Perception of Colour and Space in Virtual Reality: A Comparison Between a Real Room and Virtual Reality Models

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ABSTRACT

Virtual Reality has great potential to become a usable design tool for the planning of light and colour in buildings. The technical development has provided us with better computer graphics and faster rendering techniques. However, the reliability and usability is delimited by lack of knowledge about how humans perceive spatial colour phenomena. The setting up of parameters for material properties in light calculation software is done arbitrarily. We present a comparison between a real room and a digital model evaluated on a desktop PC and in an Immersive Projection Technology (IPT) type system. Data were collected from video recorded interviews and questionnaires. The participants assessed the appearance of light, colours and space. They also evaluated their involvement in solving this task, and their presence in each environment. Our results highlight the benefits and disadvantages of the real and virtual models. The participants had difficulties in estimating the size of both the desktop room and the room in the ITP system. The comparison of real and virtual rooms revealed unsatisfying differences in shadowing and colour appearance. We defined the magnitude of perceived colour reflections in the real room, and elaborated with some of the parameters in Lightscape/3dsmax6.

Keywords: colour appearance, virtual environments, light, visualisation, colour bleeding

1. INTRODUCTION

Due to the complexity of the interaction between light and objects, the central conceptual and practical problem of computer graphics is the problem of lighting scenes [1, p.73-74]. In most computer graphics today, the goal is not to make correct simulations of reality, but to make visualizations that look good [1,2]. The light calculation programme software Lightscape™ uses radiosity to calculate how much light that strikes back from a surface. A colour bleeding scale defines how much the colour of the surface should change the colour of the "bouncing" light. This is done arbitrarily, because there are no recommendations built upon knowledge on how coloured surfaces reflect upon each other.

It is extremely difficult to predict the way the colour of a small sample will appear, when applied in full scale in a building, since the light in the room affects the visual appearance heavily. In principle, surfaces in a room works as filters for the striking light [3]. This depends on the physical properties of the light and the room surfaces, such as flux and angle of the striking light and the texture and colour of the surface. In addition, human perception depends on the state of adaptation and the complex treatment by the brain of the information of spectral composition that reaches the eyes [4]. We, as observers, interpret the whole situation, rather than each local point.

For the last ten years, several research projects on Colour appearance in Architecture have been carried out in Sweden, and much effort has been put on methodological aspects. It is problematic to identify the colour we perceive in rooms or on buildings. No instrument can measure what one sees. A reliable method that involves human observers is therefore required. The need to study real environments to obtain meaningful and useful results requires us to consider the complexity of the context as an essential feature of the situation in study. To tackle this complexity, methods and concepts were developed as shown in [5,6,7]. The overall goal of our research programme is to contribute to a deeper understanding of the perception of colours and display differences and similarities between the experience of real and virtual reality (VR) simulated room. The outcome can provide us with tools that enable us to create reliable virtual rooms to pedagogically display various colour phenomena and to communicate colour appearance during the design process. Traditional design tools, such as plans, perspectives and sections, have their difficulties to represent the three-dimensional world correctly [8]. Laymen have usually problems to understand them [9, p.52], which hinder their

participation in the design process. Virtual reality (VR) may reduce errors due to abstract representation [9] and it enables presence [10] in another world than the real, which can be of great advantage during a planning process. Immersive VR may also give a more account sense of relative straight-line distance compared to desktop [11].

There is no absolute definition of the term virtual reality. For the present study, we define VR as a computer-generated 3D world that allows the user to feel present and interact with the world in real time. The term "present" is of vital importance and has different meanings depending on the task to be performed in the world. Many tasks are best carried out in an immersive environment while others can be done with a single monitor We have a broad approach and use 3D-Cube and desktop VR with 3D-stereo glasses for stereographic models and desktop monitor for monographic models.

There are several steps to be aware of when transforming a monographic digital model (desktop) into a stereographic VR model. First of all, information is inevitably lost during the process. The quality of light and colour is inferior in the VR model, compared to the desktop. However for the participants' sense of involvement and presence, there may be advantages of being immersed by the room (VR). A previous pilot study showed that the poor light situation in the immersive space laboratory makes it [12]. Thus, the colour and light phenomena were closer examined in reality and on the desktop.

The aim for the present paper is to discuss and exemplify the arbitrary road from reality to virtual reality. We will describe our procedure of comparing spatial experiences, especially of colour appearance, in real and virtual environments. Further, the results from interviews of the observers involved in this study are discussed. The phenomena focused on here are: contrast effects, reflections from one surface upon the other, shadow colours and perceived colour of light.

2.Experimental Procedure

2.1 The real room
In the present study, we used a multi-coloured 25 square metre experimental room (*cf.* Figure 3 and Figure 4). Three different light situations were used: tungsten, fluorescent 2700K and fluorescent 3000K. For each light situation, 20-30 observers were involved. Data was collected by video recorded interviews and questionnaires for evaluating presence and involvement. We used modified versions of the questionnaires defined by Slater et al. [13], Witmer and Singer [14].

Six methods were used for evaluating light, colour and space, as described below. Methods 1-4 were used with all observers, while methods 5 and 6 were applied with five observers with special training for the methods.

1 Free description of the room and size estimation.

2 Motivated semantic differential scaling. The observer is asked to mark twelve qualities on an open 7-grade scale and to motivate the markings[1]. It is the correspondence between evaluations made in different situations that are of importance, rather than the observer's evaluation of the particular room used in the study.

3 Visual evaluation of light [15 and adapted in 5]. The observer describes various aspects of the light, such as light distribution in the room, light level, shadows, perceived colour of light, dimness and clarity.

 4 Semantic descriptions of the colours. The observer describes and compares coloured surfaces, using everyday language and the terminology in Natural Colour System (NCS).

5 Magnitude estimation. The hue of the colour is estimated according to its resemblance to the four chromatic elementary colours, and the nuance is estimated according to the degree of whiteness, blackness and chromaticness. The method is modified from [16] by the addition of a colour reference sample used for calibration of nuance.

6 Colour matching with a Colour Reference Box [17,18]. The observer matches colour samples in a small viewing booth (*cf.* illustration on the right side of Figure 2) with colours of room surfaces.

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[1] The qualities are: beautiful, nice, uniform, distinct, heavy, light, warm, soft, cheerful, harmonious, powerful, open, calm, stable and surrounding.

2.2 From real room to desktop

The digital model used in the desktop system was built in 3D Studio Viz™, and the light calculations were made in Lightscape™. The manufacturer of the light fixtures used in the real room, supplied digital models and recommendations for calculation of light for use in Lightscape™.

Inherent colour is defined as a property of the material that does not change due to viewing and lightning conditions. It can be estimated by direct comparisons with NCS colour samples. In the digital model, the software NCS Palette™ was used to define the inherent colours of the different surfaces (see Figure 1). Adjustments of the digital NCS colours were made to minimize the discrepancies between the inherent colours of the paints and the colours chosen for the digital model. The digital inherent colours were compared with the real paints in the colour reference box illuminated with 5500K. The display was calibrated to 5500K, and deviating nuances in the NCS palette were corrected. After these preparations, the light calculation was performed, and the different surfaces in the room were rendered (meshed) to textures, in order to get the effects of reflections on the different room surfaces. This operation can be explained as taking a picture of each surface (walls, floor, sides of objects) with all lighting effects shown. This was also necessary for using the Lightscape model in the 3D-cube, which was the next step of the study.

The paints are translated into the NCS system, first by physical measurements, then by digital transformation in the NCS Palette program. The digital colours are then checked and adjusted with the real paints.

The colours are applied in the 3D-model and the light calculation is performed.
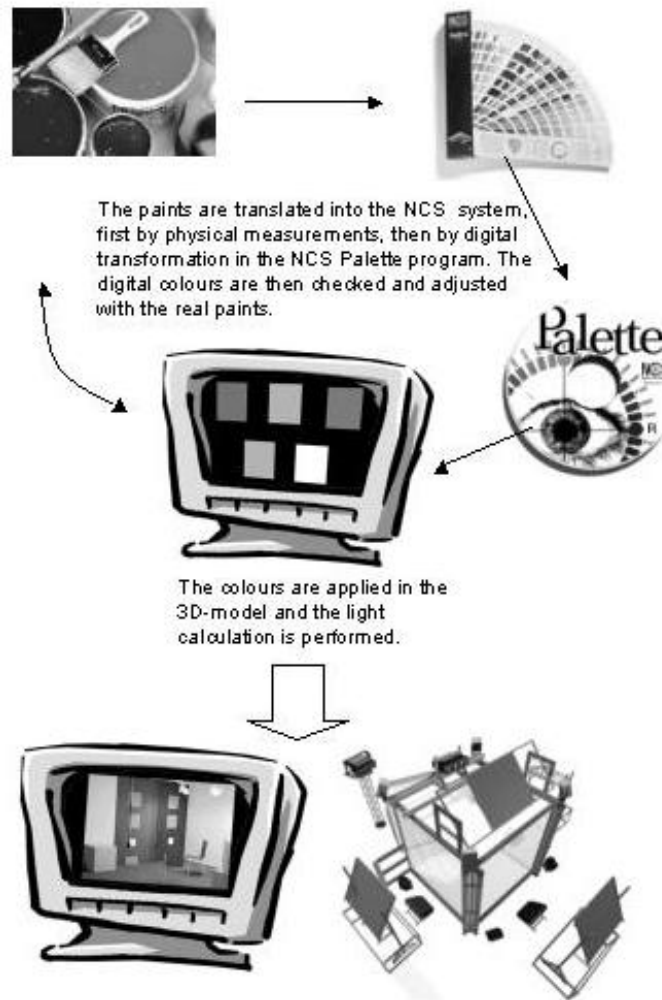
Figure 1. The procedure for translating real world colours into digital colours.

Ten observers studied the Lightscape model, simulating white fluorescent illumination (3000K), in a dark room using an extended questionnaire and methods 1-4 (described for the real room). To compare the Lightscape model and the real room, the different steps of the interview and the results of the magnitude estimation and the colour matching technique were analysed (see Figure 2). The different methods for assessing colours represent different levels of precision. The colour is determined from general terms, such as yellow, to a descriptive hue definition, such as light reddish yellow, down to a specific NCS number, such as 1035-Y15R.
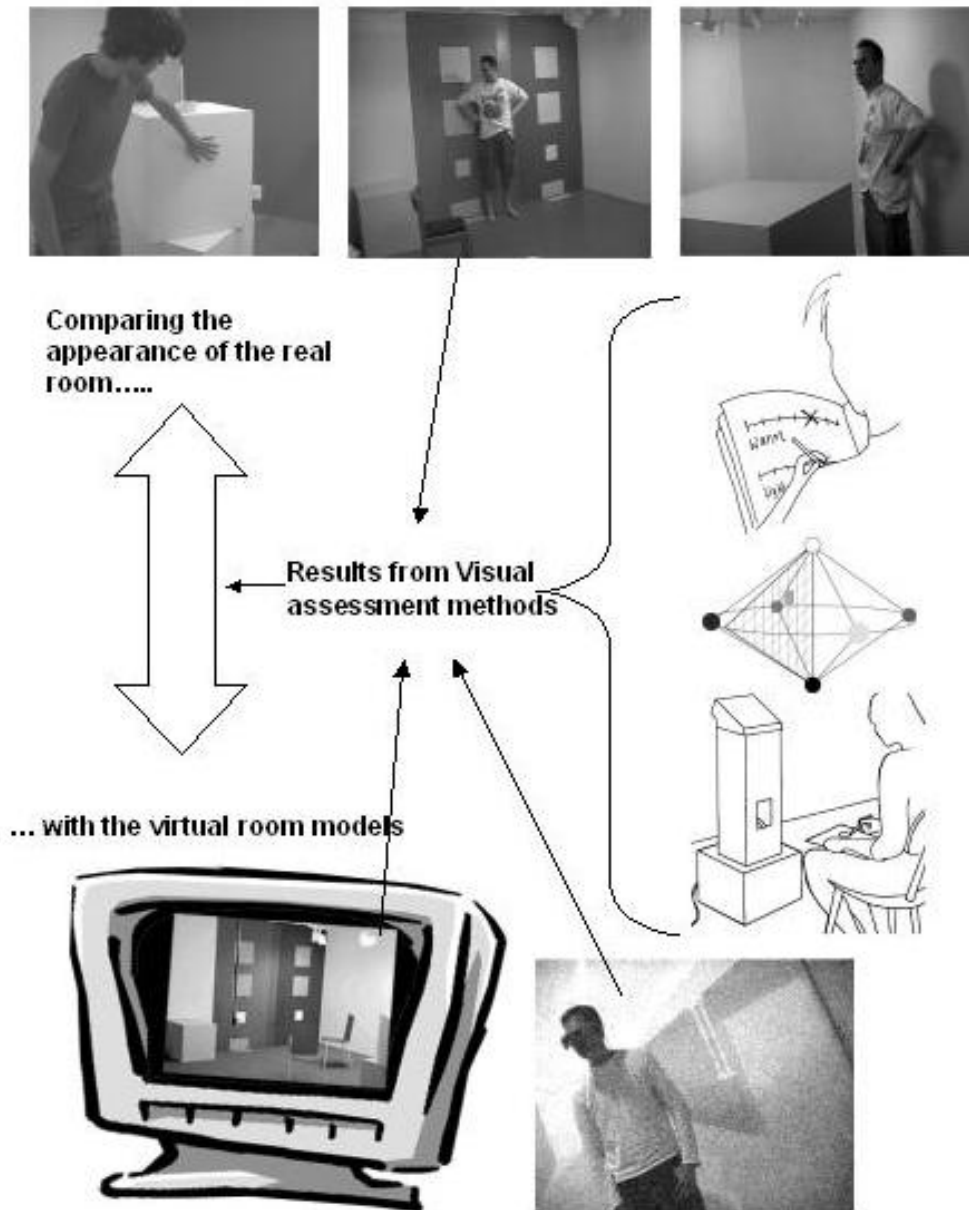

Figure 2. Real reality *versus* virtual reality.

2.3 Parameterisation of real room and digital data

The colour samples, picked out by the observers to match the surfaces in the real room, were placed in the colour reference box, to make a direct comparison between the display and the samples. With this analysis as a ground, the parameters in Lightscape describing colour bleeding, reflectance and colour temperature (i.e. the colour of the light source), were manipulated so that the digital model agreed with the real one, and noting what changes that were needed. Models simulating all three light situations (fluorescent 3000K, fluorescent 2700 and Tungsten, respectively) used in the real room were analysed. In addition, the models were also ran in 3dsmax 6.0, for the purpose of comparison.

2.4 From desktop to immersive virtual reality

The digital room model was translated in Division Mock-Up dVise 6.0 for use in Immersive Projection Technology (IPT). Due to the loss of colour quality and light level in the translation process, the colourfulness of the surfaces was increased by approximately 25%.

The IPT type system consisted of a 3x3x3 metre TAN 3D Cube with stereo projection on five walls without ceiling. The application was run on a Silicon Graphics Onyx2 Infinity Reality with 8 MIPS R10000 processors, 2GB RAM and 3 graphics pipes. The observers wore Crystal Eyes shutter glasses with a Polhemus tracking device and used the dVise 3-D mouse for navigation.

Twenty-six observers studied the IPT model, simulating white fluorescent illumination, using the extended questionnaire, methods 1-4 (described for the real room) and memory matching of one situation assessed after the other. Thirteen of the 26 observes started in the real room, going to the IPT, the others *vice versa*.

3. RESULTS AND DISCUSSION

3.1 Colour

In the real room (Figure 3), the differently painted surfaces had strong effects on each other by reflections. This caused large colour variations on equally painted surfaces that did not show in the virtual rooms. Several surfaces were painted in two different yellow nuances, one reddish and one greenish. In the real room, it appeared to be more nuances, compared to the digital models. The reddish was painted on the two cubes, on the wall behind the cubes and on the larger squares on the red part of the short wall. These appeared as more colours in the real room, compared to the digital models. For example, the cubes were painted in NCS 1030-Y10R (yellow). The sides of the upper cube faced walls painted with different colours. The different sides of the cube were so different in their colour appearance that many observers thought they were painted with different colours.
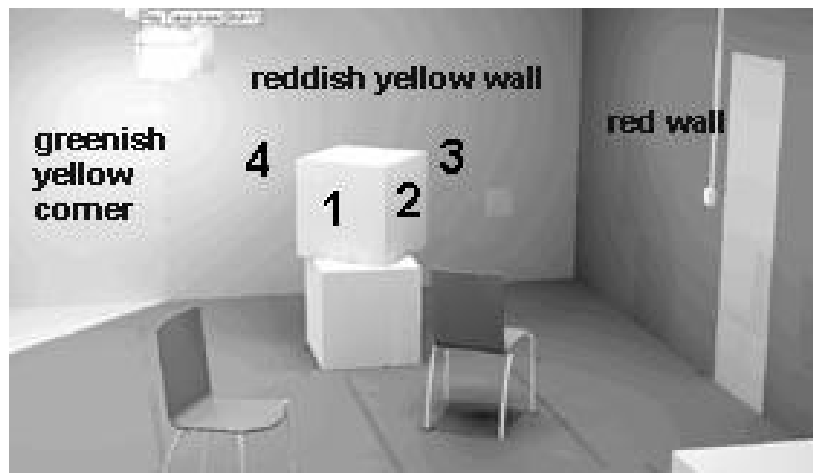

Figure 3. The cubes on the floor differed distinctly from the background wall painted with the same paint. The overall impression of them was yellowier than the wall. However, many participants questioned that they were painted equally. Side 1 had a yellow hue. Side 2 was redder. Side 3, facing the red/reddish yellow corner, was more colourful, and side 4, towards the green-yellow corner, was more greenish (lemon yellow).

In the digital model, we had problems to simulate the areas in the lightest nuances (areas 5- 8 in Figure 4). These areas, painted with NCS 0510-G90Y or NCS 0510-Y10R, became too greyish in the digital models. In the real room, the white fluorescent (3000K) illumination made the long light wall (area 6) almost white, and the short wall (area 5) was light beige. The small squares were white with a tint of pink (area 7) and green (area 8). This was not seen at all in the digital rooms. In fact, even a white wall became grey in the Lightscape rendering process.

Figure 4.The areas in the lightest nuance were difficult to simulate. They appeared too greyish in the digital models. The small squares (7 and 8) that were strikingly whitish in reality were hardly noticed in the digital models. The light areas were painted in: 5 and 7: NCS S0510-G90Y; 6 and 8: NCS S0510-Y10R. The larger squares were painted in the stronger nuance of the yellow hues. On the red and green background area 9 (1030-G90Y) and 10 (1030-Y10R) appeared almost equal in hue.

3.2 Light

The perceived light situation in the desktop model, using simulated white fluorescent illumination, corresponded well to the real room in all aspects, except for the colour of the shadows:

1. *Light level:* In the real room, the observers agreed on a light level between 6 and 8 on a 10-graded scale. The desktop model was perceived as somewhat lighter, between 7 and 9. In the IPT, the level was estimated between 3-6. The estimation was more difficult in this situation. Some observers described it as they could interpret the model as a simulation of a light room, although it was dark in the IPT model.

2. *Light distribution and shadows:* In the desktop, the shadows were found to be natural in the sense that they seemed to be in the right place. However, they were too achromatic. They were described as greyish and thin, as they were placed on a separate layer on top of the coloured surfaces. In the IPT, the observers did not accept the light distribution. The light did not seem to come from the light fixtures and the shadows were unnatural and misplaced. It was very annoying to realize that one has to "light up" the pre-rendered digital model with the software's own light!

3. *Perceived colour of light:* Most participants found the light in the room in the white fluorescent illumination to be cold or neutral in all situations. In desktop and reality it had basically no colour; some participants found it yellowish in reality. However, in the cave it was grey, and more participants found the perceived colour of light to be warmer than in the other situations.

The parameter analysis (using all three different lightning conditions) showed problems to simulate light distribution and perceived colour of light in the model simulating incandescent illumination The perceived colour of light did not turn out the same in Lightscape and 3dsmax. How were the predefined settings of illuminants in the software arrived at? None of the software's settings for incandescent light was red enough. The setting in 3dsmax was closer to the perceived colour of light i fluorescent 2700K: a yellow-greenish hue.

The way of handling the spectral power distribution of the light radiation is problematic. To put a coloured filter in front of the light source is too simple. It is possible to choose different colour temperatures, but in the software, this is only a choice of colour filters. Consequently, there is a need to programme various spectral power distributions in the software.

3.3 Manipulations of parameters

Recommendations for setting the colour bleeding level is based on praxis and experience among skilled professionals. In the present study, the parameters in Lightscape describing colour bleeding, reflectance and colour temperature (*i.e.* the colour of the light source) were manipulated to make the model resemble the real room as closely as possible. All surfaces with the same inherent colour where treated in one instance in the same way. We specially studied the colour appearance of the sides of the upper cube, the two different red walls and the two different light walls.

According to the documentation in Lightscape, the value for colour bleeding should be set to 100% in order to obtain physically accurate results during radiosity processing. However, this setting resulted in fewer colour variations, compared to the real room. Instead, the colour blending between the surfaces resulted in a room, where the grey and yellow (both are light and strong nuances) surfaces were reddish beige. The recommendation from the manufacturer of the light fixtures suggested 4-15% colour bleeding for the matt surfaces in the room, and this was used initially. However, the results from the parameter analysis showed that this setting is too low; at least 40% is needed, and different levels are needed for different colours.

To make the side of the cubes look like in the real room, we needed medium colour bleeding (40-60%). The setting was lower for the red compared with the two yellow materials, when the reflectance where on 100%. However, the high reflectance brightened up the areas around the long red wall too much. It was better to use lower reflectance on the dark areas and increase the level of colour bleeding.

In the real room, the two red walls (one long wall and one short wall partly painted in red) had distinctly different colour appearance: the long wall was much darker and more yellowish (*i.e.* browner). This difference was difficult to simulate.

For the long wall painted in light yellow, the light areas needed high reflectance in order to get the brightness around them. However, when the long light wall had high reflectance, its lightness was mirrored on the opposite long red wall that then became too light. To compensate for this, we needed to decrease the illuminance level significantly.

The long red wall in the real room had effect on all other surfaces. The effect on the opposite long wall was smaller than on the adjacent short walls, since it was illuminated directly with spotlights. In the digital model, the effects on the short walls were not well reproduced and too weak.

3.4 Interacting with the room models

The observers moved differently in the desktop, the IPT and in the real room (Figure 5). What does these differences mean to our perception of space? Although not the focus for the present study, the video recordings, the interviews and the questionnaires provide some results. In real rooms, one can walk around and take close looks at different locations and still keep a general conception of the room as a whole. Obviously, this is not possible when interacting with the virtual environments. However, our studies show that the immersive virtual environment (the 3D-cube) has advantages in front of the desktop. The IPT shares several advantages with the real room. However, the level of detail, the light quality and the physical sensations of direct contact with object are absent. In the IPT, the best illusion is perceived when one is standing still letting the room move around. In the desktop, however, the observers expressed their frustration for the difficulty to take a closer look in the model. When one gets closer, the overview is lost and the object becomes very abstract. It is also much more difficult to relate one's body to the desktop model, which is observed from "the outside".

3.5 Comments on the software

Since recently, Lightscape™ exists as a plug-in module to 3dsmax™. However, the stand-alone version of Lightscape™ has shown to be more useful. The difference is that Lightscape can provide a rather correct view of the illuminated room, while the model in 3dsmax™ is an approximation and requires making images to see the result of the light calculations. The 3dsmax™ is better suited for making animations, rather than to produce three-dimensional models.
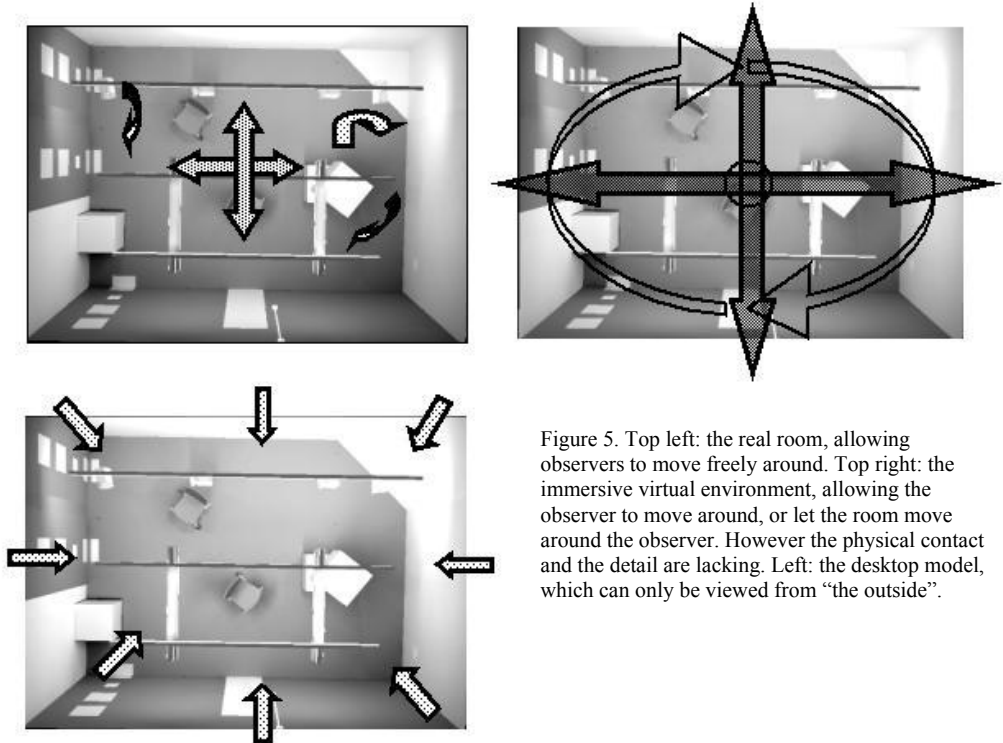
Figure 5. Top left: the real room, allowing observers to move freely around. Top right: the immersive virtual environment, allowing the observer to move around, or let the room move around the observer. However the physical contact and the detail are lacking. Left: the desktop model, which can only be viewed from "the outside".

4. CONCLUSIONS

In order to make true and realistic colour visualisations in virtual environments, the colour appearance of the real objects (rooms, buildings, etc) must be known.

Present technologies need further development to allow full manipulation of parameters, even if the real objects are known and available.

Parameters used need further exploration, both in the real and in the virtual environments.

5. ACKNOWLEDGEMENTS

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