

THE ROLE OF 3D DIGITAL TECHNOLOGY AS AN EXPLORATORY MEDIUM IN THE ZERO WASTE FASHION DESIGN PROCESS

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Abstract

The fashion industry faces significant sustainability challenges, particularly related to pre-consumer waste generated during the design and production processes. Zero waste fashion design (ZWFD) has emerged as an approach aimed at minimizing textile waste through pattern configuration; however, in manual practice, the design process is highly experimental and heavily dependent on physical prototypes. This condition often leads to high levels of iteration and the potential generation of pre-consumer waste during the design exploration stage. This study aims to examine the role of 3D digital technology as an exploratory medium within the ZWFD design process. The research employs a qualitative approach using comparative analysis, in which manual ZWFD practices are used as the analytical context, while digital exploration is conducted through the digitalization of existing designs. The findings indicate that 3D digital technology functions as a visual exploration space that enables early design reflection prior to physical realization, resulting in a shift in the role of physical prototypes from primary exploration media to final design verification. These findings suggest that integrating 3D digital technology into the ZWFD process supports a more reflective design thinking approach and offers implications for sustainable fashion design practice and education.

Keywords: zero waste fashion design, 3D digital, design experiments, physical prototype

Introduction

The fashion industry faces significant sustainability challenges. Dinny Mutiah (2023) states that the fashion industry is the second-largest contributor to waste. One form of waste generated by the fashion industry is pre-consumer waste, which includes fibers, yarns, fabrics, and garments produced during the clothing production process (Rissanen & McQuillan, 2016). Pre-consumer waste emerges during the design and production stages, particularly from pattern-cutting remnants and prototype experimentation, making the design process a crucial stage in efforts toward sustainable fashion design. This condition indicates that sustainability efforts in fashion should not focus solely on environmentally friendly materials, but should also consider the design process underlying the creation of the product.

In reducing pre-consumer waste, one approach that can be adopted is the use of the zero waste fashion design (ZWFD) method. Zero waste fashion design is a garment pattern-cutting technique that allows a maximum waste tolerance of 15% (Rissanen & McQuillan, 2016). Several studies have also demonstrated that the application of the ZWFD method can significantly reduce textile waste compared with conventional fashion design methods (Anggraini & M.Si., 2021). Thus, ZWFD is not only oriented toward the final

garment, but also positions the design process as an important component in achieving the principles of sustainability.

The ZWFD method has a design process that differs from conventional methods, as it generally does not begin with sketching. As a result, designers cannot specifically predict the final form of the garment. In practice, the ZWFD design process requires iterative and repetitive experimentation. Lei and Li (2021) also state that designers need to continuously modify patterns to achieve an optimal zero-waste garment. When such experimentation is conducted manually using physical fabric materials, the design experimentation process has the potential to generate new waste from garment prototypes that are not reused (Nursari & Nabila, 2021). This condition indicates a paradox in manual ZWFD practice, in which efforts to reduce waste in the final product may instead generate additional waste during the design exploration stage.

As digital technology continues to develop, designers can utilize 3D digital technology as an alternative medium in the fashion design process. Although there is currently no pattern-marker software specifically designed to support the ZWFD process (ElShishtawy et al., 2022), designers can utilize 3D digital technology to conduct design experiments in a virtual environment. In zero-waste practice, the use of 3D digital technology enables designers to test patterns, evaluate designs, and revise forms virtually. McQuillan (2020) demonstrates that 3D digital technology can be used in ZWFD and can contribute to establishing a design workflow based on virtual experimentation. The utilization of digital technology can also shift part of the experimentation process from physical media to virtual media, thereby contributing to the reduction of material waste during the design stage (Pasricha & Greeninger, 2018). In addition, a digital approach to ZWFD is considered capable of increasing designers' awareness of textile waste management and supporting more controlled design decision-making (Putri et al., 2024).

Therefore, this study aims to examine the role of 3D digital technology as an experimental medium in the zero waste fashion design process. The study focuses on examining how the use of 3D digital technology influences the design experimentation workflow, the characteristics of the design process, and the shifting role of physical prototypes in ZWFD practice. Accordingly, this study is expected to provide an understanding of the potential of 3D digital technology as an experimental medium for supporting a more sustainable ZWFD design process. This approach is in line with the general objectives of sustainable fashion, namely to provide design alternatives that generate better environmental and social impacts (Peleg Mizrachi & Tal, 2022).

Research Method

This study employs a qualitative approach using a descriptive method and practice-based research. This approach is used because the study focuses on the design process and design experimentation, particularly the application of 3D digital technology in zero waste fashion design (ZWFD). The study aims to understand the characteristics of the process, workflow, and role of media in the design process.

The research object focuses on the digitization process using 3D digital technology. The zero waste fashion design process examined in this study originates from an existing design that was previously developed using a manual approach. The design was subsequently transferred into a 3D digital environment for further analysis. Thus, 3D digital technology is not positioned as the starting point of the design process, but rather as an experimental medium for an existing zero waste fashion design.

As the context for analysis, this study uses documentation of the manual-based zero waste fashion design process conducted in a previous study. The data serve as the primary reference for understanding the characteristics of manual-based design and as a comparison for identifying changes that occur in the experimentation process after it is transferred to a 3D digital medium. Data were collected through analysis of the digitization process, visual documentation of the simulation results, and recording changes in garment form and construction. The data were analyzed descriptively by identifying shifts in the experimentation workflow and changes in the role of physical prototypes in the zero waste fashion design process.

Discussion

Characteristics of the Manual-Based Zero Waste Fashion Design Process

In zero waste fashion design (ZWFD) practice, this design approach generally begins directly with pattern and garment construction experimentation, as it does not involve a preliminary sketching process. Rissanen and McQuillan (2016) state that ZWFD focuses on minimizing pattern-cutting waste to below 15% as the tolerance limit for total fabric use. The garment form is developed through an experimental process that requires repeated pattern adjustments to achieve a zero-waste configuration. This understanding is reflected in the findings of this study, which indicate that the manual-based ZWFD design process is difficult to predict from the early stages of design.

In the manual approach, the physical prototype serves as the primary medium for design experimentation. Therefore, each pattern and construction modification requires the creation of a physical prototype to enable visual and structural evaluation. This dependence on physical prototypes indicates that evaluation in manual-based ZWFD design can only be conducted once the physical prototype has been completed, meaning that reflection on the garment form occurs at the final stage of the design process. An example of this can be found in the study entitled *Zero Waste and Artisanal Fashion Garment Design with Subtraction Cutting Pattern Experimentation Using the Tunnel Technique* (Ghifari, 2023).



Based on the documentation of the manual ZWFD design process used as comparative data in this study, eleven experimental garments were produced, with total fabric consumption reaching 21.8 meters. This condition demonstrates that the manual ZWFD experimentation process has the potential to generate new waste before the final zero-waste design is achieved. Nursari and Nabila (2021) emphasize that manual pattern-making has the potential to contribute to the accumulation of pre-consumer waste, not only from fabric-cutting remnants but also from prototypes that cannot be reused. These findings indicate a methodological paradox in manual-based zero waste fashion design, which aims to minimize waste in the final product, yet is not fully accompanied by a sustainable design process.

Lei and Li (2021) state that designers must repeatedly modify patterns in an effort to achieve an optimal zero-waste design. In addition to repeated design iterations, manual-based zero waste fashion design is also characterized by low levels of pattern accuracy and consistency during the design process. Small changes in pattern arrangement, cutting direction, or construction can have a significant impact on the overall structure of the garment. These changes not only affect the visual form of the garment but also alter the configuration of the available material space.



As an example of pattern inconsistency in the manual process, experimental design (a) was selected as the optimal design to proceed to the final production stage, but further adjustments were still required. These pattern adjustments affected the final garment form (b); however, the changes resulted in discomfort for the wearer, requiring further structural modifications to the garment. These structural modifications caused the final form of garment (c) to no longer represent a structure similar to that of the initial design experiment.

3D Digital Technology as a Medium for Digitization and Design Exploration in ZWFD

The methodological contradiction identified in manual zero waste fashion design (ZWFD) experimentation indicates the need for an alternative approach to the design experimentation process. The utilization of 3D digital technology can be used to bridge this issue by transferring the ZWFD experimentation process from a manual process into a 3D digital environment, where visual evaluation and design development can be conducted without direct dependence on physical materials. This approach is in line with McQuillan (2020), who positions 3D digital technology as a space for design experimentation in zero waste fashion design practice.

The findings show that through the use of 3D digital technology, designers can simulate garment forms, evaluate designs, and directly observe changes in proportions within a virtual environment. This process allows design reflection to take place at an earlier stage compared with the manual approach, as pattern and construction changes can be evaluated without first creating a physical prototype. Thus, 3D digital technology functions as a visual reflection medium that helps designers understand design outcomes before the physical production stage.



Although ElShishtawy et al. (2022) state that there is currently no pattern-marker software specifically designed to support ZWFD, the findings of this study indicate that 3D digital technology can be utilized as an alternative medium for conducting virtual exploration and evaluation of zero-waste patterns. In addition to expanding the scope of visual experimentation, the utilization of 3D digital technology also responds to the characteristics of manual-based ZWFD design, which include low pattern accuracy and consistency, a high number of iterations, and the potential generation of pre-consumer waste.



The validation results show that the garment silhouette in the 3D digital simulation corresponds to that of the physical prototype, although the two are not visually identical. These differences are influenced by the limitations of digital simulation in accurately representing material responses, resulting in technical visual deviations that remain predictable.

The findings show that, in the context of ZWFD, the use of 3D digital technology helps reduce the need for physical-prototype-based experimentation during the search for an optimal design. Iterative processes that were previously carried out through the repeated creation of physical prototypes can be transferred to digital simulation, thereby minimizing the potential generation of pre-consumer waste during the experimentation stage. As stated by Rissanen and McQuillan (2016), the zero-waste principle concerns not only the final garment but also awareness of the design process itself. Therefore, the use of 3D digital technology in this study is understood as a supporting medium for design experimentation that assists designers in finding optimal designs within the ZWFD design process.

The Shift in the Design Workflow and the Role of Physical Prototypes

The use of 3D digital technology as a medium for design experimentation brings about a change in the function of physical prototypes within the zero waste fashion design (ZWFD) process. The findings show that physical prototypes no longer serve as the primary medium for experimenting with design forms and configurations, but instead function as a final verification stage for designs that have been digitally experimented with. This shift indicates that the understanding of garment form, proportion, and construction can be developed at an earlier stage through visual simulation before physical realization.

This change in role does not eliminate the importance of physical prototypes in ZWFD practice. Physical prototypes are still required to verify fabric material characteristics, construction details, and garment drape quality, which cannot be fully represented through digital simulation. This is consistent with the perspective of Rissanen and McQuillan (2016), who argue that material experience is an integral part of fashion

design practice, particularly in the context of zero waste fashion design. Thus, in this study, the physical prototype is understood as a medium for design verification and validation rather than as the primary medium for experimentation.

This shift in the function of physical prototypes also indicates a change in the overall ZWFD design workflow. The design exploration process, which previously relied on the repeated creation of physical prototypes, can now be carried out progressively through digital media, with physical realization required only at the final stage of the design process. These findings demonstrate that the integration of digital experimentation and physical verification enables a more reflective ZWFD design process, with a clearer division of roles between the experimentation and design realization stages.

Conclusion

This study shows that the manual-based zero waste fashion design (ZWFD) process is characterized by an experimental approach that relies heavily on physical prototypes as the primary medium for understanding garment form and construction. These characteristics result in a highly iterative design process, with limitations in visual reflection during the early stages, leading to the generation of pre-consumer waste throughout the experimentation process. These findings confirm that although ZWFD is oriented toward reducing waste in the final garment, its design process still faces challenges in managing design experimentation in a sustainable manner.

The utilization of 3D digital technology in this study serves as an experimental medium for ZWFD designs. Through digital simulation and visualization, designers gain a space for visual reflection that enables the evaluation of form, proportion, and construction before physical realization. This also indicates a shift in the role of physical prototypes within the ZWFD design process. Physical prototypes no longer function as the primary medium for design experimentation, but rather as the final stage of verification and validation for designs developed through digital experimentation. This shift demonstrates that the integration of digital media and physical prototypes can establish a more structured ZWFD design workflow, with a clearer division of roles between the experimentation and realization stages. Therefore, this study provides an understanding of the role of 3D digital technology as an experimental medium in the zero waste fashion design process, as well as its implications for sustainable fashion design practices and the development of sustainability-oriented design methods.

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