

"POLYCHROMY": A STUDY ON GOETHE'S THEORY OF COLOURS AND COMPUTATIONAL DESIGN PEDAGOGY

SABRI GOKMEN

Georgia Institute of Technology, Atlanta, USA
sabrigokmen@gatech.edu

Abstract. This paper will present the main principles of Goethe's *Theory of Colours* and formulate a theoretical approach for the study of polychromy in digital design pedagogy. In the first part of the paper a survey on colour theory will be presented comparing Goethe and Newton's works on colour. The concepts of polarity [*Polarität*] and intensification [*Steigerung*] will be introduced as the two main principles of Goethe's dynamic notion of colour. These terms will be used to explain how Goethe considered colours to induce sensual effects on the onlooker. In the second part a digital design studio that focuses on colour will be presented. The pedagogy will show how a dynamic notion of colour could be studied using digital tools. Some of the student works will be presented while addressing how a Goethean notion of sensual colours could be studied as spatial parameters. The goal of the paper is to distill a theoretical approach towards the study of colour in architecture and contemplate on how it could be applied within the digital design curriculum.

Keywords. Colour; Goethe; Digital Design; Pedagogy.

1. Introduction

Throughout history colour has always been complimentary to architectural form, making it an inherent part of many stylistic movements. In Victorian England many interiors were decorated with wallpapers and tapestries to enhance spatial qualities with colourful patterns. After modernism much of this heritage was lost due to the level of abstraction and preference of colour as an artefact. Today contemporary architecture still suffers from lack of theory on colour as it has become an external and disjoint property of form.

In this paper we will introduce a historical theory on colour that could be used within digital design pedagogy. This framework is constructed around Goethe's *Theory of Colours*, a treatise that considers colour as a dynamic and generative principle based on nature's intrinsic laws. Goethe's work has been influential in our research because it considers form and colour to be produced together while producing sensual effects on the onlooker. Using this approach a studio curriculum has been formulated that starts by looking at colour and patterns as a way to generate forms. Examples of student work from the studio will be presented to show how this process is completed following the initial theoretical outline.

2. Goethe's Colour Theory

J.W. von Goethe (1749-1832) was one of the most influential thinkers during Romanticism in late eighteenth-century Germany. Although he was mostly recognized as a literary genius, he also contributed extensively in the field of natural science. On top of his work in the field of botany and osteology, he completed a treatise on colour in his life. Goethe's interest in colour began in 1790 when he tried to repeat Newton's experiments in *Optics*. In his work, Newton defined colours based on their refrangibility using a triangular prism in his dark room experiment. After reviewing such concept Goethe expected to see colours as he looked through the prism towards a white wall. However the colours he expected to see were only produced when a boundary between white and dark surface was present. Goethe became skeptical of the complex and difficult nature of Newton's experiments and conducted alternative experiments to discover the nature of colours.

In *Theory of Colours* Goethe introduced observations from simple cases towards complex ones using coloured cards (Goethe, 1971). In one of the experiments, Goethe placed a white rectangle card inside a larger black one. Looking at the cards through the prism he observed the colours red and yellow forming over the white rectangle and blue and violet at the bottom. Using alternating experiments he showed that light or cool colours appeared adjacent to white strips while dark or warm colours were adjacent to black (Figure 1). However green was not present within the spectrum he observed, as the space where Newton predicted green was still white. Green was produced by increasing the distance of the prism from the card, which refracted the yellow to blend with the blue to produce the colour green. Although Newton anticipated green to be a part of the homogeneous colour distribution out of light, Goethe argued that green was produced through the mixing of yellow and blue as they overlapped over the white rectangle (Goethe, 1971). Similarly red was produced through the mixing of violet and orange.

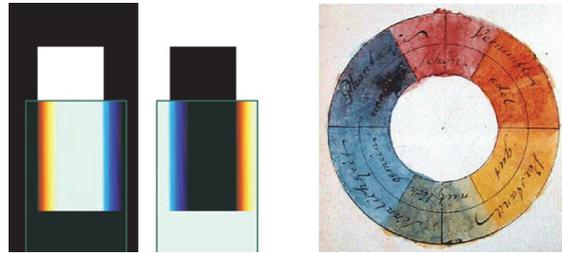


Figure 1. Left: A diagram showing the results of Goethe's experiments with black and white cards.¹ The triangular prism (Facing towards the cards) produces warm colours on white borders and cold colours on black border. Right: Goethe's symmetrical colour wheel.

In these observations Goethe found two main colour spectrums. The one that occurred over the black background in the order of orange, green and violet was the spectrum colours that were analyzed by Newton. Respectively, the ones that occurred over the white background in the order of blue, red and yellow were called "Goethe-colours" (Goethe, 1971). Goethe named these two opposing colour sequences as "border spectra." The alternating sequences of colours at borders showed that colours do not follow a sequential order but they appear in opposition to each other (Goethe, 1971). Goethe gave equal rank to the reversed spectrum where the colours appeared in harmony and contrast. However he identified yellow and blue to be primary colours and red occurring as the intensified intermediate to them. These contrasting relationships were used to construct a symmetrical colour wheel where Goethe combined both spectrums together (Figure 1).

2.1. GOETHE'S TERMINOLOGY

To understand the production of colour, Goethe introduced two main principles in his thesis. These are polarity [*Polarität*] and intensification [*Steigerung*]. The former acts a universal principle that combines quantities of light and dark for the production of colour, while the latter explains the changing gradations of colours based on quantities, as it happens in heating of metals. In a short essay titled "Polarity" Goethe explains how nature operates with both concepts as she "uses the principle of life, with its inherent potential to work with the simplest phenomenon and diversify it by intensification into the most infinite and varied forms" (Goethe, 1988). Goethe considered polarity as an inherent principle in nature that produced colours in harmony through the interaction of light and dark. This became central to his experiments with white and black coloured cards seen under prism.

Intensification is mostly observable in physical and chemical colours where colour shades could be perceived simultaneously. For instance

through the heating of steel barrels, it's possible to see a gradual shifting of object's physical colour from yellow to blue that corresponds to the rising temperature of the metal. Another case of such phenomena could be observed under different thicknesses of turbid medium by placing a stack of white stairs placed inside coloured water. In these experiments water simply acted as turbid medium producing different intensities of the same colour. Thus, intensification explained how gradations of colours were produced through the addition of positive (white) or negative (black) hues.

2.2. GOETHE'S METHODOLOGY

A key aspect to these experiments is how much Goethe placed the observer to become a central part of the process. Although he considered subjective judgment in scientific investigation to be error-prone, he explained a way to use subjectivity to guide the experiments in a positive way. In the didactic part of *Theory of Colours* Goethe systematically constructed a sequence of experiments that showed how one experiment or experience could be produced in the most diverse results. However, this process presented a paradox, as Goethe himself considered jumping hastily into experiments to validate initial hypothesis to be dangerous (Goethe, 1971). Instead, he advised to use the human intellect and ability to seek all the modifications of a single experience to diversify the observation and knowledge. Only then a "higher order" of scientific understanding could be achieved that will take out the subjective character of the experiments and lead towards an objectified view of the phenomenon. This methodology allows the scientist not to accept a single experiment as a universal fact, but help construct a dynamic path by connecting the experiments together to reach to a higher principle.

2.3. GOETHE AND NEWTON

Compared to Newton's complex experiments in the dark room, Goethe was able to show the ordering of colours using simple, sequential experiments that could be repeated by any observer using the cards and prism. However, much of Goethe's advancements and discoveries at that time were cast in the shadow of Newton's prominent figure within the scientific realm. In his book *Goethe Contra Newton* Dennis L. Sepper revisits this historical dilemma by comparing Goethe's methodology and achievements to Newton's scientific revolution in *Optics* (Sepper, 1988). Goethe believed that by placing additional elements into the experiment like apertures, prisms, and lenses Newton "erroneously puts something artificial and complex in place of the naturally simple" (Sepper, 1988). In his experiments Newton heavily relied on an analytic methodology that turned colour refrangibility into an isomor-

phic function to explain colours only through quantities of wavelengths. As a result, his assessment of colour became a science of rays that explained colour only as a secondary phenomenon due to their diverse refrangibility. In contrast, Goethe's aim is to discover an inherent polarity in nature that considers colours as opposition or in relation to each other that can reveal their different properties. For instance, green's production occurs through the subtraction of wavelengths as the light of white strip is replaced by dark. Similarly red emerges through the addition of wavelengths that adds light to the dark. Since boundary colours blue and yellow are complementary to each other in terms of wavelengths, Goethe is correct to consider them as primary colours for colour mixing (Currie, 2010).

2.4. SENSUAL EFFECTS OF COLOURS

In the last section of *Theory of Colours*, Goethe gives a detailed analysis on the sensual effects of colour "by means of which they act on the mind; producing this impression in their most general elementary character, without relation to the nature or form of the object on whose surface they are apparent" (Goethe, 1971). To experience the feelings the colours invoke on the mind, one has to be surrounded with one colour like being in a room with single coloured walls or looking through a coloured glass. Using the polar relationships of colours Goethe considers, yellow, orange and red to be positive while green, purple and blue to be negative colours and have corresponding effects. While yellow produces "a warm and agreeable impression," blue produces "a stimulating negation" (Goethe, 1971). For Goethe these characteristics or qualities also have implications on space. Blue rooms appear cold and empty, while green rooms are suitable for living spaces. Among them he considers red to produce the highest effect with the union of two contrasted extremes. Red conveys "an impression of gravity and dignity, and at the same time of grace and attractiveness" (Goethe, 1971). To study these effects one has to first see them "as a quality, instead of with the replacement of colour by measurable quantity with which it can be correlated" (Bortoft, 1996). By describing these distinct sensual effects Goethe aimed to reveal certain qualities that are inherent among different colours.

3. Polychromy

In this section we will be introducing a process oriented design pedagogy focusing on digital design and Goethean notion of colour and experimentation. The studio scope was set by Lars Spuybroek to study colour as a way to create architectural spaces under defined research topics. The studio follows a reverse methodology that begins by looking at techniques and diagrams as a

way to distill generative approaches for form finding (Spuybroek, 2004). This also enables a dynamic approach towards the study of colour in order to develop specific atmospheric qualities for architectural spaces. To achieve this goal, students considered various colours and hues to have direct correlation to program and structural components. In this section the studio approach and topics will be discussed while showing some of the examples of student work to narrate how this process was implemented.

3.1. COLOUR DIAGRAMS

The studio research consisted of two different types of patterns to be studied that are grouped under "sticks" and "tiles." While the former is mainly derived from textile techniques like felting, weaving and macramé, the latter is based on tessellation techniques such as mosaics, triangulation and non-periodic tiling. The studio is completed in two modules each spanning eight weeks. In the first eight weeks student groups work together preparing their research on colour, patterning and structure. In the second eight weeks student groups are separated to develop individual projects on a selected site and program (Gokmen, 2013).

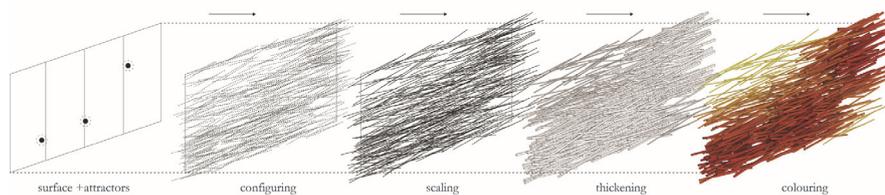


Figure 2. An example from diagramming phase of felting. The parts are converted into structural and coloured configurations using parametric tools.

In the early phase of the studio, the goal is to find examples of natural patterns and artificial techniques to extract information on how colour relates to various pattern formation processes. During this stage an analysis of figures and their configurational qualities is made to incorporate a dynamic notion of colour. For instance a densification in pattern directly relates to the intensification of colour that could be understood as parametric variations of within a particular system. Thus, the thickening and joining of parts could be achieved by continuous production of colour and structure (Figure 2).

3.2. COLOUR MACHINES

In the second half of the studio the initial colour studies are applied towards a site and program. In this section the main focus is given to the patterning

and colouring of spatial elements that can accommodate specific program components. For instance, a play between cool and warm colours could be directly incorporated towards public and private spaces. Following the connection between colouring and structuring of patterns, these techniques were applied in three dimensional configurations to create an atmosphere or mood for space (Figure 3). During this stage students produced custom parametric tools to control the openings, densities, patterning and colouring of architectural surfaces. The overall intention is to construct an abstract systemacy that can be controlled by a notion of colour and elements, before it could be applied to fit into a specific architectural space or structure (Spuybroek, 2004).

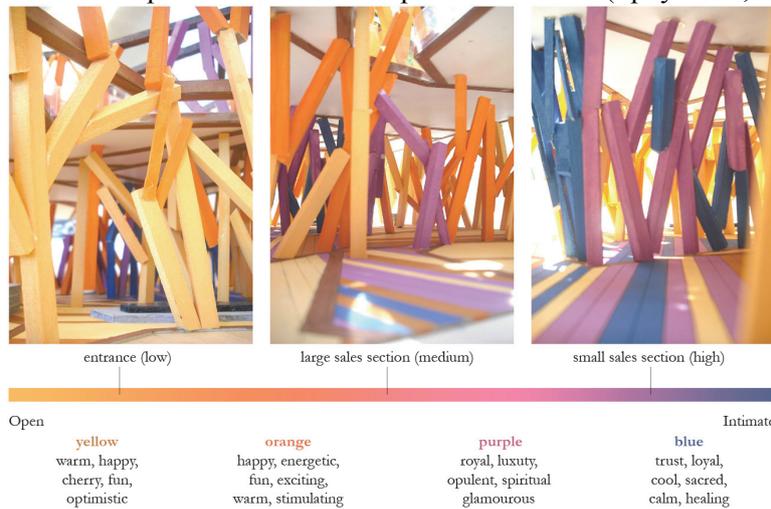


Figure 3. A study showing how colours were used as spatial components inducing sensual effects. The student chose colours as programmatic parameters and applied them to retail spaces to define different atmospheres. (Student: Hyo Jae Lee)

After the mid-term, student groups were separated to develop individual projects on a chosen site and program. Programs that can accommodate colour as a spatial component were considered throughout the second half of the studio. Students were directed to consider colour as a way to inform both structural elements and the character of programmatic spaces. The final designs aimed at satisfying both aesthetic qualities and structural properties that inform architectural organization.

3.3. CASE STUDIES

In this part we will be presenting some of the projects developed by students following the studio methodology. The following examples are taken from a group of undergraduate students that worked on textile techniques,

focusing on Claudy Jongstra's felting. In her work, Jongstra uses natural dyes, wool and techniques to achieve dynamic colouration for tectonic art projects. Working as a group in the research phase of the studio, the students studied Jongstra's felting techniques as a way to develop architectural elements and colouring relationships. In their initial group research, the students made various analog models using felt and wooden sticks to show how structural systems could be achieved with changing densities and configurations of elements. During this early stage colour was used in diagrams to show the effect of relations of members on colour hues following parametric inputs (Figure 2). The projects developed in the second half of the studio utilized these digital tools towards combining colour and materiality as a way to inform structure and space.



Figure 4. Project based on horizontal felting. This student used a wooden space-frame like structural system to define exhibition spaces with different colours. (Student: Jose Pejares)

3.3.1. Horizontal Felting

During the design phase one of the students chose museum as his program typology and picked a site in a suburban area. Using the wooden sticks as a way to achieve a felting-like systemacy, he defined a buttress type of structural system that was formed by stacking horizontal wooden members (Figure 4). The produced system enabled a continuous spatial and structural configuration while characterizing exhibition space boundaries with colour. The usage and choice of colour in design is aimed to facilitate the movement and mood of visitors throughout the building. Starting from the entrance with higher intensity (red - attractive), the visitors are directed towards temporary exhibition spaces (orange - exciting) and permanent collection (green - repose) ending their path in the auditorium (blue - calm). Using the parametric colour tools the student combined different coloured spaces to create smooth transitions of colour (Figure 5). This operation produced gradations of colours along the aisles of the building while defining a divergent space frame structure to filter light to the exhibition spaces.

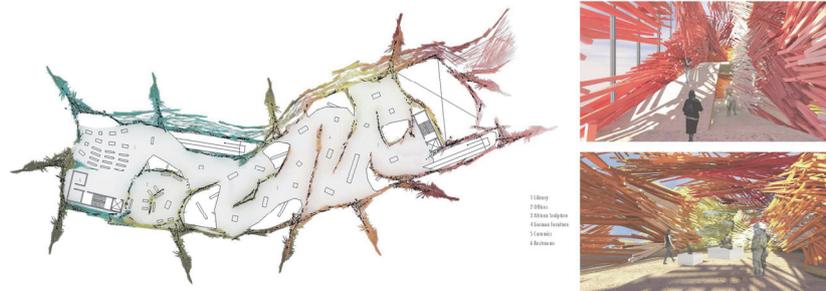


Figure 5. The plan and renderings of the horizontal felting project showing the effect of colour in spaces along the serpentine like program distribution. (Student: Jose Pejares)

3.2.2. Vertical Felting

The following project used felting technique as a way to create a vertical structural system using hierarchy of wooden members. The student chose a retail program in a confined site and defined four colours to guide customers throughout the building. For the distribution of program components mainly warm colours were chosen to fit to the energetic character of the retail store. While yellow tones were used in common circulation spaces to create an inviting effect, blue tones were applied to private pocket spaces where custom products were displayed with artificial lighting (Figure 3).



Figure 6. Project based on vertical felting. This student used coloured wooden members to define structure and walls of a retail program. (Student: Hyo Jae Lee)

The building site was located tightly within two adjacent stores which required the skin of the structure to be highly porous to allow natural light. The colouration of the members added a further emphasis on this constraint as the darker (blue and magenta) zones received less natural lighting and were designed to create a secluded atmosphere (Figure 6). The overall intention for the colours was to create a meandering experience for visitors to follow colour gradations throughout the store and discover hidden product display areas.

4. Conclusion

This paper showed an avenue for digital design research based on Goethean theory of colour. A theoretical outline of Goethe's *Theory of Colours* is presented to offer a dynamic frontier that can combine research on colour and design. Goethe's views show that colour offers two avenues to be satisfied at the same time. The first one is to be studied as a quantifiable medium that could be investigated using various parametric tools. The second one is dependent on an external observation to see the qualities of colour and associate them to spaces to invoke mood and atmosphere. This way a dichotomous but complimentary experimentation could be adopted which can help establish an architectural colour theory and study.

Although there is currently a lack of interest in colour within the digital paradigm we expect further research on this subject in the future. One of the most challenging aspects in teaching polychromy is the production of physical tectonic models and digital chromatic models simultaneously. Achieving gradations and mixing of colours in analog models seems to be cumbersome, however such information could be supplied with digital models. From a pedagogical standpoint, our research on colour aimed at combining multiple design aspects together such as light, space, atmosphere and geometry (Burghard et al., 2011). This way an objective analysis on the effects of colour could be achieved without considering it as an artefact to be added to form. As a result, colour could facilitate production of higher aesthetic designs and tools that can establish a dynamic medium for design research.

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1. Image source: <http://www.handprint.com/HP/WCL/book3.html>