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RESEARCH ARTICLE

Visual comfort is affected by urban colorscape tones in hazy weather

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Abstract
People's visual perception and recognition of urban colorscape tones change significantly in hazy weather. A psychological experiment is conducted in this study to investigate visual comfort related to commercial and residential buildings. Visual observations are performed on the tones of an urban colorscape during hazy weather and air pollution in Harbin, China. Fifty-eight color samples selected through an orthogonal method are evaluated through a Likert scale by 30 subjects in a laboratory setting. Statistical analysis is performed with the maximal information coefficient and R language. Experimental results show that the changing threshold values of color tones are related to the visual comfort levels of the subjects. The influence of the three factors of color tones on visual comfort level is relatively independent, and the effects of value and chroma contrast on color comfort level are greater than that of hue contrast in hazy weather. Furthermore, the comfort recognition threshold values of color tones in hazy weather are determined through data comparisons and analyses.

1. Introduction

Most developing countries encounter environmental observation obstacles caused by hazy weather. Low visibility in hazy weather seriously affects the daily lives of city residents, who face increased air pollution on a global

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scale; this increased air pollution results in increased respiratory illnesses and even death (Wei et al., 2016; Lawin et al., 2016; Cakmak et al., 2016). Environmental pollution in China is a typical example; various traffic accidents have occurred in major cities because of hazy weather conditions (Tu et al., 2014; Li and Zhang, 2014; Yin et al., 2016; Wang et al., 2014; Long et al., 2016).

In urban spaces, colorscape is the main factor that affects environmental recognition (Zheng, 2006). Similar to urban green space, colorscape supports the ecosystem services of urban areas and protects public psychological health (Wolch et al., 2014). It is also a specific environmental factor related to the physical activities of urban populations, particularly older adults (Wang, 2014). Colorscapes can mitigate the moods of people and alleviate visual pressure. Considering that building color occupies the largest part of the urban environmental colorscape, it is a decisive factor that affects colorscape (Yin, 2004). Building color is man-made, similar to the many components of the urban environment; this urban environment is the main target of sustainability and regeneration strategies of cities (Chiesura, 2004). However, most of the building colors in an urban environment do not exist separately. Instead, they are generally presented as combinations of two or more colors; tonal relationships are thus established. Building colors can generally be regarded as a type of form or space that consists of various colors, including main, secondary, and dotted (Ural and Yilmazer, 2010; Tian et al., 2011). This combination is based on the three color-appearance attributes and forms the abundant color tone of a building through value, chroma, and hue contrast among the different areas of the building's colors. In their semantic evaluation of architectural color design, Ural and Yilmazer (2010) found that color tone plays a remarkable role in the cognition of the color and urban space of architecture. Therefore, improving the colorscape tone of urban areas to overcome environmental visual identification obstacles in foggy and hazy weather is a critical issue that city planners and architects must address.

Research on color tone has focused on two main aspects. The first is the study of color preferences with regard to different color combinations. This area includes analyses and predictions of different preference values of color tone and emotions resulting from different color tones, such as warm-cool, light-heavy, modern-classical, and active-passive, as well as psychological assessment studies (Guilford, 1931; Ou et al., 2004). For example, Hogg (1969) investigated 12 color emotions to study the combinations of color tones. He identified four underlying factors, namely, active potency, evaluative, emotional tone, and usual/obvious. Sivik (1989) identified the factors that influence color emotion by examining 100 color emotional scales. Yang et al. (2013) used color and its luminous conditions in visual performance assessments, and Lam and Cheng (1998) explored color through environmental assessment, particularly in pollution conditions. The latter research addressed the degree of color harmony. Ostwald (1969) and Munsell (1969) proposed the principle of color order and area balance; this principle harmonizes colors based on their solid characteristics. Itten (1961) found that the color harmony model depends on the position of different colors in the hue circle.

Research on building color tone has focused on the relations of the color tones of the building façade and their functions in space. For instance, Le and Ruegg (1997) argued that color changes the distance between adjacent buildings by opening the visual perspective relationship between the buildings and breaking the feeling of extrusion between the adjacent walls. Research on the color tones of buildings has also examined aesthetic, cultural, and ethical concerns and other social aspects (Serra et al., 2012).

However, these color tone discussions regarding the creation of architectural space and form were conducted under normal weather conditions. When haze is present in the environment and visual identification is disturbed, how do human recognition and identification of the tone of the urban colorscape change? Addressing this question in the framework of color tones requires further study. Meanwhile, improving the overall urban environment, landscape recognition, and visual comfort of the urban colorscape is also an effective method. Urban colorscape designers will greatly benefit from broadening the field of building colors.

This study is conducted in the context of the foggy and hazy weather in China. This study aims to investigate the relationship between human visual comfort level and the *value contrast*, *chroma contrast*, and *hue contrast* of architectural color tones in hazy weather. Additionally, the comfort recognition threshold values of the color tone of a building in hazy weather are determined. A model is built to clarify the quantitative relationship between architectural color tone and visual comfort level in hazy weather. Experiments are designed through orthogonal methods to select the urban colorscape represented by buildings. The experiments are based on practical fixed-point measurement of the architectural color tone in both hazy and normal weather conditions. A psychological evaluation of the visual comfort levels of the subjects is also performed with the architectural color tone in normal weather as the standard. The comfort levels of the subjects are predicted by identifying the color tone range. In this manner, a quantitative index of architectural colors is provided to designers, and referential research methods for the planning and evaluation of urban colorscapes in abnormal weather are established.

2. Method

2.1. Sampling method

The experiment assessed the visual comfort level of different color tones of urban colorscapes represented by buildings. Taking photographs has been used as an effective method in investigating the color tones of buildings; it is a method proposed by Lenclos to mimic research target colors (Lenclos and Lenclos, 1990). The architectural color scale card of the Chinese color system (GSB 16-1517-2002) was used to visualize architectural colors, and a portable color luminance meter (TOPCON BM-7) was used to adjust these colors. The luminance meter was calibrated on a standard whiteboard made of barite. Photographs were obtained under hazy and normal weather conditions at 0.5 km fixed distance point shooting. The selected sampling site is Harbin, one of the most heavily polluted city

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