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Surface design and sustainability: strategies for reducing environmental impacts in textile printing

Design de superfície e sustentabilidade: estratégias de redução de impactos ambientais em estamparia têxtil

Diseño de superficies y sostenibilidad: estrategias para reducir el impacto medioambiental en el estampado textil

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Abstract

The relation between design and sustainability presents challenges, as design often drives the continuous production of new products. This article investigates how surface design can contribute to more sustainable practices in textile printing, with a focus on fashion. The gap addressed concerns the lack of clear guidelines to assist designers in creating prints with reduced environmental impact. A qualitative methodology was employed, based on a bibliographic review conducted in the SciELO, CAPES Journal Portal, and Google Scholar databases, in both Portuguese and English, covering the period from 2022 to 2025. Of the 735 studies retrieved, seven met the established inclusion criteria (printing methods, environmental data, and sustainable strategies). The analysis indicated that digital printing with water-based inks, multidirectional patterns, and brick rapport arrangements can reduce textile waste and water consumption by up to 95%, while natural pigments contribute to minimizing effluent toxicity. These strategies underscore the relevance of integrating design decisions with the careful selection of printing techniques to foster sustainability in fashion, in accordance with the principles of the circular economy.

Keywords: Design. Sustainability. Fashion.

Resumo

A relação entre design e sustentabilidade enfrenta desafios, uma vez que o design impulsiona a produção contínua de novos produtos. Este artigo investiga como o design de superfície pode contribuir para práticas mais sustentáveis na estamparia têxtil, com foco na moda. A lacuna abordada se refere à ausência de diretrizes que orientem o designer na criação de estampas com menor impacto ambiental. A metodologia adotada foi qualitativa, baseada em revisão bibliográfica nas bases SciELO, Portal de Periódicos da CAPES e Google Acadêmico, em português e inglês, com recorte temporal de 2022 a 2025. Dos 735 trabalhos encontrados, sete atenderam aos critérios de inclusão (métodos de impressão, dados ambientais e estratégias sustentáveis). A análise revelou que a estamparia digital com tintas à base de água, padronagens multidirecionais e rapport saltado reduzem desperdício têxtil e consumo hídrico em até 95%, enquanto pigmentos naturais minimizam a toxicidade dos efluentes. Essas soluções visam a integração de decisões projetuais e escolha criteriosa da técnica de impressão para promover a sustentabilidade na moda, alinhando-a aos princípios da economia circular.

Palavras-chave: *Design. Sustentabilidade. Moda.*

Resumen

La relación entre el diseño y la sostenibilidad presenta desafíos, ya que el diseño suele impulsar la producción continua de nuevos productos. Este artículo investiga cómo el diseño de superficies puede contribuir a prácticas más sostenibles en la estampación textil, con un enfoque en la moda. La brecha abordada se refiere a la falta de directrices claras que orienten a los diseñadores en la creación de estampados con menor impacto ambiental. Se empleó una metodología cualitativa, basada en una revisión bibliográfica realizada en las bases de datos SciELO, Portal de Periódicos de CAPES y Google Académico, en portugués e inglés, abarcando el período de 2022 a 2025. De los 735 estudios recuperados, siete cumplieron con los criterios de inclusión establecidos (métodos de impresión, datos

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ambientales y estrategias sostenibles). El análisis evidenció que la impresión digital con tintas a base de agua, los patrones multidireccionales y el rapport desplazado pueden reducir el desperdicio textil y el consumo de agua hasta en un 95%, mientras que los pigmentos naturales contribuyen a minimizar la toxicidad de los efluentes. Estas estrategias ponen de relieve la importancia de integrar las decisiones proyectuales con la selección cuidadosa de la técnica de impresión para promover la sostenibilidad en la moda, en consonancia con los principios de la economía circular.

Palabras clave: *Diseño. Sostenibilidad. Moda.*

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1 Introduction

The need for clothing, initially associated with protection against weather and adverse environmental conditions, has evolved over time, incorporating aspects of cultural identity, social status, and individual expression (Guimarães & Ribeiro, 2023). With population growth and technological advances, clothing production became industrialized and consolidated as one of the most relevant sectors of the global economy (Berlim, 2016).

In addition to its primary function of protection and its symbolic aspects, clothing expresses feelings, styles, and personal stories. Coelho (2008) explains that prints, through graphic elements such as color, shape, and texture, function as visual narratives. This expressive character is central to surface design, which creates patterns for fabrics and products.

Fashion plays a symbolic role in the construction of identity and in the cultural expression of individuals (Fletcher, 2010). According to Lipovetsky (2009), one of the main characteristics of fashion is its ephemerality, resulting in a pattern that influences several productive and consumer sectors, grounded in constant renewal and planned obsolescence.

The dynamism and constant renewal characteristic of the fashion system are directly related to the productive transformations that have occurred since its industrialization, which, on the one hand, brought gains in productivity and accessibility, but also resulted in significant environmental impacts (Vavolizza, 2020). The rampant consumption and high levels of clothing disposal are identified by De Gregori and Maier (2023) as critical factors contributing to the increase in textile waste.

It is estimated that between 10% and 15% of fabric is wasted even before the completion of clothing, as stated by Abou-Chakra et al. (2024). Shamsuzzaman et al. (2025) indicate that a large portion of the waste is disposed of in landfills or incinerated. In addition, printing stands out as one of the most polluting stages, both due to water consumption and the use of synthetic dyes. According to Souza et al. (2023), 12% of the dyes used worldwide are directly discharged into water bodies.

This scenario, characteristic of the current fashion system, highlights the

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need to rethink consumption habits and the ways of conceiving and producing fashion products. Design, as a project-based activity, has consolidated itself as a function oriented toward the creation of objects and systems (Bonfim, 2002). Building on this, Maciel (2021) adds that sustainable design should seek efficiency in the use of resources, durability, and the reduction of negative impacts. In this way, the incorporation of sustainable principles into design directs the discussion toward productive models capable of reducing impacts and extending the life cycle of products.

The adopted model needs to engage with sustainability, and in this context, the circular economy proposes rethinking the way consumer goods are produced, used, and discarded, in order to optimize the use of natural resources (Santos et al., 2023). According to Oliveira Junior et al. (2024), the circular economy proposes a sustainable approach, grounded in the idea of closing the product life cycle, eliminating waste and promoting reuse, recycling, and regeneration. This paradigm shift contrasts with the linear model, in which goods are manufactured from raw materials, sold, used, and subsequently discarded as waste, generating losses throughout the entire production chain.

According to the Ellen MacArthur Foundation (2015), the circular economy seeks to keep products, components, and materials at their highest value and utility for as long as possible. It is based on three principles: eliminating waste and pollution; circulating products and materials; and regenerating nature. Thus, in addition to optimizing resource use and reducing environmental impacts, it proposes the decoupling of economic growth from the intensive consumption of finite resources, operating effectively across different scales and productive sectors (Ellen MacArthur Foundation, 2015).

The circular economy is based on the premise that waste should be eliminated through design, anticipating solutions for materials to return to the production cycle or be safely reintegrated into the environment from the product's conception. Non-toxic biological materials can be composted or subjected to anaerobic digestion, while technical materials, such as polymers and metal alloys, are designed to be recovered and refurbished, preserving their economic and energy value (Ellen MacArthur Foundation, 2015).

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In the field of fashion, Andreatta et al. (2024) highlight that the advancement of the circular economy has driven the redesign of production practices, especially in response to criticisms of the fast fashion model. Printing, as part of this process, is increasingly challenged to adopt less polluting solutions and make greater use of input reuse. Therefore, it is suggested that, in the case of fashion products, surface design, when guided by sustainability principles, can contribute to reducing environmental impacts during the textile and garment printing stages.

In this context, this study aims to identify design strategies that optimize resource use during the creation of patterns and textile surfaces. The discussion presented in this article is part of an ongoing professional master's research within the Graduate Program in Design at the Federal University of Amazonas (UFAM).

2 Methodology

The research method was theoretical and project-based, with a qualitative and exploratory approach. To understand the textile printing process and its environmental impact, a literature review was conducted between January and August 2025, using three keywords in Portuguese (design de superfície, sustentabilidade, and moda) and three in English (textile printing, sustainability, fashion), defined based on the central thematic axes. The searches were carried out in the SciELO database, CAPES Journals Portal, and Google Scholar, prioritizing publications from 2022 onwards with free access. The Portuguese terms resulted in 99 studies, while the English search returned 636.

The inclusion criteria adopted for selecting references included studies addressing textile printing methods; presentation of environmental data related to printing; and proposals for developing sustainable strategies for pattern creation. After screening and reviewing the material, seven articles meeting these criteria were selected, five in English and two in Portuguese. The set of these publications, which forms the theoretical foundation and supports the discussion of this research, is summarized in Table 1.

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Table 1: Selected Articles

Title	Authors	Year	Inclusion Criteria
Ecological Sustainability of Digital Textile Printing	Tkalec *et al.*	2022	Exclusive analysis of digital printing; reduction of water, materials, and waste.
Synthetic Dyes for Textile Colouration – Process, Factors and Environmental Impact	Islam *et al.*	2022	Discussion of synthetic dyes; mention of printing; basis for transition to less harmful processes.
Estamparia com Corantes e Espessantes Naturais em Tecidos Tratados com Plasma	Giordano	2023	Experimental study with annatto and turmeric, use of natural thickeners and atmospheric plasma; artisanal and screen printing application.
Corantes Sintéticos e Seus Impactos Ambientais	Pessoa Junior e Azevedo	2024	Discussion of the ecological impacts of synthetic dyes; mention of printing.
Environmental Sustainability Analysis of Rotary-Screen Printing and Digital Textile Printing	Hoque *et al.*	2024a	Comparison between rotary and digital printing; analysis of water and energy consumption and waste generation.
Unraveling the Ecological Footprint of Textile Dyes	Hoque *et al.*	2024b	Analysis of the ecological footprint of dyes; mention of printing; support for substitution with natural dyes.
Eco-friendly Advances in Textile Printing	Hooda	2025	Covers techniques such as digital printing, pigments, natural dyes, enzymes, and plasma.

Source: Authors' personal collection (2025).

For further insight, the study also drew on reference works and reflections arising from surface design practice.

3 Analyses of Dyeing and Printing Processes

Textile dyeing, when carried out with synthetic dyes, involves the uniform impregnation of color throughout the fabric, which requires large volumes of water, energy, and toxic chemicals, potentially consuming between 50 and 300 liters of water per kilogram of fiber, while releasing effluents with a high chemical load, including salts and heavy metals (Islam et al., 2022). In addition, due to the resistant formulation of these dyes, the resulting effluents persist in the environment, accumulating in sediments and aquatic organisms (Hoque et al., 2024).

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Based on the analysis of the articles, it is observed that conventional printing, especially when carried out using screens or cylinders, requires large volumes of water and energy, as highlighted by Giordano (2023). Hoque et al. (2024a) compare the impacts of rotary and digital printing, noting that the former, responsible for about 65% of the market, is also the largest source of pollution in the sector. Digital printing, although still in the initial adoption phase, offers savings of up to 95% in water and 30% in energy.

In printing, the application of synthetic dyes occurs locally only in the design areas and not across the entire fabric surface, which reduces the total volume of dye used compared to continuous dyeing (Hoque et al., 2024a). This application is carried out using thickened pastes, generally based on synthetic or natural thickeners, which provide adequate viscosity for the localized fixation of color (Giordano, 2023). However, conventional formulations of these pastes incorporate auxiliary additives and, in some cases, solvents to improve penetration and fixation, resulting in effluents with a high load of suspended solids and persistent chemical compounds (Hoque et al., 2024b).

During dyeing and printing processes, up to 15% of the dyes may not fix to the fabric, and this excess is released into the water, compromising its quality and causing imbalances in the ecosystem. A large portion of these dyes are toxic and non-biodegradable, consequently persisting for long periods in the environment. Another negative impact caused by dyes is the interference with photosynthesis in benthic organisms, as they reduce sunlight penetration in the water, lowering oxygen levels and causing biodiversity loss (Hoque et al., 2024b; Pessoa Júnior & Azevedo, 2024).

According to Hoque et al. (2024a) and Hooda (2025), rotary printing requires screen engraving for each color and uses pastes with thickeners and large volumes of water, whereas digital printing injects the dye directly onto the fabric, minimizing resource use. This occurs because the design is printed directly onto the textile surface using inkjet printing technology, resulting in prints with high definition and detailed patterns (Hooda, 2025). In an industrial context, digital printing outperforms cylinder printing in almost all sustainability parameters: lower water, energy, and chemical consumption, while maintaining quality and design flexibility (Islam et al., 2022; Hoque et al., 2024a; Hoque et al., 2024b).

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Tkalec et al. (2022) state that the transition from rotary to digital printing will only be achieved with environmentally safe and high-quality inks, such as water-based inks, whose use is growing due to their stability and lower environmental impact. The risk of hazardous chemical inputs in the production chain has not yet been fully eliminated, making sustainable inks a commercial goal, but still distant from industrial reality. In addition to inks, new technologies for water treatment and mechanisms to control and regulate textile pollution are some of the measures that can be adopted in the industry (Hoque et al., 2024b).

In this context, Hoque et al. (2024b) emphasize that the development of eco-friendly dyes, the adoption of new technologies for wastewater treatment, and the implementation of regulatory mechanisms to control textile pollution are among the main measures currently underway. Environmental sustainability can be enhanced through the use of biodegradable dyes, bioremediation techniques, and water-free dyeing technologies. However, these actions need to be applied more rigorously and widely disseminated to effectively mitigate the damage caused by the textile industry.

Hooda (2025) suggests that the use of methods such as digital printing, sublimation, pigment printing, and natural dye printing drastically reduces water consumption and eliminates aggressive chemical steps. However, the use of sublimation is limited to fabrics composed of synthetic fibers, such as polyester, making the process less sustainable. Giordano (2023) highlights that replacing synthetic thickeners with natural ones facilitates post-printing removal and minimizes waste generation.

The circular economy model has been incorporated into textile production with the aim of reducing dye waste through recycling and the use of water-free dyeing techniques. By applying its principles, it is possible to enable the reuse of essential raw materials, reduce dependence on virgin resources, and mitigate the environmental impact of textile production (Islam et al., 2022).

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4 Surface Design: Strategies from Creation to Sustainability

Printing, according to Neves (2000), is the process of applying graphic patterns with the purpose of creating decorative effects that add value to textile surfaces. Surfaces define shapes and can be understood as part or the whole of an object; therefore, surface design is a field of Design dedicated to the creation of visual elements applied to object surfaces, with a particular emphasis on fabrics (Rüthschilling, 2008).

To meet all parameters and optimize the work, surface design follows principles for pattern construction. According to Briggs-Gode (2014), textile patterns are generally created through the repetition of elements across the fabric. The basis of these patterns is called the module, which can be defined as the smallest unit of the design, containing all the motifs to be repeated. For Rüthschilling (2008), a pattern is successful when the module disappears during repetition, creating a continuous visual effect.

Repetition (or rapport) refers to the placement of modules along the width and length of the surface, forming the intended pattern (Carvalho, 2021). This repetition can be structured using different repetition systems; Rüthschilling (2008) and Briggs-Gode (2014) propose two main types: aligned, or straight rapport; and non-aligned, also called half-drop or brick.

Straight rapport consists of repetition while keeping the module aligned both vertically and horizontally. The origin refers to the starting point of the visual composition, coinciding with the intersection between the grid and the module itself (Silva & Patrício, 2016). In non-aligned, or offset, rapport, the modules are shifted vertically or horizontally, which can be controlled by the designer during the creation process. The most common method for constructing this type is a 50% shift of the pattern base.

In Figure 1, it can be seen that the module, identified by the orange square, was designed to be repeated both linearly (straight), as shown in the first image, and non-linearly. In the second example, the bottom row was shifted by 50%, creating a

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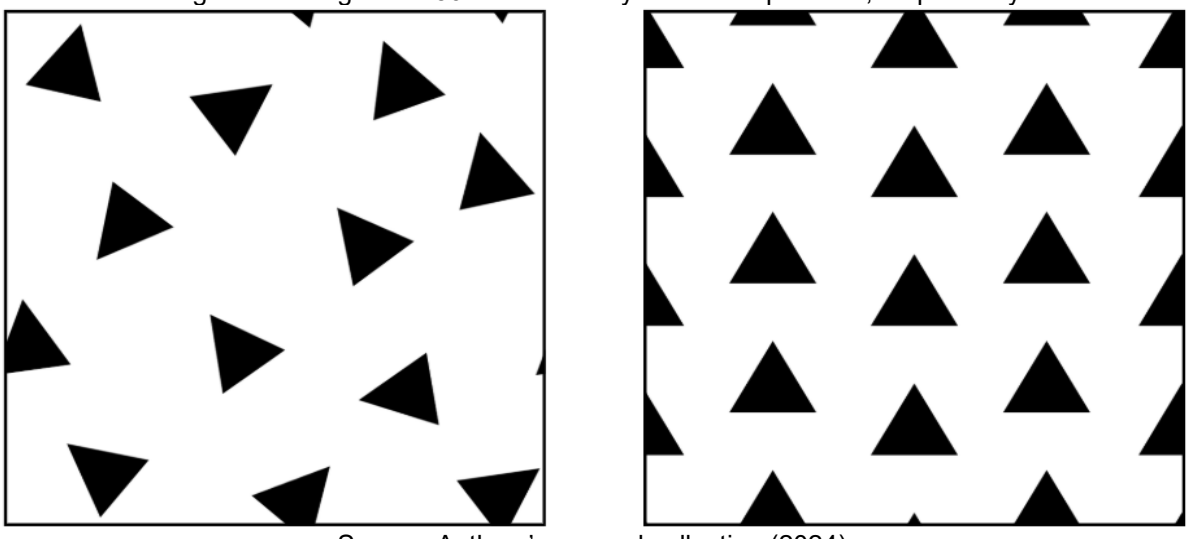
brick-like visual effect.

Figure 1: Straight and 50% Horizontally Shifted Repetitions, respectively

Source: Authors' personal collection (2021).

As the foundation of the repetition structure, the module also represents the area where the designer has the greatest creative control (Rüthschilling, 2008; Silva & Patrício, 2016). Motifs can be arranged in either a unidirectional or multidirectional manner (Figure 2). Multidirectional patterns consist of motifs rotated and positioned in multiple directions, without a defined top or bottom (Briggs-Gode, 2014).

Figure 2: Straight and 50% Horizontally Shifted Repetitions, respectively



Source: Authors' personal collection (2024).

This type of designed pattern allows for greater fabric utilization, as it enables the garment pieces to be cut in different orientations without compromising the visual integrity of the print. Unlike multidirectional modules, unidirectional patterns feature

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motifs rotated in a specific direction, conveying a sense of orientation. In this type of print, geometric and classic designs, such as stripes and plaids, are common; despite their versatility and timelessness, they can limit cutting possibilities for garment pieces, resulting in greater material waste.

According to Pezzolo (2021), woven fabrics are formed by the interlacing of two sets of yarns: the warp, arranged longitudinally and held under tension on the loom; and the weft, inserted transversely, crossing the warp in an interlaced manner. The interlacing affects the fabric's properties, such as strength, malleability, and behavior during cutting. Another important element is the bias, which corresponds to the diagonal of the fabric at a 45-degree angle between the warp and weft, and is characterized by offering greater elasticity and flexibility.

The fabric structure influences the design decisions of the surface designer, particularly regarding the composition and arrangement of motifs within the module, since in the context of printing, the pattern's directionality affects fabric utilization. Considering the environmental impacts of the textile industry, especially during the cutting and printing stages, it is important for the surface designer to make design decisions that maximize material use, optimizing fabric utilization and reducing waste (Abou-Chakra et al., 2024).

5 Discussion

The analysis of printing techniques demonstrated that rotary printing, still predominant in the market, has high water and energy consumption, as well as the generation of effluents that are difficult to treat due to the use of synthetic thickeners and non-biodegradable dyes (Hoque et al., 2024a; Giordano, 2023). Sublimation, on the other hand, eliminates water use and aggressive chemical steps, but is limited to synthetic fibers, such as polyester (Hooda, 2025), and cannot be applied to sustainable fabrics.

Digital printing, particularly when combined with water-based inks, reduces water consumption by up to 95% and energy use by 30% (Hoque et al., 2024a), while maintaining high print quality, making it the best alternative for textile surface printing in the industry, although it still depends on the development of environmentally safe

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pigments (Tkalec et al., 2022). This process is capable of printing patterns on fabrics of various compositions.

Printing with pigments and natural dyes is a low-impact alternative, as it does not require aggressive fixatives and allows for the safe disposal of effluents (Giordano, 2023); however, its adoption on an industrial scale requires improvements in color fixation and stability. The choice of printing technique should consider impact reduction throughout the product's life cycle, in order to align with the principles of sustainable design (Maciel, 2021).

Alongside the printing processes, strategies were identified that can guide conscious decisions in pattern design. The use of multidirectional compositions, for example, allows for greater fabric utilization, reducing waste during the cutting stage (Briggs-Gode, 2014). The non-aligned arrangement of modules (offset rapport) enables more versatile placements, optimizing pattern layout and minimizing leftover fabric (Rüthschilling, 2008).

The relationship between printing technique, material selection, and design decisions demonstrates that sustainability is part of an integrated vision, from the conception of the pattern (Maciel, 2021) to its printing on the textile surface. When the designer considers, at the beginning of the process, factors such as the type of rapport, motif direction, and compatibility between technique and substrate, it is possible to reduce waste and pollution (Rüthschilling, 2008; Carvalho, 2021).

The designer contributes to closing production cycles by adopting compositions that maximize fabric utilization and selecting printing methods with low water and energy consumption. In this sense, they incorporate a systemic vision aligned with the principles of reuse, regeneration, and waste reduction proposed by the circular economy (Ellen MacArthur Foundation, 2015; Santos et al., 2023).

6 Conclusion

Throughout this article, the aim was to understand how surface design can contribute to more sustainable practices in textile printing, particularly in light of the environmental impacts generated during the cutting and printing stages. The analyzed data allow us to conclude that the adoption of lower-impact printing techniques,

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combined with well-defined design strategies, is essential for aligning fashion with the principles of the circular economy (Fletcher, 2010; Ellen MacArthur Foundation, 2015). When integrated from the beginning of the design process, these strategies contribute to waste reduction and the development of sustainable products.

The analysis showed that decisions such as selecting a multidirectional rapport and choosing printing processes with lower environmental impact, such as digital printing, have the potential to reduce the textile industry's harm to the environment. Integrating these choices with conscious design planning extends the product's lifespan and allows adaptation to different textile substrates, promoting reuse and preventing premature disposal.

Educating professionals to be aware of the impact of their choices and capable of implementing innovative solutions is a crucial step toward establishing lasting change. It is recommended that future research focus on the experimental validation of the strategies identified, particularly through prototyping and pattern-fitting simulations, in order to measure actual sustainability gains. The importance of incorporating sustainable design projects into professional training is also highlighted, fostering the technical skills of designers focused on innovation and the development of environmentally responsible solutions throughout the production chain. When guided by sustainability criteria, surface design becomes a powerful tool for creating fashion that is both environmentally and socially responsible.[3]

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Supplemental material

All data required to reproduce the findings are fully available within this article.

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