Designing Colour in Virtual Reality

Comparing a Virtual Reality based and a Screen based Colour Design Method

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Designing colours for architecture with digital tools is still a challenging topic. Especially for customers and students the perception of a full-scale coloured interior room is hard to imagine. This paper presents a software prototype and a small user study, which addresses the colour design process with professional digital tools and a virtual reality head mounted device (Oculus Rift DK2). The user can navigate within an imported three-dimensional model freely and change colour, texture and light properties with a real-time updated radiosity visualization. The presented user study compares a screen based working method with the developed virtual reality based design support and interaction method.

Keywords: Virtual Reality, Colour, Design Support, Real-time, VR-glasses

INTRODUCTION

With the advent of virtual reality (VR) hardware at consumer price level, it will not be long before the architect’s everyday practice uses this media. Professional applications are already available. The continuing pressure from the computer games and hardware industry will improve the VR devices further and make them even more affordable. Thus, usual presentations and design processes of architecture will soon take place with the help of VR environments, too.

Even wearing VR glasses could complement the everyday office work utilizing screens. Currently, computer games dominate the VR software development, but also big CAD software companies start offering VR solutions in their portfolio (see e.g. Autodesk [1], Unity 3D [2]).

CONTEXT AND SETUP

This research uses a digital design support software for colour designing to compare a VR-glasses-based process and a screen-based process. Both design modes utilize the software prototype “Colored Architecture” (see Colored Architecture [3]). A single pre-calculation in this software enables the free variation of material textures and colour attributes of all architectural faces as well as the daylighting. This achieves an interactive, high-quality visualisation with radiosity light simulation. To connect the prototype with the VR glasses Oculus Rift DK2, a new network client extends the underlying FREAK software framework (König et al., 2010). This “Oculus Rift Viewer” client displays the central “Server Five” data model with the textured and shaded geometry model in VR and captures user interactions. The graphical user interface (GUI) elements in the VR environment are pie
menus (see fig. 1) and reduced windows with slider scales placed on the faces of the virtual model. An earlier projector-based augmented reality solution (Tonn et al., 2008) introduced these GUI concepts already. Users can move freely in the VR model. The view direction replaces the “mouse pointer” of a traditional screen GUI and the attached X-box-controller substitutes the “mouse button functionality”.

RELATED WORK
This work is part of a broader research topic, which might be entitled “Digital Colour Design Support for Architecture”. Within this context the application in a VR environment is just one aspect. Another aspect was the colour design support in a projector-based augmented reality (AR) setting (Tonn et al., 2008 and Tonn et al., 2009). Since then it seemed obvious to move on from desktop screen VR over projector-based AR to a head mounted VR device for colour designing. In contrast to Stahre (Stahre et al., 2004) the presented work does not target the precise reproduction of perceptual colour for virtual environments, but is rather focused on the fast real-time update of the radiosity colour visualization for the early design stages. This is achieved without off the shelf software, but is coded from scratch using C++ and OpenGL. To get an overview of state of the art VR-applications in the built environment please see Kim (Kim et al., 2013). One further application of VR together with colour design, which comes closest to the presented work, is from the studio Arrowstreet and was presented at Spar3D 2017 with a HTC Vive VR device [4]. In this application one could throw coloured balls at a predefined room’s surfaces, which in turn changed their complete appearance. In contrast, the used engine in “Colored Architecture” also supports radiosity colour interreflections and lighting changes in real-time.

INTERACTION
One objective of the interaction concept was to minimize overlaying the 3D perspective with any permanent menus or widgets. While working in VR only one single user-selected tool is active. To select a tool the users has to press a certain “start-menu” button (e.g. the “Y”-button on the X-Box controller) and a pie-
menu appears centred around the view-direction-cursor on top of the focused 3D-modell surface. The pie-menu-direction-parts depict the underlying tool function with an icon and after waiting for 3 seconds, an additional tooltip with a description text shows up (see fig. 1). Moving the cursor in the direction of the required function and releasing the button selects the tool. The interaction with the now active tool consists of the view-direction-cursor and the primary button (e.g. the “A”-button on the X-Box controller). This way, only one tool can be active and the user can choose functionality from a cascade of pie-menus with maybe even more sub-pie-menus.

TOOLSET
What tools were available to the test persons during the survey? The following tools were used in the VR as well as the desktop working method:

- The most used functionality was the “Colour Drag and Drop” tool. The users selected the colour of a surface under the cursor and then dragged it with the view-direction-cursor to another surface. After this, the other surface got the selected new colour and the radiosity visualization along with its colour reflections updated.
- With the “Change Colour” tool, it was possible to change the hue, saturation or brightness of a surfaces colour. Utilizing sliders in a small window on top of the selected surface, the user changed the colour object and got immediate feedback from the updated radiosity visualization.
- The “Change Sunlight” tool allowed altering the daytime with a slider from morning to evening, which in turn adjusted the position of the sun. In addition, the clear visibility of the sun from brightly visible to obscured and the overall brightness-adaption of the eye could be set.
- There were tools to create new colour variants and switch between them with an updated visualization. With this, one could easily compare different colour alternatives of the design.
- There were also tools to sketch with a pen onto the 3D model, but this had no impact on the radiosity colour reflections. The main purpose of the sketch functionality was to mark and discuss parts of the design during presentation.

EXPERIMENT
The experiment consists of a fictive scenario that handled well with both interaction modes. The used 3D model was a virtual living room, which is based on a real construction project of a terraced house. The abstract 3D model was additionally equipped with a fictive colour study which fulfilled two functions. On the one hand it served as a design element in this setup and on the other hand it delivered a predefined colour palette (see fig. 2).

The test persons were colleagues of the FARO 3D Software GmbH. The experiment took place on two different computers (see fig. 3). Thus, the test persons could work in parallel on one operation mode and switch to the other afterwards. The first desktop computer (CPU: Intel of Core i7-2600K) was equipped with a competitive graphics hardware (GPU: NVidia Geforce GTX 1080) to enable a good frame rate display on the VR-glasses. The second computer, a laptop (CPU: Intel of Core i7-3610QM, GPU: NVidia Geforce GTX 675M), was used for the screen-based working.

Fourteen people took part in the study. Seventy one percent of the test persons had already carried out a colour design. Judging from their job profile, all test persons are rather computer affine. The average age was 40 years.

The task for the test persons was:

*Please design colours for the living room of your new built house. A wide picture has already found its place over the future couch corner. Maybe all surfaces around the picture shall be coloured, too. Please, create a comfortable, warm colour design, which suits your taste.*
Figure 2
The virtual living room for the colour design experiment.

Figure 3
Setup - on the left: VR-based mode, on the right: screen-based mode of colour designing.
Table 1

Questionnaire statements and the answered results on a scale from is not right (-2) to is right (2).

<table>
<thead>
<tr>
<th>Statement</th>
<th>Screen-based Method</th>
<th>VR-Glasses-based Method</th>
<th>Significance Level Alpha</th>
<th>Advantage for</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. You have applied this working method often already.</td>
<td>-0.714 +/- 1.204</td>
<td>-1.929 +/- 0.267</td>
<td>0.00138</td>
<td>Screen</td>
</tr>
<tr>
<td>2. You can imagine the whole room and the colour design.</td>
<td>0.5 +/- 0.855</td>
<td>1.357 +/- 0.745</td>
<td>0.00111</td>
<td>VR-Glasses</td>
</tr>
<tr>
<td>3. You felt sick/uncomfortable (VR-simulator-effect) during your design</td>
<td>-1.538 +/- 0.877</td>
<td>0.571 +/- 1.453</td>
<td>0.00131</td>
<td>Screen</td>
</tr>
<tr>
<td>experience.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. This working method is practical for the architectural design process.</td>
<td>0.857 +/- 0.864</td>
<td>0.643 +/- 0.929</td>
<td>0.53283</td>
<td>Screen</td>
</tr>
<tr>
<td>5. This tool/interaction concept is easy to use.</td>
<td>0.429 +/- 0.938</td>
<td>1.071 +/- 0.997</td>
<td>0.15627</td>
<td>VR-Glasses</td>
</tr>
<tr>
<td>6. You trust the colour visualisation and quality of this tool.</td>
<td>-0.071 +/- 1.141</td>
<td>0.143 +/- 1.231</td>
<td>0.55148</td>
<td>VR-Glasses</td>
</tr>
<tr>
<td>7. You feel limited through the means of the tool.</td>
<td>0 +/- 1.301</td>
<td>-0.857 +/- 0.663</td>
<td>0.06073</td>
<td>VR-Glasses</td>
</tr>
<tr>
<td>8. You could compare different alternatives.</td>
<td>1.571 +/- 0.852</td>
<td>1.5 +/- 0.65</td>
<td>0.77527</td>
<td>Screen</td>
</tr>
<tr>
<td>9. The working method is efficient.</td>
<td>0.857 +/- 0.949</td>
<td>0.786 +/- 1.122</td>
<td>0.85555</td>
<td>Screen</td>
</tr>
<tr>
<td>10. You trust the tool and this working method.</td>
<td>0.714 +/- 0.469</td>
<td>0.643 +/- 1.008</td>
<td>0.77527</td>
<td>Screen</td>
</tr>
</tbody>
</table>

RESULTS

After the test, the test persons had to complete a questionnaire. Similar to the augmented reality experiment (Tonn et al., 2009), for both methods ten statements had to be answered on a scale from is not right (-2), rather not (-1), do not know (0), is right rather (1) to is right (2). Table 1 gives the asked statements for each working method together with the answered average result. The lower with plus and minus marked values represent the standard deviation of the upper average value in the table cell. In addition the significance level alpha from a two-sample Student’s t-test and a column to indicate an advantage for the screen-based compared to the VR-glasses-based method is given.

The following screenshots from the software prototype “Colored Architecture” give an impression what the colour designs from the test persons looked like (see fig. 4).

EVALUATION

The direct evaluation produced the following tendential statements. The list enumerates only the significant statements, which reached a significance level alpha smaller than 0.05 computed in a two-sample Student’s t-test:

1. The participants had not applied the VR glasses method yet.
2. The test persons could imagine the room and...
the colour design significantly better with the VR glasses.

3. The VR simulator effect (indisposition or feeling of sickness) clearly appeared with the VR glasses.

The following list sums the comments to the questionnaires ordered according to their occurrence. The threshold was that at least two test persons wrote the statements analogously.

1. A more familiar mouse interaction would be good for the screen-based method. (6 test persons)
2. The low resolution of the VR glasses irritates. (5 test persons)
3. The orientation is easier with the VR glasses. The VR glasses are very intuitively in terms of navigation. (4 test persons)
4. The X-box controller interaction in VR is not stomach-careful; on the other hand the head moving is good. (4 test persons)
5. Very good space perception with VR better than the screen. (3 test persons)
6. It is fun. (3 test persons)
7. Currently no device can reproduce colour, contrast and brightness realistically. (3 test persons)
8. There are too many different menus and switches in the screen-based method. (2 test persons)
9. The speed shall be limited with the VR based interaction method to prevent sickness. (2 test persons)
10. There were too few colours to choose from in the model. (2 test persons)
11. A functionality to lighten or darken the VR colours would be nice. (2 test persons)
12. The screen-based method is familiar. (2 test persons)
DISCUSSION
Most people experienced the so-called ‘VR-simulator-effect’ (see result-item 3, above). It manifests itself in indisposition and a feeling of sickness. The effect is known and appears when the optically perceived movements do not match the physical signals of the human senses. Among others, the reason may be:

- A too low frame rate of the VR glasses,
- A too high latency or time delay between head movement and visual image update or
- An artificial optically perceived movement without the matching physical senses.

The used X-box controller interaction method for changing position corresponds to such an artificial movement e.g. by free virtual movements and smooth rotations. It is possible to reduce the effect by moving the virtual person slowly. If the user would change position close along a surface, maybe by “sneaking on the floor” or “moving close along walls” or even by “running through virtual walls” the perceived movement appears to be fast again and the VR simulator effect is back.

In recent VR computer games, the player teleports in the virtual world from location to location in order to neutralise the effect. At the fixed locations, the user has all degrees of freedoms for the head movement (e.g. Doom, 2016). Another option for a VR control is to make the artificial movements like virtual rotations or jumping to appear extra artificial (e.g. Minecraft VR Edition, 2016). This happens through sudden hard cuts of the actually smooth movements. Thus, the user can distinguish these transaction types easily from real head movements. Instead, the tested prototype used smooth movements, sidelong movements, height movements and rotations. With reference to the applied VR control, the critic is that sometimes, less is even more.

Furthermore, the participants found the VR interaction method easier than the screen-based one. In the VR environment the test persons used only the pre-set colour drag-and-drop tool together with the movement control. Besides there were also several pie menus as well as colour scales, brightness scales, saturation scales and daytime scales available. However, the test persons could not use these, because of a lack of training. Hence this reduced method seemed more suitable. In contrast all functionality of the menu, icons, control groups and colour widgets were visible in the screen mode. Probably because of that, the screen-based method seemed more complicated.

Promising results are that the VR glasses communicated the virtual space and the colour design better than the screen (result-item 2) and an improved orientation in the virtual reality with glasses (comment result-item 3).

CONCLUSION
The proposed digital colour design support in VR seems promising after this small user study. Especially for smaller projects like colour renovations and maintenance or also larger VR presentations, the software can be a tool to improve the confidence and the trust to an architectural colour design. However the major part of the required work deals with the creation of the abstract 3D-model. Still with an integrated BIM design practise or with capturing technologies like laser scanning together with appropriate as-built evaluation methods the necessary 3D-models can be efficiently used for VR applications like colour designing.

REFERENCES
