Simulating the Atmosphere of Spaces

The AR-based Support of 1:1 Colour Sampling in and within Existing Buildings

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At present more than half of all building activity in the German building sector is undertaken within existing built contexts. Work in existing building fabric is an essential aspect of most architects' activities. The development of a conceptual and technological basis for the digital support of design directly on site, in and with the available architecture is the main focus of the research project “Spatial Augmented Reality for Architecture”. This article describes one part of the research project: the sampling of colours and materials at a scale of 1:1 using Augmented Reality technologies. This makes it possible to project the colour and material qualities of a design directly onto any surface within an existing building, geometrically corrected. A first software prototype SAR-CA has been developed and then assessed using a user study to obtain a first evaluation of the prototype to determine the direction of future research. Future research areas are discussed at the end of the paper.

Keywords: Augmented reality; design support; colour and material sampling.

Introduction

Imagine the following scenario: an architect enters an existing building charged with devising a new colour and materials concept. Out of his shoulder bag he takes a laptop, a camera and a projector. He sets up the equipment in the room, allows it to self-calibrate automatically and shortly afterwards the planning model of the room is projected superimposed life-size onto the walls of the room. He reaches into his pocket and draws out a laser pointer, switches it on and uses it (in place of a mouse) to begin editing by simply pointing the laser into the room (the camera tracks the position of the pointer). He tries out colours and materials and their impact on the atmosphere of the space – all without having to set up white projection canvases: the self-correction algorithm of the projector compensates for any uneven shapes, surface texture and colour of the walls. This is the ultimate vision of this paper.

The development of AR-supported colour and material sampling is part of an interdisciplinary research project entitled “Spatial Augmented Reality for Architecture” whose main goal is the
development of a conceptual and technological ba-
sis for the digital support of design on site, in and
within the existing built context. The technology de-
veloped allows the monoscopic two-dimensional or
stereoscopic three-dimensional projection of digital
planning data, such as colour and material variants,
onto almost any surface.

Using commercially available video projectors
and a digital video camera, the projection is cor-
corrected in real-time to compensate for the colour and
the geometry of the underlying surfaces. The goal of
the research project is a projector-based real-time
presentation of interactive three-dimensional and
two-dimensional data on any surfaces, as well as the
support of on-site design aspects. A further techno-
logical innovation includes the conception and de-
velopment of new forms of interaction, for example
the use of a conventional laser pointer, which is cap-
tured in the camera picture and serves as an input
device.

**Colour and material in the design process**

The professional support of colour and material sam-
ppling using Augmented Reality technologies has
great potential. To augment the existing architecture
life size with the colour and geometrically-corrected
digital model while designing directly on site is an
especially promising field of application.

The design of colours and materials in architec-
tural design is particularly demanding, and is often
carried out by professional specialists. It requires
good knowledge of how light, material and colour
interact with one another and the resulting spatial
impression. The tools used by professional colour and
interior designers are not yet adequately supported
in the IT environment. Instead only insular solutions
exist for architectural visualisation, presentations or
complex physical light simulation. In architectural
practice, digital colour is not yet regarded as suffi-
ciently accurate or reliable, and accordingly tools for
colour or material design are rarely employed. The
use of traditional colour charts, material samples and
small sample panels on site are still commonly used to determine a design and to present alternatives to the client (see figure 1 and 2).

However, with traditional tools, one sees only small sections – it is particularly difficult to communicate the vision and the spatial effect of large expanses of colour and materials. The projection technology offers the advantage of being able to provide large-scale colour and material proposals and enables the design to be visualized, assessed and modified on site more effectively. Whilst the advent of new affordable colour calibration tools for monitors (e.g. ColorVision Inc. “Spyder2”, 2004), beamers (e.g., Bimber et al., 2005) and printers (e.g., Richter, 2005) has made the IT-supported design of colour and material concepts a realistic proposition, such calibration tools are not the subject of this article.

**Colour design using Augmented Reality**

The software prototype “Colored Architecture” was developed to support the design process for colours and materials (Tonn, 2005; Tonn, 2007). The tool addresses the deficits of digital colour and material design and supports digital planning with colour and materials from the initial design, through the planning phase to specification. Due to the modular design of the server-client software framework used called Freak (Donath et al., 2003), it was possible to extend the software and add projection and calibration clients. The derived software prototype “Spatial Augmented Reality – Colored Architecture” (SAR-CA) is able to superimpose the digital planning model onto the existing building at a scale of 1:1.

**Description SAR-CA**

The digital support of colour and material design in SAR-CA uses and adapts existing strategies, instruments and representations, e.g. alternative variants, colour studies and colour relationships such as harmonies and contrasts. To reliably assess and evaluate the results of colour and material choices, integrated radiosity visualisation is employed as it is able to represent interactions between different surfaces such as reflections. Radiosity light distribution computation is an integral component of commercially available visualisation programs such as Cinema4D (Maxon Computer Inc.) or 3D-Studio (Autodesk Inc.). Using such software it is necessary to carry out the time-consuming radiosity calculation each time material, colour or light changes take place.

In SAR-CA a physically correct radiosity calculation is used to enable interactive colour and material design. Of particular relevance here is the visualisation of daylight. The sun is not regarded solely as a single light source but as a diffuse source – the sky lights up the model from all directions. The parameters ‘position of the sun’, ‘illumination’ and ‘material colour’ can be edited interactively, and one can assess the updated radiosity visualisation immediately (e.g. Tonn et al., 2006).

**Technology, setup and calibration**

In addition to the computer, the technology used consists of conventional commercially available projectors and a camera. Before the technology can be set up, a digital model of the architectural situation must be created. The software framework used (freak) incorporates a set of tools which support the manual surveying or the use of tacheometry and photogrammetry. In the example shown a tacheometer was used to derive a precise digital model of the room (see figure 3).

Setup begins with the installation of the projectors and the camera in the room. The projectors are pointed towards the surfaces in question. It is then necessary to determine the position, the direction, opening angle and optical axis of the projectors. For this reason a semi-automatic and an automatic calibration were implemented.

Applying the semi-automatic calibration, markers are placed in the field of projection and measured with the tacheometer. During calibration, the digital 3D measuring points are associated with their 2D picture positions in their respective projections. This association is done by clicking the physical markers
in the picture of the projector with the computer mouse (see figure 4). Afterwards a mathematical compensation calculation is launched, which determines the parameters of the respective projector.

Because the projectors are now geometrically calibrated, it is possible to superimpose the digital planning model onto the real architecture. The position of the edges and points of the model in the projection should tally with the room. As part of the research project, three further correction procedures for the projection clients are planned:

1. **Blending** – The intensities of the projections are modulated where several projectors project on the same surface (compensation for projection overlap).

2. **SmartProjector** – This correction procedure involves scanning the structure and colour of the projection surface and modifying the projection in real-time to compensate for differences. The viewer perceives the picture as if it were the original image projected onto a neutral, white surface.

3. **InverseRadiosity** – This correction procedure takes into account the self illumination of the projection. This error occurs most commonly in room corners, where adjoining wall surfaces reflect parts of the projection onto one another.

An important aspect of the research project is the integration of a Pan-Tilt-Zoom camera (PTZ) for automatic calibration, for measurement and for user interaction. The automatic calibration of the projectors using the PTZ-camera does not need physical markers in the projection. The camera can determine its position and orientation automatically in the room using a built-in laser distance measuring instrument. After positioning, automatic calibration starts and the necessary marker dots are projected and captured by the camera. Based on their mismatch, the parameters for projection can then be computed. In addition to the well-proven measurement technologies, it should become possible in future to semi-automatically capture the room geometry using the PTZ-camera and its laser distance measuring instrument. Finally, the camera tracks the position of a laser pointer to enable users to interact directly with the digital model.

**User study**

An initial evaluation was carried out using a user studies to determine the direction for ongoing research. As the integration of projection correction procedures, new interaction forms and technologies progressively continues, we plan to repeat such evaluation to allow a comparative analysis with previous studies.

The test took place with test persons in the windowless AR-Vis lab of the Bauhaus University in Weimar. Their aim was to develop a colour design...
proposal for the room and to equip the room with a window, so that the effect of natural lighting and its influence on the design could be assessed. Four different ways of working were compared using the same assignment:

4. **Traditional Sampling** – The test persons received a printed plan of the room, RAL colour charts and coloured pens for the sampling (see figure 5).

5. **Computer-aided Sampling 2D** – The test persons received the same plan of the room as a 2D digital image and the image manipulation software Adobe Photoshop CS2 (see figure 6).

6. **Computer-aided Sampling 3D** – The test persons worked with the software prototype of “Colored Architecture” using a 3D model of the room. Interactive radiosity visualisation was optionally displayable (see figure 7).

7. **Augmented Sampling** – The test persons used the software prototype “Spatial Augmented Reality – Colored Architecture” to carry out the design, using the augmentation of the room corner for visualisation (see figure 8). An interactive radiosity visualisation was optionally displayable.

After the different working methods had been completed, each test person was asked 10 questions, answered on a scale as follows: “no/never” (-2), “not really/seldom” (-1), “don’t know/neutral” (0), “probably/sometimes” (1) to “yes/often” (2) in the questionnaire.
Evaluation of the user study

25 persons aged between 21 and 57 years took part in the user study. 72% of the test persons were male and 28% female. 48% – nearly half of the test persons – indicated they had previously produced colour design proposals in professional practice.

In table 1 and 2 the evaluation of the user’s questionnaire answers are presented. The colours of the

<table>
<thead>
<tr>
<th>Question</th>
<th>Traditional</th>
<th>2D</th>
<th>3D</th>
<th>AR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Have you applied this working method often?</td>
<td>0.36</td>
<td>0.68</td>
<td>-0.96</td>
<td>-1.76</td>
</tr>
<tr>
<td>2. Can you imagine the whole room with the colour design?</td>
<td>0.28</td>
<td>0.68</td>
<td>1.44</td>
<td>0.44</td>
</tr>
<tr>
<td>3. Could you imagine the room with a window and natural light?</td>
<td>-0.04</td>
<td>-0.04</td>
<td>1.6</td>
<td>0.16</td>
</tr>
<tr>
<td>4. Do you think this way of working is suitable for architectural practice?</td>
<td>-0.24</td>
<td>0.4</td>
<td>1.4</td>
<td>0.52</td>
</tr>
<tr>
<td>5. Were you able to develop your design ideas well using this method?</td>
<td>0.12</td>
<td>0.24</td>
<td>1.6</td>
<td>0.8</td>
</tr>
<tr>
<td>6. Could you experiment and try out easily using this method?</td>
<td>-0.28</td>
<td>1.12</td>
<td>1.6</td>
<td>1.44</td>
</tr>
<tr>
<td>7. Did you feel this method was limiting to use?</td>
<td>0.16</td>
<td>-0.32</td>
<td>-1.12</td>
<td>-0.96</td>
</tr>
<tr>
<td>8. Were you able to try out different design alternatives?</td>
<td>-0.96</td>
<td>1.2</td>
<td>1.68</td>
<td>1.72</td>
</tr>
<tr>
<td>9. Could you use this working method efficiently?</td>
<td>-0.4</td>
<td>0.56</td>
<td>1.6</td>
<td>0.84</td>
</tr>
<tr>
<td>10. Do you feel you can trust this tool and this way of working?</td>
<td>0.04</td>
<td>0.24</td>
<td>1.04</td>
<td>0.64</td>
</tr>
</tbody>
</table>

Table 1
Evaluation of all test persons to the four methods (light grey = best, dark grey = worst)

<table>
<thead>
<tr>
<th>Question</th>
<th>Professionals</th>
<th>Traditional</th>
<th>2D</th>
<th>3D</th>
<th>AR</th>
<th>Laymen</th>
<th>Traditional</th>
<th>2D</th>
<th>3D</th>
<th>AR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>0.33</td>
<td>0.58</td>
<td>-0.75</td>
<td>-1.75</td>
<td></td>
<td>0.38</td>
<td>0.77</td>
<td>-1.15</td>
<td>-1.77</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>0.33</td>
<td>0.50</td>
<td>1.50</td>
<td>0.17</td>
<td></td>
<td>0.23</td>
<td>0.85</td>
<td>1.38</td>
<td>0.69</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>0.33</td>
<td>-0.08</td>
<td>1.58</td>
<td>0.08</td>
<td></td>
<td>-0.38</td>
<td>0.00</td>
<td>1.62</td>
<td>0.23</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>0.00</td>
<td>0.42</td>
<td>1.58</td>
<td>0.58</td>
<td></td>
<td>-0.46</td>
<td>0.38</td>
<td>1.23</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>0.08</td>
<td>0.17</td>
<td>1.58</td>
<td>0.42</td>
<td></td>
<td>0.15</td>
<td>0.31</td>
<td>1.62</td>
<td>1.15</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>-0.42</td>
<td>1.08</td>
<td>1.50</td>
<td>1.50</td>
<td></td>
<td>-0.15</td>
<td>1.15</td>
<td>1.69</td>
<td>1.38</td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>0.25</td>
<td>-0.33</td>
<td>-1.25</td>
<td>-1.25</td>
<td></td>
<td>0.08</td>
<td>-0.31</td>
<td>-1.00</td>
<td>-0.69</td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>-1.00</td>
<td>0.92</td>
<td>1.67</td>
<td>1.75</td>
<td></td>
<td>-0.92</td>
<td>1.46</td>
<td>1.69</td>
<td>1.69</td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td>-0.33</td>
<td>0.50</td>
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<td>0.92</td>
<td></td>
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<td>0.00</td>
<td>0.50</td>
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<td>0.25</td>
<td></td>
<td>0.08</td>
<td>0.00</td>
<td>0.92</td>
<td>1.00</td>
<td></td>
</tr>
</tbody>
</table>

Table 2
Professionals and laymen in comparison (light grey = best, dark grey = worst)
table cells represent the order of the four working methods. Light grey is the best and dark grey the worst evaluation. The columns headed “Traditional” list the average value of the user responses to the traditional sampling. “2D” stands for the computer-aided 2D sampling, “3D” for the computer-aided 3D sampling and “AR” stands for augmented sampling. The standard deviation of the responses is in the range from 0.45 to 1.61. The following trends can be derived from the study:

- Overall, the test persons gave the most favourable responses to the computer-aided 3D method, closely followed by augmented reality sampling, with traditional sampling valued worst.
- The ability to judge the room and the effect of daylight using the augmented reality method was valued substantially better by the laypeople, although the professionals preferred the traditional working method instead.
- The usability and the functionality of the computer-aided 3D sampling and the augmented sampling were valued best of all.
- The augmented sampling was valued slightly better than the computer-aided 3D sampling when checking different design alternatives.
- The laypeople accorded most trust in the augmented sampling, while the professionals favoured computer-aided 3D sampling.

During the augmented sampling, an aspect of particular interest arose during the user tests. While for the computer-aided 3D sampling using “Colored Architecture” it was very important to display the radiosity light visualisation on the display, it was almost intrusive in the projection onto the real wall. To gain a proper impression, it was necessary to simulate the room atmosphere and the depth on the display, while in the projection a more authentic impression was generated without the light calculation. A reason for this could be the absence of an InverseRadiosity-correction procedure, which will be integrated in future. The sunlight illumination onto the side walls also seemed to be more intrusive in the projection onto the walls than on the display. We plan to integrate a corrective procedure which simulates the adaptation of the human eye to the brightness level.

**Summary and outlook**

This paper has introduced the planning support software prototype SAR-CA, which supports the planning of colour and material designs in the existing built context using new augmented reality technologies. The software prototype was subjected to an initial evaluation in order to receive feedback and identify areas for future research and development. In addition to the intended integration of blending, SmartProjector, InverseRadiosity and eye adaptation correction procedures, other functionalities will also be integrated.

The software prototype SAR-CA offers the possibility of interactive radiosity visualisation in daylight conditions. At the moment this is limited to the material colour. The next step will be the integration of surface textures and surface relief texture. Using hardware-accelerated graphic card shaders these material properties will be implemented, to allow the interactive design of daylight together with enhanced material properties. We also intend to use the pictures taken by the PTZ-camera for synthesizing materials from them. In the simplest case one can use straightforward texture tiling, while for increased quality texture synthesis will be applied. Using such synthesized materials it should be possible to ‘fade out’ elements of buildings and installations (e.g., doors), making it easier to design with images within existing buildings.

The support of colour and material design using augmented reality technologies has major potential for architectural planning practice. The ongoing improvement of the projection technologies used and the concepts discussed offers much hope for a rich future of colour design in architectural practice.
References


