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THREE-DIMENSIONAL COMPUTATIONAL STRUCTURES AND THE REAL WORLD

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Abstract. In this paper, we describe a system of composite images to design virtual three-dimensional structures in an outdoor environment. The system, called AmbiViewer, consists of a modeler for three-dimensional on-site sketching, and overlapping locative technologies to orient virtual objects in a real-space, real-time setting. The system employs both GPS orientation and a visual marker system to provide a realistic and interactive augmented reality interface. While it is still under development, the authors believe it can bridge the gap between sketching on site, and creating virtual models in the office.

Keywords. Augmented reality; mixed reality, locative design; interactive mModeler; visualisation; GPS; cybrids.

1. Introduction

Recent developments in digital technology suggest that computation may lead to new forms of virtual modelling (Tonn, Petzold and Donath, ASCAAD 2009). The combination of Augmented Reality (AR) and virtual modeling on mobile devices introduces a wealth of yet unknown and potentially powerful design technologies.

The introduction of cellular smart-phones, tablet computers and camera-bearing music players gives some indication of how the capabilities – and challenges – of AR may affect the design process. Applications like ‘Urban Augmented Reality’ of the ‘Netherlands Architecture Institute’ likewise point in the same direction (www.nai.nl/uar). While the employment of AR is of a practical nature and its development is focused on practical goals, the authors propose that interaction with the spatial aspects of the environment while being a part of it can broaden and enhance creative processes.

In short, developing an architectural design with appropriate technologies while staying on-site is an improvement over gathering data on location and later designing a building with computers in the office.

2. Architectural models

Traditionally the use of architectural models has long been limited to down-scaled physical models. One-to-one scaled projects are not part of the repertoire of an architectural office. With the exception of very few but prominent projects – such as the 1993/94 Berlin Palace simulation with painted canvasses on scaffolds – on-site models are not an option. Their expense is substantial, and their effectiveness in examining alternative is slim at best. In fact, the project in Berlin is likely to have been more a fundraising and lobbying project than an architectural effort. Prior to physical fabrication, a building and its site are only linked during the design process (Abbo 1996). Their abstract union is limited to its presentation, usually at the client's or architect's office. The introduction of computed realities with CAD led to assumptions that such unity could be achieved in cyberspace. In fact such aesthetic integration is impaired by distracting technical interfaces. Because the virtual models depend on technology for their presentation, it is vital that this technology be as unencumbered and transparent as possible.

3. Early designs

Among design technologists there has been a longstanding discussion how to sketch early designs preparatory to their development into complex building schemes (Drexler 1977). With the introductions of CAD systems that question has evolved to tasks of importing early designs into the data model of a specific CAD-system (Clayton and Weisenthal 1991, Gross 1994). Based on the assumption that CAD-design is a secondary step after napkin sketches, the discussion hinges on technical issues of digital measurement, scanning, and other forms of digitization. Then, back at the office, CAD provides the means to create sophisticated, detailed models of the proposed building (Guéna and Untersteller 2008).

This gap separating on-site inspiration from off-site articulation begs the question: How can a building design employ modern computation while being on-site? Whether this can be accomplished is a foregone conclusion – every cell-phone now has more computational power than a workstation of 20 years ago. Instead a better question might be: What kind of digital design do we want? While there may be many answers to this question, our team prioritized design technology that lets an architect to be on-site while designing a new project, while the inspiration is still fresh.

4. Concepts of AR

For this to happen to the designer must be able to mix virtual architectural objects into real-world images directly on the building site, a technique achieved with present day augmented reality (AR) systems. Such systems' basic concept is to overlay images taken from the real world – digital photos or video streams, with computer-generated objects. These are commonly text messages with some graphical enhancements like images or meaningful icons (Visser 2010) Synchronization the virtual computer view with that of a camera in the real world is emblematic of nearly all Augmented or Mixed-Reality systems.

4.1. REAL-TIME

Producing composite images frame by frame as fast as the video-camera can deliver is another task demanded of AR-systems. While real-time computation is not a mandatory requirement, it is greatly desired and even expected by the user. For this reason alternatives to real-time augmentation were not considered for our project. Instead, accurate tracking of sensors and real-time computation conduce to the intuitive nature of such systems. The resulting computational augmentation feels almost natural.

4.2. MOBILITY

Another important aspect we sought is mobility. The quality of the outdoor AR experience is highly dependent on portability, for designers even more so than players of computer games. This has not been easy to achieve. Our first prototype did fit into a backpack, but impediments cropped up, like the cumbersome deployment of our system, limits of batteries and power cords, or even daylight.

4.3. PRINCIPLES OF AR-SYSTEMS

Common AR-system are divided into tracking-based and marker-based systems. (Avery et al 2008) While tracking-based system are relatively self-sufficient – sensors and processors being integrated within one device – their quality is often wanting. Synchronizing the views of both actual and virtual cameras is crucial, and there is no mediating reference within the image itself. Also the overlay image is sometimes jagged with respect to the actual camera image. Marker-based AR-systems, on the other hand, are known for their quality images. However they are bound to specific locations by the several

markers needed to calibrate the image capturing device. Both AR systems are not really ideal for a real outdoor AR-experience. (Schall et al 2009).

5. Project

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Our project was developed with the goal of designing a system for digitally sketching a building on-site. With the availability of accurate GPS signals, the ability to get accurate measurements, and the increased capacities of portable computers, we created a prototype system, AmbiViewer. This demonstrated the functionality of the idea while revealing several technical shortcomings, common and characteristic problems of developing AR-systems. In the course of integrating two very different aspects of AR we tested almost a dozen GPS receivers, and found that developing the needed software stretched our mental and financial resources to new limits. Waiting time to provide better hardware seemed to be an appealing option.

5.1. LIMITATIONS

AR-systems are commonly based on generating virtual objects as a visual layer over a video image within a display. (Kieferle et al 2003) This priority of augmenting visual impressions neglects the influence of other sensory impressions. They ignore acoustical, olfactory, haptic and other senses, and constrain their access by the designer. If a virtual object can be designed on the site where it is proposed to be, its designer will always be aware of the object's physical and sensory environment.

5.2. SYSTEM

We introduced an approach for a high-quality blending of virtual architectural objects with real-world images directly on the building site. This is done by employing components of either systems of AR: tracking devices and markers suitable for a real outdoor environment; deployable equipment; markers at a large scale adapted to the scale of buildings; and cameras with possible flexible length. By utilizing an image capturing device, some location devices and a computer the viewing field of the real-world camera is calculated and transposed as view of the virtual camera, which shows the fictional elements rendered according to the values of the input camera.

5.3. HISTORICAL ABSTRACT

A first basic prototype was created and evaluated between 1994 and 1997. After the availability of unaltered global positions the next prototype, the AmbiViewer-system, was developed with a focus on usability and deployability. It utilized a laptop-computer, external cameras, GPS-receivers and a single marker as fiduciary feature. It was in use until the introduction of the iPhone ushered in a new era in AR. An immediate prototype showed the potential, but also some downsides of the new devices. Hence, with the introduction of tablet-PCs the development has moved to a complete new system on mobile devices with large scale markers for super-modelling. It is not yet ready for presentation.

5.4. GEO-POSITIONED MODEL

One significant requirement was the determination of the model's position in relation to the camera. Although it would be easy to define a unique coordinate space like any CAD-system does the decision was very soon to tag every model with its geographical coordinates. At first hand establishing a whole three-dimensional model in GPS-coordinates seemed to be the practical implementation. If every point of a model is defined in global coordinates every virtual shape is logically located on the Earth's surface. A closer look revealed some essential shortcomings. With all data represented in an ellipsoid coordinate system all measured distance were calculated using complex algorithm, and modification by hand, e.g. moving two walls by maintaining their distance, were impossible without the underlying calculations. Even though one example of this approach had emerged, the 'Keyhole Markup Language'(KML) used by the family of 'Google's Earth' application to locate virtual models on digital maps or satellite images is absolutely based on global coordinates, those difficulties led to the approach of simply tagging the models. Therefore the representation of all of three-dimensional models in GPS-coordinates was dismissed. Maintaining an added exact orthogonal coordinate system for measurements only seemed too cumbersome. Instead the model is still based on a regular local orthogonal coordinate system with global positions at hand, but only as reference. All virtual models are tagged with global positions. Solely the real world objects like marker and image capturing device are connected to GPS-receivers.

5.5. RENDERINGS

With the introduction of OpenGl on mobile phones, especially the iPhone almost all computer related hardware issues were moved aside. Rendering shapes, applying some lighting and textures is no problem, nor is it the composition of the final images. In fact, more serious problems are introduced through the use of higher APIs like whether to user layers or not. These higher APIs very soon might cause performance issues, and in some cases, conflicts. The phone-API in the iPhone, which has always a superior status, simply blocks on incoming calls, and thus the rendering pipe is stalled.

5.6. USER INTERFACE

Complete with camera and GPS mobile devices are now designed to fit in a pocket. Portability is no longer a problem. In addition fully touch-sensitive display offer new methods of interaction. Most important, the new generation of processor deliver the necessary computational power. The example shown here is still quite simple: a loaction-aware, or locative device captures images with known position and perspective values. On top of the video are some drawings, which then are interpreted and transferred into a three-dimensional shape according to the position and view of the camera, in this special case a ball at the location in fig. 1 labelled with the red pin.

The main UI is based on common and well known mapping technologies as e.g. now ‘Google Maps’. From a today’s point of view there are no really other option to substitute the layout and the information a map can provide by any other means, especially while noted that there are no fixed scale maps. Zooming, sizing and panning are actions many users are accommodated to.

The modeler is different. It uses the new input methods of smart phones: touches, shakes and other gestures. These new input methods are still unconventional, but they have already proven to be intuitive. It is very easy to draw a shape and put it in place once the technology is available. Acoustic forms of input as e.g. voice commands or more basic whistling and clapping as well as haptic forms like shaking are options.

The implementation of the full range of these methods of interaction is an important aspect of our research. However, as modelling is a common task in digital design and the development of applications with new types of interfaces is ongoing, we recognize that all developers of software in computational design will face similar problems. Besides its demanding necessity, an iPhone has neither mouse nor keyboard and no emphasis is put on the development of new types of interfaces in the realm of CAD and mobile devices.

5.7. INTERACTIVE MODELER

While mixing views from different kind of cameras is sufficient for tasks like overlaid information or realistic animations the use of it as design tool requires something to create and manipulate virtual objects, because the three-dimensional objects are not simply rendered of ready-made designs. Therefore the Interactive Modeler was introduced. It transfers the AR-system into a design tool. From the beginning our system offered some means to create simple geometrical shapes like spheres or boxes, which then could be grouped, moved, sized or rotated; and coloured or textured. Once the system was hooked up sufficient complex shapes were rendered. On mobile devices now shapes are created with gestures on the touch screen. The virtual model always appears as realistic building in the image. Every modification is immediately displayed as augmentation.

5.8. RESULTS AS DESIGN TOOL

In two cases, each limited and experimental, it was even used as a real design tool. In one project, a design for a play house, an AmbiViewer prototype was used to design the building on site. No working drawings were needed its eventual construction. In the second project, an office space for Caltech Industries, our system was used to demonstrate the space layout to its future occupants. Visitors could walk through the actual spaces, marked with coloured tape on the floors. On the screen, however, they could see each other with the future partitions in place. Because both views, the real world image and the virtual view onto the digital model were synchronized, a composite image was produced, which was sufficient enough to offer the client some choices to work from.

6. Conclusion

In conclusion, our project demonstrates how to augment the world with virtual three-dimensional objects by composing architectural structures and real views in an outdoor environment, and how to manipulate these structures and work with them as architects. During our experiments we located a virtual three-dimensional sphere at a specific location on our site. The sphere was rendered in real time as a computational drawing and then composed onto images of the real world scene. Thus the user could simply perceive size and distance by walking around with his mobile phone. The environment was embodied in the simulation, not merely a separate mental representation.

6.1. FUTURE WORK

The current prototype is the first implementation of our system on mobile devices. Recent developments demonstrate that new technologies in computation result in novel forms of virtual modelling. The combination of AR's composite images with our interactive modelling on a mobile device gives a sense of the system's potential and capabilities.

The new version on a mobile platform with interactive modeller and locative technologies shows some possible future directions for augmenting the design process. Most mobile devices, smart phones, or tablet computers are very flexible and computationally up to the task. Therefore we should no longer assume that CAD is a secondary step after initial sketches, even if progress is difficult. Combined with new technologies like Augmented Reality and Locative Design the new hardware might trigger a change in the design process. This opens up new forms of the appreciation of unbuilt architecture. Although the objects itself are not real, the distance between them and an observer carrying the mobile device is. The same is valid for the dimensions of the virtual structures.

6.2. DISCUSSION

While our system and its development are focussed on practical goals, it has become evident that the ability to react to the spatial aspects of the environment should not be limited to the visual imagery. We have found that our tool can offer new methods of design based on senses other than the visual.

Techniques combining mobile devices with accurate sensors and capable modelling and designing software blur the boundaries separating virtual objects from the real environment. We believe that virtual architecture need no longer be synonymous with unbuilt. Tools like the Interactive Modeler already point to future methods of design while being on site. At the very least interactive modelling will enhance architects' design capabilities in the early phases. Architectural simulation can have its own validity within our physical environment, and may find uses beyond projecting future construction.

7. References

Abadi Abbo, I.: 1996, Effectiveness of Models; in: *Full-Scale Modeling in the Age of Virtual Reality, 6th EFA-Conf. Proc*., Vienna, 69-78.

Anders, P.: 2005, Cybrid principles: Guidelines for merging physical and cyberspaces, *IJAC* **3**, 391-406.

Anders, P.: 2007, Designing Mixed Reality: Principles, Projects and Practice, Proc. *of the 27th*

ACADIA Conf., Halifax, Nova Scotia, 276-283.
Anders, P.: 1999, *Envisioning Cyberspace*, McGraw-Hill, New York
Anders, P.: 2003, Towards Comprehensive Space: A context for the programming/design of cybrids, *Proc. of the 2003, ACADIA Conf*, Indianapolis, IN, 161-171.
Anders, P. and Lonsing, W.: 2005, AmbiViewer: A Tool for Creating Architectural Mixed Reality: encounters/encuentros/rencontres, *ACSA 2005 Int. Conf. Proc*., Mexico City, Mexico, 292-299; also: ACADIA 05 Conf. Proc., Savannah, GA, 104-113
Avery, B.; Thomas, B. H. and Piekarski W.: 2008, User Evaluation of See-Through Vision for Mobile Outdoor Augmented Reality; in: *ISMAR´08*, Cambridge, UK, 69-72
Bunnun, P.; Damen, D.; Subramanian, S. and Mayol-Cuevas, W. W.: 2010, Interactive image-based model building for handheld devices; *ISMAR 2010 workshop on Augmented Reality Super Models*, Graz, Austria.
Cannaerts, C.: 2009, Models of / Models for Architecture: Physical and Digital Modelling in Early Design Stages; in: *eCAADe 09 Conf. Proc*., Istanbul, Turkey, 781-786.
Chen, I. R. and Schnabel, M. A.: 2009, Retrieving Lost Space with Tangible Augmented Reality; *Proc. of the 14th CAADRIA Conf.*, Yunlin, Taiwan 22-25 April 2009, 135-142.
Choo, S. Y.; Heo, K. S.; Seo, J. H. and Kang, M. S.: 2009, Augmented Reality- Effective Assistance for Interior Design: Focus on Tangible AR Study; in: *eCAADe Conf. Proc*., Istanbul, Turkey, 649-656.
Clayton, M. J. and Weisenthal, H.: 1991, Enhancing the Sketchbook, Reality and Virtual Reality. in: *ACADIA 91*, Los Angeles, CA, 113-125.
Donath, D., Beetz, J., Grether, K., Petzold, F. and Seichter, H.: 2001, Augmented Reality Techniques for Design and Revitalisation in Existing Built Environments; *Proc. of the 21st ACADIA Conf*., Buffalo, NY, 322-329.
Drexler, A. (Ed.): 1977, *The Architecture of the École des beaux-arts*. New York.
Fite-Georgel, P.; Johnson, T. and Frahm, J.-M.: 2010, City-Scale Reality Modeling from Community Photo Collection, *ISMAR 2010 workshop on AR Super Models*, Graz, Austria.
Gatermann, H.: 2001, First step to augmented reality: Combining vrml and pano-photos, *Proc. of the 6th CAADRIA Conf.*, Sydney, Australia, 219-230.
Gatermann, Harald.: 2000, From Vrml to Augmented reality via panorama-integration and eai-java, *4th SIGRADI Conf. Proc.*, Rio de Janeiro, Brazil, 254-256.
Gu, N; Singh V. and Wang. X.: 2010, Applying augmented reality for data interaction and collaboration in BIM; *Proc. of the 15th CAADRIA*. Hong Kong, 511-520.
Guéna, F. and Untersteller, L.-P.: 2008, Computing Different Projections of a Polyhedral Scene from a Single 2D Sketch. in: *eCAADe 08*, Antwerpen, Belgium, 195-200.
Guéna, F. and Untersteller, L.-P.: 2006, Towards a Sketching Tool for Architects: 3D Reconstruction of Polyhedron, *Communicating Space(s); eCAADe 06*, Volos, Greece, 132-135.
Gross, M. D.: 1994, The Fat Pencil, the Cocktail Napkin, and the Slide Library; in: *ACADIA 94*, St. Louis, MO, 103-113.
Guéna, F. and Untersteller, L.-P.: 2008, Computing Different Projections of a Polyhedral Scene from a Single 2D Sketch, *in eCAADe 08*, Antwerpen, Belgium, 195-200.
Haeusler, M. H.: 2009, Media-Augmented Surfaces: Embedding Media Technology into Architectural Surface to Allow a Constant Shift between Static Architectural Surface and Dynamic Digital Display; in: *eCAADe 09 Conf. Proc*., Istanbul, Turkey, 483-490.
Klein, G., Murray, D.: 2007, Parallel Tracking and Mapping for Small AR Workspaces; in: *ISMAR 07*, Nara, Japan 2007.
Kieferle, J. and Wössner, U.: 2003, Combining Realities - Designing with Augmented and Virtual Reality, in: *eCAADe 03*, Graz, 29-32.
Lonsing, W.: 2007, A Mixed-Reality-System for non-destructive Reconstructions, *DACH 2007*, Tainan, Taiwan, 71-81.
Lonsing, W.: 2004, Augmented Reality as Tool in Architecture, Architecture in the Network Society, *22nd eCAADe Conf. Proc*., Copenhagen, Denmark, 495-499.

Lonsing, W.: 2007, Combining GPS and CAD, Predicting the Future, *25th eCAADe Conf. Proc.*, Frankfurt a. Main, Germany, 655-661.
Lonsing, W.: 2005, Viewing Ambispace, Digital Design: The Quest for New Paradigmens, *eCAADe 2005*, Lisbon, Portugal, 477-482.
Lonsing, W.: 2009, Composite Images on Mobile Devices Augmenting Reality in an Outdoor Environment: reForm( ) - Building a Better Tomorrow, *Proc. of the 29th. of the ACADIA Conf.*, Chicago, IL, 270-272.
Martens, B. and Voigt, A.: 2001, Virtual and full-scale modeling: A collection of resources. in: *CAADRIA 01*, Sydney, 201-204.
Meier, E. and Bruns, W. F.: 2003, *Synchronous Model Creation in Real and Virtual Spaces*, Diploma Work and internal research about Mixed Reality Modelling, Bremen 2003.
Pak, B. and Verbeke, J.: 2010, A Virtual Environment Model for Brussels Capital Region's Future Urban Development Projects: Preliminary Ideations, *28th eCAADe Conf. Proc.*, Zurich, Switzerland, 539-547.
Petzold, F.; Bimber, O.; Tonn, C.: 2007, CAVE without CAVE, Predicting the Future, *25th eCAADe Conf. Proc*. Frankfurt am Mainl Germany, 161-168.
Pierkarski, W.;Gunther, B. and Thomas, B.:1999, Integrating Virtual and Augmented Realities in an Outdoor Application, *Proc. of the 2nd IWAR, IEEE*, Washington DC, 45-54.
Pintaric, T.; Wagner, D.; Ledermann, F. and Schmalstieg, D.: 2005, Towards Massively Multi-User Augmented Reality on Handheld Devices, *PERVASIVE 2005*, Munich 2005.
Schall, G.; Wagner, D.; Reitmayr, G.; Taichmann, E.; Wieser, M.; Schmalstieg, D. and B. Hofmann-Wellenhof: 2009, Global Pose Estimation using Multi-Sensor Fusion for Outdoor Augmented Reality; in: *ISMAR´09*, Orlando, FL.
Seichter, H.: 2004, Benchworks - Augmented Reality Urban Design, CAADRIA 2004, *Proc. of the 9th CAADRIA* Seoul Korea 28-30 April 2004, 937-946.
Seichter, H. and Schnabel, M. A.: 2005, Digital and Tangible Sensation: An Augmented Reality Urban Design Studio; *Proc. of the 10th CAADRIA*; New Delhi, India, vol. 2, 193-202.
Thomas, B. H.; Piekarski, W. and B. Gunther: 1999, Using Augmented Reality to Visualise Architecture Designs in an Outdoor Environment; *DCNET 1999*, Sydney, Australia.
Tonn, C.; Petzold, F. and Donath, D.: 2009, See-Through History: 3D augmented reality for the reconstruction of the Bauhaus director's office reception area from 1923; in: *ASCAAD 2009*, Manama, Kingdom of Bahrain, 259-267.
Ventura, J. and Höllerer, T.: 2010, Real-time Planar World Modeling for Augmented Reality, *ISMAR 2010 workshop on Augmented Reality Super Models*, Graz 2010.
Venturelli, S. and Belcino Maciel, M. L.: 2007, Art and Virtual Reality Research, El arte y la realidad virtual de investigación, , SIGraDi 2007 -, *Proc. of the 11th Iberoamerican Congress of Digital Graphics*, México D. F.- México 23-25 October 2007, 393-396.
Viet, T. P; Yeon, C. S.; 2010, Augmented Reality-Based Education and Fire Protection for Traditional Korean Buildings*; IJAC* **8**(1) 75-91.
Viet, T. P; Yeon, C. S.; Hak, W. S. and Choi, A.: 2009, AR: An Application for Interior Design; *Proc. of the 14th CAADRIA*, Yunlin, Taiwan, 115-124.
Wagner, D.: *Handheld Augmented Reality*, Dissertation, Graz 2007.
Wagner, D. and Schmalstieg, D.: Handheld Augmented Reality Displays, *Virtual Reality Conf.*, Alexandria, VA, 2006.
Wang, X.: 2007, Agent-based Augmented Reality System for Urban Design: Framework and Experimentation, *Proc. of the 12th CAADRIA Conf.*, Nanjing, China.
Wang, X.: 2009, Augmented Reality in Architecture and Design: Potentials and Challenges for Application*; IJAC* **7**, 309-326.
Wang, X. and Schnabel, M. A. (eds): 2009, *Mixed Reality In Architecture, Design, And Construction*, Springer 2009, XIV, 274 p.,
Woessner, U.; Kieferle, J. and Drosdol, J.: 2004, Interaction Methods for Architecture in Virtual Environments, *22nd eCAADe Conf. Proc.*, Copenhagen, Denmark, 66-73.