

URBAN LIGHT AND COLOR

ALEX BYRNE AND DAVID R. HILBERT

Alex Byrne teaches philosophy at MIT. His main interests are philosophy of mind (especially perception and consciousness), metaphysics (especially color), and epistemology. He has written a number of papers on color with David Hilbert; they also edited a two volume anthology on the philosophy and science of color, *Readings on Color* (1997).

David Hilbert teaches philosophy at the University of Illinois at Chicago and works primarily on issues concerning color and vision. He is the author of *Color and Color Perception* (1987) and he edited a two volume anthology on the philosophy and science of color, *Readings on Color* (1997), with Alex Byrne.

MIT's Stata Center, Cambridge. Attached shadow on right-facing brick wall; cast shadow on metal cladding opposite.

¹ Tom Porter and Byron Mikellides, *Colour for Architecture* (London: Studio Vista, 1976), 10.

² Tom Porter and Byron Mikellides, *Colour for Architecture Today* (Abingdon, Oxon: Taylor & Francis, 2009), vii.

³ Jean-Philippe Lenclos and Dominique Lenclos, *Colors of the World: the Geography of Color*, translated by Gregory P. Bruhn (New York: Norton, 2004), 86.

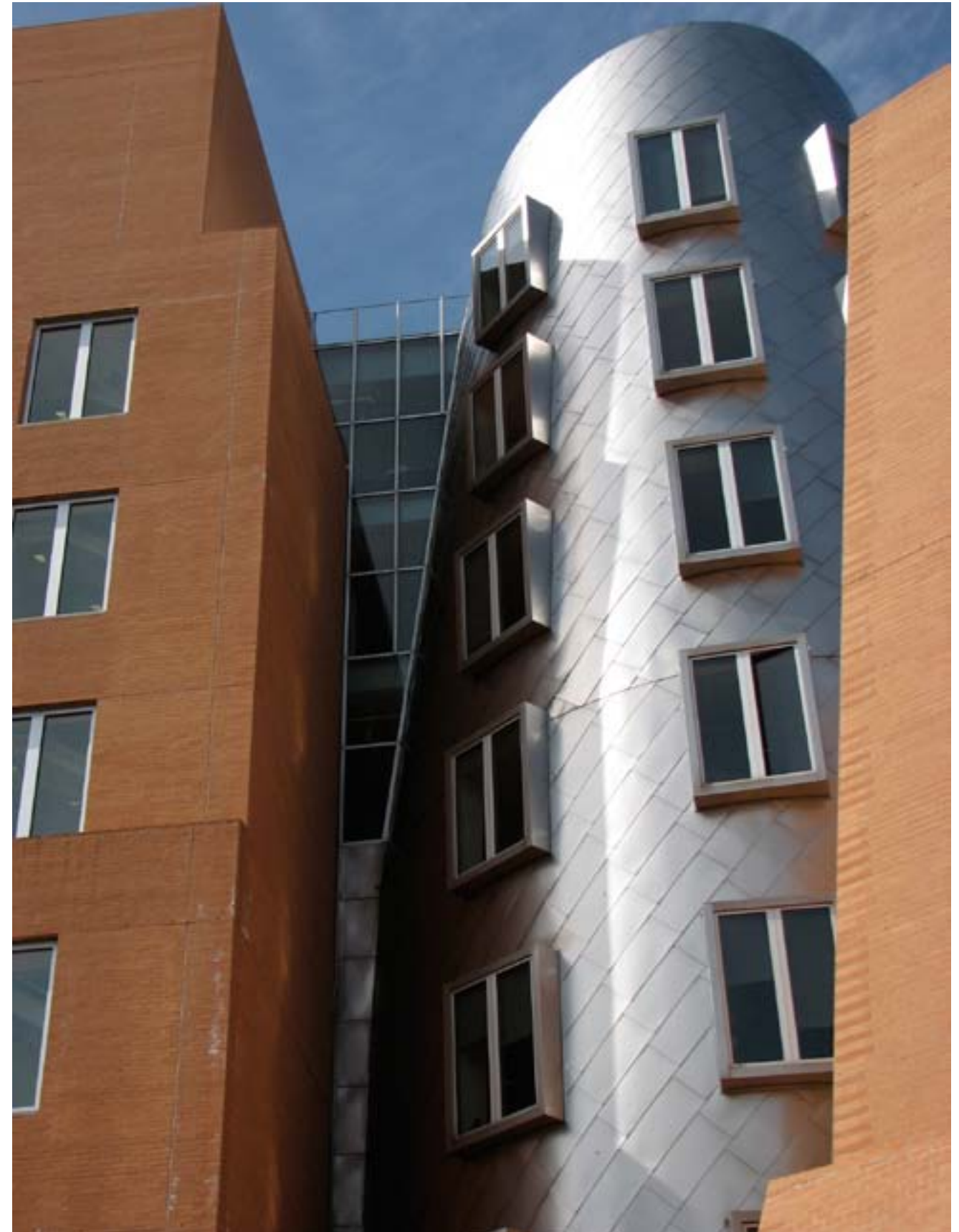
In *Colour for Architecture*, published in 1976, the editors, Tom Porter and Byron Mikellides, explain that their book was “produced out of an awareness that colour, as a basic and vital force, is lacking from the built environment and that our knowledge of it is isolated and limited.”¹ Lack of urban color was then especially salient in Britain—where the book was published—which had just begun to recoil at the Brutalist legacy of angular stained gray concrete strewn across the post-war landscape. Perhaps because the most urgent need was to inject some hue into this architectural dystopia, one of the main innovations illustrated in the book involves nothing more than cans of paint. Dull unfinished concrete façades, the interior of a subway station, a cement works, and so on, are shown enlivened by fields of bright color.

The mood is more optimistic in *Colour for Architecture's* successor, *Colour for Architecture Today*, published in 2009. The later book is itself more colorful as befits “these much more open, enlightened and adventurous times” (from Sir Terry Farrell’s foreword).² Indeed, even the cans of paint are assigned to the ash heap of history, along with all that gray concrete—“the concept of the painted surface is passé,” at least according to Jean-Philippe Lenclos.³ Screen-printed glass, enamel, dichroic film, and other materials are used to achieve exterior effects that paint never could.

The two books contain a diverse selection of interesting essays, but what largely goes missing is an examination of how our perception of color is affected by a distinctively urban setting. At night the main factor is artificial exterior lighting from street lamps, storefronts, and cars, but what about daytime city life? The question raises large and complicated issues. In this short space, we will briefly discuss how a number of features of the daytime urban environment influence color perception.

COLOR VISION: SOME BASIC FACTS

The perception of color begins, of course, with light. Take a simple case of seeing an opaque object, say a brick, in sunlight. The brick will absorb some of the sunlight, and reflect the rest back. More specifically, the brick will reflect a fixed percentage of the energy at each wavelength in the visible spectrum—this is the brick’s (surface spectral) reflectance. The reflected light can be characterized in terms of its spectral power distribution or SPD, which specifies how its energy is distributed among the wavelengths of the visible spectrum. The light then enters the eye of the observer, where it is selectively absorbed by pigments in the cones (photoreceptors used for color vision) at the back of the eye. The response of the three cone types is then subject to further processing in both the retina and various cortical areas, and the upshot is that the brick looks yellowish-red.



Reflectance is important because it is a major determinant of perceived color and, arguably, is the property we see as surface color. And, in fact, contemporary models of color vision usually assume that the primary computational task of the color vision system is to estimate the reflectance of objects from the color signal, the light reaching the eye.

But how is such estimation possible? The color signal from our brick, for instance, is the joint product of the SPD of the illuminant and the spectral reflectance of the brick. In principle, innumerable many combinations of illuminants and reflectance can produce the same color signal, so how can the visual system work out which of these combinations is the right one? It is as if the visual system were given an equation like “ $24 = X \times Y$ ”, and told “Solve for X”. Despite the fact that the visual system’s problem is in this way “under-constrained,” something close to the correct solution is often found—objects by and large look to have the colors they actually have, through a wide range of lighting conditions. The visual system accomplishes this remarkable feat—to cut a very complicated story short—by making realistic assumptions about the range of illuminants and reflectances in the real world and by treating each object in the context of the whole scene in which it is found. To re turn to our algebraic analogy, we can make an accurate estimate of X if we can discover from other sources that Y is either 6 or 8.

The stability of perceived color through variation in illumination is known as color constancy. This will be important in what follows.

ILLUMINATION

The ultimate source of outdoor light during the day is the sun. Typically, an object in the direct sun will also receive a significant amount of light from the sky. This combination of direct sunlight and skylight is known as “daylight” (a technical term in the literature) and is a common reference point in discussions of natural illumination. The SPD of daylight varies with latitude, time of day, cloud cover, and other atmospheric conditions, with the standard daylight SPD rising quickly from the short wavelength (blue) end of the spectrum to a peak and then declining slowly toward the long wavelength (red) end.

In the urban core the usual properties of daylight can be modified to a significant degree. Direct sunlight is often not present, decreasing the intensity (often dramatically), and shifting the SPD toward short wavelengths. Sometimes there is direct sunlight but comparatively less illumination from the sky, decreasing the short wavelength component. Less precisely but more plainly, this makes city daylight dimmer and bluer, or slightly yellower, than daylight in a setting lacking parallel rows of very large opaque objects.

Various atmospheric components can also significantly alter the SPD of daylight. Aerosols (small airborne particles, such as water vapor, smoke, and dust) produce variation in the SPD of daylight everywhere, while in the urban core a number of common pollutants are optically significant, including smoke, and the nitrous oxides from vehicle exhaust. Some of these effects are most visible late in the day or early in the morning, typically making daylight dimmer and yellower.

However, because of color constancy, the result of this all this variation is not to produce a dramatic shift in the perceived color of the cityscape.

When one turns a corner, going from direct sun into a street lit only by skylight, the significant change in the illuminant does not lead to a correspondingly large shift in the perceived color of one’s clothing, automobiles, and the surrounding buildings. On the other hand, it is not as if there is no perceptible change—the dimmer, bluer character of the illuminant is also clearly visible.

One natural way of describing this complicated experience of stability and change is that we see both the unchanging colors of surfaces and the changing illumination. An alternative—and less natural—description is that moving from direct sun into skylight does change color appearances, and hence there is actually no color constancy, at least as we have characterized it. What is constant, on this view, is our judgment or belief that the colors have remained the same, not color appearances. We judge that the colors have remained the same, and that the illumination has changed, because we know that buildings and the like normally have stable colors, and that illumination often changes. The second view can seem plausible if the process of vision is analogized to painting on an internal or mental canvas, an analogy that many philosophers have found tempting. A painter only has differently colored paint to achieve the effects of different illumination. A naive observer might take a canvas to be uniformly colored and differently illuminated, although in reality it is differently colored. Similarly, moving from direct sun into skylight changes the mental paint on the mental canvas, thus changing color appearances.

There is a practical difference between these two descriptions. If the second is correct then, at least in principle, it should always be possible to adjust the reflectance of an object so that viewed under skylight, it looks the same as it did when viewed under direct sun. If the first description is correct, then there is no guarantee that such an adjustment will have the desired effect, since the illumination will sometimes be visibly different.

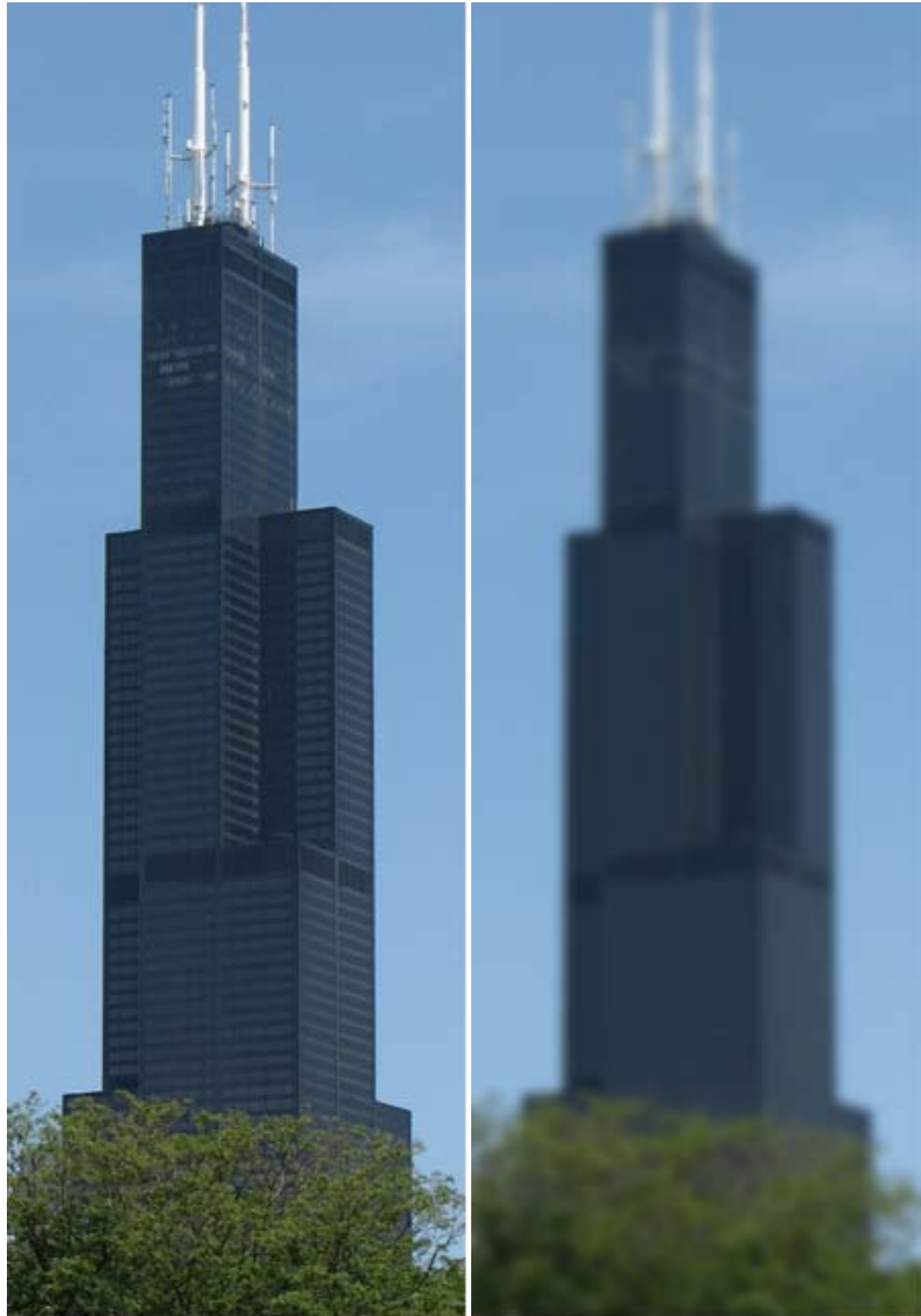
Interestingly, there is some evidence from the laboratory in favor of the first description. Subjects are sometimes unable to make two objects in different lighting conditions look exactly the same, despite being allowed to, in effect, adjust the reflectance of one of the objects at will⁴.

SHADOWS

As just discussed, the SPD of city light differs from that of other sorts of outdoor illumination. One way in which it differs, worth noting separately, is in the prevalence of large shadows. These are less frequent in suburban settings with lower, more widely spaced buildings, or in rural environments. In forests, for example, light is dappled and filtered by the leaf cover, with fewer sharp-edged large shadows.

Shadows are sometimes classified as “cast” or “attached.” A cast shadow is formed when one object blocks light from striking another; an attached shadow is formed when one object blocks light from falling on itself, as when the front of a building faces the sun, preventing the light from illuminating the back. Both sorts of shadows are shown in Fig. 1. In the city, large cast-shadow boundaries are common; the illumination in a shadow is not just less intense than the illumination outside, but often differs in its spectral characteristics, being more similar to skylight than to direct sunlight.

4 D. H. Brainard, W. A. Brunt, and J. M. Speigle. Color constancy in the nearly natural image. I. Asymmetric matches. *Journal of the Optical Society of America A. Optics and Image Science* 14 (1997): 2091-2110; A. Logvinenko, and L. Maloney, The proximity structure of achromatic surface colors and the impossibility of asymmetric lightness matching. *Perception and Psychophysics* 68 (2006), 76.



Willis Tower, Chicago. Appearance changes with increase in viewing distance. Left: approximately 1/2 mile. Right: approximately 3 miles

Return to the painting analogy. Since shadows are depicted using differently colored paints, darker and often of a different hue than the paint in a neighboring unshadowed region, a proponent of the “internal canvas” would claim that urban shadow boundaries make buildings appear variably colored. But, again, this sort of description is not faithful to the phenomenology. The most natural way to describe how the metal-clad tower in the figure looks is uniform in color, with the leftmost part in shadow. Shadows thus provide another illustration of color constancy, of unchanging color appearance under changing illumination. They also vividly illustrate how the idea that we simply see the color of an object is mistaken—we also see its illumination-dependent features.

All this makes perfect sense against the background assumption that the visual system is in the business of estimating useful properties of the perceiver’s environment, of which colors are merely a single example. Separating out shadows from darkly colored regions is worth doing, because shadows can provide information about depth, among other things. That is why the shadowing effect on the open windows of an Apple computer make the windows appear to float above the desktop surface. Color changes, on the other hand, can signal a change in surface composition, for instance from brick to glass.

DISTANCE

Inhabitants do not just see their cities at street level: Boston can be seen from the opposite bank of the Charles River, or from a plane approaching Logan Airport. And distance affects color perception. Again, the effect is reduced in suburbia, because towns and villages do not typically loom on the horizon like cities.

This is relevant to color perception because the human eye has a fixed ability to resolve spatial detail. Unlike a camera with a zoom lens, the only effective means of changing the resolution of the eye is to change the viewing distance. This implies that the color seen at a point on an object is the result of averaging over a portion of the object’s surface that increases in size as viewing distance increases. For an object whose reflectance is not constant over its surface, viewing it at different distances changes its color appearance—from having a distinct pattern of color to having a more homogeneous color, or a different pattern. Older television sets viewed close up are dramatic illustrations, but these days the individual red, blue, and green components of a pixel are hard to see with the naked eye. Less ephemeral examples are pointillist paintings, such as Seurat’s *A Sunday Afternoon on the Island of La Grande Jatte - 1884*.

The phenomenon can also be encountered by stepping outside the Art Institute of Chicago. For example, the Willis (née Sears) Tower is visible at a range of distances from a few feet to several miles. Increasing the viewing distance, the color appearance changes from the somewhat variegated range of dark grays seen standing close to the base of the building to a pattern of dark rectangular windows separated by black bands at approximately 1/2 mile, to large areas of contrasting shades of gray at 2—3 miles. For other buildings of modest size, there is the change from, say, the contrasting colors of the bricks and mortar seen from across the street to the more uniform reddish appearance seen from down the block.

This variability raises the issue of what viewing distance is the one from which we correctly perceive a building’s color, but this question is

misguided. The average reflectance really does change depending on the size of the area over which the average is taken, and so there is no reason to deny that buildings have different patterns of color at different spatial scales. The effect of changing viewing distance is to change which of these patterns we can see, not to create an illusion.

SPECULARITY

In the example of the brick, we tacitly ignored any effects of viewing angle: the seen object was treated as if it reflected diffusely—that is, indiscriminately reflected light in every direction. Since many objects, including bricks, have a reflectance dominated by their diffuse component, this is often a useful simplification. However, for other objects, some made with common architectural materials, the color signal does depend on the angle between the light source, the seen object, and the eye. This is most obvious in the case of objects that have a mirror-like (or specular) component to their reflection, like modern office buildings with large exterior areas of glass. Although glass is an important element in older buildings, the glass used until the late twentieth century reflected relatively little of the illumination, and so the contribution to the perceived color of a structure made by its windows was determined by the light transmitted through the window from the interior. Since building interiors are typically much more dimly illuminated than building exteriors during daytime, windows in these buildings mostly appear as areas of darkness when viewed from outside, unless shades or window treatments are present. With the introduction of highly reflective glass, the appearance of large-scale specularly was introduced to the city.

Highly reflective glass has two principal effects. First, because the glass reflects a substantial proportion of the incident light, tinting can make it appear strongly colored. Second, because the reflection is primarily specular and not diffuse, other objects are seen reflected in the glass, as we can see ourselves reflected in a mirror. When these two effects are combined, the color of the glass can influence the perceived color of the reflected objects. Thus the blue appearance of Boston's John Hancock building blends the blue of the sky or the white of the clouds with the blue tint of the glass. If the glass is not tinted, then we primarily see the color of the reflected object, not the color of the building. Highly reflective untinted surfaces in the built environment therefore have a certain kind of invisibility, displaying the color of the objects seen in them rather than their own color. Since the reflection that is seen depends on a complex set of factors, modern buildings can acquire some of the variability in color appearance that is characteristic of large bodies of water, whose color appearance is also primarily due to specular reflection.

CONCLUDING PHILOSOPHICAL POSTSCRIPT

The discussion above assumed that colors are properties of objects in the environment—Chicago taxicabs and the John Hancock building, for instance. More specifically, the discussion assumed that the color of an object is intimately connected to its reflectance, that is, with the way in which the object changes the incident light. Indeed, we have argued elsewhere that colors are the same as reflectances⁵, but there are other positions that also fit congenially with these assumptions⁶.

However, *Colour for Architecture* tells us that “Colour is a subjective sensation caused by light and is not properly a quality which is inherent in the object itself,”⁷ a statement that appears unchanged in the successor volume.⁸ This view has a long and distinguished history. Galileo, for instance, wrote in *The Assayer* that colors “reside only in the consciousness,” and it must be admitted that some notable contemporary philosophers and scientists agree. But this is a controversial philosophical position, and certainly not, as *Colour for Architecture Today* goes on to say, one of the “basic facts...which are the result of decades of scientific investigation.”⁹

The idea that color is a “subjective sensation” is closely connected with the painting analogy. If there is something like a painted canvas in one's mind when one looks at the golden dome of the Massachusetts State House, then if anything is colored, surely it is the canvas, not the State House. Why suppose that the dome is golden in color if the corresponding patch on the mental canvas is? To suppose that both are golden seems like gratuitous speculation. That is why colors, on this view, “reside only in the consciousness.” More ecumenically, the dome may be said to be golden but only in a derivative way—it is golden in the sense that it produces splotches of golden mental paint in the minds of suitably situated observers. This is a view sometimes called the “secondary quality” theory of color.¹⁰

As we hope the preceding discussion suggests, taking color to be a subjective sensation is not theoretically fruitful. For one thing, it tends to force unnatural descriptions of our experience, making it easy to overlook the possibility that we see both the colors of objects and the ways in which they are illuminated. The fascinating topic of urban light and color is better understood by other means.

5 See: David R. Hilbert, *Color and Color Perception: A Study in Anthropocentric Realism* (Stanford: CSLI, 1987). Also, Alex Byrne and David R. Hilbert. Colors and reflectances. *Readings on Color*, Volume 1: The Philosophy of Color. ed. A. Byrne and D. R. Hilbert (Cambridge, MA: MIT Press, 1997); Alex Byrne and David R. Hilbert, Color Realism and Color Science. *Behavioral and Brain Sciences* 26 (2003): 3-21.

6 For a discussion of one of them see Alex Byrne, and David R. Hilbert, Color primitivism. *Erkenntnis* 66 (2007): 73–105.

7 Porter and Mikellides, *Colour for Architecture*, 78.

8 Porter and Mikellides, *Colour for Architecture Today*, 13.

9 Ibid.

10 Alex Byrne and David R. Hilbert, Are Colors Secondary Qualities? *Primary and Secondary Qualities*. ed. L. Nolan (Oxford: Oxford University Press, 2010).