Real-Time Color Palette Generation: Enhancing Design Efficiency

Sustainability in the Fashion and Design Industries

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

In the digital design industry, creating aesthetically pleasing color palettes is a vital part of ensuring customers connect with products and understand the purpose behind a design. However, this process can be extremely time-consuming, requiring a great deal of manual labor from designers to thoroughly analyze and apply the best colors, then match these colors to a brand's unique palette. Given this, it is evident that there is a need for tools that automate this process, also allowing designers to focus more on the creative aspects of design rather than technical specifications. In my Capstone project, I aim to address this challenge by developing a real-time color palette generation tool using machine learning. The tool uses a *k*-means clustering algorithm to automatically extract dominant colors from a reference image, apply them to design components, and overall simplify the workflow for designers.

To compliment this topic, my STS research focuses on the environmental and social impact of algorithms in the fashion and design industries. With such a large recent rise in fast fashion, many companies are facing pressure to adopt more eco-friendly practices to combat this mass overproduction of clothing (Claxton & Kent, 2020). In exploring this issue, I found that algorithms play a significant role in influencing material choices, production processes, and tracking consumer trends that then drive demand (Dhiwar, 2024). Overall, incorporating machine learning into the design process not only aids in creative efficiency, but can also help mitigate (or reinforce, depending on how it is implemented) non-sustainable practices.

The connection between my Capstone project and my STS research consequently lies in the ethical considerations of using deterministic algorithms to shape design practices. Although the project completed for my Capstone was shown to enhance design efficiency for the fashion industry, it is worth recognizing that this does raise questions regarding the sustainability of such processes. Through the research outlined in this paper, I aim to explore how existing algorithmic design and process tools balance this efficiency with sustainability, and what currently exists in understanding responsible innovation in digital design.

Real-Time Color Palette Generation

In the digital design industry, generating and applying aesthetically pleasing color palettes to digital products remains a challenging and time-consuming task, with limited advancements having been made in optimizing its efficiency. Real-time color palette generation poses an interesting and innovative approach to this problem by taking in a reference image and outputting a coherent palette that aligns with the designer's vision. My Capstone addresses this, aiming to make the color selection process quick and more accurate by using machine learning.

At the heart of this process is a machine learning algorithm called *k*-means clustering. Essentially, this unsupervised machine learning algorithm groups data points based on their similarities to each other. In this sense, each individual pixel within the image is its own data point, with a red, green, and blue value representing its color. The algorithm repeatedly groups points by similarity, determines the error, and regroups, until a set of "most dominant" colors are outputted. To set this up, I first standardize the image in the sRGB color space to get a consistent color reading, and then run the *k*-means algorithm. Adjusting the number of color clusters allows us to control the output number of colors, ensuring it fits whatever level of detail the designer wants in the palette.

During testing, I noticed that when designers opt for a more limited palette (i.e. only three colors) the algorithm often misses some of the subtle nuances that humans identify as significant. For example, in an image of a red brick wall with a small blue door, humans would likely identify the two most dominant colors as the red of the bricks and the blue of the door. However, the *k*-means clustering algorithm, with instructions to only create two centroids (groups), would output the two most prominent shades of red from the bricks, since the blue is such a small margin of the image. So, in my solution, I tell the algorithm to always extract 20 colors from a given reference image (creating 20 centroids) and then I narrow them down using the CIELAB color space, which is a 3D representation of RGB values more on-par with how humans identify color differences. I do this by calculating the visual "distance" between each color (ΔE) and recursively eliminating colors if they are too similar (a small ΔE). This also ensures the final palette doesn't just look accurate—it also feels balanced and well-rounded regardless of the picture supplied.

To make things even more efficient, I integrated the tool directly into a popular design software, allowing designers to pull up a reference image and use the tool without switching to a new app. They have the option to adjust the number of colors, match to seasonal palettes, and even apply colors to model components randomly or in existing patterns, giving them room to experiment with combinations they may not have thought of manually, opening a new inlet of creativity for designers.

In all, this image-to-color palette generator holds significant implications for the digital design field. Not only does it improve efficacy by reducing manual labor, but it also encourages more creative freedom by providing new and unexpected color combinations. And as digital industries continue to evolve, we have seen a trend toward integrating algorithmic processes such as this one into creative workflows. In this instance, technology is harnessed to support artistic expression without limiting individual style or humanness. By furthering research on this work, I aim to contribute to a digital design atmosphere where efficiency and creativity coexist, paving the way for future advancements in automated design tools.

Sustainability in the Fashion and Design Industries

The purpose of this research is ultimately to investigate the environmental impact of using machine learning in the digital design and fashion industries. According to researchers at ASU, the revenue from the apparel industry surpassed $1.7 trillion in the year 2023, a 13.7% year-over-year economic growth rate. While this global progress has come with increases in creativity, innovation, and has even, at times, driven social movements, it is worth noting that this growth does not come without costs. The fashion industry is one of the leading contributors in carbon dioxide emissions, petroleum consumption, and textile waste (Dhiwar, 2024). It is responsible for more than 92 million tons of waste and uses 1.5 trillion liters of water each year, with fast fashion also contributing to poor working conditions and human rights violations. Even further, the limited transparency within the fashion supply chain and the increase of clothing collections have only intensified these problems. Ma et al. (2024) provides evidence that the implementation of sustainable materials, transparent supply chains, and circular economy principles (like recycling and upcycling) leads to improvements in carbon emission reduction and environmental performance enhancements.

Given this, despite machine learning’s potential to streamline these processes and reduce waste, it also risks accelerating consumption through hyper-personalized experiences and immediate access to trends. Investigating this balance between efficiency and environmental impact is crucial to understand if machine learning-driven fashion can genuinely lead to a more sustainable future. Dhiwar (2024) illustrates how brands like Adidas and The North Face have utilized artificial intelligence to enhance customization while minimizing waste—employing software to facilitate ideation, generate patterns, and monitor trends. Furthermore, Ujjawal et al. (2024) highlights how machine learning algorithms help with eco-friendly sourcing, reducing waste, and optimize energy usage. These can help prove machine learning's dual role in the fashion industry—while it can contribute to sustainable goals, it may also be encouraging overconsumption by identifying and reproducing trends Csanák (2020).

Specifically, this problem will be analyzed by focusing on both the operational practices and social/environmental impacts. Qualitative and quantitative data will be included—which will come in the form of case studies from brands currently using machine learning to enhance sustainable practices (Dhiwar, 2024), as well as survey data from designers and fashion industry experts (Ujjawal, 2024). These will be analyzed to evaluate the extent to which machine learning innovations add to or subtract from environmental objectives. Going along with this, in collecting evidence, data will be sourced from journal articles, industry reports, and case studies documenting the environmental outcomes of machine learning implementations in fashion. The *Nike Fit* app is one such example: using AI for precise foot measurements not only led to a massive increase in customer experience, but also proved to hold large sustainability benefits since customers were no longer purchasing a surplus of sizes that would eventually go discarded (Csanák, 2020). Additionally, expert opinions, such as those collected by Hur and Cassidy (2019), will shed light on designers' opinions and barriers to sustainable practices, illustrating how machine learning might aid or hinder their ability to make eco-friendly choices.

Finally, the evidence will be interpreted by looking at the correlations between machine learning efficiency and sustainable biproducts—such as reductions in carbon emissions and non-renewable resource consumption. Comparisons across companies and machine learning applications can help provide insights into best practices and potential downsides, clarifying whether machine learning represents a genuine pathway to a more sustainable fashion industry, or is merely a new outlet of consumer-driven demand.

Conclusion

To summarize, the technical aspect of my Capstone Project is a real-time color palette generation tool developed during my summer internship at a popular sportswear company to enhance design efficiency and creativity. It uses a machine learning algorithm, *k*-means clustering, to extract dominant colors from images and automate the palette creation and application process. This tool was shown to streamline the design process, minimizing product testing and material waste, as well as decreasing time-intensive manual adjustments required by designers. My STS research paper will analyze the environmental impacts of machine learning in the fashion and design industries, exploring how technology (such as the aforementioned color palette generation tool) both enables sustainable practices but also raises new challenges, particularly in waste reduction and energy consumption.

These two crucial deliverables have the potential to address key issues within the fashion industry by promoting more eco-efficient design practices and allowing for a clearer understanding of machine learning's role in sustainability. It is my hope that the end result of these projects will not only contribute to a more sustainable atmosphere in digital design, but also encourage the fashion industry as a whole to reconsider its environmental footprint. Ultimately, the expected results include a noticeable reduction in design industry waste, as well as insights that may help the fashion world adopt machine learning responsibly and effectively—allowing the industry to make more eco-conscious decisions in the future.

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