To Colour the Virtual World

- Difficulties in Visualizing Spatial Colour Appearance in Virtual Environments

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ABSTRACT

This paper discusses the problems of visualizing colour appearance in an interactive real-time virtual environment (VE) from the viewpoint of practice based architectural research. The discussion is based upon the research information project *Virtual Colour Laboratory (VCL)*, the aim of which is to visually present and demonstrate existing research results on spatial colour phenomena for educational purposes, in the shape of a software application. During the work on this project, various problems connected to the visualization of colour appearance have emerged which are discussed in relation to current research on spatial experience and visual appearance in VEs. The aim of the paper is to focus on the importance of colour appearance in digital modelling as well as to highlight the problems of visualizing colour appearance interactively. The term *colour appearance* is used here as a general concept for the perceived colour of a surface or object.

1. INTRODUCTION

This paper discusses the problems of visualizing colour appearance in an interactive real-time virtual environment (VE) from the viewpoint of practice based architectural research. The starting point for the discussion is the research information project *Virtual Colour Laboratory (VCL)*, which aims at visually presenting and demonstrating existing research results on colour phenomena for educational purposes. The project takes the shape of a software application where the research results are shown as interactive colour phenomena in an exterior and interior virtual environment. During the work with this project, various problems connected to the visualization of the virtual models have appeared. These problems are connected to both the specific pre-requisitions for reproducing colour appearance in a VE and also to more general issues regarding the design of a virtual world in terms of realism, interactivity and spatial orientation. The problems will be discussed in relation to current research on spatial appearance in VE's.

There are different focuses in studies on interactive presentation software when it comes to architecture and building design, relating to both visualization and interaction. On the one hand, there are studies from the user perspective on functional issues, such as ergonomics, disability and workspaces, where the media is used as a tool for understanding real life. On the other hand, there is a focus on visualization of architectural models, which regards issues such as the visualization of spatiality and size in the virtual models. [1, 2] When it comes to gaining information clarity in architectural presentations, so far little has been explored as to how to expand the technology's visualization capabilities [1]. Kwee notes that the realm of digital architectural presentations has taken advantage of the technology's provision for speed and ease of information retrieval. However, when it comes to the quantity and presentation of the provided information these are assumed, without proof, to be currently adequate for facilitating clear, in-depth learning. In order to understand the potential that digital visualization has for architectural presentations, there is still much rethinking and improvement to consider. [1] According to Balakrishnan et al. [3] commonly available digital tools for design visualization are characterized by emphasizing physical objects rather than the spatial experience. In current rendering technologies great progress has been made to achieve representational similarity through increased photorealism, but the challenge still lies in the experimental concordance with a corresponding real space. Balakrishnan et al. state that more work needs to be done exploring current tools of digital representation in order to improve aspects related to experience in a simulation. [3]

The aim of this paper is to focus on the importance of colour appearance in digital modeling as well as to highlight the problems of visualizing colour appearance interactively. It is important to point out that the VCL project represents research that focuses on the purely visual characteristics of colour and that uses the international colour order system NCS [4] in order to identify and specify colours. The term *colour appearance* is in this context used as a general concept for the perceived colour of a surface or object.

1.1. Visual appearance in Virtual Environments

While considerable work is being done on usability issues concerning technical interaction in VEs [5-7], there are in comparison few studies dealing with how people visually experience different VEs compared to reality. The VCL project demonstrates research results that focus on the purely visual characteristics of colours, based on their real world appearance. Other studies comparing digital simulations to real world scenes have different aims and approaches [8-11]. Part of this research takes the human visual system as a base in the aim of creating realistic scenes, while others aim for physical correctness. With very few exceptions this kind of research focuses on an "outside-perspective" when comparing models to real world scenes i.e. the observations are made from a point outside the models.[8-10]. Research on interactive illumination within computer graphics is important to consider [12-17].

The presentation of colour is a crucial factor for the understanding and interpretation of a VE [18]. However, in most research on digital visualization issues, colour has not been the main topic, but rather one aspect in the study of something else, for example in a study on size perception in virtual models [11].There are also a few studies where colour and light in spatial contexts have been the main topic of study. However, in most of these studies virtual rooms have been studied as if viewed from a distance or as two-dimensional images shown on a screen [8, 9, 17]. One exception is the research project *Simulating Colour Appearance in*

Virtual Environments (SCAVE) [17-21], which considered the impact that spatial factors have when looking at a room from within i.e. standing inside it. This project has dealt with spatial colour phenomena, comparing a real room to digital representations of the same setting. The results showed significant differences in colour appearance between the real room and the virtual models. The conclusions were that available visualization software cannot sufficiently calculate for all different conditions. Thus, to achieve adequate digital presentations of spatial colour phenomena, manual adjustments of the presentations need to be made, starting from the understanding of colour in real rooms and compensating for the shortcomings of the visualization software. These procedures do, however, presuppose deepened knowledge on spatial light and colour appearance in real rooms. The SCAVE project also analyzed the potential of VR to become a usable design tool concerning light and colour [19]. The analysis highlighted and discussed the relation between factors influencing the spatial experience, as well as the benefits and disadvantages of the applied models in the different virtual applications. The conclusions drawn were that better rendering quality led to higher task performance (in this case the evaluation of spatial factors) and that the studied models in their present state did not show rich enough light and colour variations.

In the VCL project, results from the SCAVE studies form a large part of the knowledge and research on which the project is based.

1.2. Studies on Spatial Colour Appearance

Colour is an important factor when it comes to attracting attention and is efficient for finding and interpreting information. Colour also facilitates our perception of the surrounding environment and spatial orientation. In architectural contexts, it is extremely difficult to predict the way the colour of a small sample will appear, when applied in full scale in a spatial setting, since the light in the room heavily affects the visual appearance. Our human perception depends on the adaptation and the brain's complex treatment of the information of spectral composition that reaches the eyes [20]. As observers we interpret the whole situation, rather than each local point. So far, there has been a vast amount of published research covering colour appearance in two-dimensional settings. However, spatial colour phenomena in real three-dimensional environments have not been equally investigated, and in comparison few studies have been published on the subject. The ones that exist show that size, illumination and surroundings are important factors for how we experience colour.

Of the research projects carried out over the last decade concerning colour appearance in architecture, most are conducted in Sweden. The perceived colour in rooms or on buildings is problematic to identify, since there are no instruments to measure what we see. Fridell Anter [21] has presented methods for analyzing the perceived colour on facades through different interview techniques with observers. In her studies a mixture of skilled and untrained observers performed several tests where a selection of facades was viewed and the viewers were asked the question: What colour do you see on the façade? Tendencies in the perception of different colours were discovered, showing how light, viewing distance and surrounding colours had an impact on the appearance of the façade colour. [21]

Billger [22] and Hårleman [23, 24] have shown how the inter-reflections in a room enhance both the colour and the colour experience. Billger deals with the problems of how to identify and compare colour appearances in rooms and how interior colours appear differently due to lighting condition and colour combination. She has developed different methods and concepts for colour analysis in enclosed spaces.

Hårleman [23, 24] has investigated how the colour appearance indoors differs depending on the room's compass orientation. As with exterior colouring, this is a problem often causing different results from the expected outcome of a design. Knowing what factors affect the colour appearance can help designers and architects predict the final colour experience more correctly.

Other studies have dealt with similar questions, however primarily with other aims than to provide guidance for architectural design [25]. Colour appearance models are developed for the production of constant *perceived colours* irrespective of medium. Studies within this research [26, 27] regard how different sizes of colours affect the colour appearance within full-scale rooms. The focus of these studies is however on one wall only and not on the rooms as a totality. Also, the analysis of colours is based on separate qualities of the perceived colour (value, chroma, hue etc) and not on the total colour perception.

Some of the above mentioned studies dealing with colour appearance in complete real-world spatial settings have formed the basis for the digital representations in the VCL project.

2. THE VCL-PROJECT AND ITS PRECONDITIONS

The research information project VCL is currently being carried out at the Dept. of Architecture of Chalmers University of Technology. The overall goal with this project is to contribute to a more widespread understanding of the perception of colours. The starting point is various research projects on spatial colour appearance that during the last decade have been conducted at Chalmers University of Technology and the Royal Institute of Technology in Sweden. When finished, the project will result in a demonstrator for existing research results on spatial colour phenomena visualized as digital interactive presentations. The demonstrator will have the form of an application that the user will be able to open and use without having access to other 3D-visualization software than those enclosed in the VCL package. The aims are to present research results, to develop the forms for such presentations and to identify the needs for complementary research. Users of the application will be guided through a virtual world, were they will be able to interactively explore indoor and outdoor colour phenomena as well as receive written information on each colour phenomenon. The intended users of the presentation are architects, architectural students and others professionally interested in colour.

2.1. The VCL-application – basic design

The user of the VCL application will be guided through a virtual landscape (Figure 1), approaching a building; a colour laboratory, in its centre. The starting point is placed about one kilometre from the building. The user will then follow a gravelled road through a northern European countryside setting. The walk takes place during daytime on a clear summer's day. The relatively naturalistically reproduced landscape offers possibilities to demonstrate different characteristic aspects of colour in nature. The impact of distance on the perceived colours and their interaction with the surrounding landscape is demonstrated on the exterior façade of the building. Different stops are planned along the walk, were relevant colour phenomena are pointed out.

Inside the building there are ten different rooms showing effects of different choices of colour, light, pattern and material (Figure 2). Each room will demonstrate specific research results on spatial colour appearance. The rooms are linked through a corridor system and numbered from one to ten. The surfaces of the corridor are used to demonstrate two-dimensional colour phenomena i.e. phenomena not connected to any specific spatial situation as well as optical illusions connected to perspective (Figure 3). These phenomena visualize results from research within art and psychology. At the core of the building a library is situated, containing relevant links and references.

Throughout the virtual model interactive signs are strategically placed, leading to the graphical user interface (GUI) of the application, which contains information about each demonstrated colour phenomenon. This information is presented in both text and images. The textual information is planned to come in two levels; the first level presents the current colour phenomena in broad outline; the second level gives more detailed information about each phenomenon.

Throughout the model the user will have the possibility to look around i.e. turn the head in different directions, as well as to control speed and stop of movements. The walk in the landscape and inside the house is locked to a restricted path. A few exceptions to this restriction occur at given locations, where it will be possible to walk around freely. In the exterior environment this will for example be where choices of different paths occur and in front of the building. Indoors it will be possible to freely experience most of the rooms. The walk along the corridor system will be restricted to one direction. From any point in the model it is possible to directly move to a specific room or outdoor station.

The information in the GUI presents the possibility to make interactive choices. The user will be able to choose between different colour alternatives at certain spots in the model. Outside it can for example be the choice of two or three different colours for the façade of the building, combined with equally many supplementary and detail colours. In each of the rooms the user will have the opportunity to make choices for one or a few factors affecting the spatial character. In one of the rooms the choice concerns for instance different light situations; in another room it concerns different colours for a back wall; in a third the placement of surfaces with given colours. Here, the application will switch between a number of pre-defined models, which will limit the choices of the user.

The current language in the application is Swedish; the finished product will however contain an English version as well.

2.2. The VCL-application – technical data

The application is built upon Windows based software common among architects and designers in Sweden. The interior part of the virtual setting is modelled in *3Ds max 8.0.* and the exterior part is modelled in *Novapoint Virtual Map 3.0.* The models are then exported to VR with *Open Scene Graph (OSG)* using an open source [28]. For the final versions of the models to be compatible, the export of the Virtual Map-model is done via *3Ds max 8.0.* A crucial criterion for the choice of software has been to simulate light fixtures correctly. The choice of light fixtures has governed the manufacturer's ability to provide adequate digital models that support photometric values. In order to use these models, a radiosity based renderer has been needed e.g. as in *Lightscape* and *3Ds max*. *Adobe Photoshop* has been used in order to correct the colour appearance on the rendered textures.

2.3. Spatial colour phenomena focused on in the VCL project

One important task for the VCL project is to demonstrate the relationship between the varying perceived colour in a real spatial situation and the *inherent colour*[1] of a surface (Figure 4). *Colour elasticity* [29; p.12] (Figure 5) can be described, telling how much the perceived colour of a specific material can vary within a range of given conditions. The complexity is high; the perceived colour is affected by a number of factors that will be discussed below.

In outdoor situations, the colour appearance of both a façade and the organic nature varies with changing viewing conditions, for example viewing distance, weather and season. At a long distance contrasts in lightness are emphasized while the chromaticness is smothered. Also, there is a strong tendency that distance will induce a hue change, which somewhat simplified can be described as “from yellow towards blue”. Research on the colour of painted facades shows consistent tendencies for the difference between perceived and inherent colour also from rather close up (around 50 m), or in other words between the colour appearance of a façade and the colour sample that would match the façade when placed directly on its surface. [21] The VCL demonstrator attempts to visualize these tendencies (Figure 6).

Colour appearance in interior rooms is affected by the specific light situation. Our visual sense adapts to the light that we are surrounded by, which means that large physical differences in spectral distribution and intensity of radiation have only little impact on the colours that we perceive. Still these remaining differences can be decisive for our experience of both colour and room character. This is true both for different kinds of artificial light [30] and for daylight from different compass directions [23, 24]. Also, the placement of light sources and the distribution of light are essential for the spatial understanding of the room [31].

The colours perceived in a room are also affected by the surrounding colours. Simultaneous contrast means the enhancement of perceived differences between surfaces [32; p.163]. This rather well known phenomenon is often illustrated on flat surfaces, and it is strongest between surfaces that are directly bordering onto each other, on the same level without differences in angle. In three dimensions simultaneous contrast has, however, been shown to have limited influence on colour appearance.[22] Instead, colours in an enclosed space affect each other through inter-reflection, which makes differently coloured surfaces perpendicular to or opposite each other to appear more similar [22] (Figure 7). In rooms with the same inherent colour on all walls the inter-reflections instead tend to make the colours appear stronger and darker than the corresponding colour samples [29]. Several of these phenomena are visualized in the VCL demonstrator.

The VCL application also demonstrates colour phenomena not connected to any specific spatial situation (Figure 2). When confronted with colour combinations and patterns in two dimensions, our visual sense often creates what is commonly called “colour illusions”. We can perceive lightness relationships or hue differences that do not comply with the existing inherent colours (e.g. *White´s illusion* and *Diamond illusion*) or spatial contexts that do not physically exist (e.g. *Chevreul illusion*). We can also mix the experiences of surface colour and light. Many of these illusions have been successfully presented in two-dimensional form [33-35], and the specific challenge within the VCL project is to demonstrate them in a spatial digital three-dimensional environment.

[1] *Inherent colour* is a constant quality of a surface and does not change due to viewing conditions. Fridell Anter defines it as the colour an object would have, if it was observed under standardised viewing conditions that are a prerequisite for the NCS colour samples to coincide with their specifications [21; p 24] It can be operationally determined by visual comparison to colour samples defined under these standard conditions.

3. PROBLEMS OF DESIGNING AN INTERACTIVE COLOUR DEMONSTRATOR

The work with the VCL project has revealed several problems connected to colour reproduction in virtual environments as well as general problems regarding the design of a virtual environment. Realism, interactivity and possibilities for spatial orientation within the model are issues frequently discussed in research concerning VEs, whereas the difficulties regarding colour reproduction highlight the need for further research in this field.

3.1. Problems connected to colour reproduction

Slater et al. [12] state that the problem of creating illumination realism is the central technical problem when translating reality into virtual reality. The reproduction of colour is very closely connected to the reproduction of illumination. Thus colour is essential in all virtual visualization software, not only when colour itself is the specific subject to be presented.

Reproduction of colour involves a number of problems connected to both hardware and software. A basic precondition for correct colour appearance in the digital model is that the computer is calibrated. In our practice, we have found that it is most important that the relationship between the colours in the digital model is correct compared to reality. If so, a small displacement between the colours on different displays is acceptable.

Even when perfectly calibrated, however, the display has a smaller dynamic range than the wide range of intensity levels found in reality. The process of simulating surfaces and artefacts therefore involves an overall simplification of colour information. Thus, the colour variety of the real world cannot be fully reproduced, and small but meaningful colour variations are lost in the process.

One way of solving this problem is constantly used by the computer game industry, where virtual worlds are given contrasts that go far beyond what is found in the real world or a realistic reproduction of it. This solution is obviously not useful in the VCL project where the aim is to demonstrate colour appearance in the real world.

To fully simulate the interaction between light and objects in an interactive scene would require more advanced real time technology than what is available today [36]. In order to get correct colour rendering in a scene, there is a need to program various spectral energy distributions in the software. The spectral composition for the light sources cannot be specified. Today the capacity of the computers is not enough to simulate this.[36] Radiosity is a widely used method for calculating diffuse light spread. However it can be very time consuming to use in the experimental colour design process. Another method is ray-tracing, which however is view dependent and therefore is of little use in research on interactive virtual environments.

Interesting software development is currently being undertaken [13-15]. However, in this development it is important to evaluate the fidelity of the parameter settings. Our experience is that even if correct data for light and surface colours are applied, software such as *3Ds max* cannot correctly simulate inter-reflections between coloured surfaces [37]. The SCAVE-study showed that the virtual rooms, in comparison with the real world setting, had incorrect reflections between surfaces, too few colour variations and too achromatic shadows. Also they showed incorrectly reproduced contrast effects for the lightest surfaces [38, 39]. Some of the problems were caused by arbitrary parameter settings in *3Ds max* and heavily simplified chromatic information on the illumination and shadows, light level and light colour [38].

In the VCL project, the problem of visualizing colour phenomena correctly is therefore a problem of correctly compensating for the different conditions in VEs compared to reality. Due to the fact that we cannot correctly reproduce colour realism for technical reasons, we are aware of the need to compensate for these shortcomings. In VCL it is enough to “fake” correctness, since we know the colour appearance of reality that we want to achieve. We compensate by using Photoshop to produce the correct colour reproduction. In order to do this we need to know how the colour is perceived in reality, since we cannot trust the digital simulations. This requires the comparison between real environments and digital models.

3.2. Problems connected to realism and spatial orientation

However well made, a VE can never offer the sense of real presence in a spatial context. Our bodies do not move around in the same way in a virtual model as we do in reality and our attention is not drawn by the same means. In reality, our senses collaborate through an active investigation [40, 41]. A virtual setting consists mainly of sight impressions and the active investigation is strongly restricted. Real presence in a spatial context can therefore not be fully simulated in a VE, and to make a visitor observe a specific detail of colour or a certain phenomena is difficult. Not even when only vision is considered, a VE should be treated as a copy of the real world. The field of view is limited on a desktop display compared to reality and the object shown on a display is much smaller than the appearance in reality, as well as surrounded and limited by the frame.

In addition to this, a VE cannot satisfyingly convey all the small variations and contrasts of reality, neither in form, light nor colour. Thus a total visual realism in an interactive virtual model is today not possible to achieve, and if the model is designed with that ambition it will inevitably lead to unsatisfying results. In the VCL project this is most obvious in the outdoor model where a constant problem throughout the design process of the model is that the landscape is meant to look as natural as possible, yet it does not look natural enough. This problem is connected to the model’s final appearance; although the model looked sufficiently natural in *Virtual Map* a significant loss of light and details became visible in the export via *3Ds max* to the interactive demonstrator, which does not support interactive light and where rendered textures are used for each surface. The interior environment with its straight lines and angles is less affected than the outdoor model with its rolling curves and shapes. As a result, much of what in reality is experienced as harmonic becomes dull and uninteresting in the virtual VCL model.

If the virtual model is designed with the aim of offering visual realism, the user even runs the risk of not giving notice to things that in a real environment would attract attention. Therefore, there is a need for strengthening effects in the model in order to create and hold the interest and to attract attention to parts of it that are of special interest. In the VCL project we now work with this intricate balance: How can specific details in the virtual world be exaggerated, compared to reality, and still give some illusion of the real world?

The problem of spatial orientation [42] has been obvious when designing the VCL demonstrator. The different parts of the model contain equal information, with no protruding elements. It can therefore be difficult to know what to look for and where to go i.e. to focus on relevant aspects of what is presented. This is also connected to the different experience of scale in a VE compared to reality, which is clearly demonstrated with the exterior façade in the VCL outdoor model. The changing colour of a façade according to distance is one central phenomenon to be demonstrated in the VCL project. In the real world, our attention is drawn to that which gives a contrast to the background, and thus a solitary building by the edge of a forest would be observed even if its part of our field of vision is very small. In the VCL outdoor model it showed, however, that a building of realistic size was hardly noticed, and even less its colours. Even after having largely increased the size of the front façade of the virtual laboratory, to 50 m x 20 m, at 600 metres distance the façade was only a few pixels wide, and only at 150-100 metres distance was it large enough to be able to show any changes in colour appearance.

4. CONCLUSIONS

Colour needs to be more considered in research concerning the spatial experience in VEs. This applies to the technical hardware and software preconditions for visualization software as well as to the considerations in designing a virtual environment. In order to provide a solid basis for this, there is also a need for more research on the specifics of light and colour in real spatial situations.

The VCL project aims to visualize and inform users about the colour appearance of reality in a virtual interactive environment. The work on this project has lead to the conclusion that neither a spatial context nor colour appearance with various connected phenomena can be directly translated from reality to virtual models. VEs have their own conditions that differ from the real world. In the VCL demonstrator, colour appearance and connected phenomena need to be adjusted to the virtual conditions. Here, the real world appearance of the demonstrated colour phenomena is already known. It is therefore possible to compensate for the colour appearance in the virtual model i.e. to adjust the colours in Photoshop. Important to consider is that this is only possible when the real world appearance is known and that this method is of no use when predicting colour appearance.

Scale and orientation are important factors to consider. Equally important is dramaturgy and how to create it in a none-linear story of a VE. A problem in the VCL demonstrator is how to make the visitor want to look in a certain direction or a certain angle, and how to make him perform adequate analysis in the given environment. To lead the observer through a virtual model, show him what to focus on and create the intended experience, a structure and a hierarchy of relevance connected to what is presented are needed within the model.

A possible future development for the VCL project could be to extend it to include results from other research areas connected to the whole concept of spatial experience and thus form a basis for an international collaboration. This could for example include research on sound, illumination and spatial orientation.

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