COLORREFLECTIVTY IN DAYLIT SPACES:
How color reflectivity affects experience and performance

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ABSTRACT

Color reflectivity is valuable not only architecturally and aesthetically but also in terms of performance. The higher the reflectivity of a space the more evenly light is distributed in the space. Reflectivity can improve the performance of a building's system and also increases the occupants' sense of well-being. Given the benefits of color reflectivity, why are rooms not typically designed with reflective surfaces? The research focuses on the connection between daylight and color reflectivity, the perception and performance in understanding how to optimize reflectivity in interior spaces to improve lighting efficiency and visual comfort.

1. INTRODUCTION

The manipulation of surface reflectivity in order to alter our perception of space has a long architectural history ranging from the hall of mirrors at the Chateau of Versailles to contemporary examples such as the Chapel of St. Ignatius at Seattle University in Washington.

In the Chapel of St. Ignatius, built in 1997 by architect Stephen Holl, reflectivity is used to reveal and highlight the texture of the plaster, giving it an arresting presence that causes us to focus on the diffuse surface. Reflectivity is not only valuable architecturally and aesthetically but also in terms of performance.

– Daylit spaces with high reflectivity distribute the light better, are brighter, and therefore more efficient. As the distance from the window increases, the ava ila ble da yli ght in the ro om is pr ovi de d de cre

asingly by the sky and increasingly by the reflectivity of the interior surfaces.

– Spaces that have high reflectivity have a lower contrast between the brightness of the light at the window and that of the interior room surfaces. Increasing reflectivity not only increases the daylight in a space but also distributes it more evenly, improving visual comfort.

The effectiveness of daylighting as a strategy to reduce the use of electric lighting is increased by higher surface reflectivity. This is significant because 70% of U.S. electrical energy production is used by buildings, most of it for electrical light. Therefore daylighting is an important strategy for saving energy and reducing greenhouse gases that cause global warming. The amount and distribution of daylight is a function of window size and location, room geometry and surface reflectivity. As one moves away from a window, the available daylight in the room is provided decreasingly by the sky and increasingly by the reflectivity of the interior surfaces. For example: In a room with a single window, the wall opposite the window contributes to the daylight in the room in proportion to its reflectivity. As the reflectivity of all the room surface goes from 90% to 10% the daylight factor at the back of the room drops by 13-1.75%. (Fig. 1)

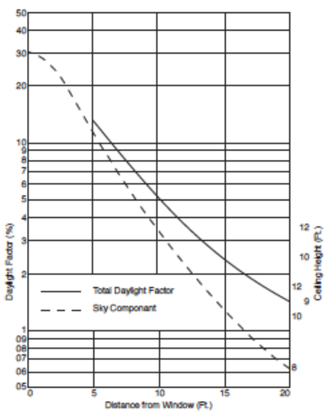


Fig. 1: After a graph by Hopkinson, R.G.: Daylighting. The variation of Sky Component and Daylight Factor with distance from window. P. 43

Given the benefits of high reflectivity, why are rooms not typically designed with reflective surfaces? There are several anecdotal reasons that interior architecture tends to use interior surfaces of low reflectivity.

- Colors that are perceived to be richer, such as deep reds and blues, have low reflectivity. Dark colors and heavy materials, such as red velvet, still seem to be more elegant and valuable than light-colored linen. Likewise, dark wood finishes like mahogany or wenge, seem richer than light-colored ones like maple or ash. This is a result of our aesthetic values. (A social reason)
- Floor coverings that have lower reflectivity are seen as easier to keep clean. (A practical reason)
- Designers overestimate the reflectivity of colors. (A physiological reason)

Our aesthetic valuing of deep colors thus conflicts with the high reflectivity that is more effective for daylighting.

2. <u>HYPOTHESIS:</u>
The average reflectivity of an interior space can be increased without changing people's perceptions of, for example, the color and reflectivity of the space.

3. <u>SIGNIFICANCE OF THE PROJECT</u>
In my research I focus on the experiment of testing and evaluating spaces. Using models, I will compare the measured reflectivity with human subjects' perceptions of the same space.

In my project I conducted experiments using color games and models of rooms to compare subjects' perceptions of colors and reflectivity to actual measured reflectivity. Although these are preliminary experiments and results, the implications were of sufficient interest to continue the work. Observations have been collected, and since the set-up and models can be reconstructed anytime, the experiments provide a source of data.

Multiple personal tests are now being conducted. The number of human subjects will be increased in a larger experiment.

This work is part of a larger project –on the design of small spaces. Small spaces are important because they conserve materials and cost less, but many of them, like hospital rooms, help determine well-being.

My hypothesis is that low reflective interior surface effects like rich color can be achieved with little change to the space's overall reflectivity. In the case of rich colors, some surfaces (for example, walls) play a less important role in delivering average room reflectivity than others. These walls for example, are candidates for locating color if those same surfaces are primary to the perception of the overall color of the space.

The higher the reflectivity of a space the more evenly light is distributed within the space, diminishing the contrast in brightness between the window and the walls, which results in greater visual comfort.

There are two ways that reflectivity apertures can improve the performance of a building's systems.

First, by saving energy: daylight is more efficient at providing light than most electric light sources, so less heat is produced for the same amount of light. Therefore, high reflectivity in a building can reduce not only the building's use of electric light but also its use of cooling energy. As a result, it can reduce peak energy use, as well as total energy consumption.

Second, visual comfort increases with the use of daylight because daylight is the light source that most closely matches the human visual response (psychological and physiological benefits). It often takes a lower level of daylight to perform a task than it would to perform the same task in electrical light. A good visual environment created by windows and reflective surfaces affects a person's ability to see objects in a room properly and to perform visual tasks.

Reflectivity also adds a sense of spaciousness to a room, which makes it an important design element. There is an opportunity to develop integral design early in the design process that incorporate reflective surfaces to help satisfy the genuine desire to have natural light in a room

Previous work in this area done by R.G. Hopkinson is described by him as follows: "The chief objective of these experiments was to trace the changes in quality of a color seen in shadow or bright light in terms of Hue, Value and Chroma”.

4. GUIDING RESEARCH QUESTIONS AND EXPERIMENTS:

A series of experiments were done to test the hypothesis. These experiments were designed to answer these questions:

- Can we achieve the perception of (deep/rich) colors while also providing reflectivity?
- How can the reflectivity of an interior be increased while maintaining the richness and depth of color to provide spatial variation?

Since everything we see results from emitted or reflected
light, the reflectivity of surfaces in a room (walls, floor, furnishing etc.) is a large factor in how we perceive and experience the space. Diffuse surfaces determine the distribution of light in a space and their reflectivity determines the amount of light in the space. Beyond its aesthetic value, surface reflectivity determines how efficient daylighting is. For example, classrooms with a window on only one side average a daylight factor that varies from 0.7% when the average surface reflectivity is low, to 1.5% when it is high—a change of 50%.

It is clear that high reflectivity is important, but most commonly used materials and finishes are not very reflective, as one can see from the measurements below.

Final finishes for surfaces common in interior spaces, such as wood, linoleum, and fabric (felt and linen), have a maximum of 40% Light Reflectance Value (LRV). (Fig. 2)

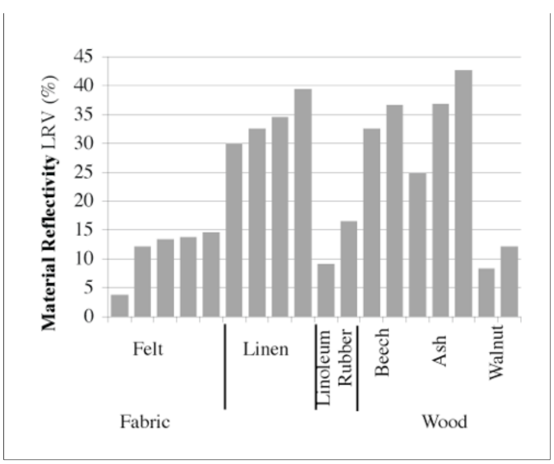


Fig. 2: Final finishes for surfaces common in interior spaces.

Furthermore, the colors most often used for interiors are in the low reflective ranges, because designers typically overestimate the reflectivity of colors, and most of the colors available in the commercial color palette are in these low reflectivity ranges. (Fig. 3)

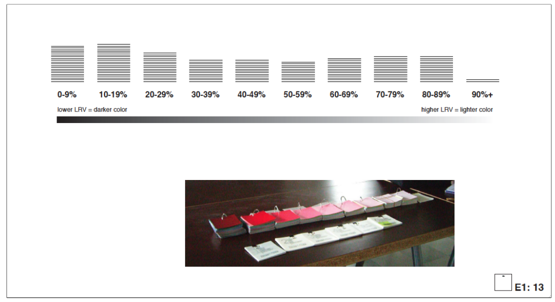


Fig. 3: Colors available in the commercial color palette are in low reflectivity ranges. Example: A manufacturers color section: “Color Preview”

The availability of high reflective colors in the **“Off White”** palette is also rather limited. (Fig. 4)

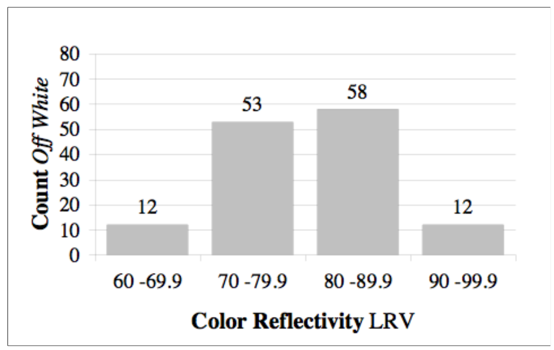


Fig. 4: colors available in the “Off White” palette by the producer BM.

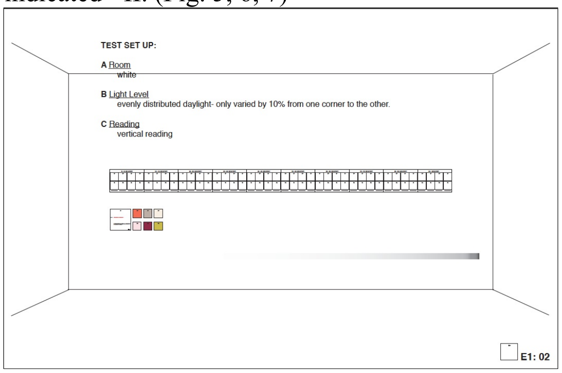
5. EVALUATION OF REFLECTIVITY. “THE COLOR GAME”

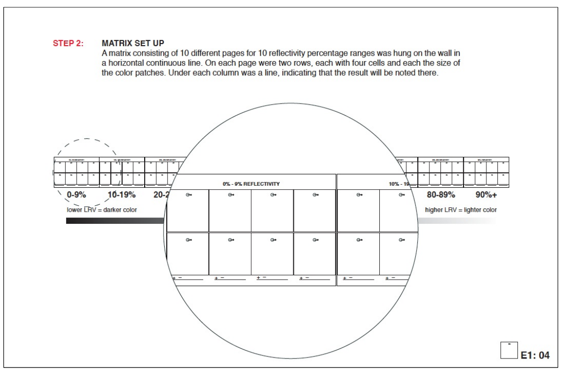
5.1 The first experiment:

The “Color Game” was an experiment set up to observe how people perceive colors, because their perception of color influences their choice of color—an issue of special importance to an interior designer.

A set of 150 colors (matte surface) with a range of 0-90+% Light Reflectivity Value (LRV) were mixed up and divided into five groups of 30 different color patches. A matrix (Figure 5) consisting of 10 different pages for 10 reflectivity percentage ranges (0-9%, 10-19%, 20-29%, 30-39%, 40-49%, 50-59%, 60-69%, 70-79%, 80-89%, 90-99%) was hung on the wall in a horizontal continuous line. On each matrix page were two rows of each four cells, each the size of the color patches. Under each column was a line, indicating that the result will be noted there.

A group of 30 people was divided into six groups. Each group was given 30 color patches and had to rank the LRV of each one by putting it in the top row of the matrix. They then checked their conclusions against the actual LRV of the colors. If they had chosen the right color, the patch remained in the top row. Otherwise, it was put in the appropriate category in the cells below, with a remark on the line where they had it before. For example, if the LRV was 20%-29% and they had the patch in 40%-49%, they indicated +II. (Fig. 5, 6, 7)





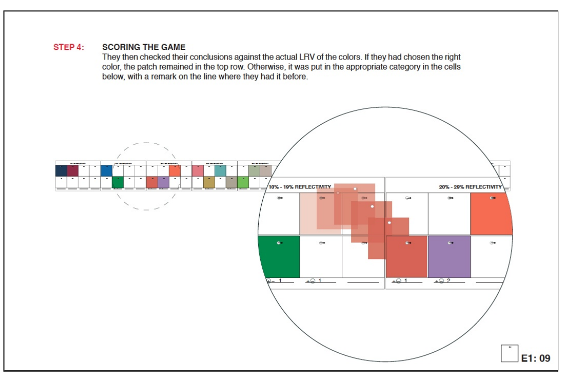


Fig. 5-7: Matrix page for the “Color Game”- set up, step 2 and 4.

Out of thirty colors, each group on average correctly evaluated only five colors. Most of the other colors were perceived to have a higher LRV than they actually had. Most colors in the range of 30%-80% were perceived as having a 20% higher reflectivity than they actually had. (Fig. 8)

This shows that designers tend to overestimate the reflectivity of colors. Colors in the LRV ranges of 0-9% and 90+% were usually correctly perceived. Obviously these colors are easier to evaluate. (Fig. 9)

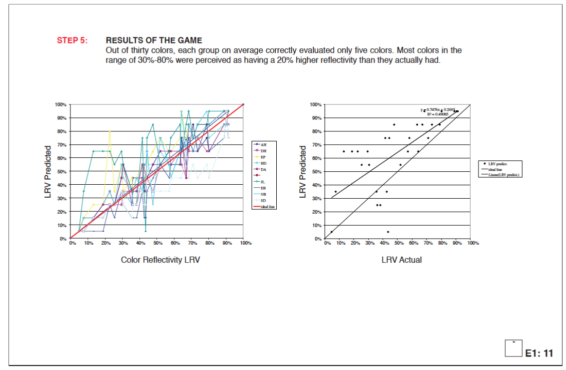


Fig. 8: The graph of “The Color-Game” shows color in the range of LRV 1%-92%

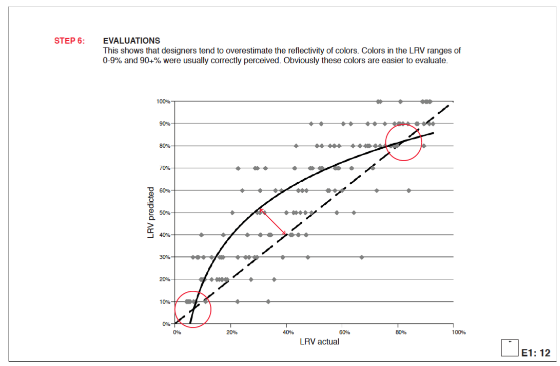


Fig. 9: The graph of “The Color-Game” shows color in the range of 30%-80% were perceived as having a 20% higher reflectivity as they really have.

5.2 <u>The colorfulness of color</u>

Colorfulness and Chroma is described by Mark C. Fairchild as comprising one dimension of color (the others being hue and brightness/lightness). In his description, “Colorfulness is to chroma as brightness is to lightness…Colorfulness describes the intensity of the hue in a given color stimulus. Thus, achromatic colors exhibit zero colorfulness and chroma, and as the amount of color content increases (with constant brightness/lightness and hue), colorfulness and chroma increase)” (p. 87).

- Colorfulness is the “attribute of a visual sensation according to which the perceived color of an area appears to be more or less chromatic.”
- Chroma is the “colorfulness of an area judged as a proportion of the brightness of the similarly illuminated area that appears white or highly transmitting.”

<u>The second experiment:</u>

In this experiment, I looked at techniques that have been used architecturally, such as reflective surfaces. I used a set of experimental measurements to test anecdotal knowledge about the perception of color in space.

Seven identical boxes, or models, were built out of black foam board so that no light could go through the edges. The inside was covered in white for high reflectivity. Each box was 8 x 8 inches in plan and 8 x 8 inches in elevation. One side had a central opening: a 2-inch square aperture, or “window.” On the opposite side was a central view port of half an inch diameter. The side, or “wall,” with the 2x2” opening was colored in a range of 7 different commercial colors, varying in Light Reflectivity Values from 0% to 99%. The colors are listed below, along with their LRVs (percentages).

Exotic Pink	68.3%
Flamingo’s Dream	40.2%
Calypso Orange	37.8%
Red	11.7%
Strawberry Red	14.2%
Red	13.2%
Raspberry Truffle	8.5%
Chestnut	7.2%

In this experiment 30 participants were tested for their perceptions of color. The boxes, each with a different shade of red on the inside surface of the wall with the window, were observed in different light levels. Observations (monocular) were made at a distance of 5 to 6feet.

Despite the actual performance of the Light Reflectivity Value in the color range of seven shades of red, the boxes with the “Flamingo’s Dream LRV 40.2% and Calypso Orange LRV 37.8%” were perceived by most of the observers to be the most colorful. This result contradicts the assumption that colors with the lowest reflectivity values are the most colorful. (Fig. 10)

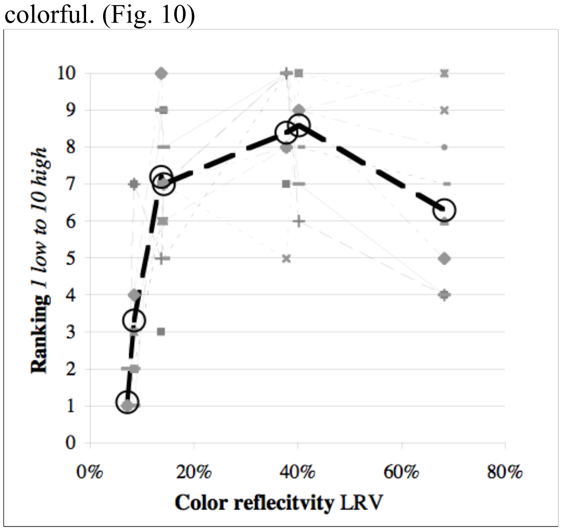


Fig. 10: Observers perceived a room to be the most colorful wall when it was in the reflectivity range of 30%.

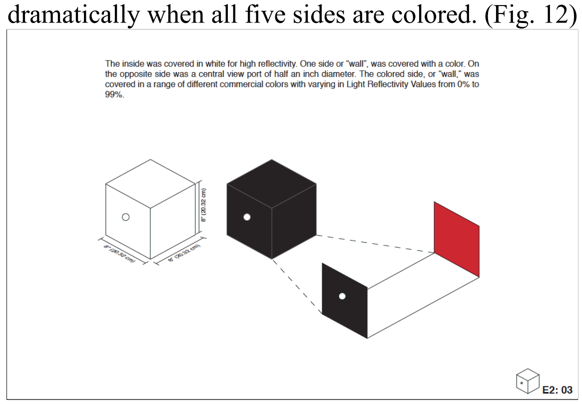
In this experiment, I built a series of boxes (as in the second experiment), or models of interior rooms, to address the question of reflectivity under changing room configurations. Each of the boxes represents a room with a window on one side, as described in the previous experiment. One set of boxes had the color at the window side. Another set of boxes had the color on all fives sides except the window side. (Fig. 11)

The project was designed to study the relationship between the amount (size) of color—and its location and reflectivity—and the human perception of it, along two variables:

- How the daylight factor changes under the same light conditions; and
- How people perceive the color of a room as the amount, location, and reflectivity changes.

The boxes provided a limited point of view. Participants could not see the whole space; they could only see the opposite wall with the window and a quarter of the neighboring walls.

The experiment shows that the Average Room Reflectivity (ARR) changes very little within the range of colors from an LRV of 7% to 68 % if only one wall is colored. But the ARR changes dramatically when all five sides are colored. (Fig. 12)



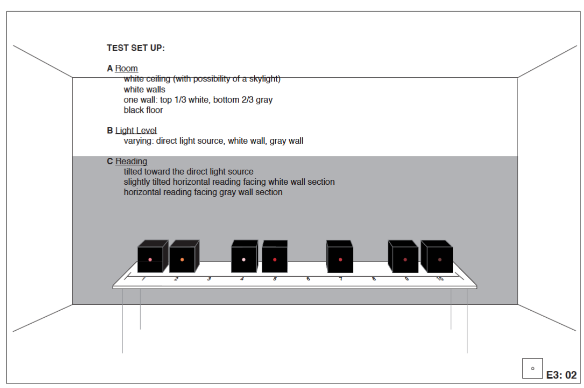


Fig. 11 and 12: The “Appearance of Color” – set up of experimental measurements to test anecdotal knowledge about the perception of color is space.

The question asked was: Which is the most colorful room? Each version of the boxes tested (1-walls colored or 5-walls colored) showed the same result, which indicates how important the field of view is and that controlling the view is a way to make a space appear colorful. (Fig.13)

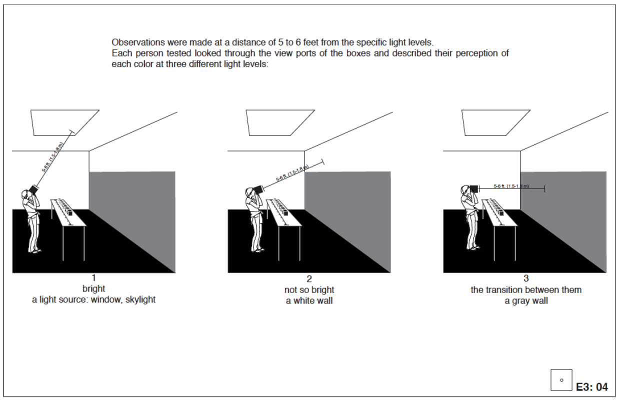


Fig. 13: Observations were made at a distance of 5 to 6 feet from specific light levels.

6. CONCLUSION

These experiments showed that the eye is capable of making separate judgments about color reflectivity, and therefore the results provide a proof of my hypothesis:

1. That designers/people overestimate colors and can't tell their Light Reflectivity by just looking at the color or the surface.
2. That the most colorful colors are not necessarily the darkest ones.
3. That the average rooms can appear very colorful without changing room reflectivity.

The implications from these results are that designers should not rely on their intuition but need tools to optimize color reflectivity and the use of other surfaces and materials of higher reflectivity in interior spaces to improve lighting efficiency and visual comfort without losing the design effect. Daylighting is well documented, as is the architectural role of reflectivity, but the connection between daylighting and reflectivity and color reflectivity needs to be further explored.

Further testing will be done to determine how position affects the perception of color. My hypothesis is that low reflective interior surface effects like rich color can be achieved with little change to the space's overall reflectivity. In the case of rich colors, some surfaces (for example, walls) play a less important role in delivering average room reflectivity than others and are candidates for locating color if those same surfaces are primary to the perception of the overall color of the space.

These results will be evaluated to find a rule for the perception of color, which will lead to design applications for the use of color in interior spaces. This will be pursued further in a large experiment.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

(1) Brown, G.Z., De Kay, Mark. Sun, Wind & Light. Architectural Design Strategies. New York: John Wiley and Sons, Inc. 2001.
(2) Hopkinson, R.G. Architectural Physics; Lighting: Light, Reflectance and Colour. London, Her Majesty's Stationery office: 1963
(3) Hopkinson, R. G,. Peterbridge, P, Longmore, J. Daylighting. London: Heinemann, 1966.
(4) Fairchild, Mark D. Color Apprearance Models. New York Wiley 2005
(5) Swirnoff, Lois. Dimensional Color ("A pro scientia viva" title). Boston; Basel: Birkhaeuser, 1988.
(6) The Oxford Pocket Dictionary of Current English, Oxford University Press