Reflection Overlay as a Potential Tool for Separating Real Images from Virtual Images in Photographs of Architecture

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Abstract. The perception of transparency in architecture poses a major cognitive challenge due to the nearly faultless quality of large-scale light-permeable materials. Previous experiments demonstrated the significance of the virtual image in the perception of light-permeable materials. The separation of this image in photographs of architecture proved crucial in the research, giving the freedom to manipulate independently the components of the perceived scene. In the paper the author presents a new methodology of separating and manipulating real and virtual images, which is based on real-life photographs, not computer-generated scenes. The paper also proposes a step-by-step image processing algorithm which helps to better understand the cognitive processes of the human visual system, and presents sample results of this method.

Keywords: transparency perception, virtual image, digital image processing.

1 Introduction

The perception of transparency in architecture poses a major cognitive challenge due to the nearly faultless quality of large-scale light-transmitting panes. Smooth light-permeable panes simultaneously transmit and reflect the luminous fluxes that enter the panes from both sides, which, in turn, generates two separate luminous fluxes affecting the observer. Those luminous fluxes are formed at the stage of distal stimuli generation. When the proximal stimulus reaches the sensory receptor organs, these luminous fluxes become con-fused (deliberate hyphen) proportionally to their value. Since they stimulate the same area of the retina, they are further processed by the visual system as two superimposed images: the real one and the virtual one. The superposition of those two images constitutes a real challenge for the visual system. The amount of information reaching the retina is the same (ca. 100 billion bits/second), but the interpretative potential is multiplied.

The specular reflection off the smooth surface of the pane and the resulting virtual image are the main perceptual cues that the human visual system interprets to identify the optical transparency of the pane. The virtual image is also used to determine the orientation of the pane in the 3-dimensional space surrounding the observer, i.e. the

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so-called "cognitive map". The cognitive process of attention carefully selects the information contained in the superimposed images, but, paradoxically, "establishing whether a given information is significant requires full processing" of said information [1, p. 115]. Conversely, research shows that if the virtual image is not present, the light-permeable pane seemingly vanishes and becomes invisible for the observer, who can accidentally walk into it and get injured. The American architect and theorist prof. Michael Bell, of the Columbia University's Graduate School of Architecture, writes: "in an idealized realm, without reflection or surface complexity, glass has always strived to disappear" [2, p. 13]. Thus, it may be stated that the formation of the virtual image determines the user's safety. The following research aims at furthering the knowledge on this issue by improving the understanding of the processes that occur.

2 Advancing the Research of Transparency Perception

The ubiquity of virtual images on smooth light-permeable panes requires one to determine specific conditions for study and experimentation. In previous research performed by the author, the virtual image, which was considered the main transparency cue, was verified through a negative control experiment. The experiment was based on a comparative estimation of the perception cues available to the human visual system before and after removing the virtual image from the observer's field of view. This virtual image is removed when distal stimuli are formed – when fluxes interact with the panes, before the con-fused luminous fluxes affect the retina. The virtual image can be eliminated because when each ray of light is reflected (i.e. it bounces off), it changes the direction of its polarization. Such polarized light can be selectively blocked using appropriate optical filters.

The general concept of this research is based on two assumptions: *(i)* the influence of the virtual image on the perception of light-permeable panes could be more adequately measured by manipulating the virtual image, to check, how it affects the perception of transparency; *(ii)* the virtual/real image ratio is more credible and explicit in real-life photographs than on computer simulations[1]. The analysis of real-life photographs of architecture lacks the precision of the analytical method and requires careful preparation of the image data, but gives the researcher a full record of the actual light field – all the luminous fluxes affecting the real-life scene at a chosen moment, from a chosen angle.

3 Terms and Recent Studies Report

In his recent research (presented at the HCI 2013 conference) the author developed a photograph-based method called "pictorial image analysis" [3]. This method

[1] The amount of light which enters a building and which is reflected could be calculated analytically based on the optical parameters of the light-permeable materials, the plan of the building and the position of the viewer.

compares pairs of corresponding photographs of the same light-permeable pane, of which one is unmodified and contains the virtual image formed on the surface of the light-permeable pane (hereinafter called *file A*), and the second is without this image (hereinafter called *file B*). *File B* was photographed using a polarizing filter to block the reflected rays of light that make the virtual image “visible” on the surface of the pane. Afterwards, the pairs of corresponding images were digitally processed using image processing software.

4 Data Acquisition Procedure: *file A* and *file B*

The image data were acquired following a strict procedure, which ensured that the corresponding images in each pair had identical values of image parameters, such as exposure, color matrix, brightness curve etc.

4.1 Image Shooting

The pairs of corresponding files, i.e. *file A* and *file B,* were captured using Sony Alpha 100 DSLR camera with Sigma 10-20 mm lens. The camera was stabilized on a tripod to assure the same field of view; the shutter speed and the aperture values were manually set. A lens-mounted polarizing filter was used to block the reflection bouncing off the light-transmitting pane. The filter’s rotation angle was set manually to achieve the best result, which was assessed visually on site. At least three images were recorded, each with different angles of filter rotation. The photos were taken as RAW images, i.e. unprocessed data directly from the CCD image sensor of the digital camera.

4.2 Image Post-processing

The RAW image data was processed using Image Data Converter SR ver. 1.1.00 by Sony, which is dedicated software for this camera model. The pairs of corresponding RAW images were converted to TIFF 24-bit true color with the same exposure values (EV) and other image parameters.

4.3 Case Study Buildings

Two case study buildings were selected for this stage of research: Thespian Housing and Office Building (Macków Pracownia Projektowa, 2010) and Wroclawski Park Wodny – a swimming pool complex (arch Horst Haag/I-Plan GmbH, 2008). The first building had been studied in the previous part of the research, published in HCII 2013 conference materials. The buildings were photographed from different vantage points and from different angles (see Fig. 1). The Thespian Housing and Office Building is prominent example of contemporary architecture, recognized worldwide, and it was a “nominee for the European Union Prize for Contemporary Architecture – the Mies van der Rohe Award” [3, p. 191].

a *b*

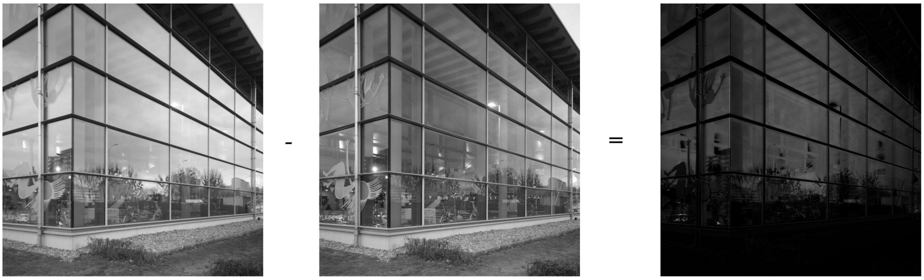
Fig. 1. Case study buildings: a) Thespian Housing and Office Building (Macków Pracownia Projektowa, 2010); b) Wroclawski Park Wodny (arch Horst Haag/I-Plan GmbH, 2008)

5 Image Subtraction

The visible image on the light-permeable pane is composed of two images: the real one, which is transmitted through the pane, and the virtual one, which is created by the rays of light reflected off the pane. These two component images: real and virtual, or, in other words, transmitted and specularly reflected, are transparently overlaid on the pane. This is the result of the con-fuse, or mix, of luminous fluxes which form the component images. If the luminance of the virtual image is higher than that of the real image, the real image is less visible than the virtual image. If the opposite happens – the virtual image is less visible. The original luminance values of the of the "weaker" images remain unaffected, i.e. darkening does not occur! The impression of attenuation of the "weaker" image results from the physiology of the human eye, which adjusts the size of the pupil in response to the amount of light present in the most intense luminous flux.

The proposed image processing algorithm bases on the analysis and comparison of color pixel values in *files A* and *B*. The observation is that the real image is less visible than the stronger virtual image, which – in terms of luminance and color values – means the brightening of the color resulting from the con-fuse. As a result of the con-fuse of luminous fluxes, the colors are mixed in an additive manner based on the RGB model values (0-255, 0-255, 0-255). Hence, it is possible to calculate the difference between *file A* with the virtual image, and *file B* without this image. This could be achieved by subtracting images from each other, where the RGB values are respectively subtracted, creating a new image, hereinafter called *subtraction image* (see Fig. 2).

The image calculation – i.e. the subtraction – was performed using ImageJ software. The obtained *subtraction image* was saved as 24-bit true color TIFF image. The calculation was carried out using the ImageJ post-production software for the analysis of medical image data [4], which was originally developed by the Research Service branch of the U.S. National Institutes of Health. This was followed by image processing operations (described below), which produced the *reflection overlay*.



file A *file B* *subtraction image*

Fig. 2. Phases of image subtraction: *file A* and *file B* and the resulting *subtraction image*, i.e. the separated reflection on a black background. The regions unaffected by the reflection are black, whereas the other regions contain different levels of luminance and color.

6 Creating the Reflection Overlay

The new concept presented in this paper, called *reflection overlay,* basically simulates a natural light-field by means of digital software. The method makes use of transparent layers, which are a common tool in digital image editing offered by popular and professional software. The layers are stacked on top of each other, and, depending on the order and the transparency settings, they determine the appearance of the final outcome.

The idea behind the *reflection overlay* method is to stack the elements of the image in the correct order. *File B* without the virtual image must always be placed at the bottom of the stack. A separate transparent *reflection overlay* layer with only the virtual image is placed directly over it. Because it is separated, it can be freely modified, duplicated or distorted without affecting the other layers. This makes it possible to observe the influence of the virtual image on the perception of light-permeable materials in architecture.

The next section presents two approaches to creating transparent *reflection overlay*, which are based on digital image post-processing, and which produce slightly different results.

6.1 Using the Alpha Transparency Channel

Additional image data can be stored in the so-called alpha channel (with a value between 0 and 1) and denote the transparency of the pixels: 0 meaning full transparency, and 1 meaning full opacity. In the *subtraction image*, the regions unaffected by the reflection are black, whereas the regions affected by the reflection contain different levels of luminance and color. A simple image processing operation: Layer → Transparency → Color To Alpha – converts this *subtraction image* into the transparent *reflection overlay*. This is achieved by assigning a channel value to each pixel based on their corresponding luminance values, e.g. a black pixel which becomes fully transparent has a channel value of 0 assigned to it; a white pixel which becomes totally opaque has a channel value of 1 assigned to it; intermediate values of alpha are assigned to other pixels depending on their luminance values (see Fig. 3).

Fig. 3. Conversion of the *subtraction image* to the transparent *reflection overlay* using Layer → Transparency → Color To Alpha. The alpha channel value of 0 is assigned to every black pixel, while the values between 0 and 1 are assigned to other pixels, depending on their luminance.

6.2 Using the "Addition" Layer Mode

Similar results can be achieved by simply manipulating layer properties. This method requires the same order of layers as in the first approach, but the alpha channel transparency is not assigned to the top layer with the *subtraction image*. The transparency of the *reflection overlay* is achieved by setting the Layer Mode to "addition".

Fig. 4. Assigning transparency to *reflection overlay* by manipulating the Layer Mode of the *subtraction image* layer

This operation "reverses" the previously performed subtraction, but allows the researcher to independently manipulate the *reflection overlay*, which is on a separate layer (see Fig. 4). The layer could be switched on and off, its transparency could be adjusted, as well as the image transformations could be applied to this layer.

6.3 Using the Alpha Channel vs. Layer Mode Approach

As depicted in Fig. 5. the results of both approaches slightly differ with the latter method delivering a more intense image. This image more accurately reproduces the original *file A*, i.e. the one with virtual image. This could be the result of the difference in the algorithms of assigning transparency for each approach. The blending of images with alpha channel usually follows the algorithm: (RGB *file B*) + (RGB s*ubtraction image* * alpha); whereas in the layer mode approach, the algorithm is a simple RGB addition (RGB *file B*) + (RGB s*ubtraction image*).

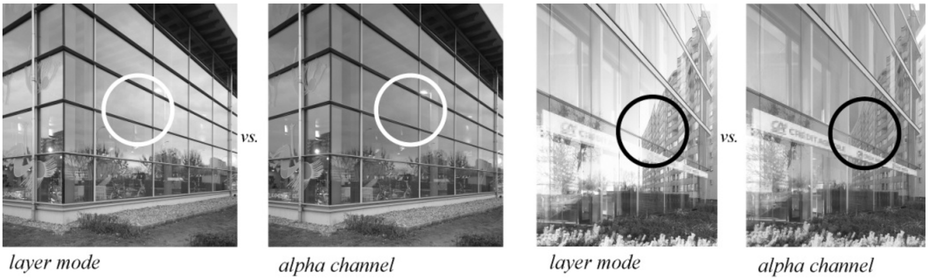


Fig. 5. The difference in the final outcome between the alpha channel method and the layer mode method of assigning transparency to the *reflection overlay*

7 Modifications of the Transparent *Reflection Overlay*

The separation of the transparent *reflection overlay* allows the researcher to manipulate the virtual image independently of the other layer. The possible modifications of the transparent *reflection overlay* include: *duplication*, *multiplication with shift* (i.e. duplication with a change of location), barrel and pincushion *geometrical distortion,* and *tinting* and *blurring* of the virtual or real image.

- *Duplication* of the virtual image increases its luminance and makes it more visible than the real image. Adding another layer, with the transparent *reflection overlay,* causes a logarithmic increase in the luminance of the virtual image, which, with each subsequent layer, adds up until the maximum value of white (255, 255, 255) is reached.
- *Multiplication with shift* leads to an interesting perceptual phenomenon: depending on the value of the shift, part of the field of view seems out of focus. This simulates a real-life optical phenomenon, where two light-permeable panes are located in relatively close proximity and the two superimposed virtual images are not recognized by the observer as separate, but as one image that is out of focus. This cognitive phenomenon is quite extraordinary. Parts of the virtual image seem blurred, while the rest of the observer's field of view is in focus.
- *Geometrical distortions* allow for the simulation of the non-linear geometry of the reflecting surface. In the case of curved panes, the visible virtual image becomes the "reflection of the environment" – that is why the use of real-life photographs

was previously postulated. The extent of the distortions and the location of highlights (regions of higher luminance) can constitute an important cue for the human visual system. It seems that the human visual system “knows” the principles that shape the image on the light-permeable pane well enough and, “guided” by the location of highlights, “decodes” the 3-dimensional form of a smooth object. Those highlights also “affect observers’ judgment of surface gloss” [5, p. 165], It seems reasonable to theorize that observation of the highlights results in the impression of “smoothness”, which occurs at mid-level perception.

- *Tint* applied to the virtual image reproduces the perception of light-permeable materials that absorb certain wavelengths of light. The light can be absorbed during transmission – in which case the real image is tinted, or during reflection, in which case the virtual image is tinted. Both processes can be modeled using the above-mentioned method with consideration of the specific results of the con-fuse of luminous fluxes. A monochromatic tint overlaying the entire field of view makes the light-permeable surface clearly recognizable.
- *Blur* applied to the virtual image reproduces the perception of light-scattering materials which cause *(i)* blurring of the edges of objects located on the other side of the pane, and *(ii)* a decrease in contrast that is much higher than the one resulting from absorption.

8 Conclusions

In comparison with the previously proposed method of “pictorial image analysis”, the new algorithm of *reflection overlay* utilizing the addition layer mode is much more precise in evaluating the influence of the virtual image on the perception of transparency in architecture and gives the researcher freedom to modify the conditions of the preformed tests. The new algorithm is more objective, less biased and less user-dependent. Provided that the conditions of the data acquisition are strictly followed the algorithm could be applied almost automatically.

Due to its relative simplicity (only basic equipment and software are required) and clear, easy-to-follow, step-by-step guidelines, the presented transparent *reflection overlay* method can be used by architects in assessing the results of their design.

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