

Digital applications to train color ordering in three dimensions for architects and designers

Juan Serra¹, Javier Cortina Maruenda¹, Ana Torres Barchino¹, Jorge Llopis¹

¹ *Grupo de Investigación de Color en Arquitectura, Instituto de Restauración del Patrimonio, Universitat Politècnica de València; juanserra@ega.upv.es, javier.cortinamaruenda@ega.upv.es, atorresb@ega.upv.es, jllopis@ega.upv.es,*

Corresponding author: ; Juan Serra (juanserra@ega.upv.es)

ABSTRACT

Gamification is one of the main motivation and learning strategies of current generations. On the other hand, the study of color from the creation of the Bauhaus through the exercises developed by Joseph Albers has always had an undeniable component of experimentation. Motivated by this double idea, from the Color in Architecture Research Group we have studied the use of games in the training of architects for color discrimination. Among all the games aimed at training colour discrimination, puzzles are probably the most widespread. It is noteworthy that almost all of them use flat geometries, ignoring the fact that colors have three perceptual variables, and the main colour notation systems render 3D solids. It is enough to name Munsell or NCS color solids to recognise this spatial variable. So space will be a variable to be taken into account in our study, becoming one of the characteristics more intimately related to the profession of architecture. Maybe one of the most important skills that an architect must have is the mastery of spatial vision. In this way, the studio tries to combine gamification, training in colour discrimination and 3D management for architects.

KEYWORDS architecture, geometry, color order system, gamification, puzzle, app

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1. Introduction

In the acquisition of skills to work with the color for an architect or an interior designer, it is important to train the visual discrimination of colors and to gain the sensitivity to display different colors in order. Both learnings are on the roots of the different color curricula in the architecture schools since the beginning of the XXth Century and are considered essential knowledge.

Gamification demonstrates to be a good way of involving students in the acquisition of these skills that not only need a rational understanding of color theory, but also need to be naturally integrated as an instinctive skill, something that happens after a dedicated training. Among all the types of games used for learning, digital color puzzles are good alternatives to train these abilities. But it is noteworthy that, despite having color three perceptual variables, most of the available color puzzles keep working with just two dimensions of color. For this reason, the app ColorDoku 3d, aims to ease the understanding that color has three perceptual variables, and to train the visual discrimination of these variables. The app also gives the opportunity to get familiar with interesting and difficult to understand polyhedron.

2. The teaching of color order systems in architecture curricula

The description of color as a visual phenomenon with three perceptual variables, hue, value and saturation, allowed the proposition of different three-dimensional models since the beginning of the XIXth century, with different shapes depending on the arrangement of the fundamental colors and specific nomenclatures for the variables.

The time for using linear systems or two-dimensional diagrams such as the ones developed by Goethe in his Theory of Colors (1810) or by Neewton in his chromatic circle (1704) is far behind us. At present, among all the three-dimensional models, two are the most popular for art and design: The Munsell Color System, and the Natural Color System (NCS) [1]. At the Munsell Color System, colors are identified by three parameters, hue, value and chroma. With this data, you can obtain the coordinates of any color in the Munsell solid. Color Solid has an irregular three dimensional shape as a consequence of this system based in visual color perception. On the other hand, the structure of the NCS color solid is based in three pairs of opponent colors: white-black, green-red and yellow-blue. Its geometry is a regular symmetric double cone (Nemcsis and Caivano 2015) (Figure 1).

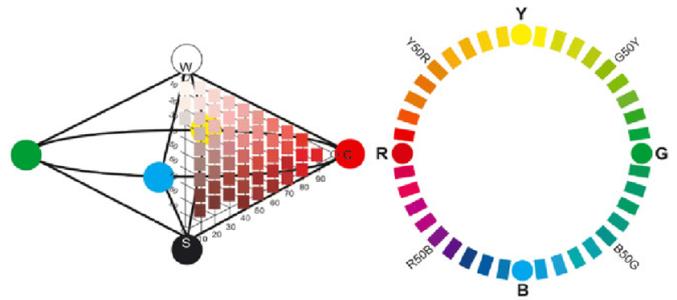


Figure 1: The NCS Natural Color System (The Natural Colour System is the copyright and trademark property of NCS Colour AB) (1979) by Anders Hård and Lars Sivik.

The ability to discriminate colors and organize them in the right order is a worth training for architects and artists, as it improves their sensitivity and expands their color abilities. For these reasons, almost all the modern color curricula for architects included the study of color circles and other similar organizations of colors with a certain logic (Hirschler et al. 2018). This was also the case of the basic courses at the Bauhaus Dessau and the Hochschule für Gestaltung Ulm, with important academics such as Albers, Itten, Maldonado, etc. Later on, Annie and Joseph Albers kept training students in color skills with interesting experiences at the Black Mountain College in North Carolina (Tóth, Molnár and Kárpáti 2021, Campos and Moya 2021).

In recent years, some of the traditional color exercises shifted into a digital version, as it happened with the perennial Interaction of Color by Joseph Albers (Franco Taboada 2015). This book has been developed as an iPad application, surpassing the original format in content. This App published by Yale University Press has been widely awarded and recognized (Figure 2). Nevertheless, some of these traditional exercises need personal involvement, are time-consuming, and not always are easy for generations of students and professionals that are becoming more impatient and less persistent. When waiting has become an intolerable matter, the impatience syndrome appears. This syndrome affects not only the current generation of students but seems to extend to future generations (Bauman 2015).

At the same time, in a completely digitalized society, gamification gives an opportunity to improve the color skills, and the pleasure of organizing colors in order is on the roots of a big number of digital games: Blendoku (Lonely Few 2015), Chroma Rush (Lonely Few 2017), I Love hue (Zut 2017), Blendoku 2 (Lonely Few 2019), Chromatic: Color Puzzles (2019), Tinge: A Color Game (Suwao LLC 2019), Chroma (Noisy Duck 2021), I Love Hue Too (2021), etc. Gamification is the use of non-

game-in-context game mechanics, elements, and design techniques to engage users and solve problems (Zichermann & Cunningham, 2011; Werbach & Hunter, 2012).

In general, this type of game provides a series of colours to be included in an incomplete two-dimensional pattern. The patterns used in these games are usually simple rows and columns of colour gradations, like in the game Blendoku. In this case the difficulty level increases with the inclusion of more pieces to place in the puzzle, and having a smaller chromatic variation. In the case of I Love Hue Too, the puzzles are based on complex mosaics and the level difficulty level increase, as in the other games, with the number of colors to fill, and the geometry complexity.

As indicated, all these apps have a two-dimensional interface and forget that color is a three-dimensional perceptual phenomenon. Nevertheless, the spatial representation of colors with their three perceptual variables results in some non-regular solids like spheroids, cylinders, double cones and many other geometries depending on the color system used. Being most of them not regular bodies, the colour discrimination learning can benefit from using three dimensional solids, as well as the understanding of complex regular bodies can be boosted by playing with the three variables of colors. For all these reasons, a puzzle in three dimensions to order colors onto regular bodies might be beneficial for architecture students.

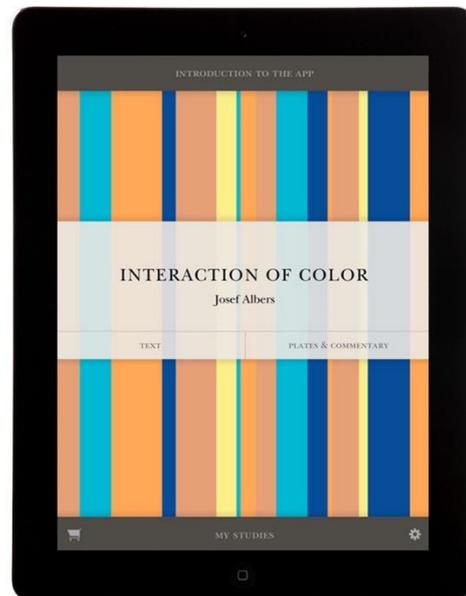


Figure 2: *Interaction of Color*, is a digital version of the traditional exercises of J. Albers in a digital way.

3. The teaching of regular bodies in architecture curricula

To have a robust spatial imagination is an essential skill for an architect, and so it is the understanding and manipulation of three-dimensional objects. If we review the European history of architecture, this ability has traditionally been cultivated with the study of regular polyhedra with complex geometries that we find since the most important treatises of geometry belonging to the Renaissance period. Even today we can find the study, drawing and analysis of these geometries forming a fundamental part of the theoretical “corpus” of Graphic Expression subjects. Books as *Beyond the Cube: The Architecture of Space Frames and Polyhedra* by Jean-François Gabriel (1997), continue to maintain the

interest and relationship between polyhedrons and architecture. Works of Louis Kahn (1910-1974), Buckminster Fuller (1895-1983) and Philip Johnson (1906-2005), among other, are a clear example of this idea.

One of the fundamental and first books that study and analyse this subject it's the *De Divina Proportione* (1509) written by the mathematician Luca Pacioli and illustrated by Leonardo da Vinci. This mathematical treatise praises mathematics as the basis of science and architecture. The book contains a small section on architecture, but undoubtedly one of its main assets is the study of regular polyhedra. These polyhedra are represented using the most cutting edged graphic resources of that period to help in the understanding of

its geometries. By alternating the drawing of solid geometries and solids represented in wire frame in more than 60 draws, it was possible an easy distinction between front and back edges, (Figure 3a).

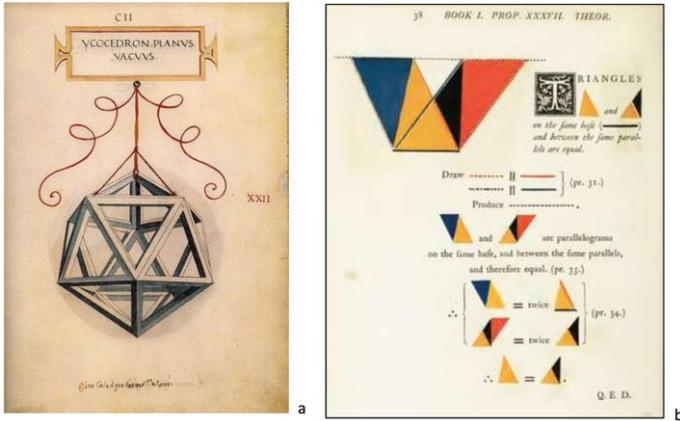


Figure 3: a) Representation of an icosahedron, Ycocedron Planus Vacuus, by Leonardo da Vinci for De Divina Proportione (Luca Pacioli, 1509); b) Oliver Byrne, The First Six Book of the Elements of Euclid, London, 1847. Book I Prop. XXXVII "Triangles on the same base and between the same parallels are equal".

In the XIXth century, the color was also used as a graphic resource for a better understanding of geometry. This is the case of the founding text of geometry The Elements (Στοιχεῖα) written by Euclides (325-265 bC), that was reedited by Oliver Byrne in 1847 with graphical codes of colors replacing the original text. As the same Byrne wrote in his foreword "we do not introduce colour for the purpose of entertainment, or to amuse by certain combinatios of tint and form, but to assist the mind in its researches after truth, to increase the facilities of instruction, and to diffuse permanent knowledge" (Byrne 1847, quoted in Higón-Calvet 2013). The combination of colors and geometry resulted in a very beautiful and easy to understand publication (Figure 3b). Nowadays, as we have already explained, as it has happened with other colour-related knowledge, the videos and animated graphics with continuous movement seem to be the most adequate means of expression to explain and understand geometries, with interesting websites explaining geometric concepts in three dimensions. [2]

4. Description of the app ColorDoku 3d

To merge the knowledge about regular bodies and color understanding, a group of academics and students

developed a digital app called ColorDoku 3d, that is available for free at the web page of the Color Research Group in Architecture UPV. [3] By the moment, it contains four regular solids with triangular faces: icosahedron (20 triangular faces), triacysthtrahedron (12 triangular faces), tetrahexahedron (24 triangular faces) and hexaquisocta-hedron (48 triangular faces) (Figure 4).

The icosahedron is a polyhedron that belongs to the Platonic solids, and has been widely represented and used since antiquity. Platonic solids are those that have all faces equal and are a regular polygon. There are only five, for this app we choose the only one that represented a certain complexity for the game.

The other three polyhedra belong to the family of Catalan solids. These polyhedra were published in 1865 for the first time by the Belgian mathematician Eugène Charles Catalan after whom they are named. There are only thirteen and are generated with two Archimedes solids. So, their faces have irregular polygons but equal dihedral angles. This type of polyhedra, besides being part of the basic teaching in architecture for the control of geometry, has also had practical applications in the use of vaults (Mallo 2013). We chose for the puzzle the triacysthtrahedron, tetrahexahedron and hexaquisoctahedron. These solids have faces with triangular bases, so they were more suitable for programming.

The triacysthtrahedron is a truncated tetrahedron, the tetrahexahedron is a truncated octahedron and the hexaquisoctahedron is a truncated cuboctahedron.

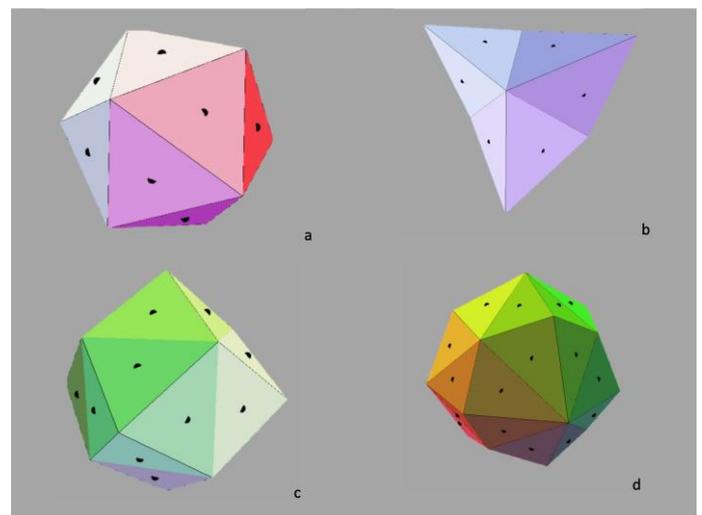
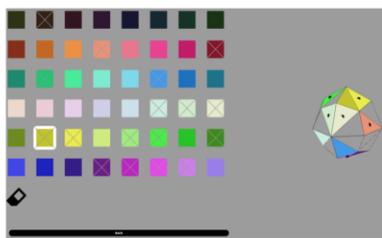


Figure 4: The four regular bodies implemented in ColorDoku 3d: a) icosahedron, b) triacysthtrahedron, c) tetrahexahedron and d) hexaquisoctahedron.



COLORDOKU 3D - TRAIN YOUR COLOR HABILITIES

Desarrolladores: Irene Cebrián Onsurbe, David de Andrés Martínez y Juan Serra Lluch



Juego para mejorar la capacidad de discriminación cromática y comprender la distribución espacial de los colores según sus variables perceptivas tono, valor y saturación. El usuario debe resolver un puzzle tridimensional colocando adecuadamente los parches de colores sobre las caras de distintos cuerpos geométricos.

Figure 5: View of the research group's website (GICA). Application login screen. https://grupocolor.webs.upv.es/?page_id=3021

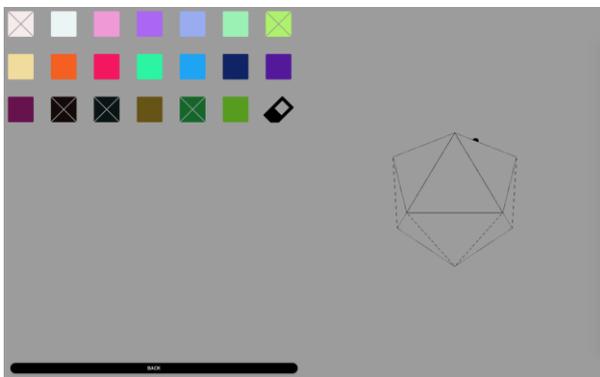


Figure 6: Interface of ColorDuku 3d with an uncompleted puzzle of an icosahedron.

In the initial screen of the app, users can choose between the four aforementioned polyhedra, and set different parameters depending on the expected level of difficulty for the game, such as the scale of the solid, its position inside the color space, and the number of faces of the figure that will appear with the colors already set. With this information, a color palette is displayed and the 3d puzzle is launched. Turning the figure round in any direction and increasing its size if needed, users can drag and drop the colors provided in the color palette into the right faces of the solid to complete the 3d puzzle.

The level of difficulty increases with the number of faces of the selected solid and with the scale of the selected solid. The difficulty is directly proportional to the number of faces and inversely proportional to the scale of the chosen solid.

In the screen of the settings, and when the scale of the regular body is under 100%, it is possible to place it in different positions inside a virtual cube. This cube represents the color space HSL (Hue, Saturation, lightness), which is an alternative model to RGB, and therefore a useful color space for digital displays. When the user selects different values between 0% and 100% for the three spatial directions X, Y and Z, is placing the solid in a different position into the HSL space. The app will automatically generate a color palette assigning to each triangular face of the solid the color corresponding to the barycenter of such a face in the HSL model.

When the 3d puzzle is launched, the interface is divided into two parts (Figure 6). On the left side there is a color palette with all the colors of the puzzle in a random order, and on the right side the user can rotate and scale the solid. Those colors preset have a grey cross on the color palette and a black dot on the corresponding face to indicate that they are locked. The rest of the colors in the color palette can be dragged and dropped onto the corresponding faces. With the

help of an eraser, the user can remove a color placed in a wrong position that will automatically move back to the color palette. When the 3d puzzle is correctly completed the indication “puzzle completed” appears.

We hope that this new app will help to improve at the same time the perceptual color discrimination ability together with the spatial vision.

5. Results and conclusions

During the 2020/21 course we invited the students enrolled in the subject Graphic and Chromatic Design of the Master in Architecture of the UPV to train with ColorDoku 3d and give their opinion. A total of 18 students (12 females, 6 males; Mean age= 23) played with the app for a couple of days and gave feedback via an online questionnaire. Regarding the selection of the polyhedra, icosahedron was the most selected (50%), followed by tetrahexahedron (27.8%), hexakisoctahedron (16.7%) and triacystetra-hedron (5.6%), therefore the selection of the polyhedra seemed to be rooted in a personal attachment and not in the number of faces of the solid or its difficulty. According to the answers, 33.3% of the respondents considered the random colors combination provided beautiful, 22.2% not beautiful and 44.4% indifferent. Considering the difficulty of the 3d puzzle, 44.4% considered it easy, 33.3% intermediate and 21.7% difficult or very difficult, with this assessment dependent on the puzzle settings of each participant. In an informal interview in the classroom, students expressed their interest in the app, indicating that it was fun and engaging, but also pointing out some aspects to improve, particularly related with the interface and the general user-friendliness of the app. Students seemed to be in favor of having an automatic preset of the parameter of the puzzle.

We conclude that ColorDoku 3d can be a useful tool for the education of students in the improvement of their perceptual color discrimination ability and spatial vision, being a complementary resource to train their color abilities out of the classroom via gamification. In the future, the app will need some upgrades to make it more user-friendly and engaging, considering the information provided by a target group of users. In future developments, it will be important to have more evidences to evaluate the improvement of knowledge of solids and colors after training with ColorDoku 3d.

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7. Conflict of interest declaration

The authors declare that they have not actual or potential conflict of interest including financial, personal, or other relationships with other people or organizations within three years of beginning the submitted work that could inappropriately influence, or be perceived to influence, their work.

8. Funding source declaration

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9. Authors short biography

Juan Serra Lluch - PhD architect, full-time professor and subdirector of research in the School of Architecture of Valencia. Member of the Color Research Group of the Heritage Restoration Institute of the Universitat Politècnica de València, with expertise in color in Modern and Contemporary architecture. Author of numerous papers and the textbook *Color for Architects* (PAPress, 2019).

Javier Cortina Maruenda - PhD architect, full-time professor and Member of the Color Research Group of the Heritage Restoration Institute of the Universitat Politècnica de València.

Ana Torres Barchino - Phd in Fine Arts from the Universitat Politècnica de València. Professor in the Graphic Expression Department in the UPV. Degree in Master in Conservation and Restoration of Architectural and Urban Heritage by the Polytechnic University of Madrid. Her research lines are focused on the analysis of colour in architectural heritage and design.

Jorge Llopis. Phd. Architect and Full Professor at the Universitat Politècnica de València in the Graphic Expression Department. His research lines are focused on the analysis of documentary and cartographic information on architectural heritage and on the study of new architectural graphic strategies after the arrival of digital drawing.

Notes

[1] There are many other systems for ordering colours in a three-dimensional space organised by three perceptual variables. Among

them, the Coloroid System developed by Nemecsis between 1962 and 1980 stands out. This system uses hue as an angular coordinate, saturation as a radial coordinate and luminosity as a vertical coordinate.

[2] <http://www.matematicasvisuales.com/index.html>

[3] <https://grupocolor.webs.upv.es/>

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