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"The Spectrum of Art": Exploring Artistic Inspiration and Sustainable Coloration in Fashion

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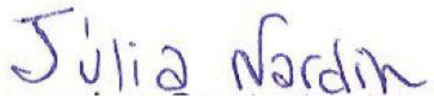

Dedicatória

Para minha família e amigos que estão torcendo por mim do Brasil.

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Resumo

A preocupação com a sustentabilidade está cada vez mais em evidência, especialmente nos setores têxtil e da moda, que são reconhecidos como algumas das indústrias mais poluentes devido ao uso intensivo de produtos químicos prejudiciais ao meio ambiente e à saúde humana, principalmente durante os processos de tingimento e estamparia. Diante deste cenário, é crucial que os profissionais destas áreas procurem soluções mais sustentáveis para a coloração dos têxteis, visando reduzir os impactos ambientais. Uma alternativa viável é a utilização de corantes naturais, uma vez que são de origem não tóxica e biodegradáveis para um tingimento e estamparia mais sustentáveis.

Assim, este estudo visa explorar a evolução do uso de cores na arte e na moda, desde os pigmentos naturais tradicionais até às inovações contemporâneas, como os pigmentos bacterianos, considerados uma abordagem mais sustentável e ecológica em comparação com os corantes sintéticos. Ao desenvolver uma coleção inspirada em Wassily Kandinsky, a pesquisa pretende destacar a relação entre arte e moda, demonstrando como a arte pode influenciar soluções criativas e sustentáveis na moda, além de promover uma consciência ambiental e um retorno às origens naturais das cores e técnicas de estamparia como uma forma de traduzir as formas abstratas e as cores de Kandinsky.

Por fim, o estudo demonstra como a sinfonia visual entre moda e arte se manifesta, celebrando a criatividade, a expressão individual e a conexão com a natureza, propondo novas abordagens sustentáveis na moda.

Palavras-chave

Tingimento natural; moda sustentável; estamparia natural; pigmentos bacterianos; design têxtil; eco-desing; obras de arte; pinturas; arte abstrata; Wassily Kandinsky

Abstract

The concern for sustainability is increasingly in the spotlight, especially in the textile and fashion sectors, which are recognized as some of the most polluting industries due to the intensive use of chemicals harmful to the environment and human health, particularly during dyeing and printing processes. Considering this scenario, professionals in these areas must look for more sustainable solutions for textile coloring, aiming to reduce environmental impacts. A viable alternative is the use of natural dyes, as they are non-toxic and biodegradable, leading to more sustainable dyeing and printing processes.

Therefore, this study aims to explore the evolution of color usage in art and fashion, from traditional natural pigments to contemporary innovations, such as bacterial pigments, which are considered a more sustainable and eco-friendly approach compared to synthetic dyes. By developing a collection inspired by Wassily Kandinsky, the research intends to highlight the relationship between art and fashion, demonstrating how art can influence creative and sustainable solutions in fashion, as well as promoting environmental awareness and a return to the natural origins of colors and printing techniques as a way to translate Kandinsky's colors and abstract forms.

Finally, the study demonstrates how the visual symphony between fashion and art manifests, celebrating creativity, individual expression, and connection with nature, proposing new sustainable approaches in fashion.

Keywords

Natural dyeing; sustainable fashion; natural printing; bacterial pigments; textile design; eco-design; fine arts; paintings; abstract art; Wassily Kandinsky

Summary

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Lista de Acrónimos

GRP	Gabinete de Relações Públicas
UBI	Universidade da Beira Interior
CAD	Computer-Aided Design
YSL	Yves Saint Laurent
MASP	São Paulo Museum of Art.
MoMA	Museum of Modern Art in New York
MOCA	Museum of Contemporary Art in Los Angeles
CO_2	Carbon Dioxide
NA	Nutrient Agar
PGP	Peptone Glycerol Phosphate
TSA	Tryptic Soy Agar
MIT	Massachusetts Institute of Technology
WGSN	Worth Global Style Network

Introduction

The relationship between art and fashion has been studied for a long time, and it shows how these two forms of expression have influenced and complement each other throughout history. Art has evolved from being merely an inspiration to becoming an integral component of fashion design, giving it a cultural capital that can elevate creations to the status of works of art. This dynamic can not only enrich fashion but also democratize art, making it part of people's everyday lives. Fashion becomes a powerful vehicle for the dissemination and appreciation of art, while art gives fashion a high cultural meaning and value (Oliveira, 2020).

This thesis explores this relationship, highlighting the importance of colors both in art and in fashion, from the emergence of natural pigments to contemporary sustainability practices. Colors have played a fundamental role in both fields, not only as aesthetic elements but also as means of communication and cultural expression (Mocquard et al., 2022; Sundararajan & Ramasamy, 2023; Yusuf et al., 2017).

Historically, natural pigments were the first materials used to dye fabrics and create works of art. These pigments, extracted from plants, minerals, and animals, connect artists and artisans to nature, imbuing their creations with a sense of authenticity and connection to the environment, thereby enhancing the ecological consciousness of their artistic endeavors. Despite this, with the advent of the Industrial Revolution, synthetic pigments largely replaced natural ones due to their availability and lower cost. However, these pigments comprise chemical and toxic elements, such as lead and mercury (Andre et al., 2021). Due to the toxicity of their components, these paints are carcinogenic to humans, and their emission of pollutants can cause environmental damage (Di Salvo et al., 2023; Qin et al., 2023; Srivastava et al., 2022). Additionally, they are not renewable or biodegradable. Consequently, growing concerns about sustainability and the environmental impacts of modern production processes have led to a revitalization of the use of natural pigments in fashion and art.

This return to natural pigments is particularly relevant in the contemporary context of sustainability. Fashion, characterized as one of the most polluting industries in the world, is responsible for approximately 28% of greenhouse gas emissions, 20% of global wastewater, $100 billion in losses due to underutilization and lack of recycling, and 9% of annual microplastic losses to the ocean. Additionally, the use of pesticides and agrochemicals in cotton fiber cultivation, along with the use of chemicals for dyeing and printing, further exacerbates environmental impacts. Notably, 95% of water usage in the textile industry is attributed to the dyeing process, with the remaining 5% allocated to upstream processes. Considering these challenges, it becomes essential to consider more sustainable alternatives that minimize environmental impacts (Adamkiewicz et al., 2022; Elsahida et al., 2019; Gomes & Soares, 2023).

The search for sustainable products has grown considerably in recent years, with consumers increasingly aware of the environmental impacts caused by the textile and fashion industries.

Various stages of the dyeing and printing processes contribute to these damages, including the abundant use of water and energy, as well as the chemicals that are later discarded into rivers and soils (Fleck, 2021). But how can we carry out the dyeing and printing processes in a less impactful way on the environment?

The use of bacterial pigments represents a promising innovation in the textile field. Produced by microorganisms, these pigments offer an eco-friendly alternative to synthetic dyes, reducing the need for harmful chemicals and decreasing the ecological footprint of textile production. According to Sundararajan & Ramasamy (2023), "bacterial pigments possess therapeutic, antimicrobial, anticancer, antioxidant, and immunosuppressive properties, which can be used against diseases and disorders [...] in addition to having greater efficacy compared to synthetic dyes." (Sundararajan & Ramasamy, 2023).

However, simply using sustainable materials is not enough. There are various techniques for developing prints that focus on sustainability. Among these printing practices, we find artisanal techniques such as stencil, shibori, batik, and tie-dye, which have been practiced for centuries, in addition to the more recent botanical printing technique. All these processes include the use of non-toxic materials, such as natural dyes and pigments, natural mordants, and preferably natural fibers. Additionally, artisanal printing techniques promote unique effects on the fabric, adding greater value to the product and creating an emotional bond with the consumer, which gives the final product a longer lasting useful life (Fleck, 2021). Thus, not only sustainability is provided but also creativity is enhanced through unique, and exclusive patterns and forms.

In this study, both natural methods and materials were used. According to Fleck (2021), this segment has been gaining ground in the market as many companies and customers are opting for eco-friendly products colored artisanally with natural dyes and pigments. Additionally, the effluents from these processes are not harmful, meaning they do not compromise the environment or human health (Saxena & Asm, 2014).

Thus, a mini collection of textile patterns will be developed, inspired by the works of Wassily Kandinsky, one of the pioneers of abstract art. Kandinsky is known for his expressive use of colors and his perception of colors as carriers of emotional and spiritual meanings. The collection will primarily explore the use of bacterial pigments as a sustainable color palette, translating Kandinsky's vibrant and dynamic compositions into fabrics made of cellulose fibers, such as cotton, along with artisanal printing techniques.

In summary, the present study aims to explore and contribute new information regarding the visual effects that can be achieved through the combination of natural dyes and pigments, textile substrates, artisanal printing processes, and the influence of art on fashion.

It is also intended to study the effectiveness of using natural pigments derived from microorganisms when applied to natural substrates, according to the applied processes, through a comparative visual analysis of samples regarding the amount of pigment used. This will demonstrate whether the pigment and the chosen technique are suitable for application in the sustainable clothing sector.

Furthermore, it seeks to preserve artisanal coloring techniques as a way to add greater value to the pieces while reducing environmental impacts through a creative process.

Finally, the study demonstrates how the visual harmony between fashion and art manifests, celebrating creativity, individual expression, and connection with nature.

Research Questions

This thesis investigates sustainability in the fashion world, with a particular focus on the use of natural pigments, especially bacterial pigments, for creating printing pastes in artisanal printing processes. The study also explores the relationship between art and fashion, analyzing how artistic inspiration can add value to fashion products and promote more sustainable practices.

How can the use of natural pigments, especially bacterial ones, in the creation of printing pastes, contribute to sustainability in the fashion sector, and in what ways can the integration of art enhance and innovate these processes?

General and Specific Objectives

The primary objective of this work is to explore the potential of natural pigments produced by bacteria as an alternative to synthetic pigments. In addition, natural dyes extracted from beets and indigo will be used to create printing pastes for unique prints. To achieve this goal, the study includes a plan of activities focused on various areas.

First, artisanal printing techniques with potential applications in fashion design will be explored. Strategies will be formulated to enhance the use of natural dyes and pigments in fabric printing processes, aiming at the production of clothing articles. Furthermore, the work seeks to create innovative, safe, and sustainable options for the textile industry, ensuring that natural dyes and pigments offer the same effectiveness, durability, and quality as synthetic pigments.

Additionally, the study will investigate the relationship between fashion and art, demonstrating how the integration of artistic elements can add value to fashion products and promote more sustainable practices. Through this approach, the work intends to show that artistic inspiration can be a catalyst for innovations in fashion design, contributing to a more creative and environmentally responsible industry.

Specific Objectives

1. Evaluate the effectiveness of bacterial pigments in creating printing pastes for use in fashion textiles.
2. Investigate the environmental, social, and economic advantages of adopting natural pigments compared to synthetic dyes.
3. Explore artisanal printing techniques and their viability as alternatives to mechanized industrial processes.
4. Analyze how the integration of artistic elements in fashion products can add value and promote sustainability.
5. Propose improvements and future research areas to increase the effectiveness and adoption of natural pigments in the textile industry.

Dissertation Structure

After the introduction, the dissertation follows the following normative structure:

Chapter I - Color, Art, and Fashion (state of the art)

This chapter briefly contextualizes color theory, its propagation, and the emotions it evokes, as well as explores its application in the domains of art and fashion.

Chapter II - Art and Fashion (state of the art)

This chapter provides a theoretical framework for the relationship between art and fashion. It discusses the historical moment when this relationship became perceptible and highlights examples of major fashion brands inspired by recognized artists. It also discusses how art can add value to fashion products.

Chapter III – Sustainability in Fashion (state of the art)

This chapter analyzes sustainability in fashion and its environmental impacts. Additionally, there is a concise and updated description of the origin of natural pigments and dyes, their definitions, and applications in the textile sector, as well as a brief investigation into artisanal printing methods.

Chapter IV – Market Study in Fashion

It presents the work carried out by various entities, such as brands, companies, and designers, using natural pigmentation through bacterial and plant pigments and artisanal printing techniques with these dyes.

Chapter V – Laboratory Development

This chapter describes the laboratory procedures for extracting pigments from bacteria and beets, the creation of printing pastes, and the adopted artisanal printing technique, serigraphy. It articulates the implemented techniques with the obtained results and records important data for later use in the creative process.

Chapter VI – Creative Process

This chapter describes the market trends for the Spring/Summer 2025 season based on data from the WGSN trend authority, which will be used in the project development. Introduces the development of the proposed project by applying bacterial pigments and serigraphy in fashion design, conceiving a capsule collection titled "The Spectrum of Art," composed of six pieces.

Chapter VII – Conclusion and Future Perspectives

Presents a synthesis of the results obtained and the relevant conclusions of the work and presents perspectives for future studies based on the results of this work.

References

Lists the bibliographic and webographic references that underpinned the scientific work.

Chapter I
Color, Art, and Fashion

Colors are everywhere, whether in the interior of a house, clothing fabrics, plants and flowers, foods, television, and advertisements. They evoke emotions and desires, prompting us to eat, consume, or buy. According to Kuehni (1996), colors have evolved to become more than just a tool for survival and communication for thousands of years. Art and design encourage us to derive aesthetic pleasure from them (Kuehni, 1996).

But what are colors? Kuehni (1996) explains that, according to the British language dictionary, color is defined as the visual impression generated by light, determined by the wavelength of electromagnetic rays perceptible by vision. It is the characteristic of an object that allows it to produce a specific visual impression based on how it reflects or emits light. We can say, then, that colors are nothing more than a complex physical phenomenon that is linked to the outcome of activities of one of our five senses, vision. They involve the interaction between three factors: a light source, an object, and an observer (Kuehni, 1996).

In summary, color perception occurs when the light reflected by an object reaches the cones of the retina, which are photoreceptors sensitive to the different wavelengths of visible light. These cones convert the reflected radiation into electrical signals, which are transmitted by the optic nerve to the brain, where they are interpreted, allowing us to see colors (Araújo & Castro, 1987; Billmeyer Junior & Saltzman, 1981; Kuehni, 1996). In the case of printed or dyed materials, the incident light is altered by the object and the dye, resulting in selective absorption of light with different wavelengths. The object then reflects or transmits the light that is not absorbed, entering the eye and creating the sensation of color that we perceive (Neves Jorge, 2000).

For Kuehni (1996), just like emotions and sensations, colors are almost impossible to define. After all, what is happiness, what is sourness, what is blue?

> “On a simple level color is first and foremost an experience. It is an important part of the total experience we have strolling through, say, the permanent collection of paintings in New York’s Metropolitan Museum of Art, when observing a rainbow against a storm-gray background over brightly colored fall leaves, or when we stand at the edge of the Grand Canyon at sunset. Persons with normally functional vision systems obtain perhaps the largest amount of information about the surrounding world from the visual system, and color plays an important part in this flow of information. [..] The evolution of our sensory capabilities and the resulting processing of information has resulted in development of what we call esthetics, the knowledge of the beautiful” (Kuehni, 1996).

Araújo & Castro (1987), in the book "Manual de Engenharia Têxtil", further state that colors have three physical aspects related to the theory of radiation. These are physiological aspects, which concern the functioning of the human eye and central nervous system; psychological aspects, which are linked to sensory and emotional functions; and cultural aspects, which are based on the diversity of symbolic interpretations of color that can be linked to religious, geographical, ethnographic, climatic, and sociological factors (Araújo & Castro, 1987).

1. The Study of Colors

The English scientist Isaac Newton (1642 – 1727) conducted an optical experiment in 1666 that became decisive for understanding the phenomenon of color in scientific terms. In this study, Newton observed that sunlight consists of colored rays, which can be visualized when sunlight passes through a triangular glass prism, as shown in Figure 1 (Araújo & Castro, 1987).

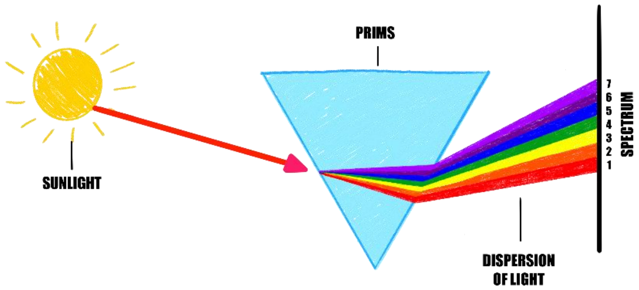


Figure 1 - Dispersion of Solar Light (adapted from Araújo & Castro, 1987).

This sequence of colored light stimuli is called the solar spectrum, and it is arranged in decreasing order by wavelengths ranging from 760 to 380 nanometers. These luminous stimuli are what we call colors, and the visible colors of the solar spectrum are "red, orange, yellow, green, blue, indigo, and violet", where red corresponds to 700 nanometers and violet to 400 nanometers, as shown in Figure 2 (Araújo & Castro, 1987; Billmeyer Junior & Saltzman, 1981). Newton believed that the colors of the spectrum could be linked to a musical scale, suggesting "tones" and "harmonies", and since then, colors have been treated in musical terms (Jones, 2005).

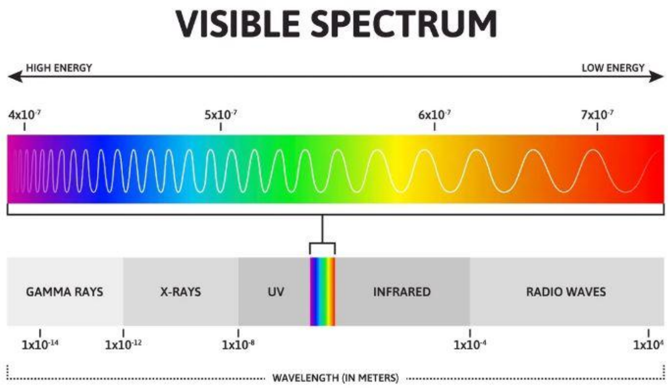


Figure 2 - Visible Spectrum of Light (Lucas, 2022).

There are two theories that explain how new colors can be formed through the mixture of lights and pigments: the additive and subtractive color theories. According to Araújo & Castro (1987), the additive theory studies color when it is only colored light. The more overlaid lights, the brighter the colors become. On the other hand, the subtractive theory studies color when linked to a material support called pigment. These absorb wavelengths, and when combined, the resulting color reflects less light (Araújo & Castro, 1987).

Considering the present study, understanding subtractive synthesis, that is, how the process of color perception in objects occurs, becomes more interesting, since in the textile industry, dyes and pigments are used to dye fibers, whether they are natural or not (Araújo & Castro, 1987).

That pigments can analyze the sunlight that falls on them, absorbing certain radiations and reflecting others. In other words, a pigment will produce a colored sensation in the observer according to the light that this substance will reflect. We use a pigment called green as an example. It is named so because it reflects only the electromagnetic wavelengths corresponding to the color green within the solar spectrum while absorbing all other radiations. Therefore, by mixing dyes or pigments of the seven colors of the solar spectrum, we will produce total absorption of the incident light, resulting in the sensation of black or absence of color (Araújo & Castro, 1987; Fleck, 2021).

We know that obtaining different colors comes from mixing colors, and there are two groups of fundamental colors, called primaries, which, when combined, can produce the others: subtractive and additive colors, as shown in Figure 3. In the subtractive color theory, opaque dyes are yellow, blue, and red, and for transparent dyes are yellow, cyan, and magenta. Mixing these three colors results in dark gray. For the additive color theory, the primary colors are considered to be green, red, and blue, and mixing all colors gives the sensation of white (Araújo & Castro, 1987; Billmeyer Junior & Saltzman, 1981; Morris, 2006).

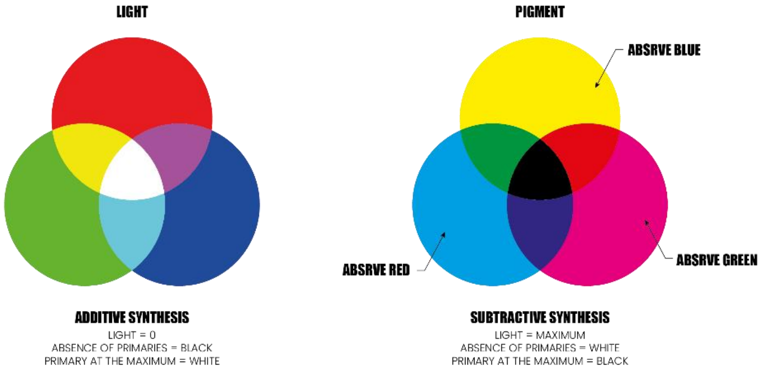


Figure 3 - Additive and Subtractive Color Synthesis (adapted from Araújo & Castro, 1987).

When we talk about the subtractive theory, mixing blue and yellow, for example, gives us green, yellow with red, orange, and blue with red, violet. These are called secondary colors, as seen in Figure 4. The mixtures of these with the primary colors give rise to tertiary colors, and so on (Araújo & Castro, 1987; Morris, 2006).

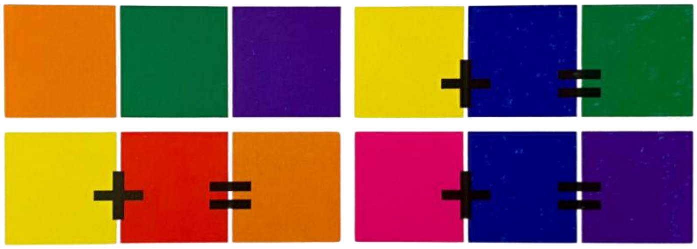


Figure 4 - Secondary Colors (Jones, 2005).

There are also what we call complementary colors. They are nothing more than colors considered contrasting, as they appear more vivid when placed close together. Complementary colors are formed by a pair of primary and secondary colors that are positioned opposite each other within the color wheel, as shown in Figure 5, and when mixed in their entirety, they produce a neutral-toned gray (Morris, 2006).

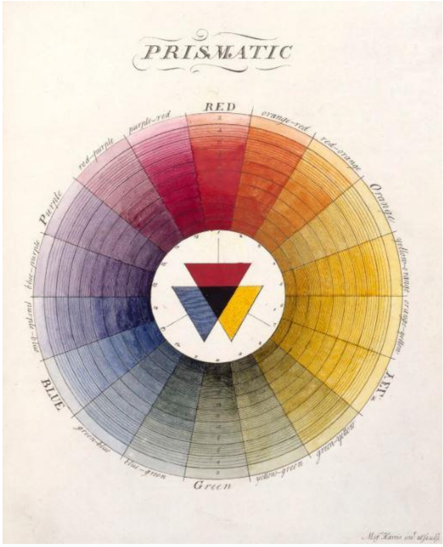


Figure 5 - Prismatic Color Wheel, Moses Harris (Harris, 1766).

2. Properties of Colors

The definition of colors by name alone is still somewhat imprecise because the human eye can distinguish approximately 350,000 colors, but we don't have names for all of them. So, when we try to describe them, we make approximations hoping that others will see them in the same way we do (Jones, 2005). For example, when we talk about the color blue, there is a wide range of shades, and we end up naming them according to familiar and universal knowledge derived from fauna and flora, foods, minerals, etc. Thus, we have sky blue, pool blue, baby blue, navy blue, turquoise, etc.

These designations vary according to everyone’s subjective and emotional experience and knowledge around the world. Whether it's a poet, a biologist, a doctor, a physicist, each will perceive color from a different perspective, which becomes an ineffective way of communicating, particularly for professionals in the textile and graphic design fields (Neves Jorge, 2000).

Therefore, to precisely describe each color, we must observe their characteristics and properties that will help us differentiate them. These include hue, saturation, brightness, tone, and brilliance (Araújo & Castro, 1987). These characteristics will help designers to identify the desired color more accurately, especially in CAD *software*.

Hue is the color itself, such as yellow or red. It directly depends on the wavelength of the reflected light (Araújo & Castro, 1987; Billmeyer Junior & Saltzman, 1981).

Saturation, or depth, refers to the intensity of the color. Two colors with the same hue and tone can evoke different sensations due to their intensity. As emphasized by Araújo & Castro (1987), when dealing with dyes or paints soluble in a liquid medium, variations in saturation are directly related to the amount of pigment present. When we dilute a pigment in water, for example, the lightness of the resulting color increases as we add more water to the dilution.

Luminosity refers to the ability of an object to reflect more or less light and is independent of the color hue. However, due to the differentiated sensitivity of the human eye, which is more sensitive to yellow-green and less sensitive to blue and violet, yellow generally appears brighter than other colors, while blue and violet may appear less bright in comparison (Araújo & Castro, 1987).

When discussing tone, it's important to note that black, gray, and white are not considered colors or hues. Instead, they can blend with any other color, modifying it and making it lighter or darker, resulting in a change in tone. Colors mixed with white result in lighter tones, known as pastel colors, while colors mixed with black or gray result in darker tones, known as shadows (Araújo & Castro, 1987).

Finally, but equally important, is brightness, which depends on the surface onto which the pigment is applied. According to Araújo & Castro (1987): "In the case of textile fibers, it depends on the fiber and its inherent ability to absorb or reflect light. For example, wool is less shiny than silk" (Araújo & Castro, 1987).

Through the study of these properties, systems inspired by Albert Munsell's method for classifying colors by their hue, luminance, and intensity emerged, such as Pantone, which is globally recognized and used by professionals in the textile and graphic industries. Pantone managed to categorize color through physical samples, standardizing the color palette and making it easier for professionals and companies to represent the same coloration, thus eliminating the subjective factor in color characterization (Jones, 2005).

3. The Psychology of Colors

Throughout the centuries, scholars have sought to decipher the meaning of colors, attributing symbols to them since the earliest days of their denominations. However, why do we persist in this desire to confer subjective meaning to colors? According to Goethe (2013), in his work "Theory of Colors", they constantly influence and sensitize us. Daily, we absorb a myriad of distinct shades without even reflecting on them, reacting, experiencing emotions, and establishing symbolic connections unconsciously.

The process of color perception occurs in several stages. First, we receive visual stimuli that allow us to perceive and distinguish the colors around us. This is the moment of sensitization, where we instinctively react to vibrant colors, feeling attracted to or repelled by them. Subsequently, through a specific context, we acquire the ability to understand the cultural meanings associated with specific colors, which, along with our individual experiences, whether positive or negative, enables us to formulate our interpretation of color and define our personal preferences (Heller, 2014). According to Calandrini (2018), "we move away from superficial and obvious meanings, from values previously attributed, to make room for subjectivity and sensations; it is the moment where we combine our knowledge and reason with our feelings and end up reflecting and analyzing" (Calandrini, 2018).

Heller (2014), in her book "Psychology of Color," discusses the relationship between colors and emotions:

> "We know many more feelings than colors. Therefore, each color can produce many effects, often contradictory. Each color acts differently, depending on the occasion. The same red can have an erotic or brutal effect, noble or vulgar. The same green can act in a comforting or poisonous way, or even calming. Yellow can have a warm or irritating effect" (Heller, 2014).

Therefore, there is no single way to perceive colors. They have the power to evoke a wide range of sensations and emotions, and this perception can vary from person to person and from context to context. This diversity in color perception reflects the complexity of the human mind and the interaction between psychological, cultural, and environmental factors (Heller, 2014).

4. Colors in Art

The colors have played a fundamental role in art throughout human history. From the earliest recorded artistic manifestations to contemporary works, colors have been used to express, communicate, and represent emotions, ideas, and concepts (Kuehni, 1996).

From cave paintings dated around 30,000 years ago, which served as a tool to depict the reality experienced by those people, to the works of modern and contemporary artists such as Pablo Picasso, Wassily Kandinsky, Mark Rothko, and many others, colors have been explored in various ways (Kuehni, 1996).

Over time, the meanings attributed to colors and their application techniques have varied according to cultural, social, political, and artistic contexts. For example, in the Renaissance, colors were often used to symbolize virtues, emotions, or social status, while in the 19th-century Impressionist movement, colors were used more freely and expressively to capture the light and atmosphere of a particular moment (Gage, 2006; Kuehni, 1996).

Artistic movements such as Expressionism, Cubism, and Surrealism continued to explore the possibilities of colors in unique ways, challenging conventions and expanding the boundaries of artistic expression (Kuehni, 1996).

4.1. Van Gogh and The Study of The Colors

Vincent Van Gogh (1853 – 1890), a Dutch Impressionist painter, was a great scholar of colors in the art world. Van Gogh once said, "Color expresses something by itself. You can't do without it; you must make use of it. A painter of the future is a colorist like never before existed" (Van Gogh Museum, Netherlands).

The artist explored various approaches to using colors, reproducing the same element or object multiple times to experiment with different palettes. Additionally, he developed his own method using colored yarns to test various chromatic combinations. Immersed in color theory, he discovered that complementary colors, such as red and green, yellow and purple, and blue and orange, intensified when placed side by side, as shown in the Figure 6 (Calandrini, 2018).

Figure 6 - Self-Portrait with Straw Hat, 1887 e Self-Portrait with Grey Felt Hat, 1887, Vicent Van Gogh (Van Gogh Museum, Netherlands).

This passion for complementary colors and their contrasts is evident in his work "The Bedroom," painted in Arles in 1889, Figure 7. The carefully chosen color palette, which includes combinations of blue and orange, yellow and purple, among others, demonstrates the conscious application of complementary colors to create a sense of balance and visual harmony while intensifying the aesthetic experience of the work. In a letter to his brother Theo, cited by Gage in his book "Color in Art," published in 2006, the artist expressed his conviction that color played a fundamental role in conveying the sensation of rest or sleep and that looking at the image should calm the mind or imagination, which highlights the artist's intention to create a specific atmosphere and convey a particular sensation to the viewer through the careful use of colors (Gage, 2006).

Figure 7 - The Bedroom, Vicent Van Gogh, 1889 (Gage, 2006).

Van Gogh is just one example of painters who used and exploited their understanding of colors, making them a versatile and powerful tool in art, allowing artists to convey a wide range of meanings and sensations.

4.2. Symbolism of Colors in Art

Based on Heller's book "Psychology of Color" (2014), let's now discuss the six main colors of the chromatic spectrum - blue, violet, green, yellow, orange, and red - within the artistic context throughout the centuries, which will be used later for the conception of this work (Heller, 2014).

Blue

The favorite color. It evokes harmony, tranquility, and freshness, suggesting purity and cleanliness. It's associated with spirituality and divinity, representing the sky and infinity, and is often used to symbolize the Virgin Mary in Christian art, Figure 8. However, it can also express melancholy, loneliness, and mystery, especially in darker tones. Since the Impressionists of the 1850s, shadows are no longer painted with brown but with blue. It conveys strength and stability in more practical contexts, such as the representation of natural elements like water.

Figure 8 - The Virgin in Prayer, Sassoferrato, 1640 (National Gallery of London, London).

Violet

The color of theology. It is associated with mystery and spirituality, often used to represent the transcendent and the unknown. Additionally, it evokes a sense of luxury and royalty, suggesting opulence and power. Artistically, it inspires creativity and originality while psychologically suggesting sensitivity and introspection. Even in softer tones, violet can convey calmness and balance, highlighting its versatility in expressing a wide range of emotions and concepts in art. The Impressionist Claude Monet made extensively use of the color in his compositions, describing it as "The true color of the atmosphere. Fresh air is violet", Figure 9. During this time, the term "violettomania" emerged as an intense devotion to the color, underscoring its importance and influence (Calandrini, 2018).

Figure 9 - The Artist's Garden at Giverny, Claude Monet, 1900 (Claude Monet Website).

Green

The color of fertility, hope, and the bourgeoisie. The color of the middle, while red is warm, blue is cold, green is pleasant; while red is active, blue is peaceful, green is reassuring. It is often associated with nature, vitality, and renewal. It also symbolizes balance, harmony, life, health, safety, and permission. It can convey feelings of calmness and relaxation, as well as represent new beginnings and opportunities. For the Romans, the color of Venus, the goddess of gardens, vegetables, and vineyards. In the Middle Ages and the Renaissance, the color of clothing showed a person's social position and profession; green could only be worn by merchants, bankers, and the aristocracy, as seen in the clothing of Mona Lisa by Leonardo Da Vinci. We may not know who Mona Lisa truly was, but we know she did not belong to the nobility, Figure 10 (Calandrini, 2018).

Figure 10 - Mona Lisa, Leonardo da Vinci, 1506 (Louvre Museum, Paris).

Yellow

The most contradictory color. The color of optimism and jealousy, recreation, understanding, and betrayal. It is associated with light, energy, and warmth, evoking feelings of joy, happiness, and optimism. The color of gold, of the eternal, the indestructible, made of sulfur and often used to create a sunny and vibrant atmosphere, stimulating creativity, and conveying a sense of vitality, as shown in the painting "The Kiss" by Gustav Klimt, Figure 11. It became known as the color of heresy and envy after medieval tradition claimed that Judas when betraying Jesus Christ, wore a yellow toga. Additionally, yellow can be used to highlight specific elements in a composition, drawing the viewer's attention (Heller, 2014).

Figure 11 – The Kiss, Gustav Klimt, 1908 (Österreichische Galerie Belvedere).

Orange

The color of recreation and Buddhism. Exotic and penetrating, yet underrated. Associated with energy, vitality, and creativity, evoking feelings of enthusiasm and dynamism. It can also convey a sense of warmth and comfort, reminiscent of fire and sunsets. Before the end of the 15th century, the color orange existed in Europe but did not yet have a specific name; it was simply referred to as yellow-red. Its presence can stimulate the viewer's attention and create striking contrasts in artistic composition. It became a significant color for Impressionist painters, such as Claude Monet, Figure 12, when placed alongside sky blue, creating a significant contrast that intensified the brightness and vivacity of both colors (Calandrini, 2018).

Figure 12 - Impression Sunrise, Claude Monet, 1872 (Claude Monet Website).

Red

The color of all passions, of kings and communism, of happiness and danger, of war and blood. It evokes intense emotions such as passion, love, anger, and energy. In the history of art, red has been used to represent powerful and emotional themes such as blood, fire, and power. It can symbolize both romantic love and violence, depending on the context and artistic representation. Additionally, red can be used to create emphasis and attract the viewer's attention, serving as a focal point in a composition. In a letter to his brother Theo in 1888, cited by Gage in his book "Color in Art," published in 2006, Vincent Van Gogh described the painting "Café Terrace at Night on Place Lamartine" (Figure 13): "I sought to express with red and green the terrible human passions. The salon is blood red, its yellow pale, with a billiard table green in the center, four lemon-yellow lamps, and rays of orange and green. It is a battle and antithesis of the most different reds and greens everywhere" (Gage, 2006).

Figure 13 - The Café Terrace at Night on Place Lamartine, Vicent Van Gogh, 1888 (Gage, 2006).

5. Color in Fashion

"Color is one of the means through which fashion is expressed. [...] Textile fibers, fabrics, patterns, and colors are thus the instruments of fashion, as it is through the periodic variation of their characteristics that the aesthetic and functional renewal of textile consumer objects, known as fashion, is achieved," stated Araújo & Castro (1987) in their book "Manual de Engenharia Têxtil."

If we stop to analyze the history of fashion, we see color as an extremely important and present factor that has changed over the decades alongside political and social events. A great example is men's clothing which, after the French Revolution, transitioned from luxurious and vibrant-colored garments, known as the Versailles style, to simple and gray attire, reflecting the rise of the bourgeoisie when moral values such as work and issues of class and social position began to overshadow under the motto "Liberté-Egalité-Fraternité" (Eco et al., 1982; Vieira-Sena & Castilho, 2011).

In the early 19th century, the "less is more" style emerged, emphasizing discretion in men's fashion and focusing on tailored suits. Black was elected as the official color for suits, believed to create a chic and urban style for men.

In the same century, with the Industrial Revolution, the visual contrast between the feminine and the masculine became apparent. Rich bourgeois men with their straight-cut garments, sober and grayish colors in simple fabrics and without ornaments contrasted with women's clothing, which showcased the wealth of these men through voluminous pieces, varied colors, and abundant shine and ornaments (Vieira-Sena & Castilho, 2011).

Another example of the importance of color in fashion is analyzing the use of blue and pink in the social context. According to Paoletti (2012), there is no evidence that blue and pink were used for gender separation until the mid-19th century. Only in the early 20th century did American children's clothing become separated by gender, and pink and blue started to be associated with this discussion. While pink was considered a decisive and robust color for boys, blue was considered a soft and delicate color more suitable for girls. Over the years, while girls continued to be able to wear any shade of blue as long as it was applied in florals and ruffles, among other ornaments, pink became increasingly rare in boys' clothing (Paoletti, 2012).

We can say that color, in addition to being linked to psychological, physiological, cultural, social, ethnographic, and climatic factors, as seen earlier, is also linked to aesthetics, the notion of the ugly and the beautiful. "[...] it is through qualitative values of beauty and ugliness that color is first felt and learned by men, in the various supports it can have" (Araújo & Castro, 1987).

Research conducted by the textile sector indicates that color is one of the first factors to elicit a reaction from the consumer. This reaction is followed by an interest in the garment's design, the tactile sensation of the fabric, and finally the price of the piece. Jones (2005) in his work "Fashion Design: The Stylist's Manual" asserts that:

> "People react intuitively, emotionally, and even physically to colors. It has been shown that blues and greens - the colors of the sky and grass - lower blood pressure, while red and other intense colors can speed up heart rate. White can make you feel cold; yellow is a sunny, friendly color; gray can be professional or depressing. The 'little black dress' exudes sophistication and elegance, while the red dress symbolizes sensuality and fun. People raised in an urban environment will react to the color palette differently than those living in rural communities. The same color can appear different or inappropriate under various environmental or lighting conditions - for example, on a cloudy day or under fluorescent lighting in a store" (Jones, 2005).

Choosing colors carefully for the palette becomes essential and should be one of the first steps when developing a fashion collection. These colors will set the tone and theme of the collection with the season, helping to differentiate it from the previous collection (Jones, 2005).

Jones (2005) explains that when creating a color palette, we should consider several factors, such as the effects of color on skin tones, hair, and eyes, the age range of the target audience, climate and seasons, as well as cultural and regional aspects. Palettes should consist of 4 to 10 colors, with dominant tones used as the base color and the others used more limitedly (Jones ,2005).

When discussing color contrasts with the body, tones of yellow and green, for example, can reflect color back onto the body and face and may not favor some skin tones. Color can also be used to enhance or accentuate a part of the body and create a focal point in the garment. Combinations of light and soft colors can produce a calming and understated effect, while contrasting and strong colors can draw attention to the wearer (Jones, 2005).

The colors used to define seasons and climate should also be considered. In autumn and winter, for example, people are attracted to colors that help retain heat in the body, such as bright, warm, or dark colors. Conversely, pastel tones or white, which reflect color, are more commonly used in spring and summer and evoke a sense of freshness. Regarding to cultural aspects, we can take the color white as an example. While many countries use white in weddings, in China, white is the color of mourning (Jones, 2005).

Chapter II
Art and Fashion

The relationship between art and fashion is complex and multifaceted, reflecting social, cultural, and aesthetic changes over time. These two fields are deeply interconnected, mutually influencing each other (Oliveira, 2020; Sant'anna, 2007). Social and artistic movements often find expression in fashion. Changes in society and the collective perception of the world are reflected in how people dress and use clothing to question and criticize traditional fashion. Sant'anna (2007) observes that fashion serves as a medium for these inquiries, allowing clothing to function as a means of rethinking life and criticizing established fashion precepts (Sant'anna, 2007).

Over time, fashion has been used as a means of individual and collective expression, reflecting ideologies, social critiques, and cultural transformations. Muller (2000) argues that depending on the era and the interpreter—be it artist or designer—fashion can serve as both an ideological expression, a social critique, or a reflection of gender confusion. This duality highlights the role of fashion as a code of social identity, capable of affirming and challenging established norms (Muller, 2000).

Since the Renaissance, the relationship between art and fashion has been evident. During this period, artists like Antonio Pissano (c. 1395 - c. 1455) created paintings and developed clothing designs and textile patterns for the Italian nobility. This demonstrates that from early on, fashion followed and reflected the artistic expressions of the time (MacKrell, 2005).

In the 19th century, the introduction of haute couture to the market marked a crucial point in the convergence of fashion and art. Charles Frederick Worth, known as the "father of couture," was a pioneer in creating and signing his own clothing pieces, elevating them to the status of artworks. Worth sought to ensure the authenticity and originality of his creations, bridging fashion with Fine Arts and establishing new standards of recognition and appreciation in the clothing market (Oliveira, 2020; Monçores, 2015). Figure 14 shows the “Evening Dress” by Charles Frederick Worth, created between 1898 and 1900, which exhibits the aesthetics of the late 19th century. With a modern reverse S-shaped silhouette and a dramatic pattern that reflected the influence of the Art Nouveau movement at the time (Krick, 2004).

Figure 14 - On the left, “Evening Dress” by Charles Frederick Worth, House of Worth (French, 1898–1900), Gift of Miss Eva Drexel Dahlgren, 1976. On the upper right, details of the dress pattern, and on the lower right, the signature and serial number inside the “Evening Dress” (Krick, 2004).

Throughout the 20th century, fashion and art became increasingly intertwined in complex and synergistic ways, reflecting and influencing the social, cultural, and aesthetic movements of the time. Many artists and designers used clothing not only as a means of expression but also as a form of entrepreneurship, highlighting the interdependence between these fields (Muller, 2000).

> "In the 20th century, multiple actions and movements demonstrated the reciprocal interest between the worlds of art and fashion. The visually observed affinities correspond to different attitudes: rethinking life through clothing, reconsidering the fashion system, creating art-fashion synergies to imbue the industry with soul, and ultimately employing clothing as a medium of artistic expression" (Muller, 2000).

Paul Poiret was one of the first designers to collaborate with avant-garde artists consciously. He drew inspiration from the creations of Gustav Klimt, Emilie Flöge, and the Wiener Werkstätte, and together with the painter Raoul Dufy, he founded the École Martine in 1911, a house of decorative arts dedicated to textile design production (Sant’anna, 2007). Designers such as Elsa Schiaparelli and Coco Chanel were influenced by these ideals, promoting the integration of art and fashion.

In 1906, the designer Emilie Flöge and the painter Gustav Klimt developed various fashion items, ranging from clothing designs and jewelry to textile patterns. Their creations featured simple cuts but abstract graphic prints that became the main focus of the pieces (Sant’anna, 2007). Meanwhile, Sonia Delaunay began her painting experiments and later applied her graphic forms to textile patterns (Figure 15) (Monçores, 2015).

Figure 15 - Patchwork Dress, Sonia Delaunay, 1913 (Oliveira, 2021).

Clothing-fashion that traverses the realm of art seeks to revolutionize both fields through experiences that break with traditional supports. In his manifesto "Le vêtement masculin futuriste" (1914), Giacomo Balla proposed breaking with the patterns of men's clothing of the time, rejecting symmetry, neutral colors, and traditional cuts in favor of futuristic, dynamic, and aggressive garments, even adorned with electric bulbs, as shown by Sant'anna (2007) in his article " Diálogos entre Arte e Moda: os anos sessenta ":

> "We must destroy traditional clothing, colorless, funeral-like, decadent, dull, and sick. In materials, we must abolish: the faded, the cute, capricious neutral colors, designs with stripes, checks, or dots. The cut and the make. Abolish the symmetry of static lines, uniform cuffs, lapels, bad cuts, etc... Put an end once and for all to these exhumed garments of hypocritical mourning appearance. The crowded streets, gatherings, theaters, cafes have a funeral atmosphere because the clothes reflect the miserable and crude mood of today's traditionalists. [...] We want comfortable and practical Futurist clothes, Dynamic, Aggressive, Astonishing, Desirable, Violent, flying (suggesting flight, soaring, running), Phosphorescent, decorated with electric lights..." (Giacomo BALLA apud GERCHMAN, 1975; Sant'anna, 2007).

It was in the 1960s that the relationship between fashion and art significantly tightened. Artists began to appropriate clothing as an extension of their issues in three dimensions and movement (Sant'anna, 2007). The Pop Art movement embraced fashion, with designers and artists collaborating and swapping roles. An iconic example is Andy Warhol, who created a paper dress printed with his famous soup cans, Figure 16 (Oliveira, 2020).

Figure 16 - Andy Warhol's "Soup Dress" originally cost one dollar and a soup can label. Today, it can sell for up to $7,500 (Aquino, 2012; McCorquodale, 2015).

Yves Saint Laurent demonstrated his interest in art in an emblematic way in 1965 when he created the famous 'Mondrian' dress, Figure 17. This sheath dress featured a pattern on the front inspired by Piet Mondrian's painting 'Composition with Red and Blue' from 1921. With this creation, Saint Laurent sought to elevate fashion design to the same artistic recognition as Mondrian's modernism. About the Mondrian dress, the Musée Yves Saint Laurent Paris states:

> "These dresses would subsequently alter the connection between fashion and art by transforming a painting into an animate work of art in a kind of "manifesto". Saint Laurent appropriated the painter's work by transforming a two-dimensional painting into a three-dimensional dress that was as powerful as the original work" (Musée Yves Saint Laurent Paris, n.d.).

Figure 17 - Cocktel YSL Dress worn by Muriel, homage to Piet Mondrian, autumn-winter 1965 haute couture collection, Paris, July 1965. Photograph by Louis Dalmas (Musée Yves Saint Laurent Paris, n.d.)

The brand did not limit itself to Mondrian, finding inspiration in other renowned artists such as Matisse, Van Gogh, and Picasso. It achieved a significant milestone by showcasing its creations at the Metropolitan Museum of Art in 1983. This exhibition opened doors for other designers to follow the same path (Oliveira, 2020).

In addition to Saint Laurent, other designers also explored the intersection between fashion and art. Paco Rabanne, for example, created aluminum dresses inspired by the mobiles of Julio Le Parc. According to Sant'anna (2007), artistic innovations enter the world of fashion not only by presenting new ways of dressing but also by justifying them through a discourse aligned with the idea of modernity. In the 1960s, fashion oscillated between high technology and naïve art, with futurism drawing inspiration from new technologies, while the hippie movement sought natural materials and oriental influences, especially from India and Morocco (Sant'anna, 2007).

According to Oliveira (2020), the relationship between art and fashion is marked by ups and downs, as fashion has always sought artistic recognition, while art has not always shown reciprocity. In the 1970s, fashion reflected political issues and the condition of women in a predominantly male-dominated society. However, in the 1980s, the relationship between art and fashion tightened again, consolidating itself to the present day (Oliveira, 2020).

A modern example of this collaboration is the partnership between Louis Vuitton and contemporary visual artist Yayoi Kusama, which began in 2006. The brand used Kusama's artistic signature, the dots and balls, in various products, shop windows, and marketing campaigns, Figure 18 (Oliveira, 2020). Another notable reference is the influence of Mexican artist Frida Kahlo on various fashion brands. Designers such as Jean-Paul Gaultier, Dolce & Gabbana, Christian Lacroix, Alexander McQueen, Marc Jacobs, Valentino, and Brazilian brands such as Cavalera and Arezzo, as well as numerous fashion magazines and editorials, drew inspiration from Kahlo's works, vibrant colors, and aesthetic elements (Oliveira, 2020).

Figure 18 - Louis Vuitton and Yayoi Kusama collaboration, 2023, promotional photo for Vogue article. (Zanmidar, 2023).

Claude Monet was also a significant inspiration for the fashion world. In 1949, Dior created a dress inspired by Monet's work "The Path Through," 1914. In 2007, the house once again used one of Monet's works in their look, and in 2011, they drew inspiration from the painting "The

Artist's Garden at Giverny," 1900, for the creation of a dress (Figure 19) (Bogucinska, 2015; Queiroz, 2019).

Figure 19 - The Artist's Garden at Giverny by Monet and Christian Dior Haute Couture dress, 2011 (Bogucinska, 2015).

In 2012, the Italian brand Sportmax drew inspiration from Monet's work "Water Lilies," 1914, to create their looks, transferring the color palette and shapes of the painting onto the fabric, resulting in wonderful sensations (Figure 20) (Bogucinska, 2015).

Figure 20 - Water Lilies by Monet and Sportmax SS2012 collection (Bogucinska, 2015).

Another example in a more recent context is the fashion house Viktor & Rolf, which drew inspiration from the Spanish painter Pablo Picasso for their Spring-Summer 2016 Haute Couture show. At the event, white dresses with cubist prints inspired by the painter's works graced the runway (Figure 21). The collection, characterized by ruffles, asymmetry, and structured fabrics, featured models who walked the catwalk with their faces covered (Queiroz, 2019).

Figure 21 - Buste de femme (Dora Maar), de Picasso and Viktor e Rolf 2016 collection (Queiroz, 2019).

And it wasn't just Viktor & Rolf who drew inspiration from Picasso's works. In 2019, Moschino's creative director, Jeremy Scott, made the artist's works wearable with raised elements, shapes, and colors in the Spring-Summer 2020 show at Milan Fashion Week (Figure 22) (Bortollozo, 2021; Petras, 2019).

Figure 22 - Picasso and Moschino SS2020 collection (Bortollozo, 2021; Petras, 2019).

In 2018, the Italian brand Dolce & Gabbana paid homage to Renaissance painters such as Leonardo da Vinci, Botticelli, and Michelangelo, with over 100 looks for their Haute Couture show (Queiroz, 2019). The inspiration extended beyond the outfits to the venue's decoration. Maximalist pieces set a dramatic tone for the show, filled with details and elegance. Exaggeration was evident in the puffed sleeves, ruffles, and mix of colors (Figure 23). In collaboration with the French atelier Maison Lesage, garments were hand-embroidered to recreate Renaissance images. Additionally, the brand invested in head accessories such as fascinators with veils and jeweled tiaras. The models also held paintings instead of handbags (Estevão, 2018).

Figure 23 - Renaissance Paintings and Dolce & Gabbana 2018 Collection (Estevão, 2018).

In Brazil, in 2021, the brand Água de Coco launched a beachwear collection inspired by one of Brazil's most famous modern artists, Tarsila do Amaral. The Brazilian essence and the vibrant colors of the countryside, strong characteristics of the artist's work, were translated into beachwear in over 120 items, including bikinis, swimsuits, kaftans, and tunics (Figure 24). Artworks such as "Abaporu" and "Anthropophagy" adorned the pieces, reproducing the paintings and blending multiple artworks into a single garment, allowing for exclusive prints that combine more than ten canvases (Dalboni, 2021).

Figure 24 - Tarcila do Amaral and Água de Coco 2021 collection (Dalboni, 2021).

In 2017, the Rio de Janeiro-based brand Osklen also released a collection inspired by the same artist's work, which quickly sold out from stores (Figure 25). The following year, the collection was reissued and made available for sale at MASP, the São Paulo Museum of Art. Additionally, the collection was launched in the international market through a partnership with the MoMA, the Museum of Modern Art in New York (Vogue Moda, 2019).

Figure 25 - Tarcila do Amaral and Osklen 2017 collection (Queiroz, 2019).

But it wasn't just luxury brands that drew inspiration from the visual arts. In 2018, paintings also began to adorn streetwear brands. Vans, known for its sporty style, launched a collection based on the works of Dutch painter Van Gogh in partnership with the Van Gogh Museum in Amsterdam (Queiroz, 2019; Galileu, 2018). The brand didn't stop there. In 2020, they teamed up with the MoMA in New York to release a collection inspired by renowned artists and artworks from the museum's collection. Artists such as Salvador Dalí, Claude Monet, and Edvard Munch were honored in clothing items, sneakers, and accessories (Oliveira, 2020). With the success of the MoMA partnership, in 2022, Vans announced a new collaboration with the MOCA, the Museum of Contemporary Art in Los Angeles. In this new partnership, three resident artists, Judy Baca, Brenna Youngblood, and Frances Stark, were invited to showcase their works on the brand's streetwear items, Figure 26 (Hoffert, 2022).

Figure 26 - On the left, Vans blouse from the Vans X Van Gogh Museum collection, inspired by 'Almond Blossom' (Photo: Vans/Divulgação). On the left, Vans shoes from the Vans X MOCA collection, inspired by resident artists (Hoffert, 2022; Galileu, 2018).

Today, we see many fast fashion brands, such as Pull & Bear and Lefties, also launching products inspired by great artists. Moreover, there are brands being created with the sole purpose of selling articles inspired by artworks, such as the American brand Galartsy. In the

"About Us" section of its website, Galartsy describes itself as follows: "Galartsy is more than just a brand; it's a movement dedicated to bringing the beauty of fine art to the masses. We believe that art is not just for the elite but for everyone to enjoy and appreciate." The brand's mission is to make art accessible to all, and they achieve this by turning world-famous artworks into wearable pieces, such as clothing, sneakers, accessories, and home decorations, Figure 27 (Galartsy, n.d.).

Figure 27 - Van Gogh's Sunflowers and Galartsy (Galartsy, n.d.).

Therefore, the intersection of art and fashion reveals a scenario where art is no longer confined solely to museums and galleries. Sant'anna (2007) highlights different approaches by artists regarding clothing:

> "[...] some artists treat clothing as a way to operate massification of art, using an industrial language, as Klimt and Dufy did, while others see clothing as a possibility - and why not an instrument - of transforming the society (via artistic thinking), like Moholy-Nagy, Rodchenko, and Stepanova. There are also artists who view clothing as an opportunity to discuss themes related to both the body and society, and even the boundaries between the two, such as Balla, Duchamp, and their surrealist and dadaist colleagues. On the other hand, we have designers/garment makers who appropriate artistic languages and/or themes for the production of fashion clothing, as we saw in Emilie Flöge, Poiret, and Schiaparelli." (Sant'anna, 2007, p. 5)

Oliveira (2020) asserts that art expands into everyday life, becoming accessible and "consumable" through fashion items, and notes how art, when integrated into fashion, becomes a way to enhance the cultural capital of the latter. According to the author, in the contemporary world, art, when incorporated into fashion, adds symbolic value to products. Since Paul Poiret, art has been used as a means to increase the cultural capital of fashion. Art offers new perspectives for brand image construction and imparts subjective meaning to fashion design. The most efficient way to add symbolic value to an object is to place it alongside another that already possesses that value. This symbiosis allows fashion to appropriate the cultural legitimacy of art, transforming clothing items into symbols of status and creativity (Oliveira, 2020).

Chapter III

Sustainability in Fashion

The fashion industry is undergoing a fundamental transformation, as consumers and manufacturers alike recognize the urgent need to adopt more sustainable practices. When discussing sustainability, it is essential to consider not only environmental aspects but also social and economic ones. As stated by Mesquita (2015), sustainable development should promote economic growth, preserve the environment, and ensure social equality for future generations (Mesquita, 2015).

As highlighted by Carvalho (2022), the fashion industry faces a series of complex challenges. Despite being one of the world's largest economies, it is also one of the leading causes of environmental impact, with excessive use of natural resources, pollution from toxic chemicals, and improper disposal of textile waste (Carvalho, 2022). In terms of numbers, garment production is responsible for approximately 28% of greenhouse gas emissions, 20% of the world's wastewater, $100 billion lost due to underutilization and lack of recycling, and 9% of annual microplastic losses to the ocean, in addition to the use of pesticides and agrochemicals in cotton cultivation and the use of chemicals for dyeing and printing (Adamkiewicz et al., 2022).

A significant response to these challenges is the movement towards circular production. According to Fletcher and Tham (2016), the circular economy aims to reduce waste and maximize resource value by promoting the reuse, recycling, and upcycling of materials. Circular business models, such as clothing rental and buy-back programs, are becoming increasingly popular to extend the lifespan of products and minimize environmental impact (Fletcher and Tham, 2016).

Another critical approach is the concept of eco-design. Fleck (2021) asserts that this strategy aims to reduce environmental impacts throughout the product lifecycle by prioritizing sustainable materials, avoiding toxic chemicals, and eliminating the use of pesticides in textile fiber cultivation (Fleck, 2021).

However, achieving sustainability in fashion requires more than just adopting circular or eco-design practices. As argued by Fletcher & Grose (2019), it is essential to address issues related to ethics and social justice throughout the entire supply chain. This includes ensuring decent working conditions for textile industry workers and promoting transparency in production practices (Fletcher & Grose, 2019).

Advancing toward sustainability in fashion is a complex process that requires collaboration from all stakeholders, including manufacturers, retailers, and consumers. As emphasized by Black (2008), consumers have the power to influence company practices and shape the fashion industry's future. By adopting innovative approaches and considering the social, environmental, and economic impact of their practices, the fashion industry can become more sustainable and ethical. Although the challenges are significant, the potential to create a more sustainable and inclusive future in fashion is immense and promising (Black, 2008).

Sustainability in Dyeing and Printing Processes

As mentioned earlier, textile dyeing practices are among the most polluting, both for the environment and human health. In addition to excessive water usage, various toxic products such as synthetic dyes and fixing chemicals are employed, which ultimately end up being discharged into rivers, contaminating the water. Associated with this is also the high energy consumption and carbon dioxide (CO_2) emissions in stages like heating baths for dyeing and chemical fiber production (Fleck, 2021).

Carvalho (2022) emphasizes that excessive water usage can be addressed through methods such as recycling liquid effluents and recovering products and by-products. However, this alone is not sufficient, requiring a more comprehensive approach (Carvalho, 2022).

An alternative gaining prominence is the use of natural dyes and pigments, primarily derived from plants and bacteria, in the textile industry. Considered eco-design products, these dyes are obtained from renewable sources, require minimal inputs, often do not necessitate the use of pesticides in cultivation, and are biodegradable (Fleck, 2021).

Given this context, a creative and sustainable approach to the printing process is necessary. Therefore, throughout this chapter, we will focus on possible methods and raw materials to reduce environmental impact and promote sustainability in the fashion industry.

1. Natural Dyes and Pigments

As mentioned in Chapter II of this dissertation, color is one of the fundamental aspects when it comes to the purchasing choice of a clothing item by the end consumer. And when we talk about the textile sector, colors are imparted to substrates through dyes or pigments, which can be extracted naturally or synthetically.

Natural dyes are those extracted from minerals, plants, insects, mollusks, lichens, mushrooms, or microorganisms and can be used in coloring textile materials, fabrics, ceramics, etc. (Behan, 2018; Boutrup & Ellis, 2018). However, according to Fleck (2021), these extracted materials cannot always be considered dyes, as they may not be absorbable by fibers or dissolve in water. Thus, we classify these materials into two categories: dyes and pigments (Fleck, 2021). Dyes are transparent and will be mixed with the base color of the fiber; these materials are water-soluble, capable of penetrating fibers, and have little effect on the textile surface's properties besides not being able to conceal or cover possible imperfections in the fabric. On the other hand, pigments, which are insoluble in water, are applied to the fiber's surface with the help of synthetic resin fixatives or auxiliaries. They can alter the brightness and texture of the fabric and because they are not transparent, they can hide underlying colors in sufficient quantities (Boutrup & Ellis, 2018).

When it comes to the textile sector, we must consider that the coloring of fibers with natural dyes depends on an additional step: mordanting. The so-called mordants are responsible for creating or improving the affinity between the dye and the fiber and contributing to the color fastness, especially when dealing with cellulosic fibers (Fleck, 2021).

The arrival of synthetic dyes has greatly facilitated the coloring of textile products. The ease of large-scale production has ensured a greater variety and fixation of color in fibers, low cost, resistance to light and washing, and better color uniformity. But along with these benefits come concerns: these toxic substances are directly absorbed by human skin and can cause allergies and serious health damage, as well as severe damage to the environment (Carvalho, 2022).

In the quest to obtain products that fit within the concepts of sustainability and do not cause harm to human health, for this study, it is necessary to analyze only natural dyes, which we will address next.

1.1. Brief Historical Contextualization

The record of the use of natural pigments dates to the Stone Age. Initially these pigments were created from animal blood, charcoal, and soil and were used to portray the experiences of humans on cave walls (Pinheiro & Bezerra, 2022). Due to the durability of these pigments, the cave paintings preserved to this day (Figure 28) are one of the most evident traces of the use of natural compounds for coloring various elements of everyday life. With the growth of civilizations, new techniques emerged, and natural pigments also began to be taken from plants and minerals, which allowed a greater variation of colors to be created (Yadav et al., 2023; Yusuf et al., 2017).

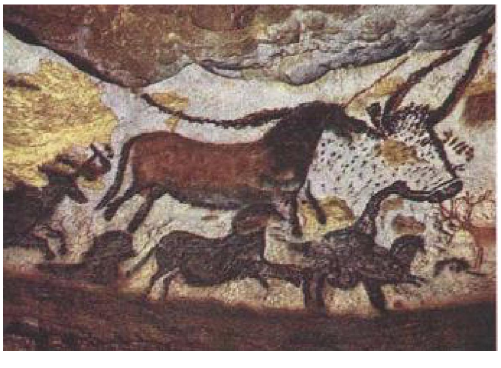


Figure 28 - Cave Painting, 1200 BCE. Lascaux, southwestern France (Itten, 1996).

The Egyptian and Chinese civilizations were one of the great revolutionaries in the creation of paints. They understood that pigments could be extracted from minerals and that their color could change if they were calcined. They were the first to develop the blue color; in the case of the Egyptians, the blue ($CaCuSi4O10$) occurred through the calcination of a mixture of silica, copper oxides, and calcium salts. The Chinese blue, called Han Blue ($BaCuSi4O10$), was developed through the calcination of a mixture of silica, copper oxides, and barium salts. Both civilizations mixed gum Arabic, egg white, or yolk with the pigment to obtain the paint paste. In addition, they were also the pioneers in the creation of black ink, which we now know as nankin (Mello & Suarez, 2012; Pinheiro & Bezerra, 2022; Yusuf et al., 2017).

The Greeks and Romans learned from the Egyptians and improved the technique of mixing pigment with eggs (Mello & Suarez, 2012). Studies show that the Phoenicians were the pioneers in creating purple paints, in mid-1439 BC, this was obtained through murex shells (Yusuf et al., 2017). Furthermore, they developed the technique of using dyes to dye fabrics (Mello & Suarez, 2012).

With the arrival of the Renaissance in the middle of the 14th century, the development of oil painting took place. Vegetable oils began to replace eggs in the production of paints and varnishes (Mello & Suarez, 2012). Linseed oils mixed with already known pigments allowed the creation of new color tones, and new painting techniques, such as sfumato created by Leonardo da Vinci, which consisted of the transition of gray tones that evoked lights and shadows. Furthermore, according to Mello & Suarez (2012), "this new material provided excellent chemical stability against humidity and other adverse weather conditions and improved the quality of the paintings obtained" (Mello & Suarez, 2012).

The Industrial Revolution that occurred in the 19th century brought with it the invention of synthetic paints, which could now be produced on a large scale, were more stable, and did not need to be diluted. The use of biomass-derived pigments was abandoned little by little and replaced by fossil carbon inputs (Mello & Suarez, 2012). The starting point for the use of synthetic products in the production of paints was through the research of William Henry Perkin, in 1856, in which he attempted to produce quinine through the oxidation of allyl toluidine ($C10H12N$) and managed to obtain a purple dye, called aniline purple (Mello & Suarez, 2012; Pinheiro & Bezerra, 2022; Venil et al., 2020). From this discovery, new research began to be developed to produce paints based on heavy metals, such as lead (Mello & Suarez, 2012). But these materials now used not only cause harm to the environment but also to the health of those who use these paints. As was the case of the Brazilian painter, Cândido Portinari, diagnosed with lead poisoning, he died in 1962, due to the continuous use of paints with a high level of toxicity (Andre et al., 2021).

The creation of synthetic paints brought several advantages and facilities, such as color variation, durability, and color resistance, in addition to being a potential market. But these products, if used intensively, as previously mentioned, can lead to environmental problems, as is the case with synthetic dyes used in the textile industry (Pinheiro & Bezerra, 2022; Venil et al., 2020).

Nowadays, with awareness for a more sustainable world, the production of paints using natural pigments is being revived, and new possibilities are being studied. This trend extends to the textile industry, where natural dyes are increasingly used to create eco-friendly dyeing and printing fabrics.

1.1.1. The Emergence of Color Pigments

Based on Heller's book "Psychology of Colors" (2014), we will briefly discuss the emergence of dyes related to the six main colors of the chromatic spectrum: blue, violet, green, yellow, orange, and red (Heller, 2014).

Blue

The production of the blue pigment historically relied on mining. For instance, the Egyptians would mix limestone, sand, and copper-containing minerals such as malachite, then heat the solution to temperatures between 800 and 900°C to create an opaque blue glass. Ultramarine blue, on the other hand, was derived from the semi-precious stone lapis lazuli, composed of minerals like lazurite, which is responsible for its characteristic blue color. This rock required complex mining and processing processes, often associated with specific regions like Badakhshan in Afghanistan. In contrast, indigo was extracted from tropical plants like Indigofera, widely used for dyeing fabrics, wool, and luxury tapestries during the 17th and 18th centuries. This process involved fermentation and extracting the plant's leaves to obtain the desired dye (Heller, 2014).

Violet

The violet pigment had its origins in Neolithic caves, where it was used to depict animal figures and was produced from minerals such as hematite and magnesium. In antiquity, the pigment acquired noble value among the Phoenician peoples, especially Tyrian purple, extracted from sea snails. Additionally, shades of violet were obtained through mixtures of other available pigments, such as the blue from lapis lazuli and the red from cochineal. However, it was with the advancement of chemistry, particularly in the development of synthetic pigments in the 19th century, that violet pigments became more accessible and reproducible in a variety of shades, thus expanding their use and popularity in art and industry (Heller, 2014).

Green

Unlike violet, Neolithic cave paintings generally do not show traces of green pigments. However, Neolithic peoples in Northern Europe developed a green dye for clothing made from birch leaves. Over time, different civilizations developed various methods to produce shades of green, using plants such as mallow, hawthorn, and holly, as well as minerals like malachite and azurite. In ancient Egypt, finely ground malachite was used to create shades of green. At the same time, the Romans produced a green earth pigment for murals in Pompeii, and they used verdigris pigment, which was made by immersing copper plates in wine fermentation. In the 18th and 19th centuries, synthetic green pigments and dyes were discovered and produced, quickly replacing natural ones. Although more stable and vibrant, some of these synthetic dyes contained high levels of arsenic, which were eventually banned (Heller, 2014).

Yellow

The most well-known yellow pigment is called yellow ochre, which has been used in art for ages. Records show that it was used to paint horses in France over 17,000 years ago in the Lascaux cave. This pigment can be obtained from goethite (an iron hydroxide), limonite (a mixture of hydrated iron oxides), or a combination of both, and it was widely used to represent gold and skin in Egyptian tombs and later in murals in Roman villas. Between the 18th and 19th centuries, there was a shift in the methods of producing yellow pigment, and it began to be produced using arsenic, cow urine, and other substances (Heller, 2014).

Orange

The orange pigment, initially called "yellow-red," was present in Europe before the end of the 15th century. Its designation as orange only occurred after the introduction of the first orange trees from Asia to Europe at the end of that same century. In ancient Egypt, artists began to use the mineral pigment realgar orange in their tomb paintings, while medieval artists used it to color manuscripts. Pigments were also produced in antiquity from the mineral known as orpiment, an important item in the trade of the Roman Empire and used as medicine in China, although it was highly toxic due to the arsenic it contained.

The alchemists, both in the East and in the West, also had an interest in the orange color of orpiment, hoping that through it, they could discover a method to produce gold. The discovery of the mineral crocoite, or lead chromate, by Louis Vauquelin in 1797 represented a significant milestone that led to the creation of synthetic orange chrome pigment. Subsequently, other synthetic pigments, such as cobalt red, cobalt yellow, and cobalt orange, were developed, further expanding the possibilities of color in art and industry (Heller, 2014).

Red

Lastly, the red pigment. Its use has been around for over 35,000 years. Throughout history, this pigment has been obtained through different types of materials, including metals such as iron and mercury. During the Paleolithic period, red was extracted from clays and reddish earth, while in the Neolithic period, the discovery of the madder plant allowed to produce a reddish color from its roots. In the 16th and 17th centuries, the most popular red pigment was obtained through the extraction of an insect called cochineal. Nowadays, cochineal dye is still used in the production of some cosmetic items, such as lipsticks and nail polishes (Heller, 2014).

1.2. Classification of Natural Dyes

Natural dyes can be classified in various ways, whether by their origin, which can be plant-based, mineral-based, or animal-based, alphabetically, by color, by application method, by chemical structure, or by being divided into substantive and additive categories, as shown in Figure 29 (Fleck, 2021).

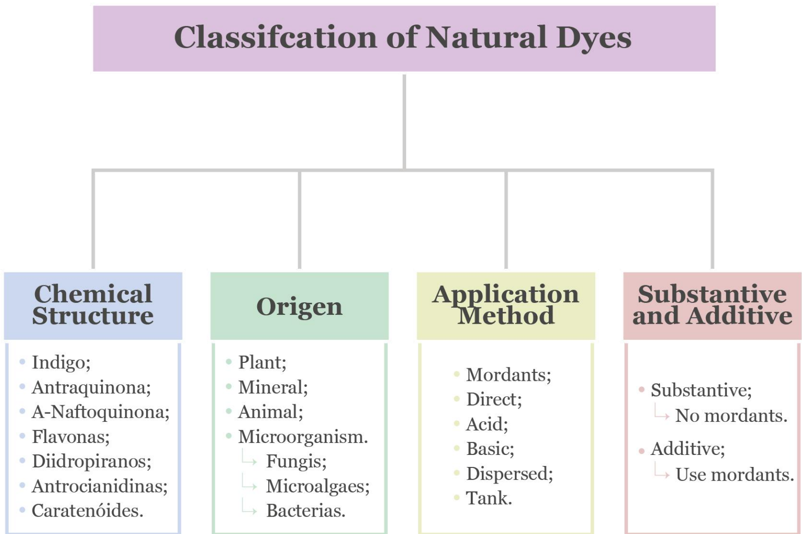


Figure 29 - Scheme of Classification of Natural Dyes (adapted from Costa, 2018).

When it comes to the classification by substantive and additive categories, it refers to the need to use of mordants for fixation. According to Kozlowski & Mackiewicz-Talarczyk (2012), substantive dyes are natural dyes with a high tannin concentration, allowing them to dye fibers directly. They are usually extracted from leaves, barks, and fruits, such as *Indigofera tinctoria*. On the other hand, additives require the application of a mordant to fix the color to the fibers, for example, red extracted from cochineal (Fleck, 2021; Kozlowski & Mackiewicz-Talarczyk, 2012).

According to Behan (2018), when we classify dyes by their origin, we distinguish whether they belong to the animal, vegetable, or mineral kingdom. Dyes derived from minerals such as sand, clay, and ochre are considered of mineral origin. Those extracted from insects and shells, for example, are of animal origin. And those found in plants, flowers, barks, seeds, etc., such as indigo, beetroot, saffron, and mate, are considered of plant origin (Behan, 2018).

Plant-based dyes are considered of greater importance among the three categories because they allow us to extract dyes of various colors using different parts of the same plant. However, it is necessary to consider that external factors can affect their hue, such as the time of harvest, climate, presence or absence of pesticides, and soil conditions (Ribeiro, 2019). Therefore, when creating a fashion collection that will use natural dyes, we must always pay attention to these details to avoid future problems. However, this approach can also make the items unique.

Research shows that a new category has been studied in recent years: microorganisms, along with dyes and pigments extracted from fungi and bacteria. We will discuss their characteristics and benefits further ahead.

1.3. Advantages of Using Natural Dyes in the Textile Industry

The use of natural dyes in the textile industry offers significant benefits for both humans and the environment. Known as eco-friendly, these dyes are derived from renewable sources such as plants, insects, and minerals, reducing dependence on non-renewable resources (Baran, 2019). Furthermore, their biodegradability is a crucial advantage as they contribute to reducing environmental pollution by decomposing naturally in the environment, thus helping to minimize negative impacts on ecosystems (Blackburn, 2009; Fleck, 2021).

Another important factor is their low toxicity. Although not all natural elements are completely free of environment or human health risks, natural dyes are generally recognized as less harmful than synthetic ones, offering significant benefits for textile industry workers and end consumers (Nambela, 2023; Saxena & Asm, 2014). Their lower propensity to cause allergic reactions and skin irritations makes them a safer choice, especially for people with sensitive skin.

It is also essential to consider the safety of natural dyes, especially when applied to textiles worn directly against the skin. According to Saxena & Asm (2014), the skin can absorb the components present in textiles, making the analysis of the healthiness of these dyes even more important. In this context, the use of plants with healing and medicinal properties for textile dyeing paves the way for the creation of so-called "medicinal textiles" (Fleck, 2021; Saxena & Asm, 2014).

The production of natural dyes often involves sustainably cultivated plants, supporting more ecological and ethical practices. This encourages the adoption of cultivation methods that preserve biodiversity and reduce the use of harmful agricultural chemicals. Additionally, Fleck (2021) exemplifies that some surplus generated in the manufacturing indigo can be repurposed as fertilizers, contributing to the sustainability of the production cycle (Fleck, 2021).

It's important to highlight that many natural dyes have a long cultural and traditional history in various regions of the world, reflecting the deep connection between dyeing practices and local traditions (Chen & Zhao, 2020). The use of these dyes in the textile industry not only preserves these traditions but also promotes cultural appreciation and recognition of the communities and peoples who have developed them over time and generates employment and income for the workers involved in the process.

1.4. Major Challenges of Using Natural Dyes in the Textile Industry

While natural dyes offer environmental and health advantages, their use in the textile industry also presents significant challenges to be considered.

One of the main challenges is their limited availability compared to synthetic dyes. While synthetic dyes can be produced on a large scale and in a nearly unlimited variety of colors, natural dyes rely on seasonality, climate, and the availability of specific plants, insects, or minerals for their production (Blackburn, 2009). This can result in difficulties in obtaining consistent quantities of natural dyes to meet the demand of the textile industry.

Another significant challenge is the cost associated with natural dyes. In many cases, natural dyes can be more expensive than synthetic ones due to the complexity of the extraction process and the lower efficiency in mass production (Baran, 2019). Additionally, the high cost considers specialized labor, the quantity of dye required for production, the time for dyeing, and the complexity of the process (Fleck, 2021; Saxena & Asm, 2014). These additional costs may be passed on to manufacturers and end consumers, making textiles colored with natural dyes less accessible in terms of price.

Natural dyes can also pose challenges in terms of color consistency and durability. Due to the variable nature of natural color sources, achieving consistent colors from batch to batch can be difficult, which can be problematic for manufacturers wishing to maintain quality standards and uniformity in their products (Nambela, 2023). Additionally, some natural dyes may be less stable over time and more susceptible to fading when exposed to light, washing, or adverse environmental conditions (Fleck, 2021).

Fleck (2021) explains that natural dyes do not offer a wide range of colors, so they must be combined to generate new shades. However, it is necessary to consider that due to the resistance properties and dyeing methods, which vary for each dye, they provide a limited mixture (Fleck, 2021).

Therefore, limited availability, high cost, color consistency, and durability are some of the concerns manufacturers faces when adopting natural dyes in their dyeing processes. Overcoming these challenges will require innovation, research, and collaboration across the textile supply chain.

2. Bacterial Pigments

Bacterial pigments has been gaining popularity due to its low environmental impact and diverse range of colors, and it is increasingly being applied in the industry (Gomes & Soares, 2023; Yusuf et al., 2017). While plant-derived pigments are disadvantaged by being affected by weather conditions, and sensitive to light, heat, pH, and low water solubility, microbial pigments are not affected by the climate and can be created quickly and easily. This is because microorganisms are easy to analyze, select, preserve, and genetically modify and have a high growth rate and varied functions (Di Salvo et al., 2023; Sundararajan & Ramasamy, 2023).

In addition to being a biodegradable product, bacterial pigment possesses therapeutic properties that are beneficial to health, such as anti-cancer, antioxidant, antibacterial, antiviral, UV protection, etc. (Gomes & Soares, 2023; Qin et al., 2023; Srivastava et al., 2022). In the textile industry, these therapeutic properties become a significant advantage, as they can be used for dyeing various textile materials. Additionally, they can prevent the growth of microorganisms that cause odor, color loss in fabrics after multiple washes, fungal formation, clothing degradation, skin infections, allergies, and other related diseases (Elsahida et al., 2019; Kramar & Kostic, 2022).

According to Kramar & Kostic (2022), when we discuss the use of bacterial pigments in the textile industry, we can perceive them more as dyes than pigments. Even though these pigments are not water-soluble, when chemically bonded with textile materials, they form connections with functional groups of fibers, behaving like dyes to (Kramar & Kostic, 2022).

Various bacteria can be used to create pigments for textile materials. These bacteria can be sourced from soil, water, plants, insects, etc. (Kramar & Kostic, 2022; Mazotto et al., 2021; Mumtaz et al., 2019). The most used bacteria are called *Serratia*, *Streptomyces*, and *Pseudomonas*. Through them, diverse colors can be created, such as pink, red, yellow, blue, green, etc. (Abdulkadir et al., 2017; Mohammadi et al., 2022; Stankovic et al., 2014). The use of bacterial pigments in dyeing textile materials generally follows the following order: preparation of the dye solution (dissolution of the pigment with solvents, pH adjustment, and addition of salts); dyeing (temperature and duration); post-dyeing (washing and drying) (Kramar & Kostic, 2022; Mohammadi et al., 2022).

It is important to understand that the shades of colors generated by pigments may not always be the same after dyeing fibers and fabrics. The color results may vary depending on the nature of the substrate used and the dyeing conditions, such as temperature, pH, and the use of mordants. In other words, the same pigment can produce various shades of colors on different fabrics (Kramar & Kostic, 2022).

Table 1 - Bacteria producing pigments used in different industries (adapted from Carvalho, 2022; Costa, 2018).

Industry	Microorganism	Pigment	Color
Textil	*Serratia Marcescens*	Prodigiosina	Red
	Serratia Rubidaea	Prodigiosina	Red
	Serratia Plymuthica	Prodigiosina	Red
	Rugamonas Rubra	Prodigiosina	Red
	Pseudomonas Sp	-	Brown
	Corynebacterium Insidium	Indigo	Blue
	Janthinobacterium Lividum	Violaceína	Violet
	Streptoverticillium Rubrireticuli	Prodigiosina	Pink
	Chromabacterium Violaceum	Violaceína	Violet
	Chryseobacterium Shigense	Flexirubin	Yellow/Orange
Cosmetic	*Janthinobacterium Lividum*	Violaceína	Violet
	Streptomyces Virginiae	Violaceína	Red
	Staphylococcus Aureus	Zeaxanthin	Yellow
	Flavobacterium Bacillus	Zeaxanthin	Yellow
	Thuringiensis H-14	Melanin	Brown
Food	*Pseudomonas Aeruginosa*	Phenazine	Yellow/Orange
	Serratia Spp	Prodigiosin	Red
	Kluyveromyces Marxianus	Melanin	Black/Brown
	Alteromonas Rubra	Prodigiosin	Red
	Vibrio Sp	Prodigiosin	Red
	Streptomyces Echinoruber	Rubrolone	Red
	Agrobacterium Aurantiacum	Astanxantin	Salmon
	Bacillus Subtilis	Riboflavin	Yellow
	Paracoccus Xanthinifacilus	Zeaxantin	Yellow
	Bradyrhizobium Spp	Canthaxanthin	Dark Red
	Dietzia Maris	Canthaxanthin	Red
	Brevibacterium Spp	Canthaxanthin	Reddish-Orange
Pharmaceutical	*Rhodococcus Maris*	β-caroteno	Reddish-Blue
	Pseudomonas Aeruginosa	Pyocyanin	Blue-Green
	Corynebacterium Insidiosum	Indigo	Blue
	Streptomyces Aureofaciens	Indigo	Blue
	Aspergillus Sp	Melanin	Black/Brown
	Alteromonas Rubra	Prodigiosin	Red
	Chryseobacterium Shigense	Flexirubina	Yellow/Orange

2.1. Others Benefits of Their Use in the Textile Industry

Kramar & Kostic (2022) affirm that therapeutic properties such as antimicrobial, anticancer, and antioxidant effects can be transferred to the textile material along with its dyeing process to (Kramar & Kostic, 2022). Studies by Venil et al. (2021) show that the use of pigment from the bacterium *Serratia marcescens* SB08 to dye silk and cotton resulted in fibers exhibiting a good level of antibacterial activity and inhibition zones against pathogenic bacteria such as *Bacillus subtilis*, *Escherichia coli*, and *Pseudomonas aeruginosa* (Venil et al., 2021).

Speaking in terms of production, bacteria can be easily cultivated in short periods, allowing for greater control of their growth in laboratory settings, as it is not seasonal, and their use can be considered a cheaper alternative to synthetic pigments (Di Salvo et al., 2023). Thus, we can say that the production of bacterial pigments is beneficial both for the economy and for health and the environment.

2.2. Microorganisms Studied (brief description)

Chryseobacterium shingense

Chryseobacterium shingense, a bacterium of the *Flexibacter* genus, is characterized by its elongated, non-motile, Gram-negative cells that produce a yellow pigment known as *flexirubin*, Figure 30. It is an aerobic bacterium that utilizes organic compounds as an energy source. It is cultivated on Nutrient Agar (NA) culture medium and grows within a temperature range of 5 to 30 °C, with a pH between 5 and 8. The pigment demonstrates remarkable stability even when exposed to UV light, sunlight, dark conditions, and temperatures ranging from 25 to 100 °C (Guimarães, 2018; Venil et al., 2014).

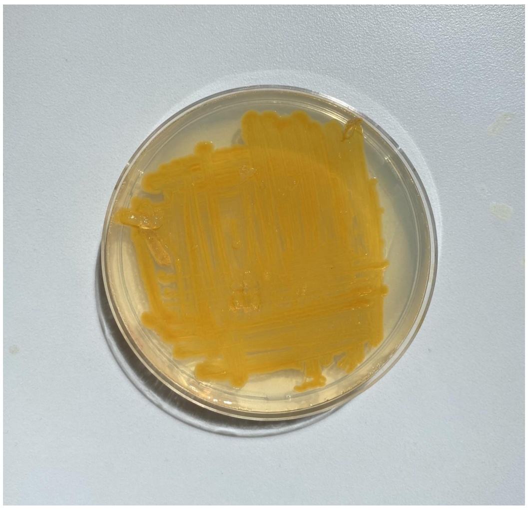


Figure 30 – Bacterial Pigment *Flexirubin* Yellow (The author, 2024).

Serratia plymuthica

Serratia plymuthica is a bacterium belonging to the *Enterobacteriaceae* family, characterized as Gram-negative and anaerobic, with elongated cells. It is recognized for producing a pink/red pigment called *prodigiosin*, Figure 31. These microorganisms are commonly found in soil and can be isolated from various types of foods (Guimarães, 2018). Its culture medium is Peptone Glycerol Phosphate (PGP), and it grows at a temperature of 20 °C.

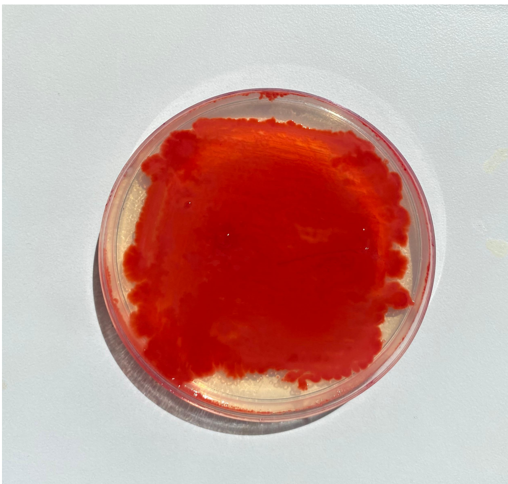


Figure 31 – Bacterial Pigment *Prodigiosn* Red (The author, 2024).

Pseudomonas sp.

Pseudomonas sp. is a bacterium belonging to the *Pseudomonadaceae* family, characterized by being Gram-negative and encompassing 191 species. It is known for its ability to produce pigments in various colors, such as *pyocyanin* (blue), *pyoverdine* (yellow-green), *pyorubin* (red), and *pheomelanin* (brown). These microorganisms exhibit great metabolic diversity and can colonize a wide range of hosts, proliferating easily in water and plants (Carvalho, 2022). Tryptic Soy Agar (TSA) culture medium is used to produce the brown pigment, with a growth temperature of 30 °C, Figure 32.

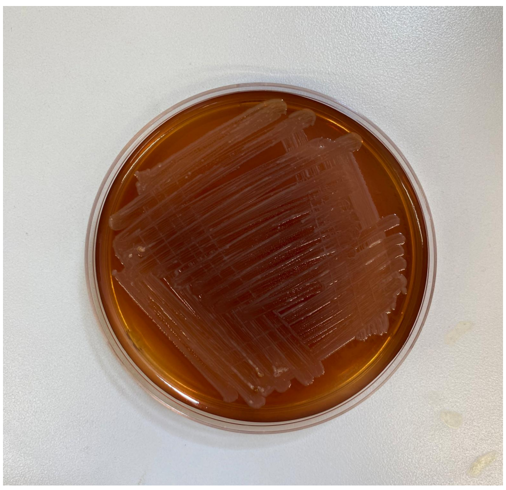


Figure 32 – Bacterial Pigment Brown (The author, 2024).

3. Mordants

When we talk about natural dyes and pigments, it's essential to understand the importance of using mordants to achieve successful results in textile dyeing.

Boutrup & Ellis explain in their book "The Art and Science of Natural Dyes: Principles, Experiments, and Results," published in 2018, that a mordant is a metal salt used to fix the dye to textile fibers. It can bind directly to the fiber, particularly in the case of protein fibers, or it can be left as an insoluble compound on the fiber for the dye to attach to; this latter process occurs when using cellulose fibers. They further explain that the quality and quantity of mordant applied will affect the final color of the dyeing and that the use of mordant is essential when considering the resistance to sunlight and washing of the dyed fabric (Boutrup & Ellis, 2018).

When using a small amount of mordant, we will obtain a pale color, whereas using a larger quantity of the solution will allow more dye to adhere to the fiber, resulting in a more intense color. Because natural dyes are typically the most expensive material, the advice is to use a smaller quantity of dye and not of mordant when aiming for lighter shades, Figure 33 (Boutrup & Ellis, 2018).

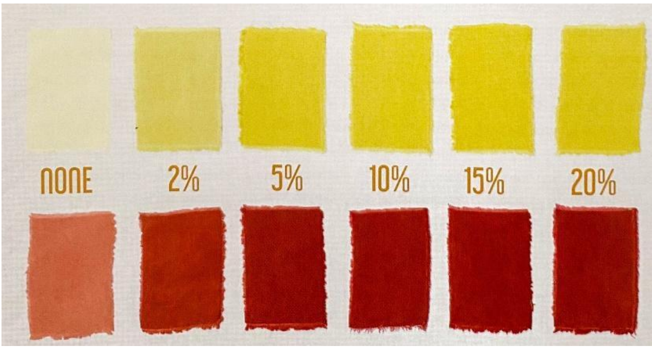


Figure 33 - The samples show how the amount of dye was able to adhere to the fabric as the quantity of aluminum mordant increased (Boutrup & Ellis, 2018).

These mordants can be applied to the fabric through pre-mordanting, meta-mordanting, and post-mordanting. The pre-mordanting process involves applying the mordant to the fabric before the dyeing process, where the substrate is immersed in an aqueous mordant solution for a specific time and temperature (Fleck, 2021). The fabric is then rinsed and dried before being subjected to the dyeing process. This is done to prepare the fibers to receive the dye more effectively and to fix the color permanently. According to Saxena & Asm (2014), pre-mordanting baths are a more economical and sustainable option compared than other mordanting processes because there is less mordant waste, which can be reused whenever more quantities are needed.

Meta-mordanting is when the dyeing and mordanting processes are done in a single bath. Although it is a shorter process, it is recommended for small-scale productions, as the mordant cannot be reused, resulting in excessive material consumption (Fleck, 2021; Saxena & Asm, 2014).

The post-mordanting process is carried out after the initial dyeing of the fabric and involves the application of mordants to fix or modify the color. Like pre-mordanting, the dyeing and mordanting baths occur separately. This technique may be necessary when the initial dyeing does not achieve the desired color, or when it is necessary to improve the color's resistance to washing and light; thus, we have the final color revealed only after the mordant application (Fleck, 2021; Saxena & Asm, 2014).

After extensive research and experimentation, Boutrup & Ellis (2018) concluded that mordanting and dyeing processes achieve better results when done separately. They demonstrate that if the mordant and dye are placed together in the dye pot, they combine into an insoluble component before they can effectively penetrate the textile. Therefore, once the mordant is properly applied to the textile, it is stable and ready to receive the dye, allowing immediate dyeing or drying for future dyeing (Boutrup & Ellis, 2018).

According to Fleck (2021), mordants can be classified into three types: metallic, tannins, and oil. We will briefly explain each of them next (Fleck, 2021).

Metallic Mordants

Mordants can be derived from metallic salts such as sulfates (magnesium, aluminum, zinc, copper, cobalt, nickel, manganese, or tin), chlorides (stannic, ferric, copper, zinc, aluminum, and even neodymium or zirconium), hydroxides (calcium), and oxides (ferric or lanthanum). They help to fix the dye to the fabric through chemical bonds with the textile fibers (Fleck, 2021).

When it comes to copper, it's important to consider that its use is restricted, meaning there is a maximum allowed quantity for its application. As an alternative, we can use mordants derived from iron and aluminum. Depending on the dye used, aluminum can enhance and brighten the final color, and iron can bring out the details of the prints with a more intense color (Fleck, 2021).

It's important to know that mixing different metallic mordants can influence the color resistance and its own hue. Fleck (2021) provides us with some examples: red generated by the mixture of aluminum and alizarin; violet through alizarin and iron; yellow, from onion skins which, when mixed with stannous chloride, produce an orange color or gray when combined with ferrous sulfate (Saxena & Asm, 2014).

Tannin Mordants

Tannin mordants are natural substances derived from various parts of plants, such as bark, branches, leaves, roots, fruits, and husks, which contain tannins or tannic acid. Their concentration of tannins can vary depending on the age, season, region where they were collected, and the part of the plant from which they were extracted. They can bind to both dyes and textile fibers, providing lasting color fixation. Generally, the use of tannin mordants imparts darker shades to the dyeing process (Fleck, 2021; Saxena & Asm, 2014).

Saxena & Asm (2014) explain that tannic acid can be an excellent conductor between cellulose fibers and metallic mordants, making the absorption of these mordants easier by the fiber (Saxena & Asm, 2014).

Oils Mordants

These mordants are usually natural oils, such as linseed or soybean oil, which act as fixing agents for specific dyes. They are particularly useful in dyeing processes for oil-based fabrics, such as silk. Fleck (2021) explains using the oil mordant in conjunction with alum mordant is advisable as this combination provides excellent color (Fleck, 2021).

4. Textile Dyeing and Printing Techniques for Surface Design

Textile dyeing is an ancient art and a modern science that plays a fundamental role in fashion, interior design, and cultural expression. Since ancient times, man has sought ways to dye fabrics using resources available around him (Storey, 1992). Today, this interest is being renewed with the incessant search of creating more sustainable products.

When we talk about textile dyeing techniques, we refer to methods that can be used for dyeing or printing on a textile. Natural dyeing is one of the most traditional techniques for coloring fabric. This method utilizes dyes derived from natural sources such as plants, flowers, fruits, roots, insects, and microorganisms. Each natural material offers a unique color palette, and this technique requires knowledge of the specific properties of each dye and the appropriate fixation processes (Fleck, 2021).

Today, the textile sector offers a variety of dyeing and printing techniques that can be performed using conventional, digital, or artisanal methods. The choice between simpler or more complex techniques should always consider several factors, such as the type of fabric being used, the purpose of the print, whether vivid and vibrant colors are required, the concept behind the piece or collection being developed, etc. (Fleck, 2021; Storey, 1992).

It is well known that many of these techniques often result in abundant water wastage and frequent use of toxic chemicals for their implementation (Fleck, 2021). Therefore, the quest for methods and materials that reduce this impact is increasingly growing.

A great example is the choice to use natural dyes combined with conventional or artisanal printing techniques to develop textiles aimed at garment manufacturing, in addition to choosing not to use synthetic dyes, which reduces their toxicological impact, conventional and artisanal printing techniques such as screen printing, batik, shibori, block printing, stencil, tie-dye, and eco-printing offer differentiated and unique aesthetic results to the product. This creates an emotional bond with the consumer and contributes to the prolonged use of the garment, generating less waste and reducing environmental impact (Fleck, 2021).

Considering the objectives of this study to create patterns on textiles using natural dyes and minimize environmental impacts, in this subsection we will briefly discuss some mentioned artisanal techniques, along with the conventional technique of screen printing.

4.1. Batik

Batik is an artisanal dyeing technique originating from Asia, and its greatest development was in Java, Indonesia. The word derives from "*tik*," an onomatopoeia that can mean "drop" or "dot." In this technique, wax creates resistance areas on the fabric before immersion in the dye. The application of hot wax on both sides of the fabric is done using a tool similar to a pen called "*canting*", Figure 34, with which artisans create the intended designs. The areas protected by the wax retain the fabric's original color, while the unprotected areas absorb the color of the dye, resulting in complex patterns and designs (Fleck, 2021; Storey, 1992).

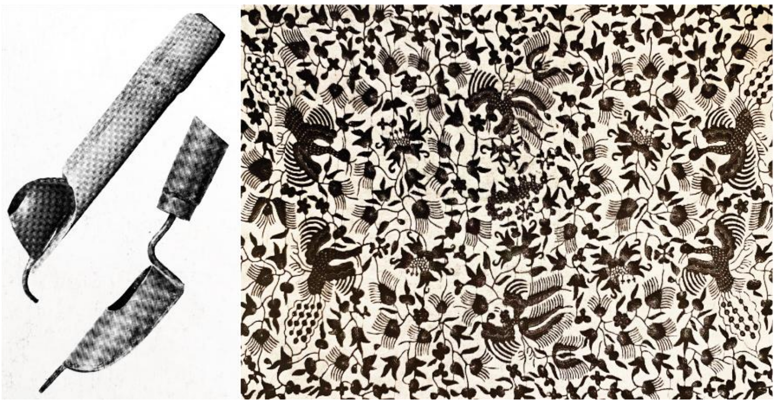


Figure 34 - On the left (above), the traditional Canting from Java and (below), the modern Canting from Malaysia. On the right, an example of Javanese Batik (Storey, 1992).

Storey (1992) highlights the long history and prestige associated with the technique by explaining that since the time of the Sung Dynasty (960 to 1279), Batik cotton clothes were considered of great value. They not only adorned the elite's bodies but were also given as gifts to princes and individuals of high social standing. This technique was exclusively produced by Javanese women and girls belonging to the highest layers of society, including the nobility (Storey, 1992).

For many centuries, the designs and quality of Batik prints remained practically unchanged, demonstrating the skill and mastery passed down by these people through generations (Storey, 1992).

With the advancement of industry around 1850, a way to simplify the Batik technique and streamline the process emerged: *tjap* prints (Storey, 1992). This new method involved copper strips welded into blocks that were open at the back, Figure 35. Hot wax was transferred onto these blocks, which were then pressed against the fabric, and deposited the wax on the surface (Fleck, 2021). According to Storey (1992), this new method allowed around twenty *sarongs* to be ready for dyeing per day, in contrast to the old method (Storey, 1992).

Figure 35 - On the left, an example of a *tjap* block with Javanese *Parang* pattern (Storey, 1992). On the right, execution of a *Parang* pattern using the *tjap* batik (Elphick, 2014).

4.2. Shibori

The Shibori technique is a traditional Japanese form of textile dyeing that involves the use of bindings, folds, twists, and compressions on the fabric, where the protected areas remain uncolored, creating unique and intricate patterns. According to Gunner (2007), this technique, which dates back to the 8th century, was originally developed as a way to decorate fabrics for clothing and household items and was widely used, especially for creating patterns on Japanese kimonos. Over time, Shibori has evolved and diversified into a variety of regional styles and techniques, each with its own distinct aesthetic and methodology (Gunner, 2007),

There are various Shibori techniques, including *Itajime*, *Ne-Maki*, *Kanoko*, *Kumo*, and *Arashi*, each with its unique approach to creating patterns, Figure 36. *Itajime* Shibori, for example, involves the use of folds and wooden boards that apply pressure to the fabric, creating geometric patterns such as squares and triangles, while *Arashi* Shibori uses bindings and compressions to produce patterns resembling rain (Wada et al., 1999).

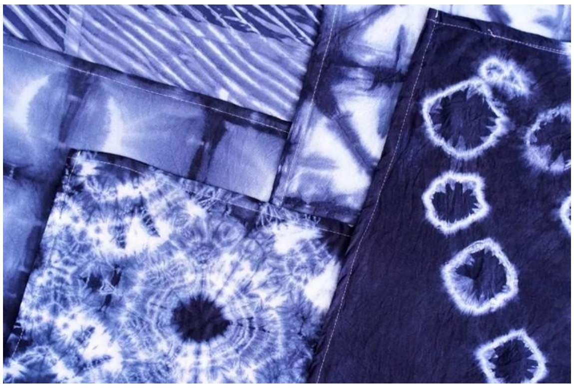


Figure 36 - Examples of fabrics that have been dyed using the Shibori technique (Poskin, 2019).

Wada et al. (1999) report that between the 19th and 20th centuries, over a hundred distinct illustrations were developed. With the advent of the Second World War, this practice became less prevalent, only to regain appreciation in the 1980s, when it was applied primarily as a craft work (Gunner, 2007).

4.3. Block Print

According to Storey (1992), the Chinese and Hindus can be credited with the discovery of the block printing technique. It is believed that letterpress was printed with wooden blocks in China over two thousand years ago, although it is unlikely that people at that time would have thought to apply the same technique directly to fabric. In India, during the early Christian era, an industrially printed floral pattern that used blocks (Storey, 1992).

In the 18th century, many textile companies in England and Europe already used various block printing techniques (Storey, 1992). The block printing process begins with the creation of wooden blocks, where artisans carve the desired pattern by hand, Figure 37. Each block is carefully carved to ensure that the pattern is precise and uniform. Then, the block is dipped in ink or dye and pressed onto the fabric, leaving behind the printed pattern (Fleck, 2021).

Figure 37 - On the left, a wooden block being made at David Evans Printworks, Crayford, Kent. On the right, block printing at David Evans Printworks, Crayford, Kent (Storey, 1992).

Each piece of fabric is hand-stamped, lending authenticity and uniqueness to every item. This technique allows a wide variety of designs, ranging from simple geometric patterns to intricate landscapes and florals. These designs can be portrayed repeatedly, in monochrome or color, enabling mass production with a handmade aesthetic (Fleck, 2021).

4.4. Stencil

The stencil originated in Japan in the mid-18th century, and despite being a somewhat primitive technique, it was a discovery that allowed the Japanese to achieve intricate details and patterns in their works (Storey, 1992). Initially, the illustrations were printed on paper, but they soon began to be printed on textiles. Its importance grew during the Kamakura period, when it was used to adorn samurai armor, banners, and horse mantles. Over time, this technique was refined and came to adorn the garments of the Japanese court (Fleck, 2021).

Stencil printing is a printing process that involves creating patterns or images using a stencil, which is a cut-out mask that allows ink to pass through only in desired areas of the substrate, Figure 38. The process typically starts with the creation of the stencil, which can be made from materials such as paper, acetate, or metal, where the areas to be printed are cut or perforated. The stencil is then placed onto the substrate, and ink is applied through the openings using brushing, spraying, or rolling techniques. Thus, when the mask is removed, the desired design is formed (Fleck, 2021).

Figure 38 - On the left, a Japanese stencil, showcasing its intricate cutting and delicate connections. On the right, a beautiful Japanese fabric printed using the stencil technique (Storey, 1992).

The technique is recognized for its versatility, allowing for the reproduction of simple or complex designs on a variety of surfaces, including paper, fabric, wood, and metal. According to Storey (1992), stencil printing preceded and gave rise to frame printing, also known as screen printing, which we will discuss next.

4.4. Screen Printing

The manual technique of screen printing and its derived mechanical methods saw their development between the 1920s and 1930s. It was the greatest contributions in this century to the field of textile printing. According to Storey (1992), the manual screen-printing process changed the character of design in fashion and fabrics for furniture throughout Europe. In her book *The Thames and Hudson Manual of Textile Printing*, published in 1992, the author states: "The great importance of hand screen printing as an industry is that it affords the creative and imaginative designers the means of putting on cloth extremely varied ideas and effects" (Storey, 1992).

The development of the technique arose from the need to find a method that allowed for printing new designs for art silks and fabrics such as viscose and rayons, which was faster and more economical (Storey, 1992).

This printing technique involves transferring ink through a stretched screen onto a frame and can occur in three different ways: manual, automatic, or semi-automatic, Figure 39. Each screen is prepared with a specific pattern, and ink is pressed through the empty areas of the screen onto the fabric below. The final pattern design requires a separate screen for each color used. Therefore, the more colors in the final pattern, the more screens are needed for production, making the production more expensive (Fleck, 2021).

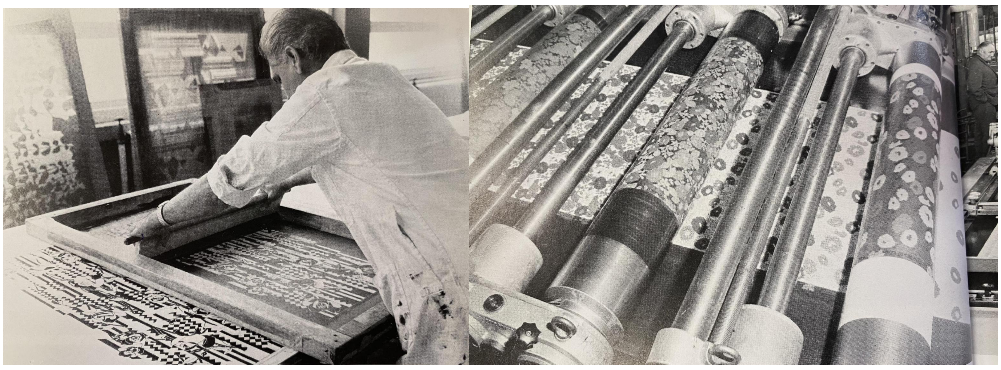


Figure 39 - On the left, manual screen printing. On the right, a close-up of a rotary automatic screen-printing set-in operation on the Johannes Zimmer machine (Storey, 1992).

The choice between manual, automatic, and semi-automatic processes for fabric printing is determined by various factors, including the quantity to be produced, the required speed, the desired effect, and the cost involved (Fleck, 2021).

Chapter IV
Market Research in Fashion

Natural dyeing and printing using bacterial pigments have been studied by many, but not many brands are developing products with their use. Below are some examples of designers, brands, and companies that are studying its development or have already launched collections using natural coloring techniques, whether derived from bacteria, plants, or vegetables.

Faber Futures

Faber Futures is a design agency founded by Natsai Audrey Chieza, a designer specializing in synthetic biology applied to the fashion industry, focusing on the production and development of biomaterials, in London. Aiming to innovate in the fashion world and operate at the intersection of nature, design, technology, and society, the company uses alternative methods in the execution of its pieces, allowing the large-scale production processes of biomaterials and enabling their application in market products (Duarte, 2021; Faber Futures, n.d.; Mota, 2023).

In 2011, she began her research on the bacterium *Streptomyces coelicolor*. The designer explains that if exposed to the right conditions, this organism can obtain pigments in shades of purple, blue, and pink for dyeing natural textile fibers. This method can reduce water waste and the use of chemicals compared to traditional processes (Duarte, 2021).

With research focused on the dyeing and printing industry, the project "Rise and Fall of a Micropolis" (2017), Figure 40, explored the interaction between pigment-producing bacteria and silk fibers over a fermentation period of 816 hours (34 days). This study revealed that prolonging the incubation period can bring beneficial effects to both the dyeing process and the aesthetic results obtained. The collaboration between the designer and the living organism allowed for an in-depth analysis of the impact of this biological process on the material (Faber Futures Lab, 2017).

Figure 40 - Project “Rise and Fall of a Micropolis”, Faber Futures, 2017 (Faber Futures Lab, 2017).

Through the study and exploration of pigment-producing bacteria, the company, in partnership with Ginkgo Bioworks, created the Ginkgo Bioworks Residency to develop various innovative projects focused on the textile industry. Ginkgo Bioworks, an American biotechnology company founded in 2009 by MIT scientists and led by Jason Keely, collaborated in this effort by bringing its expertise in genetic engineering and synthetic biology to the field of textile design, aiming to develop microbial strains and build custom tools through digital fabrication. Together, they explored the ability to develop graphic textile prints with larger-scale patterns and the possibility of personalized printing applicable to clothing pieces. This collaboration originated in three distinct lines of investigation: Scale, Void, and Assemblage 01 (Carvalho, 2022; Ginkgo Bioworks & Faber Futures, 2017).

The Scale line explores how Ginkgo's infrastructure allowed for larger lengths of fabric to be dyed, enabling the parametric design to be extended to longer lengths of fabric, as seen in Figure 41 (Ginkgo Bioworks & Faber Futures, 2017).

Figure 41 - Project "Scale", Faber Futures x Ginkgo Bioworks Residency, 2017 (Ginkgo Bioworks & Faber Futures, 2017; immatters, 2018).

The Void line explored existing prototypes for custom-designed tools aimed at controlling the growth patterns of the bacterium *Streptomyces coelicolor* for use in larger-scale textile printing. Two printing experiments were conducted to obtain large-scale graphic prints, which helped the company understand how this mechanism worked and how the new tools could influence existing protocols, Figure 42 (Ginkgo Bioworks & Faber Futures, 2017).

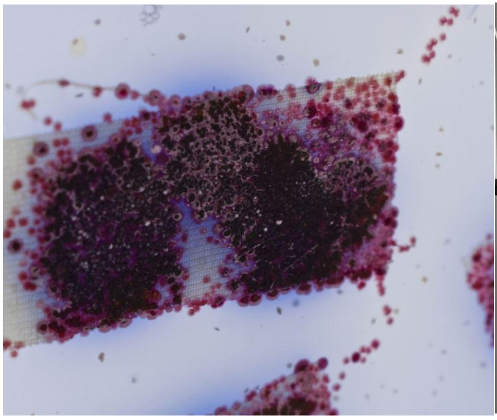
 

Figure 42 - Project "Void", Faber Futures x Ginkgo Bioworks Residency, 2017 (Ginkgo Bioworks & Faber Futures, 2017).

The Assemblage 001 is the world's first garment to incorporate bacterial pigments in its construction, as seen in Figure 43. For this experiment, a pattern-cutting method was developed, allowing a garment to be disassembled into its component parts before in-vitro dyeing, enabling each part to receive the necessary finishing. The development of the garment was a significant milestone in the customizable dyeing process and in the creation of a new method for biofabricating complex textile products (Carvalho, 2022; Ginkgo Bioworks & Faber Futures, 2017).

Figure 43 - Project "Assemblage 001", Faber Futures x Ginkgo Bioworks Residency, 2017 (Ginkgo Bioworks & Faber Futures, 2017).

Assemblage 002 is a reversible silk coat dyed with the bacterium *Streptomyces coelicolor*, produced by Faber Futures at the request of the *Cooper Hewitt* Museum (Figure 44). In this project, the bacterium was cultivated in a liquid medium and directly applied to the silk fibers, which infiltrated the fibers and resulted in colors ranging from blue, purple, and pink to red. This color variation is due to the pH of the medium in which the bacterium was cultivated (Faber Futures, 2019; Mota, 2023).

Figure 44 - Project "Assemblage 002", Faber Futures Commission to Museu Cooper Hewitt, 2019 (Faber Futures, 2019).

Pili Bio

Pili Bio is a French start-up that produces effective natural pigments based on microbial enzymes and renewable resources (Mota, 2023). The company claims to be one of the pioneers in discovering the use of bacteria for textile dyes combined with fabric dyeing without the use of chemicals (Duarte, 2021).

The best ones for color production were discovered through research with various microorganisms. These organisms have two types of enzymes: one that can break down sugar molecules, such as those found in beets, and another type of enzyme that can join these fragments to create a dye molecule (Duarte, 2021). Enzymatic synthesis allows alignment with microbes to create sustainable materials, saving energy and reducing waste. Currently, they are developing a dyeing technology that designs enzymatic cascades, transforming renewable carbon raw materials, like sugar, into textile dyes with various shades and color applications (Carvalho, 2022). This process occurs through fermentation, where bacteria consume glucose from sugar to produce the color that will result in the dye, in this case, blue (indigo). This process takes about a week to complete. The mixture is then subjected to high temperatures during drying, transforming the formed paste into a solid substance composed of very fine and biodegradable particles (Duarte, 2021).

Currently, 99% of the colors produced by Pili are made from fossil resources, and their mission is to produce sustainable dyes and pigments as a way to reduce environmental damage. The company's current focus is on radically changing the textile industry and its reliance on synthetic dyes, as well as addressing the water pollution caused by the dyeing process. The products offered by the start-up are compatible with existing dyeing infrastructure and processes, providing an alternative for those seeking sustainable fashion (Carvalho, 2022).

Vienna Textile Lab

Another laboratory dedicated to using bacteria for fabric dyeing is the Vienna Textile Lab. The company produces colors for organic textiles using a well-known bacterium and believes this is the best way to sustainably produce dyes and dye fabrics. Compared to the traditional method of producing textile dyes, the process used by this company does not require any water, making it extremely advantageous. This benefit applies not only to synthetic dyes but also to natural dyes. While natural dyes are derived from plants, fruits, or vegetables and depend on the right season or greenhouse cultivation to obtain the color, this company's method eliminates those needs (Duarte, 2021).

ColoriFix and H&M

ColoriFix is a British biotechnology company founded in 2016 by synthetic biologists Jim and Orr. While developing biological sensors to monitor heavy metal contamination in Nepal's drinking water, the biologists began studying the impact of the dyeing industry on water quality and human health. They realized they had the necessary tools to address this contamination problem. Thus, ColoriFix's mission is to transform the industrial dyeing process into an environmentally friendly, socially responsible, and economically viable method, focusing on improving dyeing practices regarding natural resources and pollution (Carvalho, 2022).

The first step was to discover a color that would pique interest, then identify the genes responsible for this color and the microorganisms capable of producing the pigment. The bacteria then read the inserted information, and the microorganisms were cultivated using sugar, yeast, and other plant by-products. The result is a dye that is then placed in dyeing machines. A small percentage of glycerol (non-toxic) is also added to increase the affinity between the pigment and the fiber/fabric. All processes are carried out without the use of chemicals or toxins (Mota, 2023). Additionally, compared to conventional cotton dyeing, for example, ColoriFix technology reduces water consumption by at least 49%, electricity by 35%, and CO2 emissions by 31% (Carvalho, 2022; Mota, 2023).

In the fashion industry, the company ensures brands of a more environmentally friendly product that maintains its quality. To reach a large scale, natural pigments must meet industry standards, including high color scores. ColorFix provides the first non-toxic and cost-competitive solution, with results comparable to synthetic dyes in independently certified tests (Carvalho, 2022).

In 2011, the fast fashion retailer H&M partnered with the company to launch "The Colour Story Collection," which utilized bacterial pigments for color production. In this project, the color palette included warm tones of orange and red, indigo, sage green, and soft yellows. These imparted a sense of organic, harmonious, and optimistic energy to the garments, taking a further step towards sustainability, as depicted in Figure 45 (Adobo Magazine, 2021; Mota, 2023).

> “We’re continually aiming to create elevated pieces with ground-breakingly more sustainable materials and processes. With this collection, our forward-thinking designs work together with revolutionary dye processes to make a positive change – be that lower water consumption or reformed manufacturing. This collection has a charming free-spirit; our customers will no doubt love these contemporary pieces, but we hope they’re inspired by the empowering sustainable narrative too.” – Ann-Sofie Johansson, Creative Advisor at H&M (Adobo Magazine, 2021)

Figure 45 - "The Colour Story Collection," H&M X ColoriFix, 2011 (Lorenzo, 2021).

Living Colour and PUMA

Living Colour is an experimental Biodesign research project initiated in 2016 by the company Kukka. The project aims to explore the natural and sustainable aesthetic possibilities derived from sustainable dyeing with bacterial pigments. Kukka seeks to promote sustainability in the fashion world: “Growing bacteria as a dye factory can lead to a more sustainable way to colour the world” (KUKKA, n.d.).

With the “live dying” method – cultivating bacteria on fabric – a highly innovative and artisanal process, they manage to capture the entire life cycle of the bacteria, resulting in unique visual patterns in each dye bath. In their dyeing process, the company claims to remove all redundant steps that generate environmental impact, thus avoiding the use of toxic chemicals and textile treatments, utilizing minimal water and low temperatures. This process results in vibrant colors with natural longevity and presents a means to challenge the dye industry (KUKKA, n.d.).

In 2020, the company collaborated with the sports brand PUMA, resulting in the first capsule collection titled “Design to Fade,” featuring sportswear dyed with bacteria. The collection prototype was showcased at the Milan Design Week 2020 fashion show (Figure 46) (KUKKA, 2020).

> "After more than 3 years of research with Kukka's biodesign project Living Colour, we teamed up with PUMA innovation to lead the way to a regenerative future" (KUKKA, 2020)

Figure 46 - Collab Puma x Living Colour Kukka, 2020 (KUKKA, 2020).

Breno Abreu and FARM

Breno Abreu is a design professor at the University of Brasília (UnB) whose research aims to unite fashion, design, diversity, inclusion, and science. He spearheaded the "A Cor é Rosa" collection (Figure 47), which utilizes bacterial and plant-based dyeing techniques on clothing to promote environmental care, design innovation, and sustainability. In 2023, his research project won the *RE-FARM CRIA* grant, launched by the clothing brand Farm and the *Precisa Ser* Institute. As a result, in early 2024, a capsule collection was released aimed at the *LGBTQIAPN+* community, an acronym referring to lesbians, gays, bisexuals, transgender and transvestite individuals, queer, intersex, asexual, pansexual, non-binary, and other identities (Nery, 2024).

The Brazilian brand Farm is known for its vibrant fashion and colorful prints that reflect the culture and nature of Brazil. Founded in 1997 in Rio de Janeiro, Farm draws inspiration from the cultural diversity and exuberance of Brazilian flora and fauna. Its collections feature feminine and laid-back pieces celebrating the joy and tropical lifestyle. Additionally, the brand strongly commits to sustainability, using eco-friendly materials and supporting social and environmental projects. With stores throughout the country and an increasingly international presence, Farm continues to enchant its customers with its authentic and creative fashion (FARM, n.d.).

In partnership with the *Precisa Ser* Institute, the brand created the *RE-FARM CRIA* project in 2022. This initiative is aimed at supporting young professionals who are shaping the future of fashion in Brazil by developing projects for products or services related to the textile industry, accessories, footwear, and that relate to the fashion ecosystem (FARM, 2023).

Graduated in Industrial Design and Biological Sciences with a master's degree in design and a Ph.D. in Art from UnB, the designer explains that the idea for the collection arose during his master's degree, when he wanted to merge his two degrees to generate something innovative. For him, the future of fashion is not only about appearances but about meanings, purposes, and celebrating life in its forms and colors (Nery, 2024).

In his research, Breno Abreu adopted an innovative approach by exploring bacteria and testing colorations on various types of fabrics. The professor explains that the technique of dyeing fabrics with plant and bacterial matter requires an initial preparation, which includes washing to remove possible chemical residues. Then, a mordant, a chemical substance used in dyeing and textile printing processes, is added to fix the pigment to the fibers (Nery, 2024).

In vegetable dyeing, the pigments were obtained from crajiru, a plant native to the Amazon Rainforest and the Atlantic Forest. Breno explains that dried leaves were boiled to extract the pigment, producing a plant extract like tea. As for the bacterial pigments process, bacteria were cultured in a specific growth medium in the laboratory for 72 hours. Then, the pigment was separated by centrifugation, using only the liquid obtained and not the bacteria. The pigment was then boiled with the fabric at 60 °C for an hour, resulting in a vibrant pink color (Nery, 2024).

The researcher emphasizes that the collection promotes a collaborative and social approach, focused on inclusion and diversity: "There are three main aspects in this research: collaborative design, environmental sustainability, and diversity of bodies and genders, so that everyone can feel represented in fashion productions" (Nery, 2024).

Figure 47 - "A Cor é Rosa" Collection, Breno Abreu x RE-FARM CRIA, 2024 (Nery, 2024).

Flávia Aranha

Flavia Aranha is a Brazilian fashion designer whose company has been certified by the B Corporation since 2016, an initiative presented in over 50 countries that prioritizes transparency in production processes and their environmental impacts, alongside profitability in company management. With a focus on sustainability, ethics, and diversity, the brand invests in research and machinery focused on biodegradable processes and innovations in dyeing and printing to optimize its production and generate positive impacts (Figure 48) (Carvalho, 2022; Pires, 2022).

In the dyeing process of its pieces, the brand uses flowers, herbs, teas, coffee, tree bark, etc., all raw materials are 100% natural and from renewable sources, without any use of heavy metals. These materials can still have a new use before being discarded, generating a circular economy. In addition, natural dyeing connects the brand with important values: biodiversity, ancestral knowledge, and sustainable and technological development. The use of Brazilwood, crajirú, annatto, chamomile, mate, pomegranate, jabuticaba, and many others used in the brand's dyeing process carry with them their origin and history, deepening the relationships with the land and with those who produced it (Carvalho, 2022; Flavia Aranha, n.d.; Pires, 2022).

The botanical printing technique is also one of the company’s trademarks. The process aims to highlight and enhance the properties of each plant used and the manual and delicate work carried out by the team (Carvalho, 2022).

Figure 48 - On the left, shibori technique applied to Flavia Aranha's clothing. On the right, eco-printing technique applied to Flavia Aranha's clothing (Flavia Aranha, n.d.).

Chapter V
Laboratory Development

Sustainable fashion has gained prominence as a necessary approach to reduce the negative environmental impacts of the fashion industry, particularly in the textile design sector, where there is excessive use of toxic chemicals, whether in synthetic dyes or other products used in the dyeing and printing processes of textile substrates.

The present laboratory study aimed to analyze artisanal printing methods using natural pigments, namely indigo, beetroot, and predominantly bacterial pigments, in order to develop a product that fits within the concept of sustainable fashion. The goal was to explore the opportunities provided by reviving artisanal techniques and utilizing natural pigments, particularly bacterial pigments, for fashion design, as well as the future's environmental and clothing advantages.

The printing techniques, stencil and manual screen printing, were chosen for their widespread use and ability to create unique, easily reproducible patterns using natural materials. The study aims to evaluate the effectiveness of these techniques on natural fiber textiles, such as cotton, seeking innovative, viable, and sustainable solutions for application in the textile and clothing industry.

To achieve this, the growth conditions of the bacteria *Pseudomonas* sp. for the production of brown pigment, *Serratia plymuthica* for the production of red pigment, and *Chryseobacterium shingense* for the production of yellow pigment were initially optimized. The pigments were then extracted in paste form and mixed with other ingredients to create ink pastes for use in textile printing.

The powder form that had already been extracted was used to create the indigo pigment paste. For the beetroot pigment, the vegetable was cooked and blended with a small amount of water, then boiled to reduce and obtain a liquid-paste form for creating the ink paste. After creating the ink pastes, the manual screen-printing technique was used to print the textile material, creating patterns with unique shapes and colors.

The results obtained throughout the different stages were analyzed to subsequently assist in the planning of the collection. The analysis included evaluating the effectiveness of artisanal printing techniques with natural pigments, considering the durability, color fastness, and overall quality of the dyed fabrics, along with their environmental advantages.

1. Experimental Work

In this experimental project, all the necessary equipment for microbiological procedures was properly sterilized using an autoclave in a standard 21-minute cycle. The protection of all materials with aluminum foil was applied, ensuring their safety and preservation. The extraction and reproduction experiments of the pigments were conducted in the laminar flow hood, which was previously sterilized in a 10-minute cycle with UV light to ensure sterile working conditions. Additionally, 70% ethanol was used to ensure the sterility of the chamber surface and all materials.

1.1. Production and Extraction of Bacterial Pigments

1.1.1. Flexirubin Pigment (Yellow)

To produce the Flexirubin pigment, the bacterium *Chryseobacterium shingense* was used, characterized by its yellow hue. The first step was to prepare the Nutrient Agar (NA) culture medium for the growth of the bacterium and production of the pigment.

Table 2 - Recipe for Nutrient Agar (NA) Culture Medium (The author, 2024).

Nutrient Agar (NA) Culture Medium		
	Nutrient Agar Powder	**Water**
Quantities/ L	28 g	1 liter
Recipe used	14 g	500 ml

The culture medium was prepared according to the recipe shown in Table 2 and inserted into an autoclave for sterilization at 121 °C in a 21-minute cycle. After completing the cycle, the culture medium was distributed into sterilized Petri dishes inside a laminar flow hood. The use of the hood is essential as it allows work to be done in a sterile environment without the risk of contamination. All the plates filled with the liquid culture medium were left to solidify at room temperature. After the plates solidified, they were inoculated with the bacteria and placed to grow at 30 °C in an incubator for 48 hours. For inoculating the plates, small amounts of pigments from existing plates were extracted and spread onto the new plates in back-and-forth motions. After this period, the generated pigments were extracted from the plates to be used later in the creation of paint pastes, and the medium was discarded, Figure 49. These processes were repeated until enough pigment was obtained.

Figure 49 - From A to L, photos of the process of production and extraction of the yellow pigment (The author, 2024).

1.1.2. Prodigiosin Pigment (Red)

For the production of the Prodigiosin pigment, the bacterium *Serratia plymuthica* was used, characterized by its pink-red hue. The first step was to prepare the Peptone-Glycerol-Phosphate (PGP) culture medium for the growth of the bacterium and production of the pigment.

Table 3 - Recipe for Peptone-Glycerol-Phosphate (PGP) Culture Medium (The author, 2024).

Peptone-Glycerol-Phosphate (PGP) Culture Medium					
	Peptone	**Glycerol**	**K2HPO4***	**Agar**	**Water**
Quantities/ L	5 g	10 ml	2 g	15 g	1 litre
Recipe used	2.5 g	5 ml	1 g	7.5 g	500 ml

*Dibasic Potassium Phosphate (K_2HPO_4)

The culture medium was prepared according to the recipe shown in Table 3 and agitated before and after the addition of the Glycerol component. It was then inserted into an autoclave for sterilization at 121 °C in a 21-minute cycle. After completing the cycle, the culture medium was distributed into sterilized Petri dishes within a laminar flow hood. Once all the dishes were filled with the liquid culture medium, they were left to solidify at room temperature. After solidification, the dishes were inoculated with the bacteria and placed to grow at 20 °C without light for 48 hours. For the inoculation of the dishes, small amounts of pigments were extracted from existing plates and spread onto the new plates using back-and-forth motions. After this period, the pigment generated from the plates was extracted to be subsequently used to create the paint pastes, and the medium was discarded, as shown in Figure 50. These processes were repeated approximately until a sufficient quantity of pigment was obtained.

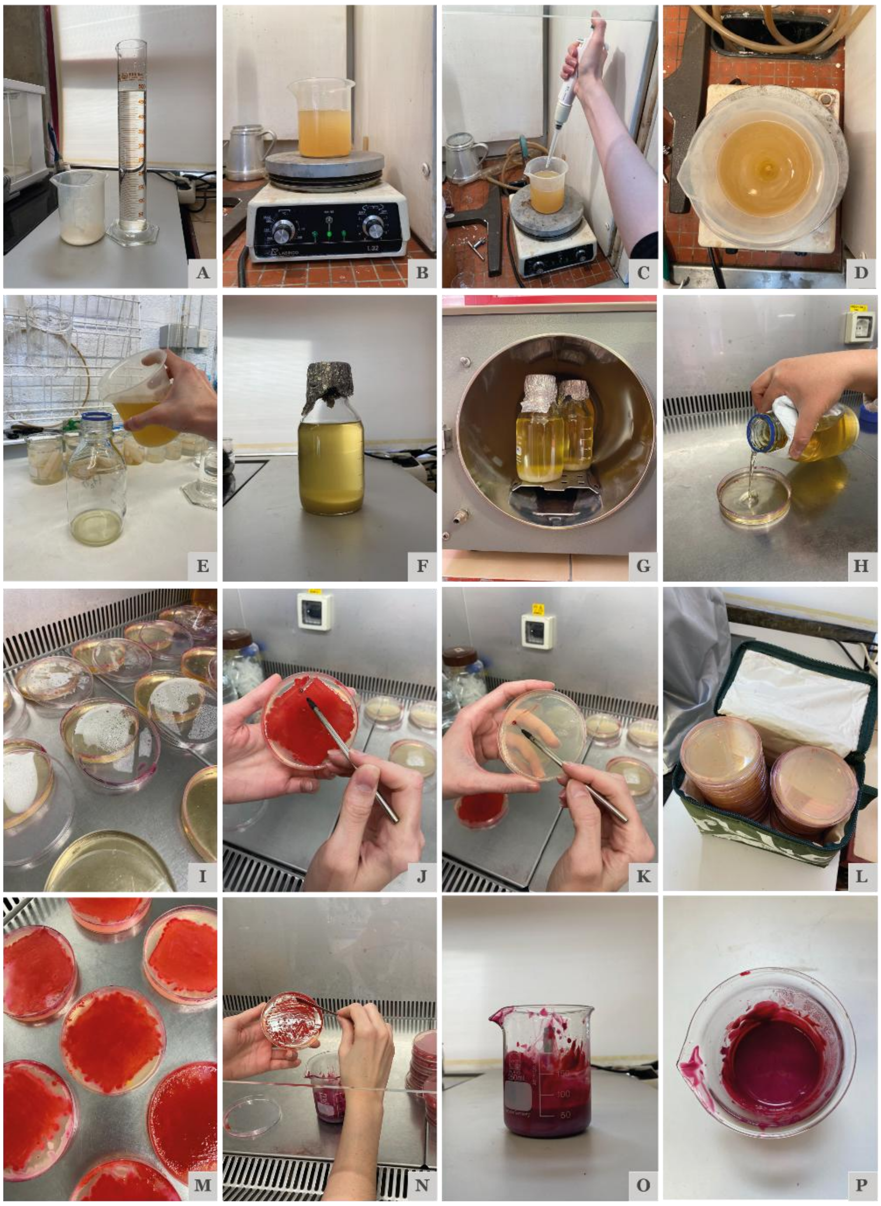


Figure 50 - From A to P, photos of the process of production and extraction of the red pigment (The author, 2024).

1.1.3. Brown Bacterial Pigment

To produce the Brown pigment, the bacterium *Pseudomonas* sp. was used. The first step was to prepare the culture medium, Tryptic Soy Agar (TSA), for the bacterium's growth and pigment production.

Table 4 - Recipe for Tryptic Soy Agar (TSA) Culture Medium (The author, 2024).

Tryptic Soy Agar (TSA) Culture Medium		
	Tryptic Soy Agar Powder	**Water**
Quantities/ L	40 g	1 liter
Recipe used	20 g	500 ml

The culture medium was prepared according to the recipe shown in Table 4 and placed in an autoclave for sterilization at 121 °C in a 21-minute cycle. After completing the cycle, the culture medium was distributed into sterilized Petri dishes inside a laminar flow hood. All the dishes filled with the liquid culture medium were left to solidify at room temperature. After solidification, the dishes were inoculated with the bacteria and placed to grow at 30 °C in an incubator for 48 hours. For inoculation, small amounts of pigments were extracted from existing plates and spread onto the new plates using back-and-forth movements. After this period, the pigment generated from the plates was extracted to be subsequently used to create the paint pastes, and the medium was discarded, as shown in Figure 51. These processes were repeated until enough pigment was obtained.

Figure 51 - From A to K, photos of the process of production and extraction of the brown pigment (The author, 2024).

1.2. Pigment Extraction from Beetroot

In this process, two peeled and precooked beetroots were blended in a blender with a little amount of water. The resulting liquid was heated over medium heat until boiling for 40 minutes to reduce it. After the reduction process, the liquid was strained twice to remove some pulp and ensure that the liquid-paste mixture was as smooth as possible, Figure 52.

Figure 52 - From A to D, photos of the beetroot pigment extraction process (The author, 2024).

1.3. Stamping Pastes Preparation

In this process, five printing pastes of different colors were prepared. The pigments used to create the pastes were Indigo (already extracted powder), beetroot, and bacterial pigments: brown, yellow, and red (Figure 53). These were mixed with emulsifying agents, thickeners, binders, and water.

Figure 53 - Created printing pastes (The author, 2024).

1.3.1. Indigo 94% Pigment

The Indigo stamping pastes were prepared following two different recipes.

– Recipe 01

For the first recipe, the process began with the preparation of the thickener, where sodium alginate was slowly added to distilled water at a concentration of 6.0% (w/v) (6 g of sodium alginate in 100 mL of distilled water) using a high-speed mechanical stirrer. Then, the printing paste was prepared with the natural blue Indigo 94% dye following the recipe for 1 kg of paste shown in Table 5.

Table 5 - Recipe 01 of the Indigo 94% Stamping Paste (The author, 2024).

Recipe 01 - Indigo 94% StampingPaste								
	Indigo Dye	Urea	Sodium alginate	Lioprint RG	Sodium carbonate	Sodium dithionite	Water	Sample
1kg	30 g	200 g	550 g	10 g	15 g	10 g	185 g	
50g	1.5 g	10 g	27.5 g	0.5 g	0.75 g	0.5 g	9.25 g	

*Carbonate and Dithionite work as fixatives for this type of dye

However, only 50 g of paste was prepared for this research work. Thus, the components were weighed using a balance according to the values included in Table 5 for 50 g of stamping paste. The preparation process of the paste involved blending the dye, urea, Lioprint RG, sodium carbonate, sodium dithionite, and water in a high-speed stirrer. Once these components were well mixed, the thickener was added, and the mixture was stirred again at high speed. After finishing the paste preparation, the printing process began on the printing table, following the steps described below.

– Recipe 02

For the second recipe, 100 g of Indigo 94% paste was prepared following the recipe provided in Table 6. This recipe incorporated components typically found in printing pastes proposed for water-insoluble pigments, similar to many bacterial pigments, as represented in Figure 54. The components include the thickener Lyoprint PT-RV new, the emulsifier Lyoprint LFF, and the binder Lyoprint PBA.

Figure 54 - Components used in the printing paste mixture used in the Recipe 02 (The author, 2024).

Table 6 - Recipe 02 of the Indigo 94% Stamping Paste (The author, 2024).

Recipe 02 - Indigo 94% Stamping Paste						
	Indigo Dye	Lyoprint PT-RV new	Lyoprint LFF	Lyoprint PBA	Water	Sample
1kg	30 g	20 g	30 g	150 g	770 g	
100g	3 g	2 g	3 g	15 g	77 g	

*Lyoprint PT-RV new (thickener); Lyoprint LFF (emulsifier); Lyoprint PBA (binder)

The thickener was initially blended into the water to prepare this stamping paste and stirred with a high-speed stirrer until achieving a homogeneous mixture. Next, the pigment and emulsifier were added, followed by thorough mixing using the stirrer. Finally, the binder was added and further blended at high speed until a fully homogeneous paste was obtained (Figure 55).

Figure 55 – Photos A to D show the process of producing the Indigo 94% paste (The author, 2024).

1.3.2. Prodigiosin Pigment (Red)

The Prodigiosin stamping pastes were also made following two different recipes.

– Recipe 01

For recipe 01, the printing paste containing Prodigiosin pigment (red) was prepared following the procedure indicated for the recipe 01 of the paste composed of the Indigo dye. However, in this case, only urea, sodium alginate thickener, Lioprint RG emulsifier, and water were combined with the Prodigiosin pigment, as shown in Table 7.

Table 7 - Recipe 01 of the Prodigiosin (Red) Stamping Paste (The author, 2024).

Recipe 01 - Prodigiosin Bacterial Pigment (Pink/Reddish) Stamping Paste						
	Pigment	Urea	Sodium alginate	Lioprint RG	Water	Sample
1kg	80 g	200 g	560 g	10 g	150 g	
50g	4 g	10 g	28 g	0.5 g	7.5 g	

– Recipe 02

For the second recipe, 100g of Prodigiosin pigment (red) paste was prepared using the same components as recipe 02, which was prepared using the Indigo 94%. However, the aqueous pigment extract was replaced in the place of the pigment and water, with adjustments to the other components, as detailed in Table 8.

Table 8 - Recipe 02 of the Prodigiosin (red) Stamping Paste (The author, 2024).

Recipe 02 - Prodigiosin Bacterial Pigment (Pink/Reddish) Stamping Paste					
	Aqueous Pigment	Lyoprint PT-RV new	Lyoprint LFF	Lyoprint PBA	Sample
1kg	790 g	30 g	30 g	150 g	
100g	79 g	3 g	3 g	15 g	

*Lyoprint PT-RV new (thickener); Lyoprint LFF (emulsifier); Lyoprint PBA (binder)

The printing paste was prepared by stirring all components in a high-speed stirrer until a uniform and homogeneous paste was obtained (Figure 56). Moreover, it is important noticed that when the prodigiosin was mixed with the other components, and due to the waiting time between pigment extraction and paste production, the pigment oxidized, turning more purplish rather than pink-reddish.

Figure 56 – Photos A to D show the process of producing the *Prodigiosin* (red) paste (The author, 2024).

1.3.3. Flexirubin Pigment (Yellow)

The Flexirubin stamping pastes were done following also two different recipes.

– Recipe 01

The preparation of the printing paste with the Flexirubin pigment (yellow) followed the same procedure as for recipe 01 for Indigo dye and Prodigiosin pigment pastes, with adjustments to the amounts of each component as specified in Table 9.

Table 9 - Recipe 01 of the Flexirubin (Yellow) Stamping Paste (The author, 2024).

Recipe 01 - Flexirubin Bacterial Pigment (Yellow) Stamping Paste						
	Pigment	Urea	Sodium alginate	Lioprint RG	Water	Sample
1kg	80 g	200 g	600 g	10 g	110 g	
50g	4 g	10 g	30 g	0.5 g	5.5 g	

– Recipe 02

For the second recipe, 100g of Flexirubin pigment (Yellow) paste was prepared as shown in Table 10, using the same procedure previously described for the Indigo dye and Prodigiosin pigment in recipe 02.

Table 10 - Recipe 02 of the Flexirubin (Yellow) Stamping Paste (The author, 2024).

Recipe 02 - Flexirubin Bacterial Pigment (Yellow) Stamping Paste					
	Aqueous Pigment	Lyoprint PT-RV new	Lyoprint LFF	Lyoprint PBA	Sample
1kg	810 g	10 g	30 g	150 g	
100g	81 g	1 g	3 g	15 g	

*Lyoprint PT-RV new (thickener); Lyoprint LFF (emulsifier); Lyoprint PBA (binder)

The printing paste was prepared by stirring all the components in a high-speed stirrer until a uniform and homogeneous paste was obtained (Figure 57).

Figure 57 – Photos A to D show the process of producing the *Flexirubin* (Yellow) paste (The author, 2024).

1.3.4. Brown Bacterial Pigment

The Brow bacterial pigment stamping paste was prepared according to a recipe similar to the recipe 02 used for the Flexirubin pigment (Yellow), as shown in Table 11.

Table 11 - Recipe of the Brown Stamping Paste (The author, 2024).

Recipe - Brown Bacterial Pigment Stamping Paste					
	Aqueous Pigment	**Lyoprint PT-RV new**	**Lyoprint LFF**	**Lyoprint PBA**	**Sample**
1kg	810 g	10 g	30 g	150 g	
100g	81 g	1 g	3 g	15 g	

*Lyoprint PT-RV new (thickener); Lyoprint LFF (emulsifier); Lyoprint PBA (binder)

The printing paste was prepared by stirring all the components together with a high-speed stirrer until a uniform and homogeneous paste was obtained (Figure 58).

Figure 58 – Photos A to D show the process of producing the Brown paste (The author, 2024).

1.3.5. Beetroot Pigment

The Beetroot pigment paste was prepared using the recipe for the Brow bacterial pigment, with some adjustments to the amount of each component, as shown in Table 12.

Table 12 - Recipe 02 of the Beetroot Printing Paste (The author, 2024).

Recipe - Beetroot Pigment Stamping Paste					
	Aqueous Pigment	Lyoprint PT-RV new	Lyoprint LFF	Lyoprint PBA	Sample
1kg	800 g	20 g	30 g	150 g	
100g	80 g	2 g	3 g	15 g	

*Lyoprint PT-RV new (thickener); Lyoprint LFF (emulsifier); Lyoprint PBA (binder)

The printing paste was done by stirring all the components together using a high-speed stirrer until a uniform and homogeneous paste was achieved (Figure 59).

Figure 59 – Photos A to D show the process of producing the Beetroot paste (The author, 2024).

1.4. Stamping Process Screening

The chosen handmade printing process for this project development was the manual Screen-Printing technique. Upon analyzing the proposed designs in the concept of this project, which will be presented later, it was seen that the best alternative would be the use of the screen-printing technique. For this, some previous experiments were conducted, which will be presented below, outlining the steps taken until the final pieces were printed. These experiments were essential to validate both the colors and the shapes, ensuring that the final printed materials met the desired standards of accuracy and quality.

The materials and equipment used for the experiments were the previously produced printing pastes, screen-printing frames, acetate sheets, a printing table, and a thermofixer (Figure 60).

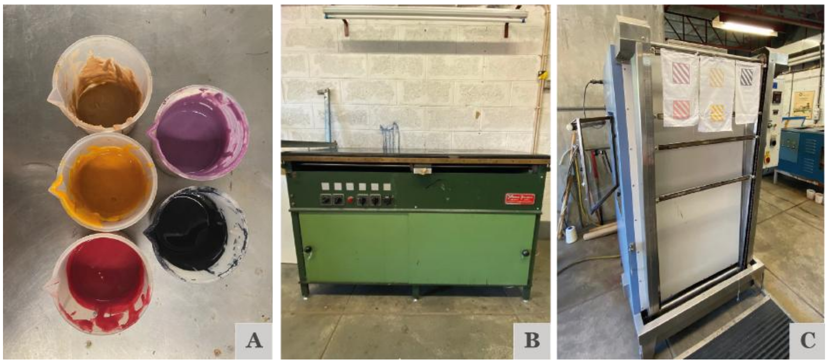


Figure 60 – From A to C, photos of the materials and machinery used in the process (The author, 2024).

1.4.1. First Experiment

The **First Experiment** was necessary to validate the colors of the stamping pastes prepared from recipe 01 for Indigo, Prodigiosin (red), and Flexirubin (Yellow). For this purpose, existing screen-printing frames in the Textile Printing and Dyeing Laboratory at the University of Beira Interior (UBI) were used.

A4 polyester/wool and cotton fabric samples were utilized to test the recipe 01 printing pastes. The textile sample was placed on the table, followed by the printing frame. Then, the squeegee and printing paste were positioned next to the sample, and the squeegee was moved across the frame in two back-and-forth passes, with a pressure of 6.

Subsequently, the printed textile sample was placed in a fixer for heat setting under dry steam at 150 °C for 5 minutes. After fixing the dyes on the samples, they were washed/rinsed in hot water at 80 °C with a detergent FELOSAN TAK-NO using 1 g of detergent per liter for 10 minutes. Finally, the printed samples were placed in a centrifuge to remove excess water and then returned to the thermofixer for a more durable and effective result (Figure 61).

Figure 61 – From A to D, photos of the stamping process in the First Experiment (The author, 2024).

1.4.2. Second Experiment

A new test was conducted to validate the colors of the stamping pastes, this time using the printing pastes produced with recipe 02 for Indigo, Prodigiosin (red), and Flexirubin (Yellow) and the recipe for Beetroot and Brown Bacteria.

For the **Second Experiment**, only A4 samples of cotton fabric were used because cotton offers several distinct advantages for the present dissertation. The cotton fabric was placed on the table, followed by the printing frame. Then, the squeegee and printing paste were positioned next to the sample, and the squeegee was moved across the frame in one direction only with a pressure of 2. Finally, the printed textile sample was placed in a thermofixer for heat setting under dry steam at 150 °C for 5 minutes (Figure 62).

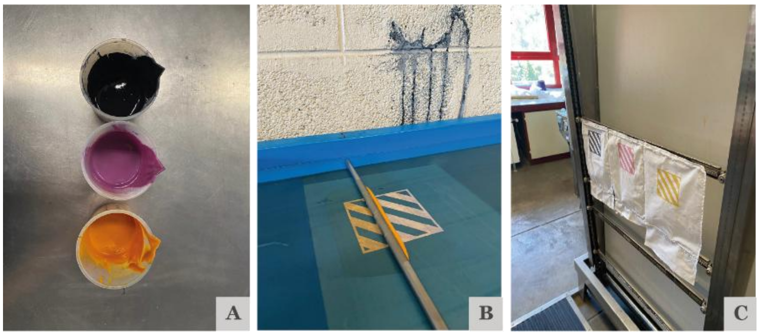


Figure 62 – From A to C, photos of the stamping process in the Second Experiment (The author, 2024).

1.4.3. Third Experiment

In the **Third Experiment**, frames were manufactured for screen printing since no available frames matched the required shapes needed for the stamping. Thus, with the assistance of Mr. Nuno, the technician responsible for the UBI FabLab, the frames were created using leftover pallets that would otherwise be discarded (Figure 63). After assembling the frames, a piece of fabric was engraved, which proved suitable for ink passage.

Figure 63 – From A to D, photos of the frame creation process at the UBI FabLab (The author, 2024).

With the frame assembled, an initial test was conducted using acetate sheets. For this process, an A3 sample of cotton fabric was used. The fabric was placed on the printing table, and the acetate sheet was positioned on top of it. The produced frame was placed on the acetate sheet. The squeegee and printing paste were positioned next to the sample, and the squeegee was moved across the frame in only one pass with a pressure of 2. Finally, the printed textile sample was placed in a thermofixer for heat setting under dry steam at 150 °C for 5 minutes (Figure 64).

Figure 64 – In test A, only the acetate was positioned over the cotton sample, and the squeegee was passed with the printing paste. In B, the order was: the sample, the fabric frame, and on top of it, the acetate. In C, the order was: the sample, the acetate, and on top, the fabric frame. Image D shows one of the results obtained (The author, 2024).

1.4.4. Fourth Experiment

After the Third Experiment, another approach (**Fourth Experiment**) was tested, drawing directly on the fabric screen and sealing the areas where no printing was desired with an appropriate varnish (Figure 65).

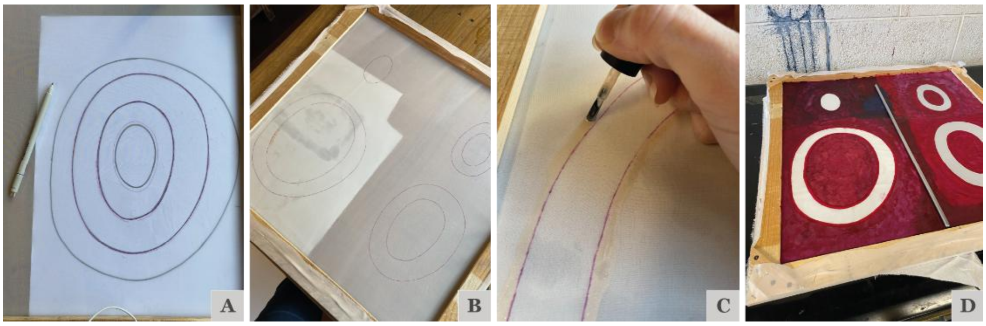


Figure 65 – From A to D, photos of the sealing process of the fabric frame (The author, 2024).

Thus, with the screen sealed, the fabric printing process began using an A3 cotton fabric sample. The fabric was placed on the printing table, and on top of it, the frame was positioned. The squeegee and printing paste were placed next to the sample, and the squeegee was moved across the frame in only one pass with a pressure of 2. Finally, the printed textile sample was placed in a thermofixer for heat setting under dry steam at 150 °C for 5 minutes (Figure 66).

Figure 66 – From A to D, photos of the stamping process in Experiment 02 (The author, 2024).

The process was repeated for each frame used for printing. For changing colors, the frame was washed with water to remove the paste present and dried with a hairdryer to accelerate the process (Figure 67).

Figure 67 – From A to B, photos of the washing and drying process of the frame (The author, 2024).

1.5. Stamping Final Pieces

After the colors, shapes, and technique were validated, the final pieces were stamped. The designs were directly stamped onto the clothing molds using the process described above in the **Fourth Experiment** using the sealed screen (Figure 68).

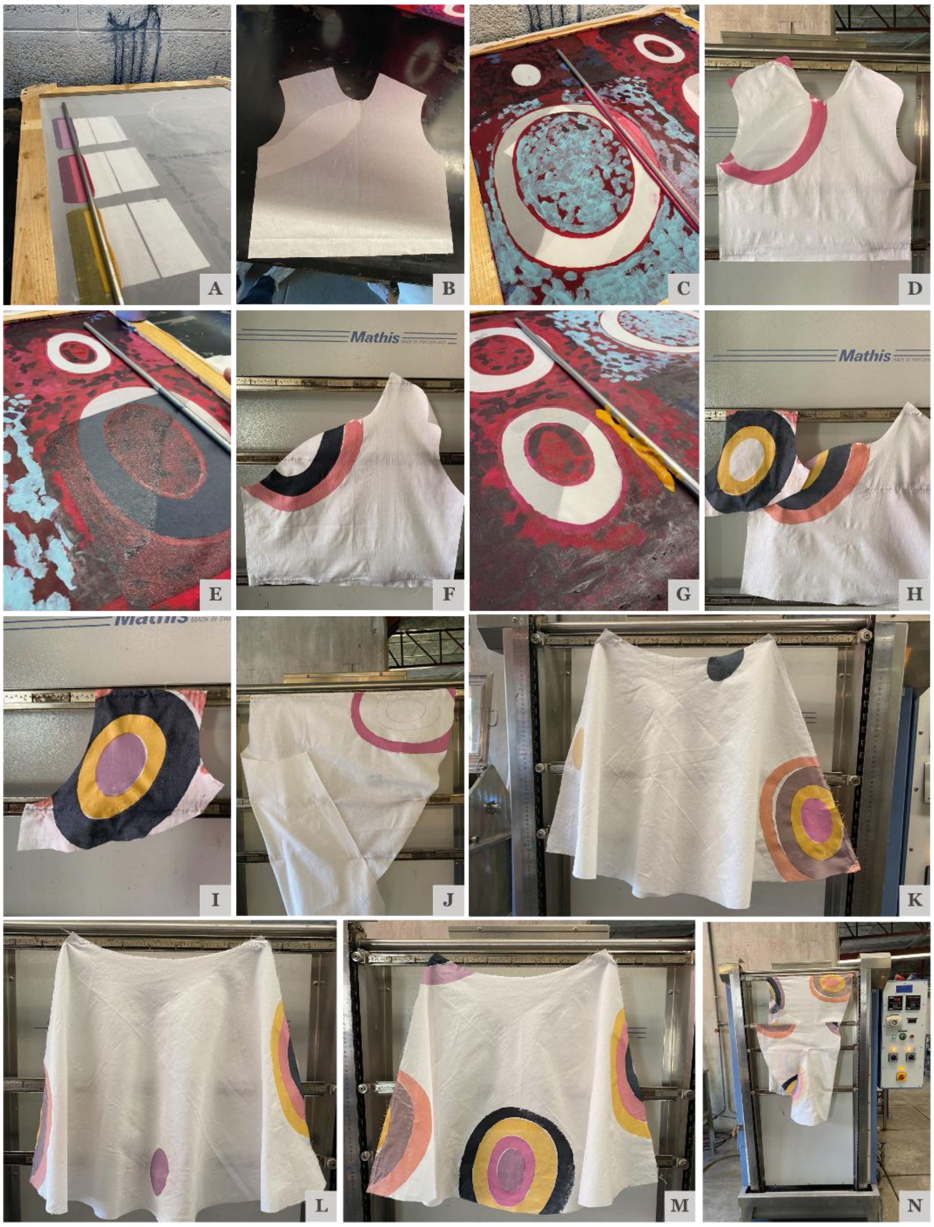


Figure 68 – From A to N, photos of the stamping process of the final piece molds (The author, 2024).

2. Presentation and Discussion of Results

The results obtained from the **First Experiment** revealed that when stamping, the printing pastes made from bacterial pigments were very light and had little vibrancy, which did not align with the conceptual purpose of this work (Figure 69).

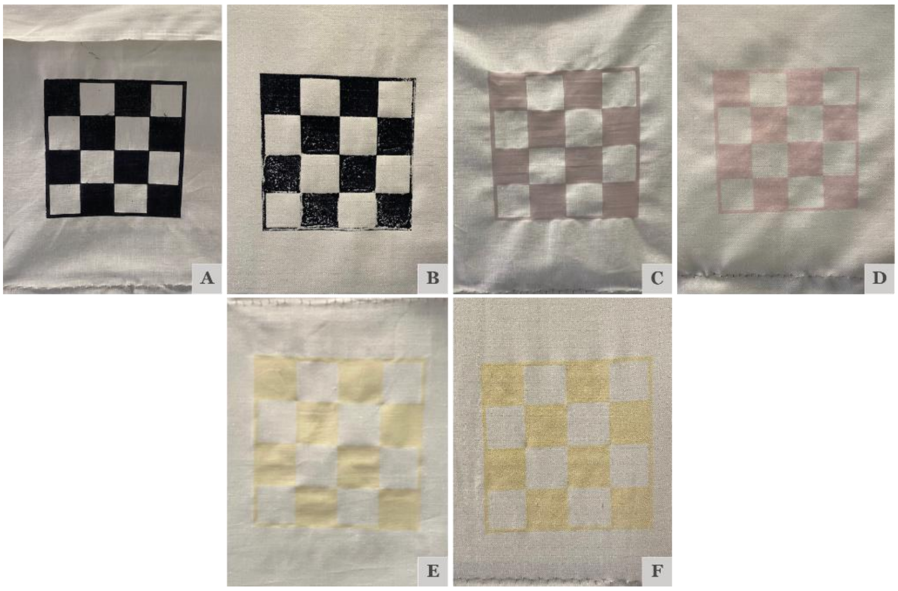


Figure 69 –A, C, and E: cotton samples. B, D, and F: polyester/wool samples (The author, 2024).

In addition, significant fading of the colors was observed during the washing of the samples. In the samples with bacterial pastes, the result after washing was almost nonexistent, as shown in Figure 70. A positive point of this experiment was the choice of the cotton sample as the fabric for the final piece prototype. It was found that the cotton absorbed the ink and provided a more suitable finish in contact with the printing pastes.

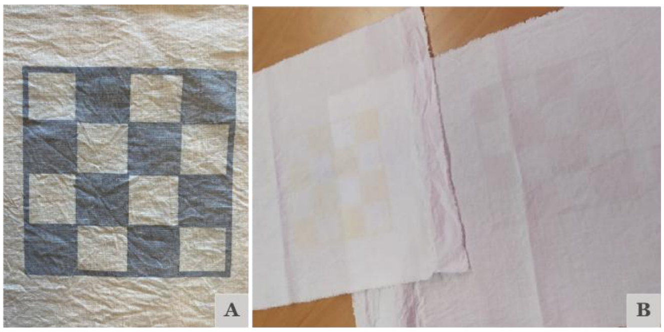


Figure 70 – Results after washing (The author, 2024).

Given the non-desirable color results obtained in the **First Experiment**, a new test was conducted. In the **Second Experiment**, the amount of pigment used for the production of printing pastes from bacterial pigments and beetroot was increased, and the other components of the pastes were more suitable for insoluble pigments, using components commonly used in pigment printing pastes, which are compatible with most bacterial and plant-based pigments.

Thus, positive results regarding the colors were achieved, which aligned with the project's concept (Figure 71). From this experiment, the fabric was not washed after stamping to preserve the originality and intensity of the printed colors, ensuring that the final design accurately reflected the artistic intention and the quality of the pigments used. Additionally, this approach simplified the production process, reduced water consumption, and decreased the costs associated with post-stamping fabric treatment.

Figure 71 – Final color samples (The author, 2024).

After validating the colors of the printing pastes, the process advanced to validate the technique and the designed shapes. The **Third Experiment** aimed to use acetate sheets to delineate the design and facilitate the stamping process. However, during the process, despite testing various ways to use the acetate (Figure 64), it was found that this technique needed to be more feasible because the ink seeped under the acetate, compromising the design, as shown in the various tests in Figure 72.

Figure 72 – From A to D, printing tests with acetate (The author, 2024).

Consequently, the most feasible approach was to adopt the fabric printing frame with varnish sealing. Concerning that, the **Fourth Experiment** ensured well-defined designs, confining them within intended stamping areas (Figure 73).

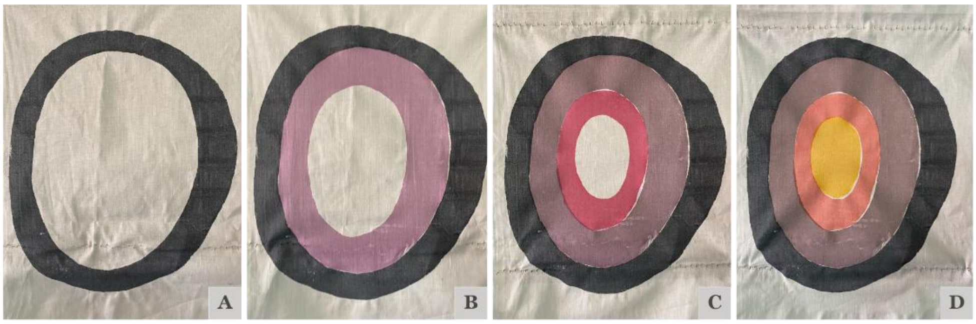


Figure 73 – From A to D, tests with the varnish-sealed fabric frame. The images also show how the color changed after passing through the heat fixer (The author, 2024).

Once the colors, shapes, and technique were validated, the final piece was stamped. The objective involved direct stamping onto the pattern pieces. Thus, employing localized stamping technique ensured precise positioning of the design, thereby minimizing the use of printing paste and reducing waste of printed fabric. During the stamping process of a piece that had many positioned designs, it was noticed that placing it in the thermofixer after each color application caused the colors to lose their vibrancy. Therefore, to maintain the color impact, it was decided to pre-dry the colors quickly at a lower temperature using a hairdryer. After completing all the desired designs on the piece, it was then placed in the thermofixer for a final set (Figure 74).

Figure 74 –Difference in colors: In A, the first pass with the beetroot paste; in B, the same pink tone modified after passing through the heat fixer (The author, 2024).

Additionally, it was observed that the amateurishly created frame became loose due to the numerous washings and dryings required. Consequently, some defects were evident in the last prints made with the frame (Figure 75).

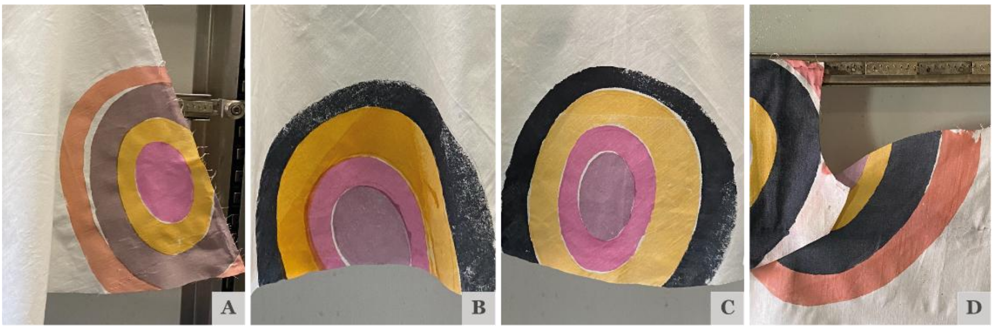


Figure 75 – Some imperfections obtained during the stamping process (The author, 2024).

Throughout the laboratory experiment, it can be concluded that the creation and production of pigments extracted from bacteria is a time-consuming process that requires several stages. Despite this, it is a method that allow to achieve satisfactory color results and serves as a viable alternative to synthetic dyes and natural dyes from other sources. This contributes positively to environmental impact and human health, as bacterial pigments are biodegradable and possess bioactive properties.

Regarding the printing pastes, their development was quicker, and despite being favorable, it was observed that achieving the desired color tones required a significant amount of pigments. Thus, using more pigment during paste creation results in more intense color and properties. Moreover, these pastes performed best when applied to natural fibers, such as cotton.

In turn, the printing technique presented was the best alternative for the chosen design. Despite some challenges, such as accurately layering one design on top of another, these imperfections were embraced within the project's concept, highlighting the handmade and unique nature of the work.

Therefore, this dissertation highlights that both bacterial pigments and the revival of artisanal printing techniques present an opportunity and a solution to the challenge of making the textile industry more sustainable.

Chapter VI
Creative Process

1. Trends

The creative process in fashion is an important step for designers and goes beyond simple creativity involving various aspects. Inspiration plays a crucial role in the development of ideas and products since clothing significantly influences the expression of social identity. When creating a piece, designers need to consider the type of consumer they aim to reach, their experiences, feelings, preferences, and past aesthetic influences (Pires, 2022).

Additionally, the creative process must be based on solid methodologies, such as trend analysis, which includes forms, colors, styles, pieces, etc. These trends not only help anticipate the future of fashion but also influence the creative process, allowing a more targeted approach to reach a specific audience and minimize risks (Pires, 2022).

The trend research for this work was conducted through the WGSN platform, an authority in the trend market, where inspirations for the development of the collection were sought through indications of macro and micro trends present in the Spring/Summer 2025 session.

1.1. Macro tendency – "Restorative Realms"

Restorative Realms explores how design will respond to the end of resource abundance, focusing on the environment and industry. It seeks processes and products that are regenerative rather than extractive, aiming to reduce planetary tensions and restore a sense of peace, balance, and rest. This trend is an evolution of the Fall-Winter 24/25 forecast, "Future Terrains" (Palmer, 2023).

> “Restorative Realms explores how design can create a sense of balance in an unpredictable world. Women's textiles skew towards simple designs, folk traditions, and natural and regenerative materials” (Palmer, 2023).

Nature is at the heart of this trend, manifesting through forms, materials, and plant-based ingredients (Figure 76). Science also plays a crucial role in exploring the rise of biosynthetic or lab-grown ingredients that leave a lighter footprint on the planet (Palmer, 2023).

> “Restorative Realms is underpinned by the impulse to preserve and conserve, but it is far from a conservative trend; rather, it is about bold moonshot concepts that can re-nurture people and the planet, putting them on a more nourishing track” (Palmer, 2023).

Figure 76 – Inspiration Photo Restorative Realms (Palmer, 2023).

1.2. Micro tendency

Plant Pigment

The trend centers on using restorative fibers with natural healing properties and natural dyeing from flowers and plants. These methods are safe for developing casual fabrics that offer natural performance. The focus is on using fibers and yarns from organic materials such as cotton, linen, ramie, and merino wool, with an emphasis on botanical and soft tones (Figure 77) (Palmer, 2023).

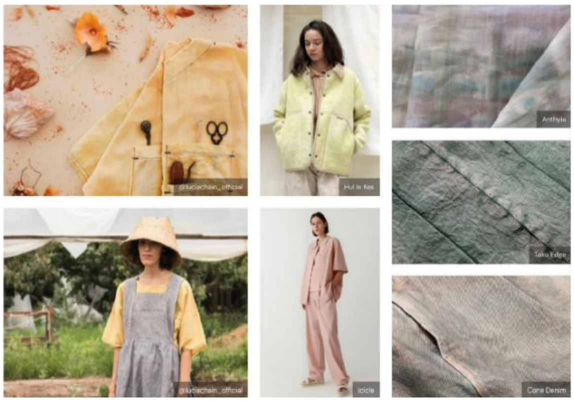


Figure 77 – Inspiration Board Plant Pigments (Palmer, 2023).

Sustentability & Inovation: Bacteria Colour

The trend concept involves using microbes as vivid color agents, with pigments produced by bacteria that create natural dyes without the need for toxic chemicals and excessive water usage associated with traditional dyes (Figure 78) (Palmer, 2024).

Figure 78 – Inspiration Photo Bacterial Colour (Palmer, 2024).

1.3. Color Palette

Seasonal Color

The season's color palette, Figure 79, will feature nostalgic and calming medium tones. Nature will play a significant role in design as the world navigates extreme climate issues. Brands should aim to protect biodiversity by prioritizing natural and responsible dyes, emphasizing the importance of color and its natural bases (Yiannakou, 2023).

Figure 79 – On the left, color palette for S/S 25 season. On the right, color palette for year 25/26 (Yiannakou, 2023).

Uplifting Pinks with Grounding Naturals

The palette is linked to natural beauty, with tones ranging from mossy and mountainous to fresh floral branches of Panna Cotta and Transcendent Pink, Figure 80. The emphasis remains on the importance of nature in design and environmental preservation (Yiannakou, 2023).

Figure 80 – Inspiration Board Uplifting Pinks (Yiannakou, 2023).

1.4. Keys Details

Extravagant Sleeves

"Bridge the gap between historical and modern design through the inclusion of volume sleeves, adapting them for modern consumers. Bold sleeve designs bring a playful and exuberant mood to fashion (Figure 81)" (Khumalo, 2024).

Figure 81 – Inspiration Photo Extravagant Sleeves (Khumalo, 2024).

Wrap Blouse

"Evolve structured wraps with peplum detailing and maxi length proportions to achieve the modest-friendly long over long aesthetic, Figure 82" (Khumalo, 2023).

Figure 82 – Inspiration Photo Wrap Blouse (Khumalo, 2023).

Fluid Trouser

> "Pursue growth within wide-leg assortments, with dressed-up effortless elegance created by fluid fabrics (Figure 83)" (Cheung, 2024).

Figure 83 – Inspiration Photo Fluid Trouser (Cheung, 2024).

Refined Heritage

> "An influential continuation of modern Chinese style with core details for the local consumer. [...] Keep the traditional Qi Pao style refreshed in new patterns and colours with discreet minimalist detailing such as side ties and buttons (Figure 84)" (Cheung, 2024).

Figure 84 – Inspiration Photo Refined Heritage (Cheung, 2024).

2. The Spectrum of Art – Capsule Collection

2.1. Concept

"The Spectrum of Art" is a capsule collection that combines fashion and art, drawing inspiration from the vibrant works of Wassily Kandinsky. Each of the six looks in the collection is dedicated to a color of the spectrum, highlighting the importance of colors in both art and fashion. The collection celebrates Kandinsky's artistic legacy and the relationship between color and expression.

The designs of the pieces are inspired by traditional Oriental garments, such as kimonos and Chinese qipaos, reflecting the significance of Eastern artisanal dyeing and printing techniques. The elegant shapes of these garments are perfect for the bold and dynamic prints that characterize the collection. Each look will showcase one of the spectrum colors – violet, blue, green, yellow, orange, and red – capturing the essence of the colors. The prints will be applied using natural pigments like indigo, beetroot, and bacterial pigments, emphasizing sustainability and connection with nature, much like in Kandinsky's works.

The collection will use natural cotton fabrics chosen for their versatility and ability to retain vibrant colors. Cotton also aligns with the collection's commitment to sustainability and eco-conscious fashion. Traditional manual printing techniques, such as screen printing, will be used to create the prints, celebrating Oriental craftsmanship. These methods ensure that each piece is unique and bears the mark of human touch.

"The Spectrum of Art" celebrates color, art, and fashion, designed to evoke emotions and inspire creativity. By combining Kandinsky's abstract art with the elegance of Oriental garments, this collection pays homage to artistic heritage and paves the way for sustainable and innovative fashion.

2.1.1. Wassily Kandinsky

Wassily Kandinsky (1866-1944) was a Russian painter and teacher at the Bauhaus (a school of design, visual arts, and architecture of the early 20th-century German avant-garde) who introduced abstraction into the field of visual arts. He developed non-figurative studies and is considered the first Western painter to produce an abstract canvas, spreading abstractionism throughout the West (Paulo, 2016).

Kandinsky focused his compositions, treating them as if they were music, constructing them based on the rhythm of geometric shapes such as circles, ovals, triangles, squares, lines, dots, ascents, descents, and rotations, using vivid colors. These colors, combined with shapes, evoke sensations and emotions and create a harmony that aligns with the human body. The artist studied colors and how they behaved together, examining their dynamic and emotional powers (Paulo, 2016).

The painter reflected deeply on art and how it emerged, and described the notion of creative freedom, saying that art is born from the artist mysteriously and secretly, and it is from him that it gains life and becomes a being. Regarding art history, Kandinsky stated: "In each image, there is an entire life trapped, a whole life of fears, doubts, hopes, and joys. Where is the path in this life? What is the message of the qualified artist? [...] Harmonizing the whole is the task of art" (Kandinsky, 1914, apud Paulo, 2016).

2.2. Target Audience

According to Galão et al. (2012), the target audience corresponds to the set of recipients that are of interest to an organization, which should extend its effects beyond its current customers if we are talking about an existing company but also include potential customers, influencers, and distribution agents. The central point of marketing communication with its audience is to understand that there is a need to communicate with various audiences, often simultaneously, and to understand their requirements (Fill, 2002).

This capsule collection aims to target women who lead an active lifestyle and are concerned about environmental issues. They seek to consume in a balanced and conscious manner, and have a relaxed style, apart from fads and fast trends. They are mostly women with more liberal and artistic professions, aged 23 to 35. They are part of the millennial generation, born between 1980 and 1990, who are always connected and informed about what they want and need. They seek personal fulfillment and prefer to have more experiences than to consume.

They enjoy being in nature and aim through their actions for a sustainable life that preserves the environment. They are always looking for brands and companies that embody this same philosophy in their products and services.

2.3. MoodBoard

A moodboard is a visual tool designers use to capture and communicate an idea or concept for a fashion collection. It typically consists of a composition of images, fabrics, textures, colors, patterns, and anything else that inspires or represents the collection's theme, aesthetic, or desired atmosphere. The goal is to help designers visualize and develop a consistent creative direction. In addition to serving as a source of inspiration, the moodboard also helps ensure that all design team members are on the same page regarding the collection concept, facilitating communication and collaboration.

The panel represented by Figure 85 demonstrates the inspiration, with essential elements for reflection, including the predominant colors of the collection, varied among the tones present in the color spectrum, reminiscent of the printing pastes developed through bacterial pigments, indigo, and beetroot, as well as the artworks of Wassily Kandinsky.

Images of oriental clothing models can be used to realize the type of garment that will be produced: blouses, skirts, pants, and dresses inspired by kimonos and qipaos. The type of fabric, technique, and main materials used in the laboratory will also be presented - cotton, screen printing, and natural pigments.

Figure 85 – MooadBoard and Color Pallet (The author, 2024).

2.4. Material Choices

The selection of materials is a crucial aspect in the development of any fashion collection, especially when aiming to combine aesthetics, functionality, and sustainability. For this collection, materials were chosen that not only meet quality and durability requirements but also reflect a commitment to sustainability and respect for the environment.

In this collection, 100% cotton fabric was chosen for its numerous advantages. Cotton is a natural fiber known for its excellent absorbency, which facilitates the application and fixation of the natural pigments used in the prints, as we saw in the experiments presented in Chapter V. Additionally, cotton is comfortable, breathable, and hypoallergenic, essential characteristics to ensure the wearer's well-being. Being a biodegradable and recyclable fiber, cotton aligns perfectly with the ecological and circular product proposal.

2.4.1 Cotton

Cotton is a pliable fiber originating from plants of the genus *Gossypium*, native to tropical and subtropical regions such as the Americas, Africa, and India. Its fibers have a diameter of 15-25 µm and a length of 10-50 mm, with waxes and fats on the surface that contribute to its softness and flexibility, helping to maintain the integrity of clothing shapes during use (Pires, 2022).

In addition to clothing, cotton is commonly used in towels, robes, upholstery, napkins, bedding, curtains, cushions, diapers, and other household products. It is often combined with other natural and synthetic fibers to create composite textile materials. Furthermore, organic cotton cultivation is carried out without the use of pesticides and chemical additives in the fertilization process (Pires, 2022).

2.5. Development of Patterns and Initial Sketches

For this collection, six works by the artist Wassily Kandinsky were selected as inspiration for developing the patterns. Each work represented a color within the spectrum, as seen in the following images, Figures 86 to 91. The patterns were developed using the color palettes present in the artworks, and after their creation, the final palette for the collection was applied.

Violet

Artwork: "Yellow-Red-Blue," Kandinsky, 1925

Figure 86 – A, "Yellow-Red-Blue," Kandinsky, 1925 (Wassily Kandinsky Website, n.d.). B, pattern developed with the original colors from the artwork. C, pattern with the collection's color palette (The author, 2024).

Blue

Artwork: "Blue Painting," Kandinsky, 1924

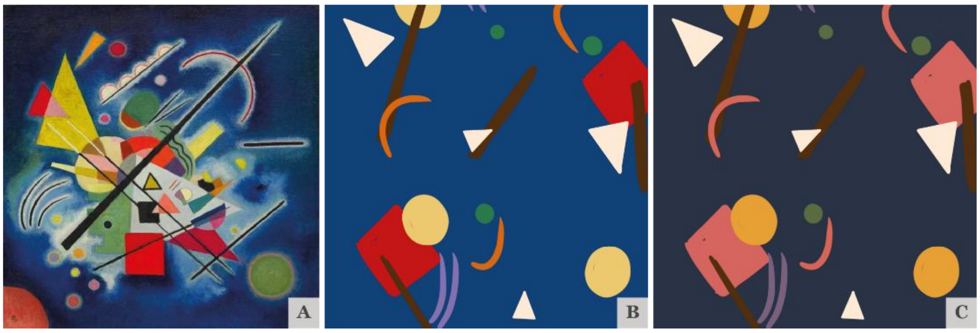


Figure 87 – A, "Blue Painting," Kandinsky, 1924 (Wassily Kandinsky Website, n.d.). B, pattern developed with the original colors from the artwork. C, pattern with the collection's color palette (The author, 2024).

Green

Artwork: "Circles in a Circle," Kandinsky, 1923

Figure 88 – A, "Circles in a Circle," Kandinsky, 1923 (Wassily Kandinsky Website, n.d.). B, pattern developed with the original colors from the artwork. C, pattern with the collection's color palette (The author, 2024).

Yellow

Artwork: "Black and Violet," Kandinsky, 1923

Figure 89 – A, "Black and Violet," Kandinsky, 1923 (Wassily Kandinsky Website, n.d.). B, pattern developed with the original colors from the artwork. C, pattern with the collection's color palette (The author, 2024).

Orange

Artwork: "Color Study, Squares with Concentric Circles," Kandinsky, 1913

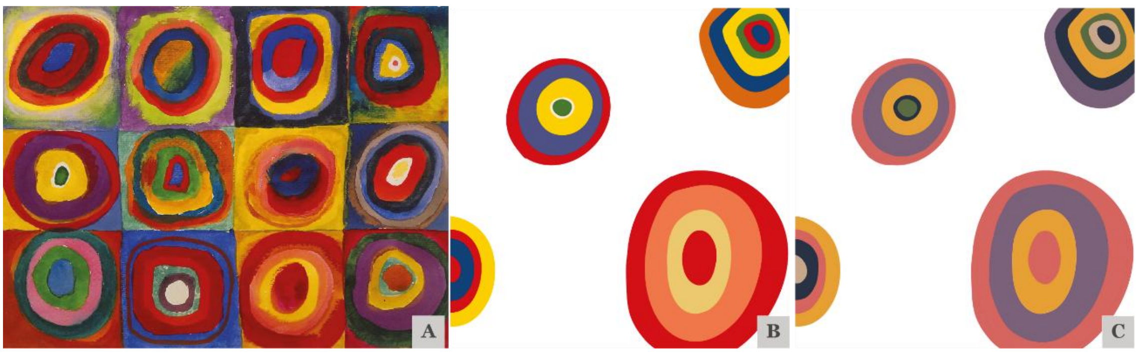


Figure 90 – A, "Color Study, Squares with Concentric Circles," Kandinsky, 1913 (Wassily Kandinsky Website, n.d.). B, pattern developed with the original colors from the artwork. C, pattern with the collection's color palette (The author, 2024).

Red

Artwork: "Merry Structure," Kandinsky, 1926

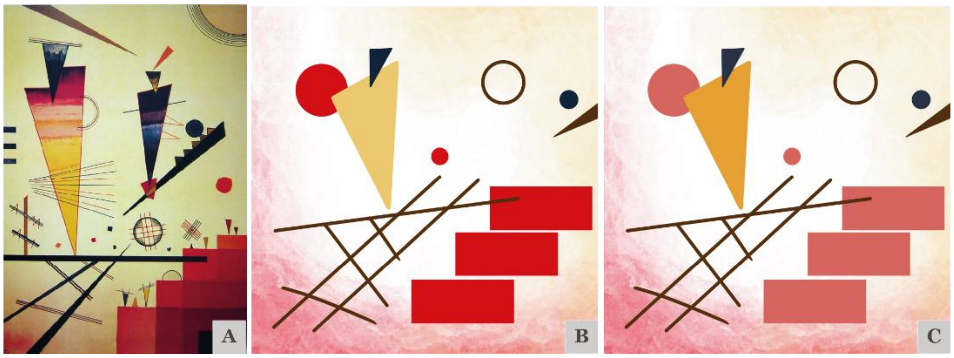


Figure 91 – A, "Merry Structure," Kandinsky, 1926 (Wassily Kandinsky Website, n.d.). B, pattern developed with the original colors from the artwork. C, pattern with the collection's color palette (The author, 2024).

With the creation of all the prints, the first sketches of the collection were developed, Figure 92.

Figure 92 – First Sketches of the Collection (The author, 2024).

2.6. Illustration of the "The Spectrum of Art" Collection

Figure 93 – Illustration of the "The Spectrum of Art" Collection (The author, 2024).

2.7. Description of the Pieces of "The Spectrum of Art" Collection

The **first ensemble** consists of a wrap dress with mid-length and wide sleeves, inspired by oriental kimonos. The look also includes a sash to accentuate the waist. The print applied to this ensemble is Violet, inspired by the artwork "Yellow-Red-Blue."

The **second ensemble** consists of three pieces, two of which are printed and one plain. The upper part of the look features a modern short-sleeved kimono with a straight cut and a cropped tank top with cutouts in the style of Chinese qipaos, dyed with beetroot pigment. The lower part consists of wide-leg pleated pants with low waist, invisible side pockets, and a print. The print applied to this ensemble is Blue, inspired by the artwork "Blue Painting."

The **third ensemble** consists of two distinct printed pieces. The first is a cropped baby tee in the style of a qipao, and the second is a pair of shorts with a unique waistband and invisible side pockets. The print applied to this ensemble is Green, inspired by the artwork "Circles in a Circle."

The **fourth ensemble** consists of two printed pieces. The first is a wrap blazer with wide sleeves and pockets on the lower front. The second piece is wide-leg pleated pants with a low waist and invisible side pockets. To complete the look, there is a belt to accentuate the model's waist. The print applied to this ensemble is Yellow, inspired by the artwork "Black and Violet."

The **fifth ensemble** consists of two printed pieces. The upper piece is a cropped tank top in the style of a qipao with side cutouts. The lower piece is a half-circle flared skirt. The print applied to this ensemble is Orange, inspired by the artwork "Color Study."

The **sixth ensemble** consists of two printed pieces. The first is the wrap blazer from look 4, in a cropped model with wide sleeves and waist ties. The second piece is a half-circle flared skirt. The print applied to this ensemble is Red, inspired by the artwork "Merry Structure."

2.8. Pieces to Manufacture

To apply the study conducted throughout the dissertation, the coordinated outfit number 5 (Figure 94) was planned to be manufactured. For the development of the pieces, the molds, which were printed with the stamping pastes made from the extracted natural pigments, had to be executed beforehand.

All the fabric was carefully measured and utilized to avoid waste. The remnants were used for stamping tests.

A detailed technical sheet (Figures 95 and 96) and a photographic editorial of the manufactured pieces (Figure 97 to 108) can be found in the following sections.

Figure 94 – Illustration of Outfit number 5 (The author, 2024).

2.9. Technical Sheets

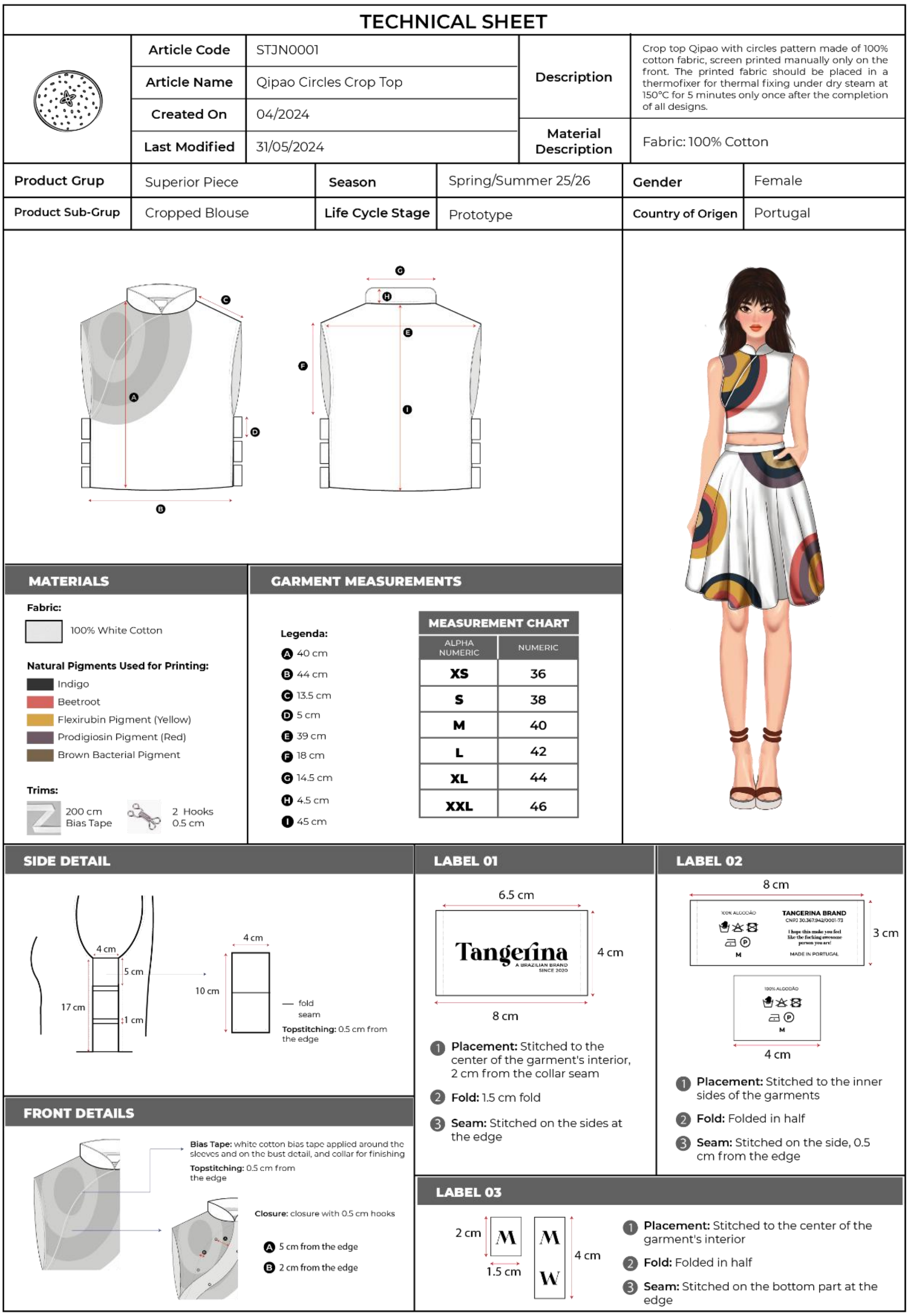
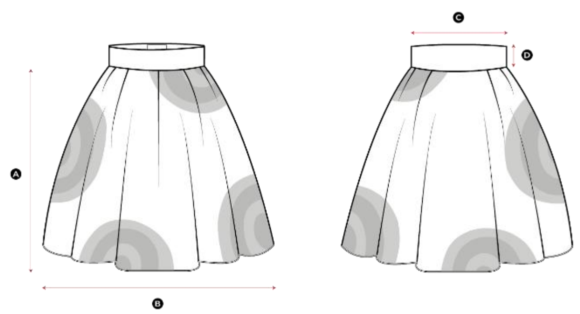


Figure 95 – Top Technical Sheet (The author, 2024).

TECHNICAL SHEET

	Article Code	STJN0002	**Description**	Half Godet Circle Skirt made from 100% cotton fabric, manually screen-printed all around, closed with a side invisible zipper, and finished with bias tape at the hem. The printed fabric should be placed in a thermofixer for thermal fixing under dry steam at 150°C for 5 minutes only once after the completion of all designs.
	Article Name	Circle Godet Skirt		
	Created On	04/2024		
	Last Modified	31/05/2024	**Material Description**	Fabric: 100% Cotton

Product Grup	Bottom Piece	**Season**	Spring/Summer 25/26	**Gender**	Female
Product Sub-Grup	Skirt - Godet Skirt	**Life Cycle Stage**	Prototype	**Country of Origen**	Portugal



MATERIALS:

Fabric:
- 100% White Cotton

Natural Pigments Used for Printing:
- Indigo
- Beetroot
- Flexirubin Pigment (Yellow)
- Prodigiosin Pigment (Red)
- Brown Bacterial Pigment

Trims:
- Invisible White Zipper 20 cm
- 250 cm Bias Tape

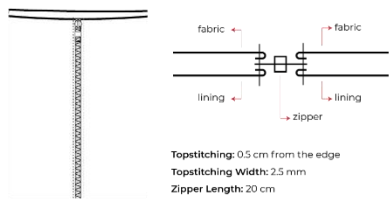
GARMENT MEASUREMENTS

Legenda:
- A 50 cm
- B 98 cm
- C 36 cm
- D 6 cm

MEASUREMENT CHART

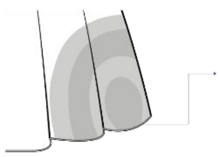
ALPHA NUMERIC	NUMERIC
XS	36
S	38
M	40
L	42
XL	44
XXL	46

INVISIBLE WHITE ZIPPER DETAIL



Topstitching: 0.5 cm from the edge
Topstitching Width: 2.5 mm
Zipper Length: 20 cm

HEM DETAIL:

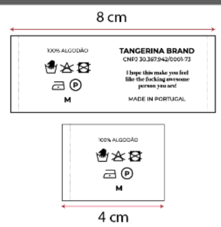


Bias Tape: white cotton bias tape applied all around the hem
Topstitching: 0.5 cm from the edge

LABEL 01

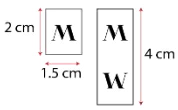
1. **Placement:** Stitched to the center of the garment's interior, 2 cm from the collar seam
2. **Fold:** 1.5 cm fold
3. **Seam:** Stitched on the sides at the edge

LABEL 02



1. **Placement:** Stitched to the inner sides of the garments
2. **Fold:** Folded in half
3. **Seam:** Stitched on the side, 0.5 cm from the edge

LABEL 03



1. **Placement:** Stitched to the center of the garment's interior
2. **Fold:** Folded in half
3. **Seam:** Stitched on the bottom part at the edge

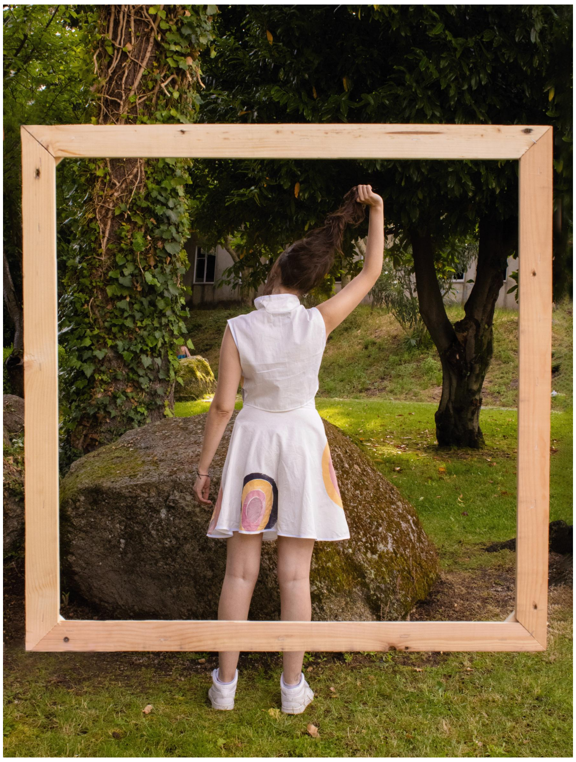
Figure 96 – Skirt Technical Sheet (The author, 2024).

2.10. Photographic Record

Figures 97 e 98 – Photographic Record "The Spectrum of Art" (The author, 2024).

Figures 99 e 100 – Photographic Record "The Spectrum of Art" (The author, 2024).

Figures 101 e 102 – Photographic Record "The Spectrum of Art" (The author, 2024).



Figures 103 e 104 – Photographic Record "The Spectrum of Art" (The author, 2024).


Figures 105 e 106 – Photographic Record "The Spectrum of Art" (The author, 2024).


Figures 107 e 108– Photographic Record "The Spectrum of Art" (The author, 2024).

Chapter VII
Conclusion and Future Perspectives

Conclusions

The fashion industry is constantly evolving and needs change. Society must reflect on its values and how it wants to survive, adopt conscious consumption, and explore alternatives to reduce environmental impact. This study exemplifies one such alternative in the textile sector: the use of bacteria to create textile pigments as a sustainable source, replacing synthetic pigments in printing pastes.

The pigments obtained from the bacteria studied, *Pseudomonas* sp., *Serratia plymuthica*, and *Chryseobacterium shingense*, proved effective in creating printing pastes. This demonstrates that it is possible to use bacterial pigments in fashion textiles. This innovation promotes sustainable practices in fashion design and opens new pathways.

The use of artisanal printing techniques as an alternative to mechanized industrial processes allows for creative and functional variations in textiles, without excessive use of water and energy, and without toxic chemicals. However, it is essential to continue improving this solution to achieve efficient production methods. The choice of materials, such as cotton, was crucial due to its ability to absorb pigments, its sustainable properties, and the feasibility of organic cultivation without chemical pesticides.

The study also investigated natural pigments derived from beetroots and indigo for printing pastes, showing promising results in color shades and vibrancy, although areas still need improvement. For instance, colorfastness and searching environmentally friendly components for printing pastes remain important research fields.

Laboratory tests confirm the potential of using natural pigments, especially bacterial ones, in the textile sector due to their low cost and ease of production, which can reduce the overall cost of textile production and increase profit margins for companies. Moreover, they represent a positive economic alternative for traditional textile regions and small businesses, benefiting both human health and the environment, responding to all research questions raised.

The integration of scientific knowledge with laboratory tests has shown that this sustainable alternative can be adopted in fashion design and other contexts, offering numerous natural possibilities while preserving the environment. The study also explored the relationship between fashion and art, demonstrating how artistic inspiration can add value to fashion products.

Finally, this study aimed to contribute to the advancement of sustainable practices in the fashion sector by providing evidence on the feasibility and benefits of natural pigments, especially bacterial ones, and demonstrating how the union between art and fashion can generate innovative and environmentally responsible products.

Future Perspectives

We can affirm that creating printing pastes through bacteria presents a significant positive transformation for the textile and fashion industry, and it is believed that its adoption brings great environmental, social, and economic advantages. To extend the studies presented in this dissertation, the following proposals for future work are suggested:

- Explore the possibility of increasing the biodye extracted from the culture, expanding its volume without altering the size of the culture.
- Study the potential for new biodyes by introducing new microorganisms that have not yet been explored for color extraction.
- Investigate possible components for the fabrication of stamping pastes that are entirely natural and non-chemical.
- Research potential biomordants that more effectively aid in fixing the dye to the fabric.
- Study improvements in colorfastness generated by the biodyes on textile substrates.

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