

DESIGNING WITH IMAGES

Augmented reality supported on-site Trompe l'oeil

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Abstract. Activities in the building industry in Germany concentrate increasingly on a combination of renovation and new-build. A look at current computer aided applications reveals a serious lack of IT support for the whole architectural design process with and within existing buildings (e.g. building surveying, designing on site and the preparation of information for further use in later planning stages). An ongoing interdisciplinary research project undertaken jointly by the faculty of media and the faculty of architecture is investigating methods and techniques for the computer-aided support of the design process with and within existing buildings. The goal is to develop a hardware and software concept for a “design-toolbox” based on SAR (spatial augmented reality) and to implement aspects of it as prototypes.

The paper focuses on one aspect of the research project – designing with images in an AR-Environment. The paper presents an overview of the project, a description of the core model based on a client-server architecture, the historical / theoretical architectural background and first results of this research part. The project is funded by the “German Research Foundation (DFG)”.

1. Introduction: the changing face of the building sector and the use of “new” technologies in architecture

The focus of building activities in Germany is characterized by a mixture of new-build and renovation work. After the period of reconstruction following World War II and the expansion of the built environment in the last 20-30 years, a process of consolidation and renewal of existing building stock has begun. A variety of factors contribute towards this development:

sinking population figures are leading to a general decrease in demand for living space; population drift away from the former industrial regions; and not least a steadily increasing need to renovate existing buildings.

Since the early 1990s, the focus of planning activities has shifted away from new building towards renovation and building within existing built contexts. More than half of all building investment is now in the renovation sector and this proportion looks set to increase still further in the coming years (Hommerich, 2005).

In contrast to new building, planning within existing built contexts necessitates a more complex interaction with the existing building substance and infrastructure and their respective special requirements. Not least, the actual presence of the building, including an analysis of its history and changes made during its lifetime are a central aspect. The existing building substance is in all cases the basis for the design and planning tasks that follow.

A second starting point was to examine current computer aided systems in daily architectural work. An analysis shows a lack of IT-support for the design and planning of existing buildings. Currently available software and hardware in this field is characterized by a variety of individual products, mostly adaptations of CAAD-Systems or specific computer-supported solutions already available for new building, or else adaptations of products from other fields, e.g. VR/AR supported design in the automobile sector or SAR applications (Bimber and Raskar, 2005).

2. Technological basis – an overview of the sARc research project

Immersive and semi-immersive projection displays, such as CAVEs™, walls, workbenches, cylinders, and domes are being used to support virtual reality (VR) applications in many professional domains. The visualization of data using these displays, however, requires dedicated rooms for setting up and installing immobile screens, and allows the interaction with purely synthetic information only.

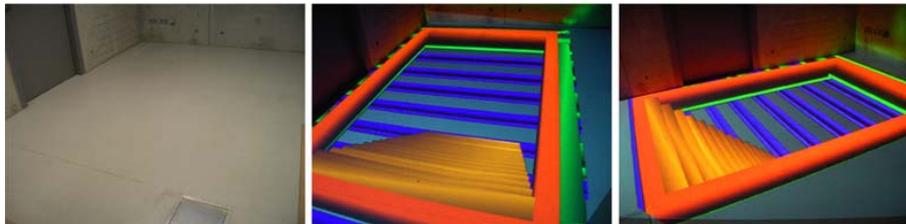


Figure 1. Stereoscopic projection in real environments – visualizing the structure of a stairway in a real environment / false-colour visualization

The aim of the “Spatial Augmented Reality for Architecture” (www.sarc.de: July 2007) research project is to investigate and develop the conceptual and technological foundation for the ad-hoc visualization of interactive three-dimensional (stereoscopic) and two-dimensional (monoscopic) data on arbitrary surfaces in real-world indoor environments using a mobile hardware setup.

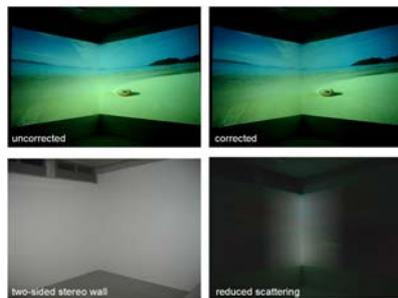


Figure 2. Conventional forward-projection onto two-sided wall. Projection with reduced secondary scattering (scattering reduction is visualized)

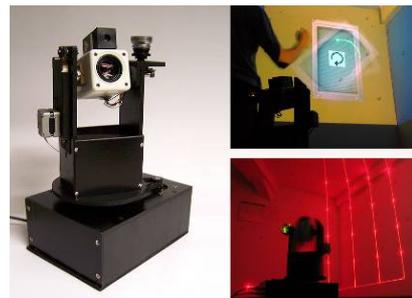


Figure 3. Current PTZ camera prototype (left) and basic object manipulation techniques (right). Augmentation can be projector-based or via video-see-through

A core part of the project is the development of fundamental (standalone) algorithms and hardware components. Using methods of view-dependent, image-based and geometric warping together with radiometric compensation and multi-focal projection we have been able to achieve view-dependent visualizations projected onto ordinary surfaces within everyday environments (see fig. 1). By ‘ordinary’ surfaces we mean surfaces that can be geometrically complex (i.e. non-planar), coloured and textured (Bimber et al., 2005). The system compensates for first-level and higher-level secondary scattering effects in real-time (see fig. 2), i.e. can cope with concave projection surfaces and room corners where a portion of the light is scattered onto neighbouring surfaces (Bimber et al., 2006).

An important aspect for user acceptance is interaction. We have developed a custom-built pan-tilt-zoom camera for laser-pointer tracking (see fig. 3) in arbitrary real environments (Kurz et al., 2007).

This is a prerequisite for developing systems that can support the architectural design process in real-world environments, in other words, the interaction with and within existing buildings at a scale of 1:1, and the support of design and planning processes at true scale.

3. Spatial Augmented Reality for Architecture – supporting the architectural design process from survey to design

An aim of the project is to develop solutions that support the architectural design process in existing buildings, based upon the new mobile projection technology. The projection technology enables one to project data in real-time onto almost any surface of an existing building, colour-calibrated and geometrically rectified to fit the real context. The setup can be positioned freely, much like pointing a torch. The technology makes it possible to provide both purely immersive virtual environments as well as to augment real situations with additional virtual data to show changes in surfaces of objects.

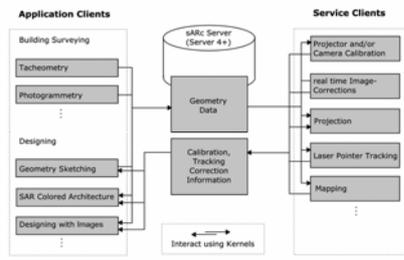


Figure 4. Schematic diagram of the software framework

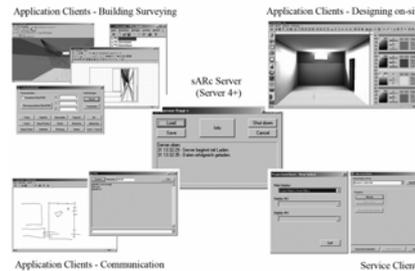


Figure 5. Screenshots of the server and the specific clients

The concept of the system follows a modular principle, like an architectural toolbox, based on a client-server principle (Petzold and Tonn, 2006). Different modules for information capture, design and planning can be combined as required. The individual modules form a continuous, extensible, flexible and in real-time dynamically adaptable system, which covers all aspects from the initial site visit to detailed planning. Each tool was developed for an individual aspect taking into account its role and the requirements of the entire planning process, e.g. initial site visit, building surveying based on tachymetry / photogrammetry or colour-design.

4. An architectonic application – on site design using AR

4.1. HISTORICAL AND THEORETICAL BACKGROUND - TROMPE-L'ŒIL

Trompe l'oeil is a term in French and means, literally, “that which deceives or fools the eye” or a “trick of the eye”. It is the use of painting techniques to

create an illusion of textured surfaces as well as to give three dimensional appearances to flat walls and ceilings. Through careful use of shading, architects and artists are able to produce the illusion of three dimensions. Unlike purely decorative painting, which only serves to embellish a surface, this attempts to lend it the appearance of depth.

Trompe l'oeil painting has been employed for over two thousand years and as a painting style dates back to 400 BC, part of the rich culture of the Greek and Roman Empires. The earliest remaining examples are the tile floors and Roman frescoes at Pompeii and Herculaneum, preserved by the ash that filled the rooms when Vesuvius erupted. In the centuries that followed after the fall of the Roman Empire, trompe l'oeil fell into disuse during the period known as the “Dark Ages” in Europe. It did not resurface again until the Renaissance and Baroque. During these eras, many great houses and churches in Europe employed some of the best artists of the day to produce stunning masterpieces. The church's primary concern was to embellish the house of God and to give it the splendour they felt it deserved, literally “opening” the walls or the ceiling (to the heavens).



Figure 6. Fresco painting on the ceiling of the Church of Saint Ignazio in Rome, created by Andrea Pozzo during 1691-1694

The muralists of the 1400 and 1500s, e.g. Andrea Mantegna, Paolo Uccello, and Paolo Veronese, experimented with perspective and found they could use trompe l'oeil architecture as they strove to paint what architect Leone Alberti called “a window into space”. These trompes ranged from small “carved” ornamentations on walls and ceilings to altar pieces with elaborate architectural effects. Today artists and architects still use this technique for paintings, interior designs or designs of building facades.

For our purposes, trompe l'oeil represents the starting point of “designing with images”. Our thesis is that spatial augmented reality is a modern kind of

trompe l'oeil – “painting” in real-time, and onto arbitrary surfaces whilst also offering the possibility of direct interaction with the user.



Figure 7. Advertising

<http://www.marketing-alternatif.com/2006/05/17/jobintownde-trompe-loeil>: July 2007



Figure 8. A trompe-l'œil in Lyon, France, early 21st century

http://en.wikipedia.org/wiki/Trompe_l'oeil: July 2007

4.2. DESIGNING WITH 2 DIMENSIONAL IMAGES

Our project aims to harness the techniques used in illusory painting for supporting the design process and to adapt these to the possibilities offered by the computer. A tool was developed that allowed the user to insert images into spaces, both with a desktop computer or using AR projections.

The veritable flood of images, both real and virtual, which pervade our everyday environment gains ever increasing importance and also influences the work of architects. The “Designing with Images” project allows one to capture optical impressions and to work with them in the design process. Typical approaches to designing with images in this way are most well-known from image editing programmes in the creation of photomontages. These are currently limited to two dimensions, but by extending the same principle into the third dimension, collages can be experienced spatially.

Planning with images and photos allows the designer to compose photo-realistic spaces in the early phases of the design process and is especially useful for interior design, where photorealism is particularly desirable.

The program uses the same modular server-client software framework described earlier and is therefore available as an integral tool across the whole planning process. To begin with a model of a space is needed. This could be derived from a building survey or created with a simple modelling tool such as SketchClient.



Figure 9. Building survey

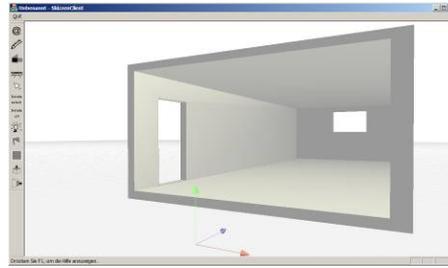


Figure 10. The “SketchClient” modelling tool

The program can access the “Colored Architecture” client module, also attached to the server, for generating realistic radiosity-based light simulations. These provide a near-photorealistic environment for designing with images.

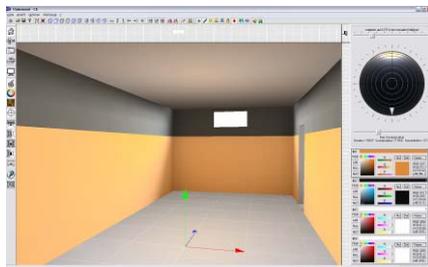


Figure 11. Light simulation model in “Colored Architecture”



Figure 12. User interface of “Designing with Images”

Once the “Designing with Images” program has been started, it connects with the server and determines all necessary parameters, such as geometry, colour, light calculations and dimensions.

Using simple interactive means it is possible to navigate freely within the model. A palette on the right of the screen shows a library of available building elements or surface textures which can be freely extended by the user. Different libraries can be set up for different projects in which standard elements such as doors and windows can be stored.

The images can be inserted into the scene via drag and drop and adapt their position to the surfaces of the model. A second click displays the edge “grips” for resizing, scaling or rotating the element that are familiar from graphics programs. These elements can be accessed on-screen with a traditional desktop mouse or in a real environment using a laser pointer in an AR projection. Where images are laid on top of other images they stack making it possible to design in layers.

Drag and drop using the right-hand button replaces an existing image with the new image, making it possible to rapidly assess and save different variants.

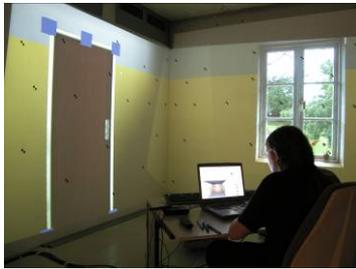


Figure 13. Scaling and shifting

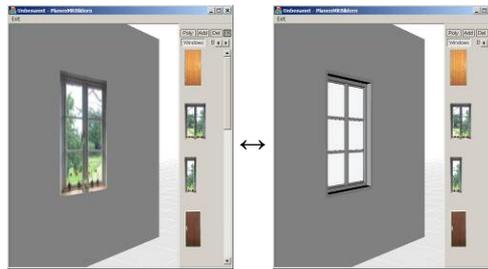


Figure 14. Sketch: Conversion of a photo into a building element

A further central function of “Designing with Images” is the ability to transform favourite photos into building elements. For this a building element modelling tool is to be integrated that creates a 3D-element based on the photo. From then on, the building element is associated with the respective image. The three dimensional building element represents so to speak a more detailed building element, but one that is represented by its image.

4.3. USING EXISTING BUILDING ELEMENTS AND SURFACE TEXTURES

To design with images, the designer needs images of different building elements, such as windows and doors as well as a variety of surface textures. One possibility is to photograph elements directly in the building or space itself. By masking the desired element from the photo, the building element can be extracted, distortion-rectified and stored in the library (see fig. 15). From then on the photographed door can be positioned anywhere in the room, or in a neighbouring room, and its impact evaluated. As such all the necessary existing elements can be quickly recorded ready for further use for planning on screen or on site (see fig. 16).



Figure 15. Masking of a door



Figure 16. Visualisation of a planned window and door

A further important application when “designing with images” is the ‘fading out’ and shifting of existing building elements. When planning on site, the aim is to ‘cancel out’ what is already there and to display the new design. Sometimes it is necessary to generate a surface texture, e.g. wallpaper or a stone wall, in order to ‘take out’ the door. The approach used in the software prototype is called “Texture Synthesis”: based upon a selection of the background from around the door, a texture is generated of a sufficient size to cover the door and blend in with the existing background. It is likewise possible to synthesise surface textures from catalogue images or photos, and to then scale and geometrically distort these to fit the scene on screen or for projection into the real space.

4.3.1. The software prototype “TextureMan”

A software prototype called “TextureMan” was created (see fig. 17) to assist in the generation of such textures, that can be accessed both as a module from within “Designing with Images” or started as a standalone application. There are four basic steps:

1. Define source image
2. Determine parameters and source area
3. Start texture synthesis
4. Save generated image

The source image can be a photo or a pre-generated image. For a photo is necessary to define the area which should be replicated and rectify any perspective distortion. A texture synthesis algorithm is then chosen and the synthesis is then run. All generated textures are saved as swatches so that they can be assessed and compared easily. Parameters can be defined for output resolution, compare window, initial random number and two threshold values for so-called “feature detection”. The individual settings are described below:

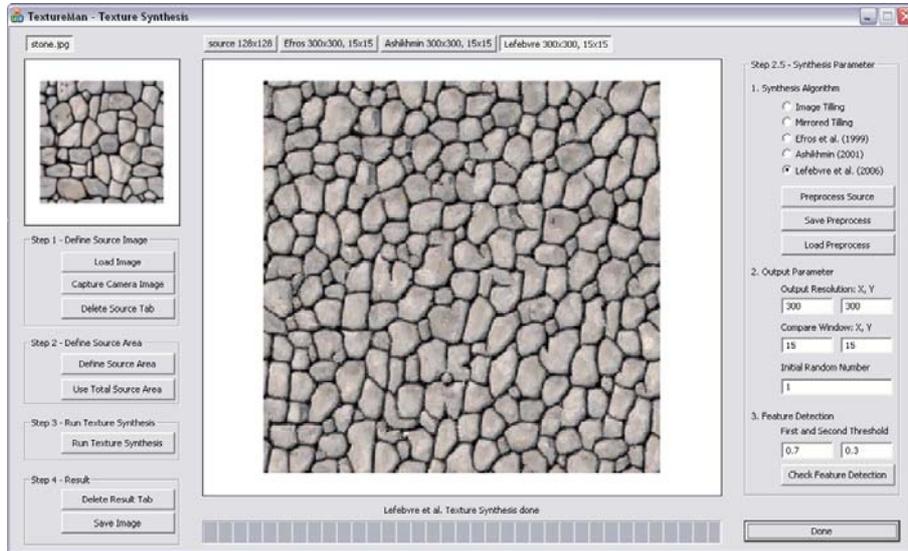


Figure 17. Software prototype “TextureMan”

4.3.2. The synthesis of surface textures

The simplest algorithm for synthesising textures is “tiling” or “mirrored tiling”. However, there are two main problems associated with tiling: visible edges and patterning resulting from the repeating texture (see figs 19 and 20). It is also possible to scale the original image, although this changes the scale and therefore the applicability of the texture.



Figure 18.
Source image



Figure 19.
Image tiling

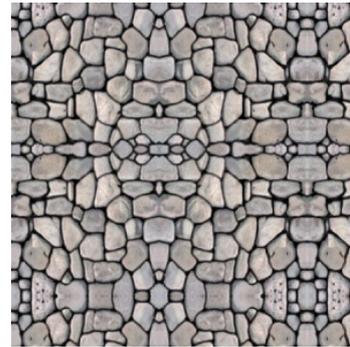


Figure 20.
Mirrored image tiling

Texture synthesis has become more and more widespread in computer graphics since its beginnings in 1981 (see Garber, 1981). In recent years, the

original algorithms have been developed considerably and the quality of the end result has improved markedly. Three approaches have been implemented in “TextureMan”. The methods chosen are a factor a) of their free availability (Efros and Leung, 1999; Ashikhmin, 2001) and b) how advanced they are (Lefebvre and Hoppe, 2006).

4.3.3. Principles of texture synthesis

Starting with a small image, a larger image with similar appearance and optical characteristics is to be generated. The target image is first occupied with randomly chosen pixels from the source image and then each pixel is successively analysed as follows:

A ‘compare window’ defines the size of a field around a pixel, which forms its neighbouring area. This neighbouring area is compared with the neighbouring areas in the source image. Using a 2D Gauss-function, the value of the neighbouring area is weighted and the sum of square differences between target ‘neighbourhood’ and source ‘neighbourhood’ is calculated. The source pixel that best fits to the target neighbourhood is then inserted into the target image.

This process is repeated for all the pixels in the target image so that the target image becomes successively similar to the original source. This basic process is processor-intensive and a series of different optimizations and adaptations of the process have been developed. “TextureMan” includes three different algorithms, which are explained and compared below. In addition these approaches also allow one to interact with and manipulate the images that are generated, though this aspect is not discussed in this paper.

4.3.4. Texture synthesis: the Efros and Leung method.

The approach to texture synthesis taken by Efros and Leung (1999) is one of the first algorithms of its kind that has been published. The algorithm uses the basic approach as described above but takes a different approach to initialising the target image. In their approach, the source image is copied 1:1 into the centre of the target image. The target image is then expanded outwards pixel for pixel in a spiral until the edge of the target image is reached.

The disadvantage of this method is the time it takes. The blue plaster texture below (see fig. 24) took over 24 hours to generate. By comparison, the Ashikhmin method took only 1 minute for the same image. In addition, as the target image “grows”, artefacts can arise. The structure of the image is preserved quite well, however the time taken means that it is only really usable for smaller source images.

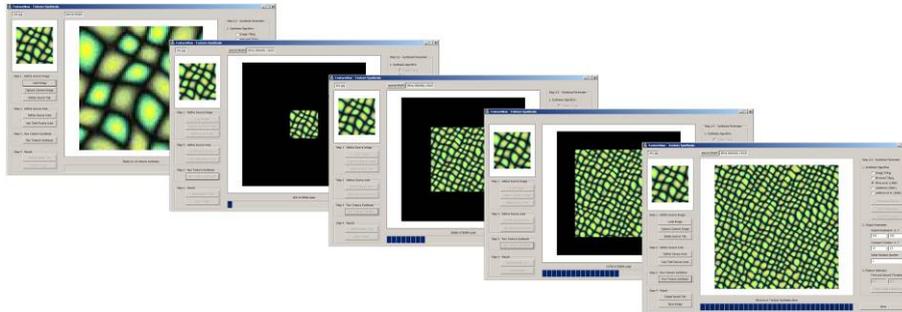


Figure 21. The principle of texture synthesis (after Efros and Leung, 1999)

4.3.5. Texture synthesis: the Ashikhmin method.

The Ashikhmin (2001) method is essentially an optimisation of the texture synthesis method described above. In the original principle, each pixel neighbourhood in the target image is compared with each neighbourhood in the source image. The Ashikhmin method instead first determines all potentially suitable comparison candidate neighbourhoods and as such does not need to compare all the source image pixels. As a result, this algorithm is much more efficient.

The disadvantage is that this method can affect the structure of the image. Important junctions and edges in the source image are separated. In the case of stochastic textures, this method can generate good results and due to its speed, it is well-suited for use in practice.



Figure 22. The principle of texture synthesis (after Ashikhmin, 2001)

4.3.6. Texture synthesis: the Lefebvre and Hoppe method.

The texture synthesis model put forward by Lefebvre and Hoppe (2006) uses more recent computer graphics concepts, for example, the step-by-step pyramidal image synthesis using an image pyramid of the original, candidate

lists and principal component analysis for the pixel neighbourhoods as well as the detection of special “features” in the source image. These features could be for instance spaces between stones that must be maintained in the synthesised texture. In “TextureMan”, feature detection employs the method developed by Wu and Yu (2004). The user can set two threshold values to optimise the detection results.



Figure 23. The principle of texture synthesis (after Lefebvre and Hoppe, 2006)

An advantage of Lefebvre and Hoppe’s texture synthesis algorithm is the separate calculation of the source analysis and the target synthesis. The source image can be pre-analysed and a series of larger target images generated from it. The structure of the original image is preserved well using this method and speed-wise it is also suitable for use in practice.

Figure 24 shows a comparison of the three texture synthesis algorithms used. The source images together with their principle “features” are shown on the left with the respective synthesised textures following to the right: Efros and Leung (1999); Ashikhmin (2001); Lefebvre and Hoppe (2006). One can see that each algorithm has its strengths and weaknesses and that the different methods are better suited to different kinds of source textures. The “TextureMan” software prototype allows the user to choose the most appropriate algorithm for each case.

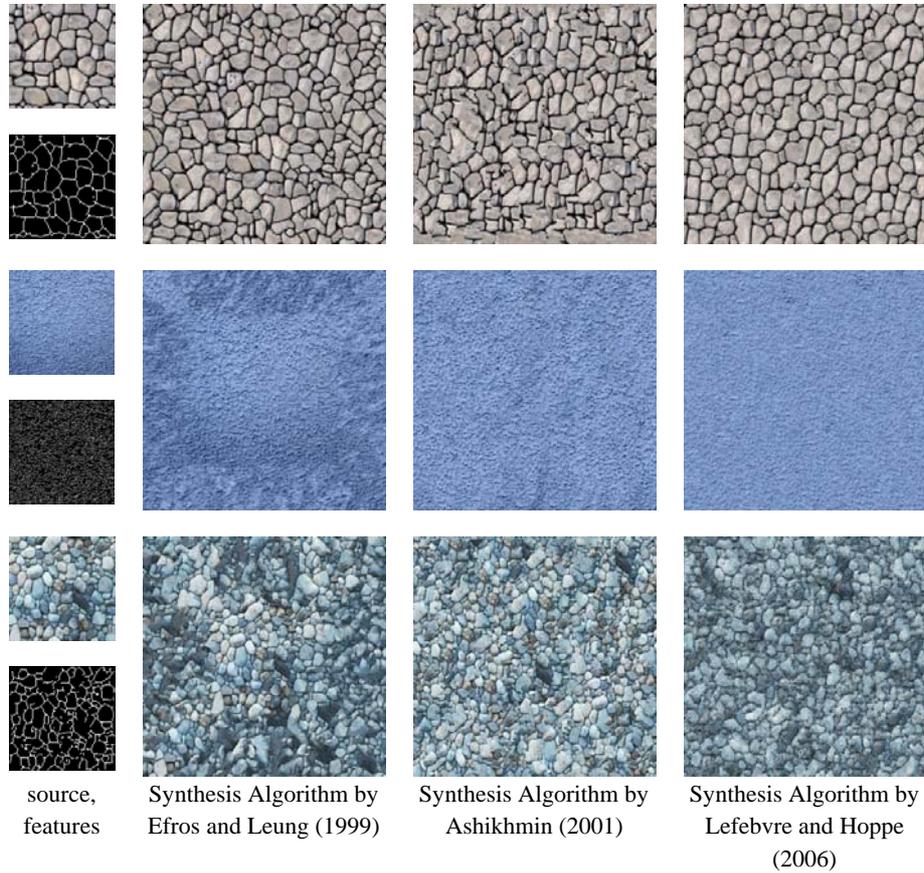


Figure 24. A comparison of synthesised textures

4.4. PERSPECTIVE DEPTH EFFECT

A further aspect of the “Designing with Images” prototype is the ability to change one’s position when designing with two dimensional images in a three dimensional environment. Three-dimensional effects and appearances such as shadows, perspective distortion and overlap must be taken into account. For this one needs to know the position of the observer and the direction of incident light. To determine the position of the observer dynamically, a camera-based tracking technique using LED-markers has been integrated (Kurz et al., 2007). Likewise, with the help of the radiosity light simulations in the “Colored Architecture” module, the direction of incident light can be simulated. Using this method, the user appears to see a

truly three-dimensional element of a building, although in actuality this is communicated through a two dimensional image – a modern version of illusory painting.

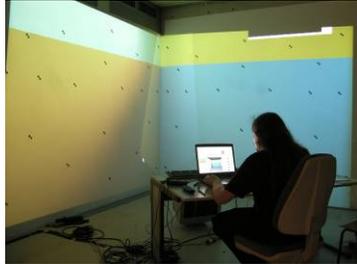


Figure 25. Designing Color-schemes on site



Figure 26. Designing with images on site

5. Outlook

The concepts described and the technology implemented facilitates a simple and intuitive approach to architectural design, both in the office as well as directly on site.

Future research will concentrate on the continued development of a mobile hardware setup and real-time algorithms for geometric and colour correction. In addition the implementation and evaluation of further architectural applications will be pursued.

A further aspect is the integration of hardware shaders in graphic cards to improve the representation of depth in building elements and material surfaces. This perspective-like illusion of depth represents a high-tech analogue to Trompe l'oeil. We plan to assess the quality of the different representation methods used and the quality of the impression they make on users. The long-term vision of this research project is to take architectural design to a new level.

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