The illusion of color: the chromatic interactions of Josef Albers in 3D spaces

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ABSTRACT

Josef Albers, a central figure in the evolution of 20th-century color theory, profoundly influenced both the artistic and scientific understanding of chromatic interactions. In his work, particularly *Interaction of Color* (1963), he explores how colors affect one another and how these interactions can alter visual perception. Albers believed that color was not an intrinsic quality of an object, but rather a relative phenomenon, whose perception is shaped by context and environmental conditions. This principle of chromatic relativity was illustrated through a series of practical exercises demonstrating how the same color can appear different depending on the surrounding colors, emphasizing the importance of chromatic contextualization. This perspective opens interesting possibilities in three-dimensional design, where Albers' theories can be applied to influence spatial perception. Delving into his ideas within three-dimensional environments presents an engaging experimental challenge. Through immersive virtual simulations and real-time rendering, it is possible to explore the effects of certain chromatic interactions described by Albers on visual perception of space. Applying Albers' theories to 3D environments is not merely a theoretical exercise, but carries significant practical implications for architectural design, as it addresses the perceptual manipulation of space through the interaction of light and color. Reflecting on Albers' theories using advanced technologies allows for a deeper understanding of his work and the creation of visually stimulating and perceptually dynamic spaces.

KEYWORDS Josef Albers, 3D space, VR, Simultaneous Contrasts, Afterimage

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1. Introduction

The 20th century was marked by intense intellectual ferment that led to conceptual revolutions and new practical frontiers in fields such as art, architecture, design, and visual perception. In these disciplines, as well as in psychology, Gestalt theory –originating in Germany in the 1920s– provided a crucial contribution to the understanding of perceptual processes. This theory, focusing on the organization and interpretation of visual perception, shifts the emphasis from individual elements to the overall configuration, based on the principle that “the whole is greater than the sum of its parts” (Koffka, 1935). As a result, an image or form is not a mere aggregation of visual components, but generates more complex perceptual experiences. Movements such as the Bauhaus, developed at the intersection of art and industry, proposed an integrated vision of the creative disciplines, redefining the relationship between form and function. Color theory played a central role: the contributions of figures such as Johannes Itten and Josef Albers introduced radical approaches and experimental explorations of color. Although their approaches diverged –Albers emphasizing practice and relational perception, Itten developing a more spiritual and symbolic use of color– their dialogue at the Bauhaus provided a fertile ground for the subsequent evolution of modern color theory. These contributions extended beyond the two-dimensional realm and influenced applied arts and architecture, opening new possibilities for the perception and use of color in space.

Albers occupies a pivotal role in rethinking chromatic perception in terms of interaction. Through his teaching at the Bauhaus, Black Mountain College, and Yale, he developed a hands-on approach to color, privileging “practice before theory” (Albers, 1963). His work *Interaction of Color* challenges the perception of color, shifting it from its intrinsic qualities to its relational nature. The book, composed of a series of practical exercises, explores the mutability and deceptions of chromatic perception. For Albers, color is not a fixed and stable characteristic but a phenomenon subject to variation depending on context (Weber, 1988). His theory of “chromatic relativity” departs from static color models such as Goethe’s color wheel (1970), asserting instead that colors are perceived in a “continuous flow,” where the same color may appear lighter, darker, warmer, or cooler depending on its combinations. Albers’ approach resonates with the principles of Gestalt theory, which he himself references (Albers, 1963). The optical illusions produced by his experiments demonstrate that the perception of color depends on its interaction with other colors, as well as with shapes and positions, creating visual configurations that alter perceptual experience (Arnheim, 1974). Albers thus highlights how the perception of color is closely linked to environmental conditions, generating what he describes as a “discrepancy between physical fact and psychic effect” (Albers, 1963; Albers, 1969).

In the field of architecture, Albers’ work offers compelling insights, despite having focused primarily on color applied to flat surfaces. Contemporary architects such as Le Corbusier and Luis Barragán explored the use of color in architecture not only for aesthetic purposes, but also for functional and plastic effects. Le Corbusier used color to modify spatial perception and guide attention (Morgado, 2020), while Barragán integrated color into the architectural structure to evoke emotion and transform space (Ambasz, 1976).

Albers’ theories on chromatic interaction have thus proven applicable even in spatial design, despite originating from two-dimensional considerations (Serra Lluch, 2023). This contribution aims to explore the three-dimensional effects of the chromatic interactions described by Albers, experimenting with the transposition of these theories into architectural contexts. The use of immersive technologies, such as virtual reality, allows for the manipulation of color in controlled environments and the study of perceptual effects of chromatic interactions from within architectural spaces.

2. Simultaneous contrasts and post-images

In the experimental explorations of color interaction conducted by Albers, numerous visual phenomena, effects, and illusions are referenced and interconnected – some of which were already known or studied by other theorists of the time. Many of the cases discussed relate to two closely connected concepts, according to the author: simultaneous contrast and afterimage.

Within the divergence between physical fact and psychic effect emphasized by Albers, simultaneous contrast is a phenomenon that occurs when multiple colors placed next to each other appear to influence one another, making them seem “different from what they actually are.” This is rooted in the human eye’s tendency to interpret visual (not only chromatic) information holistically and in relation to its context. For instance, a neutral gray may appear slightly bluish when placed next to an orange color, or yellowish when adjacent to purple (fig. 1). This is a clear example of how color perception is relative and unstable (Albers, 2013). The scientific explanation of this phenomenon lies in the way retinal cones, responsible for color perception, (inter)act. These cones are divided into types, each sensitive to a specific wavelength of light. When observing multiple colors, the cones are activated depending on the amount of light reflected, but color perception is also influenced by the activation of neighboring cones. In simultaneous contrast, this interaction among cones in different areas of the retina leads the brain to emphasize chromatic contrasts to heighten visual differentiation, causing colors to appear different from their physical reality (Goldstein, 2017).

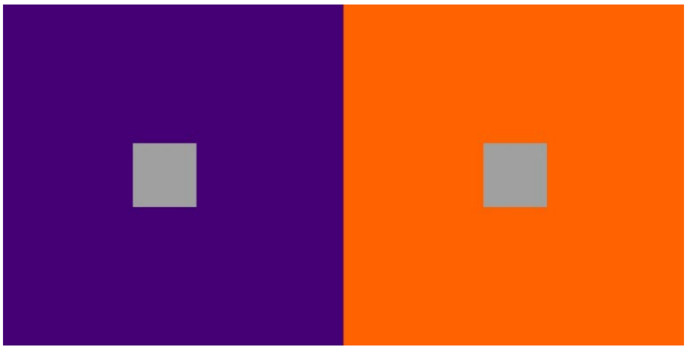

Fig. 1. In this reproduction of one of the exercises, the same neutral gray may appear more bluish or yellowish when placed against an orange or purple background, respectively.

Also related to the behavior of retinal cones, the afterimage is a phenomenon that occurs when, after staring at a color for a certain period of time, a residual image of its complementary color continues to be perceived –even after shifting one's gaze to a neutral surface. This effect is caused by temporary fatigue of the cones: when an intense color is observed, the cones that respond to that specific wavelength become overstimulated and less sensitive. As a result, when the gaze shifts to a neutral surface, the cones sensitive to the complementary color become more active, causing the appearance of the afterimage (Pinna, 2010). In one of his exercises, Albers invites the viewer to focus intently on a red circle (against a black background) for several seconds before shifting their gaze to a white disc, upon which a residual green image –the complementary of red– will briefly appear (fig. 2). This also highlights how color perception is not a passive representation, but rather a dynamic psychophysiological process.

An important consideration was raised regarding the critical relationship Albers establishes between simultaneous contrasts and afterimages, which he often refers to interchangeably, as though they were the same phenomenon (Lee, 1981). Clear differences exist in both spatial and temporal terms: simultaneous contrast occurs immediately and regardless of whether the gaze is moving or fixed, whereas afterimages are only visible after a period of focused attention on a color, followed by a shift to a neutral background. Nevertheless, both phenomena remain interconnected and can, in various ways, help explain the underlying mechanisms of many chromatic effects and illusions that result from color interaction.

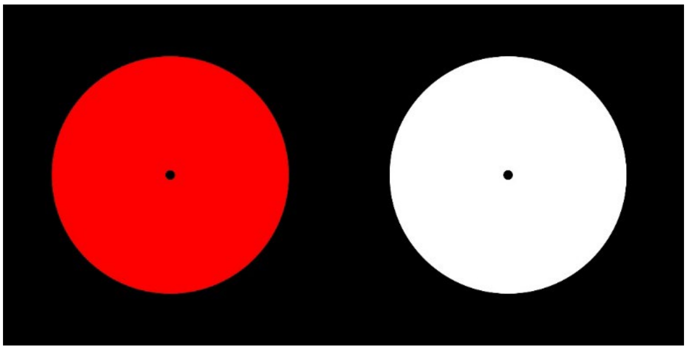

Fig. 2. Authors' reproduction of an exercise proposed by Albers to explore the phenomenon of afterimage.

3. Chromatic interactions in virtual reality: *Albers's Chambers VR*

The three-dimensional experimentation on the chromatic interactions described by Albers stems, first and foremost, from a necessary selection of specific exercises he proposed, in order to transpose them effectively into a virtual environment. In this sense, the various categories of effects and phenomena he described were carefully analyzed to identify those experiments that could be meaningfully and interestingly translated into three dimensions, potentially offering new insights. This selective process was driven by the increased complexity inherent in 3D transposition: it became clear from the outset that some of Albers' exercises could hardly be rendered in spatial terms without losing effectiveness or adding little beyond what could already be experienced on paper in two dimensions.

One of the strengths guiding this research lies in the ability, within a virtual environment, to control and isolate color interactions more effectively, eliminating interfering elements that in physical reality can at best be reduced, but not entirely removed. Lighting, shadows, and the material qualities of surfaces can be freely defined to best convey the perceptual experience. For instance, in the immersive experiences described below, the user has no corporeal presence in the scene: they can move and interact immersively, yet remain invisible, thus avoiding any chromatic interference with the environment.

Similarly, the three "Albers chambers" are designed to be isolated from one another. For this purpose, a teleportation system was implemented in the VR environment to allow users to move between rooms without transitional spaces or doors, which might compromise the experiment.

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Nevertheless, the virtual experiences devised here are digital simulations of physical phenomena; they can mostly approximate the real effect, but with inherent limitations stemming from the nature of the medium itself. These divergences from reality, however, can be deliberately exploited to achieve results that would otherwise be unattainable –such as the total elimination of shadows within the workspace.

The design of the chambers was intentionally kept as essential as possible, directly inspired by the simplicity of Albers's original exercises, where basic shapes, colors, and spatial relations generate perceptual effects. The goal was to transpose these principles from the bidimensional plane into space, without unnecessary complexity. In particular, the second chamber openly draws inspiration from Barragán's plastic and chromatic strategies, further grounding the design in architectural practice. Three immersive experience rooms were therefore developed as part of a single, interconnected experiment entitled *Albers's Chambers VR*. Some of them directly reference the plates featured in *Interaction of Color* (2013), while others present alternative versions of the processes outlined in certain chapters. The methodology for creating the Albers rooms began with a rapid concept phase, using hand-drawn sketches to evaluate possible 3D interpretations of the experiments. The project then moved directly into NURBS-based 3D modeling using Rhinoceros 7 (fig. 3). The completed experience-rooms were then converted into mesh surfaces for the next stages and imported into Unreal Engine 5.3, the platform through which the VR experience described below was developed.

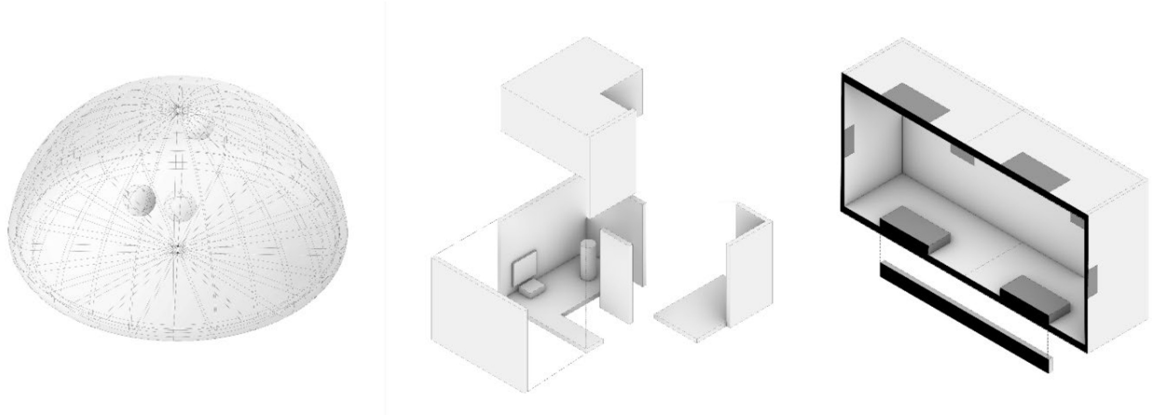

Fig. 3. The models of the three Albers's chambers elaborated for the subsequent experimentation in virtual reality

The first room (fig. 4) takes as its reference the theme of color subtraction, focusing on the interaction between the elements and the background on which they are displayed. The original exercise involved the use of three different red samples placed against varying backgrounds –either matching or contrasting with the subject colors. Albers observed that when the background changes, the red samples tend to emphasize their differences rather than disappear entirely, even when the background matches one of the three reds. Building on this idea, a space was designed in which three differently shaded red spheres float in motion, allowing users to dynamically explore the effects of background color variation on the scene's objects. The room was conceived as uniform as possible, enabling free movement without excessive interference from the user's own shadow or form. An initial idea proposed a monochromatic spherical environment, but this shape restricted user movement across its base. Therefore, it was replaced with a dome measuring 12 meters in diameter, smoothed at the base where it meets the ground. This form –often used for applying HDRIs in rendering scenes– offers a wide horizontal plane for movement, while minimizing the shadows on the backdrop. Some light shadows remain visible to aid the user's spatial orientation. The three spheres were animated to float slowly and steadily within the empty space, occasionally overlapping to create temporary color interactions. The dome's surface was programmed using a typical Unreal Engine blueprint so that the user, by clicking a button, can interactively change its color –cycling from the initial white to each of the three reds, and finally to a fourth, different red tone. Instructions on how to interact with the scene are provided via a black holographic text placed at the edge of the environment, at the user's starting point, designed to be as unobtrusive as possible. Additionally, visual contrast and shadows were minimized by manipulating the observer's digital vision using a *PostProcessVolume*, enhancing the visibility of interactions between the spheres and the background.

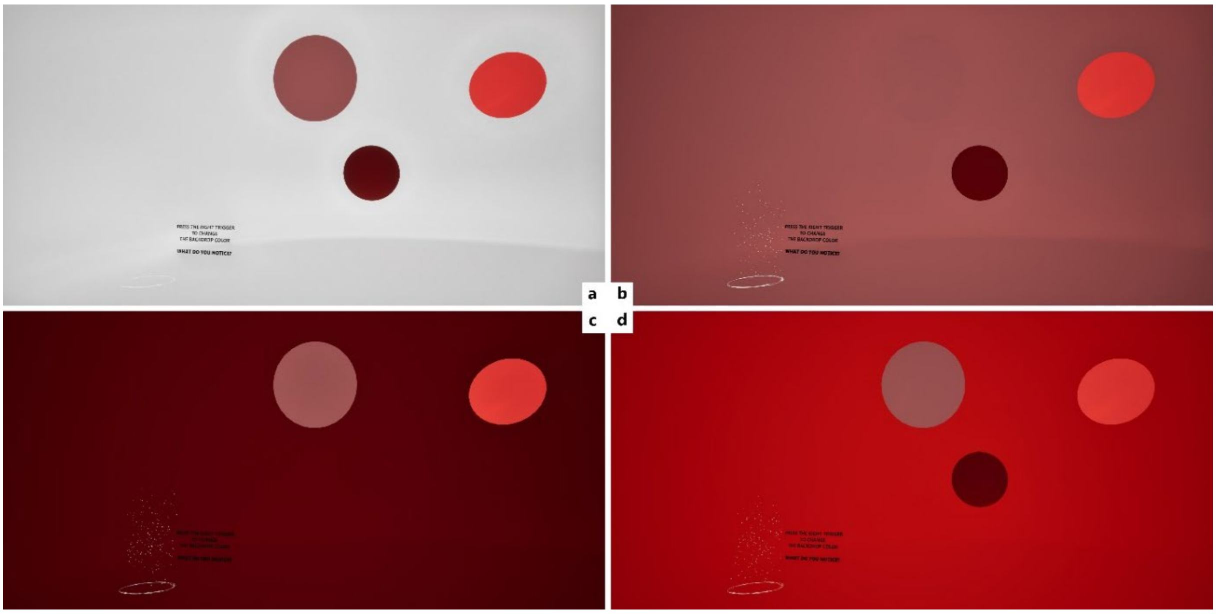

Fig. 4. Albers's First Chamber. The spheres, visible against the white background (a), blend into the background when it matches their color (b, c), and appear altered when the dome shifts to a fourth tone different from the others (d).

Albers's second chamber (fig. 5) takes inspiration from the plates related to the afterimage effect (VIII-1 / VIII-2), seeking to recreate the same phenomenon within an architectural environment. To achieve this, the design draws on the iconic plasticity and use of color characteristic of Luis Barragán's work, creating a square-based space populated by simple, essential volumes. The main walls, ceiling, and floor were rendered in nearly neutral tones, while the other elements were colored with stronger, more saturated hues –better suited to producing pronounced afterimage effects than more muted tones.

In the initial phase, as in Barragán's architecture, the surfaces were given a pronounced materiality, using rough concrete, plaster, and reflective materials. However, the same experiment was later repeated with these material qualities removed, as they clearly interfered with color perception and interaction within the space. In this version, the chamber is softly and naturally lit from a skylight, creating an environment free of harsh contrasts.

Based on the hexadecimal codes of the selected colors, complementary hues were calculated to create new materials applied to the scene. Each of these was also rendered in a white version, retaining only the original surface texture, in order to allow the retina to project the afterimage onto it. Once again, the user is allowed to move freely within the space and is prompted –via another hologram– to focus intently on a specific point of the scene for at least 30 seconds before pressing a button. This action switches the environment from its complementary color version to the white one, enabling the user to perceive the original chamber as an afterimage.

Fig. 5. Albers's Second Chamber, in its different color versions: complementary (a), neutral (b), and original (c), which is the way the chamber should look like in its post-image

The third experience-room designed (fig. 6) recreates, in 3D, the theme of inverted backgrounds, drawing on the forms of plate VI-4 and the colors of VI-3. These two exercises illustrate how different backgrounds affect the perception of a third, identical color, which appears as two distinct hues depending on its surrounding context.

In this case, a large, single space was designed, measuring 20×10×10 meters, softly lit with artificial lighting to avoid harsh shadows. Visually, the room appears as the juxtaposition of two cubic spaces joined through one face; this is further emphasized by the two distinct colors (yellow and purple) that define the walls, ceilings, and floors of each half. Squares of a third color are embedded in each surface, and on the floor plane, they become two separate, disconnected platforms.

The user is teleported onto one of the platforms and can observe the effects produced by the background colors on the perception of the third tone. As in Albers's original exercise –where a strip of paper was used to connect the two smaller squares and demonstrate that they were in fact the same color– the user here is given the option to press a button, which causes a bridge to appear or disappear, visually connecting the two platforms that initially seemed to have different colors.

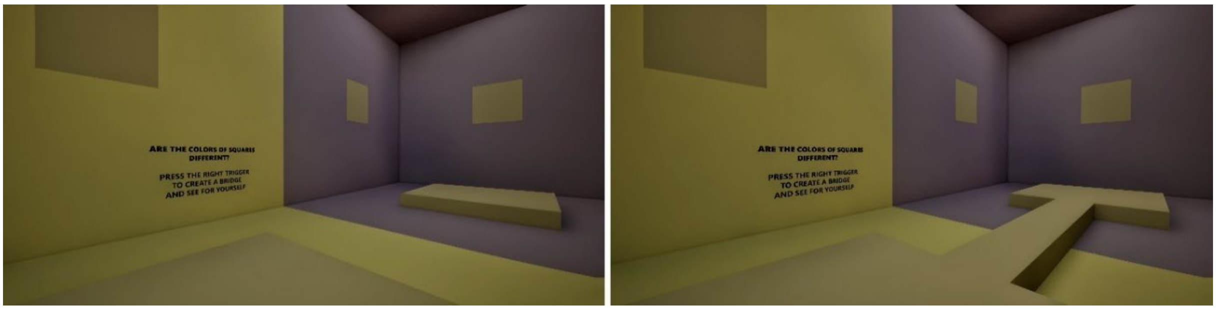

Fig. 6. Albers's Third Chamber. The squares/platforms, seemingly of different colors (left), are in fact the same color, as demonstrated by the activation of the connecting bridge (right).

4. Conclusions

The three virtual experiences presented in this contribution aim to reinterpret Albers's exploration of color interactions in a three-dimensional key, attempting to transform some of his exercises into dynamic and interactive virtual experiments. In this regard, the potential of VR allows for engaging and innovative demonstrations and analyses of specific phenomena, enabling the construction of digital laboratories that are controlled, expandable, and constantly evolving. In the future, the Albers's Chambers described here could be further developed through the addition of new experience-rooms.

In the first chamber, by changing the color of the dome, the visitor observes how some spheres seem to disappear entirely and reappear elsewhere, or even shift in hue; chromatic interaction is intensified by both the objects and the user, who generate ever-changing configurations (and overlaps) of colors. The second chamber introduces two distinct approaches to the afterimage effect, with slightly different results compared to the original exercise: in the material version, it is the surface qualities –along with the light and shadow of the plastic forms– that tend to dampen the phenomenon, especially along edges and corners where shadow variation is greatest. In the immaterial version, the effect is clearly more successful, although still subject to light-related interferences, and remains perceptible, though less intense than on paper. In this respect, it is essential to consider how the colors themselves –due to light reflection– interfere with chiaroscuro, creating apparent colors that alter the perception of surface tones (Calisi, 2013).

The third chamber allows the user to perceive how adjacent backgrounds alter the perceived color of the squares, which appear as two distinct hues –until the activation of the bridge/connector, which immediately cancels the illusion by enabling a direct comparison of their actual identity. In all three cases, albeit in different ways, it becomes evident how the third dimension adds further layers of complexity to be considered, such as the forms and shadows of the objects; these inevitably influence scene perception and may potentially distort the outcome of the exercise if not properly managed.

The developed scenarios represent only three out of many exercises that could be reimagined in three-dimensional experimental form. Furthermore, starting from the same plates and exercises, numerous other ways of reconstructing similar experiences on these themes are conceivable. It should also be stressed that perceiving color through electronic devices inevitably differs from the sensation conveyed by pigments and materials in real space; this limitation must be acknowledged when validating virtual experiments against physical reality, although it also opens reflections on possible calibration tools bridging the two domains. In this sense, the Albers's Chambers VR project highlights the potential –though not without limitations– of using virtual laboratories to engage with topics such as color interaction in a dynamic, interactive, and immersive way, whose future developments may further enrich the analysis and narration of the complexity behind perceptual phenomena.

5. Conflict of interest declaration

No financial/personal interests have affected the author's objectivity and potential conflicts do not exist.

6. Funding source declaration

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7. Short biography of the authors

Daniele Calisi - Architect, PhD in Representation and Survey Sciences. He is an associate professor at Roma Tre University. His research deals with drawing and digital representation, particularly related to the historical rereading of the major theorists and coders. It is also active in the survey and representation of the city with new virtual reconstruction technologies. He collaborated in various research concerning virtual reconstruction.

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Licensing terms

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