaptor. In general, however, our experience is that the hand held devices are easier to use while moving around outdoors, and video glass solutions being better acceptable in indoors applications where the users are located e.g. safe inside their offices.

For video see through glasses we started with an iVisor model from 2002, inexpensive enough but having too narrow (below 30 degree) field-of-view for serious AR applications. Our next choice was to purchase the TriVisio ARVision-S video glasses in 2004.TheTriVisio glasses have a camera integrated and they offer a sufficient 40 field-of-view, however as a drawback we found they provided too little control for adjusting the eye distance. In 2005 we found the eMagin Z800 3Dvisor glasses, made a pre-order already before their production started, and have been happy with them ever since. In our opinion, eMagin provides better image quality than some much more expensive alternatives we’ve tested, and it is also easy to attach a superior quality camera to them. Actually, the eMagin glasses also have a gyrometer integrated, but we use our vision based tracking instead to track the user’s head movement. One of our future plans is to place the camera in the gyroscope’s case, this way getting rid also of some eye offset that remains with the current solution.

Generally, we have been observing with satisfaction how fast the hardware has developed, up to the point that many things that were difficult when we started our work with Digitalo and required clever software solutions at the time have today been solved by hardware development alone. Today we have powerful processors and 3D graphics cards on hand held devices, miniaturisation of hand held

PCs, great improvement in camera image quality, good inexpensive video see through data glasses, and constant decrease of prices overall. The next improvement we would like to witness would be wireless data glass systems, because having to wear all the cables around one's head raises still quite strong resistance among (non-technical) users. Battery life of mobile devices is another general problem still waiting to be solved. However, this is not so important in the building/construction applications where the use of the devices takes place typically in just short periods at a time.

5.2 *General software components*

We started our Augmented Reality development in the early 2000's using the ARToolKit version 2.52 to provide the basic solutions for marker detection and VRML rendering (cf. ARToolKit 2003). Since 2004 we have used the commercially licensed version v. 4.0 of ARToolKit, available by ARToolWorks (2007). Over the course of time, we have developed the system with various new features and functionality, also integrating image processing functionality of the OpenCV computer vision library (OpenCV 2007), all of which is now used throughout our AR applications. The integrated functionality is summarized in the following paragraphs.

We have implemented a hybrid solution using markers and feature based tracking to stabilise our system, e.g. when a marker is not detected and to allow for camera movement away from the markers. We use the feature detection method by Shi and Tomasi (1994) and our own light weight statistical tracking method (Honkamaa et al. 2007) for real time mobile implementations.

Kalman and median filters are used to further stabilise camera/marker movement in the video stream. In our applications, we have found the simple median filter works almost as well as the more sophisticated Kalman, and with much less computational effort of course. Additionally, we use a special prefilter to take care of larger normal variations that typically occur when viewing the markers straight ahead.

Marker detection is actually done from thresholded b/w images, and to detect the markers even in difficult and alternating lighting conditions the thresholding method must be adapted accordingly. We use an adaptive thresholding method based on the algorithms by Ridler and Calvard (1978) and Pintaric (2002).

The accuracy and range of many applications can be significantly improved/extended using several markers instead of just one; see for example the applications in Figures 4 and 7. Our so-called marker field implementation (Siltanen et al. 2007) enables the most easy to use and set up (calibration) of several markers, with the relative positions between the markers calculated automatically by the system.

Marker erasure is a novel idea developed by VTT, to hide the markers from the video stream shown to the user. This allows us to use even large and/or numerous markers in the application without the user having to see them in the augmented view, cf. (Siltanen and Woodward 2006). Our latest marker erasure implementation works in real time and also over textured backgrounds (Siltanen 2006); see video at (VTT Demos 2007).

We use our soft shadow algorithm (Honkamaa and Woodward 2005) to cast soft shadows to a reference plane, e.g. the floor, table or wall defined by the marker. The implementation is software-only, with the shadows mapped as semi-transparent alpha textures to the reference plane. Thus, the shadows become part of the virtual object description, needing to be updated only with changes to the layout between the objects and virtual light sources.

For 3D rendering in the Digitalo applications, we used the OpenVRML library integrated with ARToolKit (2003). Currently, we have ported our applications to use the OpenSceneGraph 3D graphics toolkit (OpenSceneGraph 2007), providing support to quite a wide variety of file formats, e.g. 3D Studio Max (3ds) and Collada (dae).

5.3 *Outdoors augmenting*

In 2003, we developed a mobile augmenting system to display the Digitalo building at the actual construction site on a PDA device. The hand held devices at the time were not capable of handling complex 3D models and all the other computation, so we implemented a client/server approach with a laptop PC to handle the 3D computations and tracking, with the PDA grabbing the camera image and displaying the augmented view. Video and thresholded images were streamed both ways between the client and server using WLAN connection and our in-house developed MVQ video codec (Valli 2002).

After a lot of work and tuning, we reached a reasonable display speed up to 2 frames per second. We actually implemented the system also over GPRS, with 5 seconds per frame. As we did not have any markerless tracking solutions developed at that time, we used relatively large size markers to position the building. This obviously limited the mobility of the user, but it was sufficient for the experimental work we were aiming at, i.e. to prove the validity of the technical solution and to gain use experiences on site. Digitalo is shown augmented in its current place in Figure 4b (poor image quality due to strong daylight). A video clip of the same setting is available at (VTT Demos 2007).

a

b

Figure 4. Digitalo augmented at the construction site: (a) marker setting; (b) PDA view.

A detailed description of the system, field tests and use experiences with Digitalo is given in (Pasman et al. 2004). Later on we have developed the mobile augmenting system considerably, calling it now "ARMobile". The modern miniature PCs like the Sony Vaio enable all the computation to be performed locally on the hand held device, so we obtain much better speed, accuracy and image quality than before. Our markerless tracking methods now enable the user to view around the scene even when no markers are visible in the camera view. We provide a dedicated stylus operated user interface designed to fit in the small screen, with interactions to add and transform the 3D models and lights on the fly, storing all the scene settings in a project file, as well as storing the video while viewing.

Our most recent research aims to implement completely markerless outdoors augmenting. The AROnSite system (Honkamaa et al. 2007) is based on determining the building's intended location by placing the 3D model in Google Earth and saving the information into a separate KML file, meanwhile the user's location is determined by GPS, linked wireless to the hand held device (Sony Vaio). Thus the size, perspective and orientation of the building are updated dynamically while the user moves around. In the current implementation, the user is left the task of placing the building to the right spot when stopping to view it; the building is then kept in place using vision based feature tracking of the environment. Figure 5 shows Digitalo placed in Google Earth and augmented with AROnSite. See further Honkamaa et al. (2007) for some future plans for making the system fully automatic.

a

b

c

Figure 5. Digitalo (a) placed in Google Earth; (b) augmented on site; (c) screen shot of mobile device.

5.4 *Augmented web camera*

Later in 2003, just about when the construction work was starting, we implemented an augmented reality web camera running in the Internet, where anyone could then observe the construction site with the virtual model of Digitalo superimposed in the web camera view. The applications for the ARWebCam served for presentation for future users of building and other interest groups, as well as for follow-up and comparison with original plans.

The web camera was placed on the roof of the neighboring Helsinki University of Technology (HUT) building inside a weather proof heated camera dome. The video cable was connected to the server computer inside the office, where the server had an internet connection provided by HUT. For software development and updating we used a remote FTP connection from our offices to HUT.

The setup procedure for the system required the placing of the model in the right position compared to the camera view and the PTZ values. For this we implemented a simple application to transform the 3D model in the web camera view, for placing it visually in the right position using some known landmarks. After the model was correctly aligned, the application created the initialisation file for the ARWebcam server.

We used Apache as the web server. The client software was implemented as a Java Applet, so the client software was automatically downloaded to the client side with the web page. This solution allowed the client to see ARWebCam video stream without any extra installation in the client side. In some cases though the client side firewalls rejected the TCP/IP connection to the required TCP/IP port so for these clients we implemented an alternative Tomcat servlet version.

The ARWebCam server captured the video stream from the camera as well as the camera PTZ values. The server then augmented the Digitalo virtual model to the video stream using the camera parameters, i.e. always updating the image of the virtual building to match the camera's view of the construction site. After augmenting the model, the server encoded the video stream with our proprietary MVQ video codec (Valli 2002). This video was delivered to the all the clients in the video pool. For handling several users at a time, we implemented a queuing system so that each user could interact with the system for a period of one minute at a time, before the control was given to the next user in the queue.

The ARWebCam features included an option whether to display the virtual building or not, panning and zooming with the PTZ camera, and clipping planes to display only part of the building e.g. first floor. The commands were operated either by arrow icons or by pointing in the camera image. Figure 6 shows some screenshots of the ARWebCam in operation 2003. Unfortunately, the Digitalo model in these (historical) images is not the final one provided by Adactive; also it should be noted that video coding degraded the image of the virtual model quite a lot, and a more lossless video coding scheme would probably have served our purposes better.

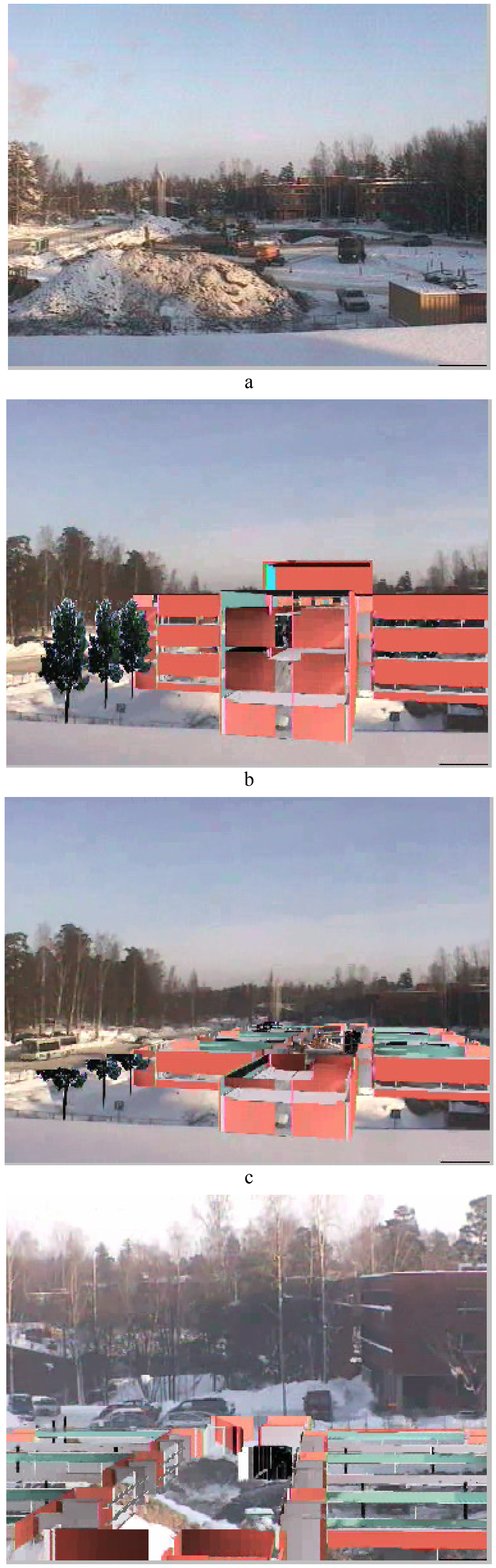


Figure 6. (a) Web camera view of the construction site; (b) with Digitalo augmented; (c) top floors removed; (d) close-up zoom.

The ARWebCam was in operation throughout the construction work till the end of 2005, but now removed as we had to dismantle the setup at the HUT offices. Today we are working with an improved version of the ARWebCam, featuring e.g. improved calibration routines and more automatic placement of the building in the webcam view. Also, instead of having all the computations done at the server side, we are working with a “professional” version having the 3D visualisation carried out at the client side, thus providing better image quality and design flexibility. Among further new features in the planning we have automatic lighting of the virtual building based on the intensity of the image (indicating light or dark, cloudy or sunny day) and the time of day (providing sun light direction), to adjust it to the actual conditions in the real world.

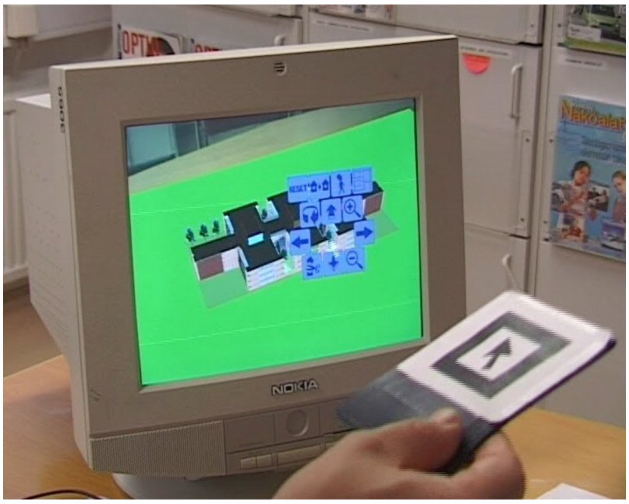
5.5 *Augmented scale model*

Getting closer to the completion of Digitalo in 2005, we implemented an augmented scale model system for viewing the virtual building on a meeting room table with data glasses. The intended use of the system would be to 1) provide an alternative to physical scale models offering much wider interaction possibilities, and 2) support collaborative work between different interest parties in the building’s planning phase. Thus, we were somewhat late with the system for real application with Digitalo. However, we describe the application here for general interest, and also as Digitalo was used as the primary example model during the development of the system.

Basically, the augmenting of the building is accomplished using ARToolKit’s multimarker method with an array of markers on the table. Having several markers present enables the users to move their gaze freely around the table, it suffices that just one marker is visible at a time. Integrating our feature based markerless tracking solution to the system enables the user to lift his/her gaze from the table without losing the augmented building from sight. In fact, today we could generalise this even further in order to eliminate the marker array altogether, tracking just some general features on the table.

Figure 7. Digitalo scale model augmented on a table.

Instead of the mouse/menu user interface which would be quite awkward with data glasses on, we tried a few alternate user interaction approaches with the ARScaleModel. First, we implemented a simple “mouse”-driven menu interface with dynamically changing popup menus for different program states. Naturally, instead of the normal restricting mouse one can use it also with a wireless mouse or trackball. In addition, we implemented support for the so-called “tangible cursor” as a “mouse”. The tangible cursor is a marker with a cursor image which the user holds in his/her hand, and lifting it to the camera view (user’s sight) brings a pop-up menu to the screen. As the marker is moved, the menu stays in place, while selections from the menu are done by holding the cursor still at an icon for one second; see Figure 8.



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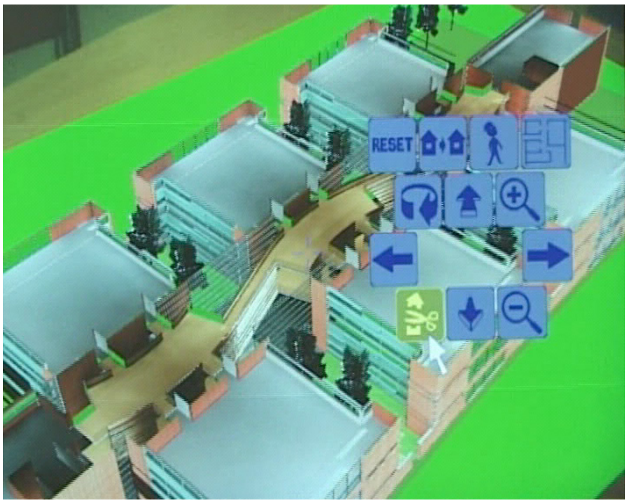

b

Figure 8. Tangible cursor: (a) external view; (b) user’s view.

While testing the user interface we further noticed that when using the system with a headset it is often easier to make the required mouse movement (e.g. while drag-and-dropping) by turning one’s head with a cursor fixed in the middle of the view, i.e., the “eye cursor” instead of using any of the physical “mouse” devices. One of the future research tasks is to evaluate in more detail the user experience and efficiency of applying the various interaction methods in different interaction tasks; cf. (Thomas 2006) for some related work already done in this field.

The functionality of the ARScaleModel system includes moving, scaling and rotating, adding and deleting parts, moving light points around, clipping planes to look inside to the model, pre-recorded walk through paths, and hyperlinks e.g. to display more detailed parts of the model, rooms or any other information associated to the model. Furthermore, we implemented an augmented catalogue, cf. "Magic Book" by Billinghurst et al. (2002), to display additional construction elements and furniture, and enable drag/dropping them into the scale model.

Yet as a further feature with the ARScaleModel, we implemented a Virtual Reality mode using feature based tracking. This enables the user to "jump into" the building and see around there simply by turning around in the real room. Moving forward, sideways and vertically is accomplished again with the tangible cursor and a dedicated pop-up menu in the user's view. Among other benefits, the method offers stereo depth effect virtual reality with any existing computer e.g. laptop PC, with minimal extra costs (currently some €500 for the eMagin video glasses and the camera altogether).

We also tested a networked solution where programs running in separate computers are kept in synch by sharing the commands. The system enables several users observe the augmented model at the same time, each seeing the model from his/her viewpoint while sharing the interactions e.g. moving of parts performed by others. In principle, this allows the same session to have not only several simultaneous users around the same table, but also several users at separate physical locations. Sharing the interactions is achieved by a simple web server which takes care of sharing all the commands between the users. The networking test was quite preliminary and we did not solve completely all the conflict problems. For example, when using the tangible cursor we should use different markers for different users to prevent unintentional launching of the commands for bystanders who happen to see the same tangible cursor.

6 DIGITALO EMBEDDED IN 3D MAPS

Among further work during Digitalo's construction, the 3DTerrain system was implemented with the purpose of automatically generating 3D visualisation models of built and unbuilt environments from aerial and satellite images (Parmes and Rainio 2007). Other types of data, e.g. architectural and CAD models, can also be imported to the 3DTerrain visualisation system. Thus, various data sources can be combined into an interactive 3D map, and large amounts of data can be easily understood. Potential application areas for the system are found in e.g. architectural and city planning, leading to significant cost savings by automising large amounts of tedious manual work currently related to 3D content creation.

Figure 9 shows a visualisation the Espoo/Otaniemi campus area with 3DTerrrain, including the 3D Digitalo model. Except for the trees in Digitalo's front yard which were manually 3D modelled, all the other trees – conifer and leaf trees classified – have been automatically generated based on satellite image data. Other parts of the demonstration, e.g. terrain colours and basic geometry, have been extracted from aerial images and laser scanning data using traditional methods of remote sensing.

Figure 9. Digitalo visualised with 3DTerrain.

7 INTERIOR DESIGN

Today, the whole Digitalo is furnished in a uniform style. The selection of furniture was done based on Virtual Reality visualisations of a model room in summer 2005. For this purpose, Adactive created a detailed room model, which was afterwards slightly retouched by VTT according to the architect's instructions. The 3D furniture models were provided by the furniture manufacturer Martela Ltd., and different alternatives were then tried out by LumePortti visualisation. Figure 10 shows an image from LumePortti and the real room side by side.

Later on, after having already moved into Digitalo, we also made some furnishing experiments with ARInteriors, our solution for augmenting furniture in still images of existing environments (Siltanen and Woodward 2006). A video of one of the experiments is available at (VTT Demos 2007). Obviously it was not possible to use the augmenting approach for interior design while the construction was still under way; however for future renovation needs the Augmented Reality methods (ARInteriors, ARMobile) would provide a most viable approach.

a

b

Figure 10. (a) Virtual Digitalo room; (b) real room.

8 DISCUSSION AND FUTURE WORK

Figure 11 shows an interior photograph of the completed building. Comparing with Figures 2 and 3, we see how the design of the building was changed during the course in some respects: for example the floor material was changed from a lighter option to darker stone, and the walls of the loft were changed from wood to painted white. Due to our well planned visualisation data flow, these changes were easy enough to incorporate into our VR/AR rendering applications. Now that the building is finished, it is apparent that the updated virtual model gave a rather good idea how the space will look like after the material updates.

Figure 11. Photograph of Digitalo interior today.

From the general workflow point of view it is evident that high quality visualisations may still require a lot of manual work and that the transfer processes between construction CAD and 3D modeling and lighting tools can still be rather tedious. One of our recent efforts to streamline the data flow is presented with the VTT-coordinated EU-project CADPIPE, targeting to automating the visualisation production chain for the most common CAD file formats (CADPIPE 2007).

In the future, the efficient use of Virtual or Augmented reality technologies in design and construction processes will most likely be based on seamless integration into the building information modeling (BIM) process. Thus, 3D geometry will be more and more often produced during the design process and by the designer without a separate 3D modeling work process. In order to work properly the BIM integrated VR and AR applications should also include 3D geometry optimisation based on standard and open file formats like IFC. As a structured file format, IFC would in principle also allow the manipulation of the 3D geometry's spatial organisation to be better optimised during the real time visualisation.

Beyond the use of VR/AR for professional applications (architects and others involved in the planning and construction process), we see great opportunities for Augmented Reality to provide public services for citizens to view plans of future buildings in their real surroundings. The augmented web camera as well as 3D representations in Google Earth and terrain maps provide paths towards this direction. In not so distant future, we envisage having augmented viewing of 3D buildings available also on commonly available mobile devices. Combined with 3D models and position information available with Google Earth, camera phones offer already all the technical components to realise mobile 3D augmented reality: powerful processors with built-in 3D graphics, GPS and good quality cameras. Figure 12 shows our prototype system AR-Phone already running such applications with the Digitalo model.

a

b

Figure 12. (a) Digitalo augmented on top of real building in camera phone view; (b) screenshot from camera phone.

9 CONCLUSIONS

In this article, we have described a wide range of Virtual and Augmented Reality solutions applied in a single building project, together with the creation of the 3D CAD model and its data flow to the visualisation applications. We have described the current status of the methods and provided directions for future work. The usefulness of the VR/AR methods is probably at its highest in the planning stages of the building, involving solutions such as immersive VR visualisation; augmented scale models; and mobile augmenting on site. Virtual interior design helps in deciding about the furnishing of the buildings during planning and construction, while augmented solutions are available for later refurnishing and renovation. Before and during the construction work, augmented web cameras and interactive 3D maps can provide useful information both for the architects and proprietors of the building, as well as for public audiences, marketing and sales. Future work is still required for the 3D CAD modelling systems to be able to react quickly to changes, and we hope the BIM approach to provide improvements for this. In the near future, we expect to see augmented building visualisation available on everyday mobile devices, i.e. camera phones, with Google Earth employed as the global data repository for 3D models and other geo-context applications as well.

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