https://doi.org/10.65646/3cp3es20dpp2r151

Materializing Sustainability: Exploring 3D Printing for Innovative Ready-to-Wear Garment Design

G.G.I.M. Perera
Department of Textile & Apparel Technology
The Open University of Sri Lanka
Nawala, Sri Lanka.
Ishaperera123@gmail.com

D.S. Wijerethne*
Department of Textile & Apparel Technology
The Open University of Sri Lanka
Nawala, Sri Lanka. dswij@ou.ac.lk

Abstract— **Under the concept of "4th Industrial Revolution Garments," this study explores the integration of FDM 3D-printed elements with conventional textiles for innovative ready-to-wear garments. Using Rigid Origami and the Interloped technique, the study conducted 10 material experiments with PLA, TPU, and wood-based filament, resulting in six principal designs and six garment prototypes. TPU provided greater flexibility, while PLA and wood-based filament produced more structural forms, with hinged panels explored to connect printed components while allowing movement. The findings demonstrate the feasibility of FDM 3D printing as a complementary technology in conventional garment construction and highlight the need for further research into material efficiency, durability, and environmental performance.**

Keywords: ***FDM 3D printing, Additive manufacturing, Conventional textiles, Material development.***

INTRODUCTION

The fashion industry has increasingly explored digital technologies as alternatives to conventional design and manufacturing practices. Among these, 3D printing has gained attention as a computer-controlled additive manufacturing process that produces objects layer by layer from digital models created using CAD software (Berman, 2012). Originally developed for rapid prototyping, advances in 3D printing, materials, and digital design have expanded its applications to functional components and end-use products. In fashion, the technology has been explored for accessories, footwear, garment components, surface structures, and experimental garments, offering opportunities for complex geometries, customized forms, and small-batch production (Weller et al., 2015; Michalik et al., 2015; Vanderploeg et al., 2017).

Despite these developments, the application of 3D printing to complete ready-to-wear garments remains relatively limited. Existing research has demonstrated 3D-printed garment components, accessories, textile structures, and experimental fashion concepts, while commercial applications are more established in areas such as footwear and accessories. This highlights an opportunity to investigate how digitally fabricated 3D-printed elements can be integrated with conventional textiles and garment-construction practices to support innovative ready-to-wear garment development.

A. Research Gap & Problem

Although 3D printing has gained attention in fashion design, many garment applications remain experimental or conceptual. While previous studies have demonstrated its potential to create innovative forms, textures, structures, and garment components, limited research has explored the practical integration of 3D-printed elements with conventional textiles for ready-to-wear garments.

Material selection is also important when exploring biodegradable or potentially lower-impact alternatives. However, the sustainability of 3D-printed fashion depends on factors including material composition, production processes, energy consumption, product lifespan, and end-of-life treatment. Therefore, this study addresses the limited practical exploration of combining 3D-printed elements with conventional textiles, with a focus on material and design feasibility. The study addresses the following research question: "How can 3D-printed elements be integrated with conventional textiles to develop innovative ready-to-wear garments?"

B. Significance of the study

This study explores 3D printing as a complementary digital fabrication technique that can be integrated with conventional textile and garment development practices rather than replacing traditional textile manufacturing.

Through the practice-based development of 3D-printed garment elements and their integration with conventional textiles, the study provides insights into fashion designers and researchers interested in digital

fabrication, material experimentation, and innovative

garment development. It also highlights the need for further quantitative research into the environmental implications of 3D-printed fashion products.

C. Research Aim & Objectives

The aim of this study is to explore the feasibility of integrating 3D-printed elements with conventional textiles for the development of innovative ready-to-wear garments, with consideration of material and design possibilities.

The objectives of the study are to:

1. Explore the application of 3D printing technology in ready-to-wear garment design.
2. Investigate suitable 3D-printing materials and digital fabrication approaches for garment applications.
3. Develop 3D-printed garment elements using computer-aided design and additive manufacturing techniques.
4. Investigate the integration of 3D-printed elements with conventional textile materials.
5. Develop ready-to-wear garment prototypes incorporating 3D-printed elements.
6. Examine the material and design feasibility of the developed prototypes.

I. MARKET RESEARCH & DESIGN CONCEPT

A. Market Research

The market research examined potential market segments, customer expectations, and design opportunities for developing innovative ready-to-wear garments incorporating 3D-printed elements. It identified an opportunity to extend 3D printing beyond prototypes and accessories by integrating digitally fabricated components with conventional textiles, combining textile-based wearability with three-dimensional forms and innovative construction possibilities while considering more responsible material choices.

B. Target Customer

The collection targets fashion-conscious young adults aged 30–40 who are interested in contemporary fashion, technological innovation, and sustainable design. The intended customer values individuality, distinctive visual qualities, and innovative garment construction.

The collection aims to balance innovative visual and structural elements with the practical requirements of ready-to-wear garments, including comfort, functionality, wearability, and ease of styling.

C. Customer Needs & Preferences

The research highlighted the importance of balancing aesthetic innovation with practical garment requirements. While 3D printing enables complex and unconventional forms, the resulting garments should also consider wearability, comfort, and freedom of movement. The design direction therefore focused on combining innovative three-dimensional elements with conventional textile garments while exploring alternative materials and additive manufacturing approaches.

D. Seasonal Consideration

The collection was developed for the Spring/Summer season, with seasonal considerations influencing the selection of fabrics, silhouettes, colors, garment proportions, and placement of 3D-printed elements. To maintain the practical requirements of ready-to-wear garments, the weight, scale, placement, and flexibility of the printed components were considered to minimize impacts on comfort, movement, and garment functionality.

E. Market Positioning

The collection is positioned within the contemporary ready-to-wear fashion segment, bridging conventional garment production and experimental digital fashion. Rather than focusing on highly conceptual or couture applications of 3D printing, the project explores how digitally fabricated elements can be integrated with conventional textiles while maintaining the wearability and functional characteristics expected of ready-to-wear garments. The combination of conventional textiles and 3D-printed structures creates a distinctive design identity and demonstrates how emerging manufacturing technologies can support innovative garment development and material experimentation.

F. Sustainability Considerations

Sustainability was incorporated into the market and design development by exploring alternative materials and digital manufacturing methods. Attention was given to biodegradable 3D printing materials as a potential alternative to conventional plastic based filaments. However, biodegradability alone does not make a garment fully sustainable, as factors such as material sourcing, energy consumption, durability, production methods, and end of life disposal also contribute to its environmental impact.

The integration of 3D printed elements with conventional textiles was therefore explored as a potential approach to reducing material waste and supporting more responsible garment development. Overall, the market research informed a collection that combines contemporary aesthetics, ready-to-wear functionality, digital manufacturing, and more sustainable material choices.

I. CONCEPTUAL APPROACH

"Materializing Sustainability: Exploring 3D Printing for Innovative Ready-to-Wear Garment Design" was taken as the concept, because we live in an age that is witnessing what many call as the 4th Industrial Revolution: 3D printing, more professionally called one of the most famous additive manufacturing technologies. It has the potential to move us away from an era of mass production and one-off production. And

while 3D printing will most likely influence fashion through homemade gadget-like-items that will pop up in the streets and on street style blogs, the real revolution is happening in Haute Couture as well as in Ready-To-Wear clothing & accessories (Berman, 2012; Weller et al., 2015).

A. *Inspiration for design*

"Liberty Leading the People" by Eugène Delacroix was selected as the primary inspiration for the collection for its representation of liberty, movement, progression, and collective action. The artwork was transformed through pixelation to abstract its visual elements into simplified geometric forms. These forms were then analyzed and developed through experimentation into three-dimensional components suitable for 3D printing and integration with conventional textiles. This process translated the original artwork into a contemporary digital design language while maintaining its conceptual connection to the source.

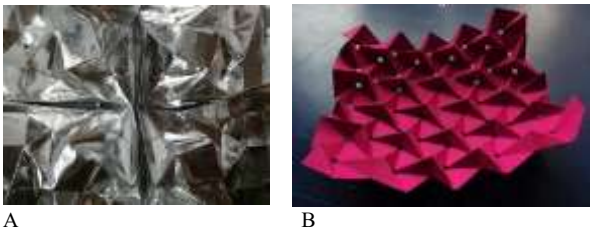


A B

Figure 1. *Conceptual Approach: A – the original inspirational reference "Liberty Leading the People", B – the pixelated image to identify shapes.*

B. *Technique for fabric surface modification*

At the initial stage of the research, 3D structures were developed manually using the Rigid Origami or paper-folding architecture technique (Figure 2). This technique uses flat rigid sheets connected through hinges to create three-dimensional folding structures. Rigid Origami provided a starting point for developing structural forms that could later be translated into digital models for 3D printing. Experimentation with folding patterns, angles, and geometric arrangements enabled different forms to be explored while considering the relationship between the rigid printed elements and the flexibility of conventional textile materials.

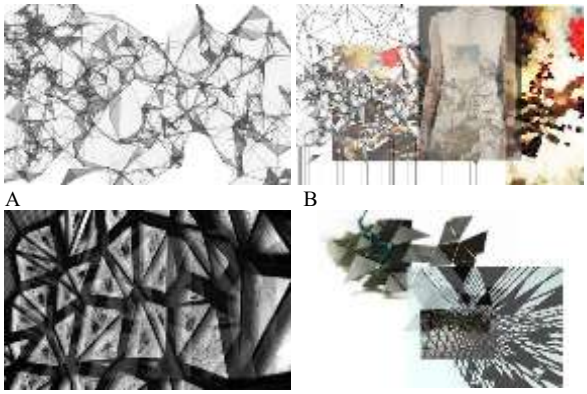


A B

Figure 2. *Paper Folding Techniques (Rigid-Origami): Branch of origami which is concerned with folding structures using flat rigid sheets joined by hinges.*

In 3D printing, these folding structures can be made by using 3D modeling software, such as Blender, Fusion 360, Solid works, etc.

C. *Concept Developments*



A B C D

Figure 3. *Concept developments: A – initial drawing of the pixelated image, B – concept development, which is digitally composed, C – digitally imposed concept development, D – handmade development.*

D. *3D Printing: An Innovation*

In recent years, the fashion industry has shown increasing interest in 3D printing technologies and digital design tools. 3D printing is considered an important component of the digital revolution, with the potential to transform conventional manufacturing processes (Marić et al., 2016). Technology has already been applied across industries including aerospace, healthcare, and design (Petrick & Simpson, 2013). Research has also highlighted its potential to support innovation in product development, design, and production by offering new approaches to product performance and growth (Michalik et al., 2015).

E. *3D Printing*

3D printing, also known as additive manufacturing, is a computer-controlled process that creates three-dimensional objects by building material layer by layer. Using computer-aided design (CAD), a digital model is created and converted into a printable format through slicing software, which generates the required build path or G-code (Sun et al., 2016). The G-code is then transferred to the 3D printer, where filament is deposited layer by layer to produce the final prototype.

F. *Transformative effects of 3D printing*

3D printing allows marvelous innovative designs or products as production is no longer constructed by physical limitations of traditional construction methods. This technology can produce any 3D model, letting products be designed according to their intended function. It allows the creation of customized items without the need for investments in set-up, tooling or machine changeovers. Finally, 3D printing enables localized production. With this technology design or manufacturing happens anywhere, without or reducing transaction costs (Berman, 2012; Weller et al., 2015; Petrick & Simpson, 2013).

G. Feasibility of the design

Thrimána 3D Printers provided technical guidance and support throughout the project, particularly on 3D printing processes and their practical application. The integration of 3D-printed materials with fabrics can be technically challenging; however, FDM printing can be applied to suitable textile surfaces using filaments such as PLA, allowing the flexibility of the fabric to be retained while incorporating printed elements into garment components.

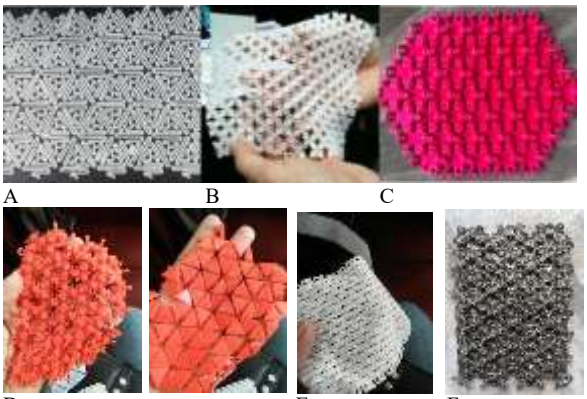
The approach can be applied to net, tulle, lace, and similar open-structured textiles, with printed elements incorporated into garment areas such as sleeves, pockets, and collars, either on fabric yardage or constructed garment sections.



A B C

Figure 4. *A, B,C - Printing Selected Fabric Samples and identifying the differences.*

Following are the tested samples with different types of filaments:



A B C D E F

Figure 5. *Sample testing using different filaments: A – TPU, B – PLA, C- ABS, D – PLA, E – PLA, F – Nylon.*

H. Limits to 3D printing

This technology, 3D printing, faces many challenges. The marginal cost is higher when compared with conventional manufacturing processes. The lack of materials is another issue and the lack of highly qualified engineers, designers and firms to promote 3D technologies.

II. RESEARCH DESIGN

A. Research Approach

This study adopted a practice-based experimental design approach to investigate the feasibility of integrating 3D-printed elements with conventional textiles for the development of innovative ready-to-wear garments. The research combined preliminary investigation, digital design development, material experimentation, 3D printing, textile integration, and garment development.

The research process was organized into three sequential stages: (1) preliminary research and topic identification, (2) design and material development, and (3) fashion product development. The outcomes of each stage informed the subsequent stage. This approach enabled the investigation to progress from the identification of relevant technologies and design possibilities to physical experimentation and the development of final garment prototypes.

B. Preliminary Research & Topic Identification

The preliminary stage established the theoretical and practical basis for experimental development. Research was conducted on the principles and applications of 3D printing in fashion, including 3D-printing processes, available materials, advantages and limitations, and existing examples of 3D-printed fashion collections.

Market and brand research was also undertaken to identify existing applications of digital fabrication in fashion and to examine emerging design directions. Attention was given to the use of geometric forms, structural elements, and digitally fabricated components in garments.

Design techniques including rigid origami, geometric modelling, computer-aided design (CAD), and additive manufacturing were investigated as potential approaches for generating three-dimensional garment elements. Alternative approaches for creating three-dimensional forms and integrating them with conventional textiles were also considered.

C. Design & Material Development

The second stage translated selected design concepts into experimental 3D-printed elements. Sources of inspiration were analyzed in terms of form, line, shape, composition, movement, and visual characteristics, and then abstracted into geometric forms suitable for digital fabrication. Their feasibility was assessed based on size, shape, material properties, flexibility, attachment methods, and compatibility with conventional textiles. Autodesk Fusion 360 was used for CAD modelling and Cura for slicing and print preparation.

The experiments were conducted using a Thrimána 3D printer and Fused Deposition Modelling (FDM), investigating PLA, TPU, and wood-based filament through 10 material tests. The tests examined flexibility, structural behaviour, appearance, and textile compatibility. TPU demonstrated greater flexibility and suitability for fabric-like applications, while PLA and wood-based filament provided greater structural definition for rigid or geometric forms. The main printing parameters were an approximately 0.3 mm layer height, 190–200°C printing temperature, 60°C heated bed, and 40–60 mm/s printing speed, using textile samples with an approximate 60 mm fabric

width. The experiments focused on practical material and design feasibility rather than comprehensive environmental assessment.

D. Integration of 3D-Printed Elements with Conventional Textiles

Following the material experiments, the selected 3D-printed structures were investigated for integration with conventional textiles. The experiments examined how the printed elements could be attached to and combined with textile surfaces while maintaining the intended visual and structural characteristics of the designs.

One of the developed approaches involved creating individual panels connected through hinge structures, allowing adjacent panels to be attached while providing movement between the components. This approach was explored as a method of combining rigid or semi-rigid 3D-printed elements with textile-based garment structures.

The experiments were used to identify suitable combinations of filament type, geometric structure, and textile integration method for subsequent garment development.

E. Fashion Product Development

The findings from the material and textile integration experiments informed the development of six principal designs, resulting in six ready-to-wear garment prototypes incorporating 3D-printed elements. The designs were selected based on observed material behaviour, structural requirements, visual qualities, technical feasibility, and compatibility with conventional textiles. TPU was used for components requiring greater flexibility, while PLA and wood-based filament were explored for more structurally defined forms.

The product development process included initial design sketches, digital development, final design selection, technical drawings, production planning, and fabrication. The resulting prototypes were examined in terms of their appearance, structural characteristics, functionality, wearability, and integration of digitally fabricated elements with conventional textile construction.

F. Technical & Recourse Support

The practical development was supported by RCS2 Technologies, which provided access to 3D-printing resources, including machinery, filament materials, and technical knowledge. This technical support enabled experimental investigation to be conducted using appropriate equipment and materials.

No formal interviews or surveys were conducted as part of the study. Therefore, the research findings presented in this study are primarily derived from the practice-based experiments, material observations, design development, and physical prototypes produced during the research process.

G. Evolution & Selection

The experimental outcomes were evaluated through practical observation and comparison of the printed materials and garment prototypes. The evaluation considered material behaviour, textile compatibility, design feasibility, visual qualities, functionality and movement, and wearability. These criteria were used to assess the suitability of different material and design combinations for garment development.

Based on the evaluation, the most suitable material and design combinations were selected for the development of the six final garment prototypes.

H. Reliability, Validity, and Limitations

As a practice-based experimental study, the findings are based on physical experimentation and observation rather than statistical generalization. The study was limited by the scale of experimentation, number of material types, and subjective nature of design evaluation, focusing primarily on the practical and design feasibility of integrating 3D-printed elements with conventional textiles. Although biodegradable or potentially lower-impact materials were investigated, no quantitative life-cycle assessment or formal environmental impact assessment was conducted.

Long-term material behaviour was observed through retained samples, with changes identified in some printed materials after extended periods; however, these observations were not based on controlled environmental testing. Future research should expand material testing and include controlled mechanical, environmental, and quantitative sustainability assessments to further evaluate the performance and environmental implications of 3D-printed garment components.

III. RESULTS

The experimental process resulted in ten material and filament tests, six principal design concepts, and six completed ready-to-wear garment prototypes. The results demonstrate the practical feasibility of combining FDM 3D-printed elements with conventional textiles and show that the properties of the selected filament influenced the form, flexibility, structural behavior, and application of the printed components.

A. Material & Filament Experimentation

Ten experimental tests were conducted using three filament categories: PLA, TPU, and wood-based filament, to examine their behaviour when combined with conventional textile surfaces and identify suitable materials for different garment applications. The experiments showed clear differences in physical behaviour among the materials. TPU demonstrated the highest flexibility, making it suitable for garment areas requiring movement, while PLA and wood-based filament provided greater structural definition for rigid, geometric, or three-dimensional components.

These findings indicate that filament selection directly influenced the design possibilities of the 3D-printed garment components. Rather than using a single material throughout the collection, different filament characteristics were selected according to the functional, structural, and visual requirements of each design. Table 1 shows the comparative observations of filament behavior:

TABLE 1: – Technical specifications of 3D-printed components used in the six garments.

Filament	Observed flexibility	Structural behaviour	Observed design suitability
PLA	Relatively low	More rigid and structurally defined	Geometric and structural components
TPU	High	Flexible and deformable	Components requiring movement and flexibility
Wood	Relatively low	More structurally defined	Form-oriented and decorative structural components

The comparison provided a basis for selecting appropriate materials during subsequent design development. The results also demonstrated that material selection should be considered together with the intended position and function of the 3D-printed component within the garment

B. Integration of the 3D Printed Elements with Conventional Textiles

The material experiments were followed by practical investigations into integrating 3D-printed elements with conventional textiles. The findings demonstrated that printed components could be incorporated into textile-based garment structures without requiring the entire garment to be 3D printed. One approach involved connecting individual printed panels using hinge structures, allowing the components to remain connected while providing movement between adjacent panels. This was particularly suitable for three-dimensional garment structures requiring flexibility and articulated movement.

The suitability of each material depended on its relationship with the textile substrate and the functional requirements of the design. TPU components were more appropriate for areas requiring movement and deformation, while PLA and wood-based components were better suited to applications requiring stronger geometric or structural effects. These findings support the use of 3D printing as a complementary technology to conventional textile construction, rather than a replacement for traditional textile materials.

C. Design Developments Findings

The findings from the material experiments were incorporated into the development of six principal garment designs. The design development process translated the experimental geometric forms into wearable garment components while considering their relationship with conventional textile structures. The selection of materials for each design was informed by the observed characteristics of the filament types. Flexible components were developed using TPU where movement was an important design requirement, while PLA and wood-based filament were considered for elements requiring greater structural definition. The experimental process therefore influenced not only the visual appearance of the designs but also the construction and positioning of the 3D-printed elements. This demonstrated that the material behaviour of the printed components was an important design consideration during the transition from digital models to physical garments.

D. Final Ready-To-Wear Prototypes

Six final garment prototypes were developed by integrating 3D-printed elements with conventional textiles. The designs incorporated geometric forms, structural panels, and articulated components, demonstrating how 3D printing can be selectively applied within conventional garment construction rather than being used to manufacture the entire garment.



Figure 6. *Final Outfits: A,B,C,D,E & F presents the completed garments alongside the 3D-printed component developed for outfit A-F. The comparison demonstrates how the digitally fabricated element was integrated with conventional textile construction to produce the final ready-to-wear prototype.*

E. Technical Development of the 3D-Printed Components

The technical development of each garment was documented through the dimensions and quantity of the individual 3D-printed panels required for garment construction. The number and dimensions of the

printed components varied according to the geometry, scale, and structural requirements of each design. The technical drawings document the dimensions of the individual panels and their arrangement within the final garment.

TABLE 2: – *Presents the technical dimensions of the 3D-printed panel developments used in each garment prototype.*

Design	Filament	Number of panels	Panel dimensions	Integration method
01	PLA	25	12.32 × 11.5 × 0.6 cm	Hinged panels
02	PLA	25	12.25 cm*12,25 cm	Hinged panels
03	TPU	45	10 cm*13 cm	Glued + textile attachment
04	WOOD	02	32" bust size	Hinged panels
05	TPU	50	10 cm*13 cm	Glued + textile attachment
06	PLA	11	6cm*6cm	Textile attachment

Design 01 - 3D Collar Fall:

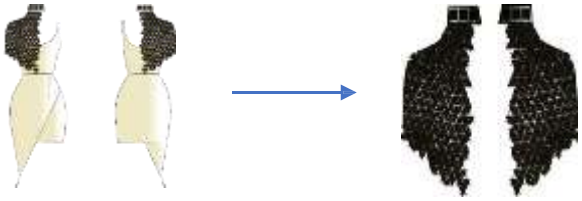


Figure 7. *Technical 2D drawings of the final garment prototypes with their corresponding 3D-printed panels*

Design 02 - 3D Hexogown:

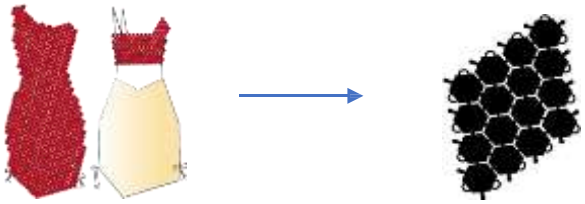


Figure 8. *Technical 2D drawings of the final garment prototypes with their corresponding 3D-printed panels.*

Design 03 – 3D Meso Top:

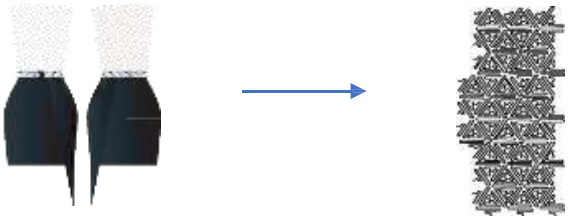


Figure 9. *Technical 2D drawings of the final garment prototypes with their corresponding 3D-printed panels.*

Design 04 – 3D B. Dress:

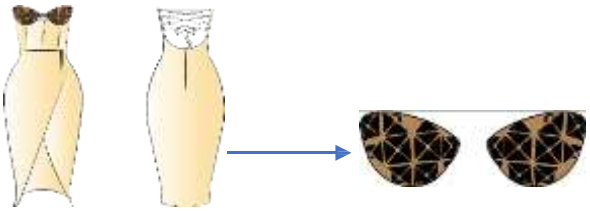


Figure 10. *Technical 2D drawings of the final garment prototypes with their corresponding 3D-printed panels.*

Design 05 – 3D Meso Jacket:



Figure 11. *Technical 2D drawings of the final garment prototypes with their corresponding 3D-printed panels.*

Design 06 – 3D One shoulder Jumper:

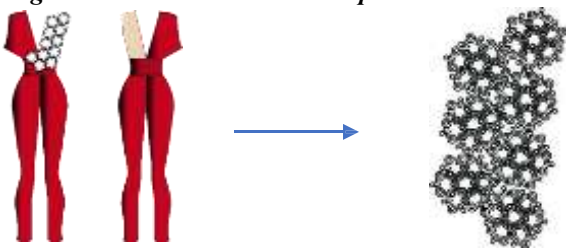


Figure 12. *Technical 2D drawings of the final garment prototypes with their corresponding 3D-printed panels.*

F. Long-Term Material Observation

Retained samples showed physical changes after several years, indicating that the investigated materials can change over time. However, no controlled biodegradation, environmental degradation, or life-cycle testing was conducted, so these observations cannot be considered evidence of biodegradability or overall environmental performance.

The retained samples highlight the need for further research into the long-term durability and degradation behaviour of 3D-printed materials used in garment applications.

G. Summary of Results

The experimental results demonstrate the technical feasibility of integrating FDM 3D printing with conventional textiles for ready-to-wear garment development. The 10 experiments showed differences in flexibility and structural behaviour among PLA, TPU, and wood-based filaments, which influenced material selection. TPU provided greater flexibility for components requiring movement, while PLA and wood-based filament produced more structurally defined forms suitable for rigid or geometric applications. The use of hinged panels also

demonstrated an approach for connecting 3D-printed components while allowing movement between elements.

These findings informed the development of six final garment prototypes, with technical drawings and measurement ranges demonstrating the translation of 3D-printed elements into garment-scale applications. The findings should be interpreted primarily as evidence of design and material feasibility, as the study did not quantitatively assess environmental impact, biodegradability, mechanical durability, or consumer acceptance. Further research should incorporate controlled material, environmental, and user or expert evaluations.

IV. DISCUSSION

A. Interpretation of the Findings

The results demonstrate the practical feasibility of combining FDM 3D-printed elements with conventional textiles for ready-to-wear garment development. The study produced 10 material and filament experiments, 6 principal designs, and 6 completed garment prototypes. Rather than replacing conventional textile construction, 3D printing was selectively used to introduce three-dimensional, geometric, and structural elements into textile-based garments.

The material experiments showed that filament selection influenced the characteristics and applications of the printed components. TPU provided greater flexibility and was more suitable for areas requiring movement, while PLA and wood-based filament produced more structurally defined forms for geometric applications. Therefore, material selection should consider not only printability but also flexibility, structural behaviour, garment position, and compatibility with the textile substrate.

B. Integration of 3D-Printed Structures with Conventional Textiles.

The main contribution of this study is the integration of digitally fabricated components with conventional textile construction. Previous applications of 3D printing in fashion have demonstrated the ability of additive manufacturing to produce complex geometries, experimental structures, accessories, footwear, and garment concepts. However, the present study focuses specifically on using 3D printing as a complementary process within textile-based garment development.

The experiments demonstrated that conventional textiles could provide the primary garment structure while 3D printing is used to create selected components that provide additional geometric or structural characteristics. This hybrid approach avoids the requirement for the entire garment to be produced using additive manufacturing.

The development of hinged panels provided one approach to integrating multiple 3D-printed components while allowing movement between adjacent elements. This was particularly relevant to the development of wearable structures because rigid or semi-rigid components need to accommodate body movement when incorporated into garments.

Therefore, the contribution of the research is not the introduction of 3D printing to fashion, which has already been widely explored, but the practice-based investigation of how 3D-printed elements can be selectively integrated with conventional textiles to develop wearable garment structures.

C. Relationship with Sustainability

The findings indicate that 3D printing may offer opportunities for more sustainable fashion practices, but this study did not quantify material waste or environmental performance. The sustainability of 3D-printed garments depends on factors such as material composition, energy use, durability, and end-of-life treatment.

Changes were observed in some retained printed samples over time; however, these were not based on controlled biodegradation testing. Therefore, the study demonstrates potential for further sustainable design exploration rather than proving environmental benefits.

D. Additive Manufacturing and Zero-Waste Potential

An additional finding relates to the relationship between additive manufacturing and zero-waste garment development. Although 3D printing is an additive process, the complete garment-development process used in this study was not entirely additive. Conventional textile components and established garment construction processes remained part of the prototypes.

Therefore, the study does not demonstrate a zero-waste garment production system. Instead, it identifies an opportunity for further research into combining additive fabrication with textile-based zero-waste pattern development and material-efficient garment construction.

Future investigation could examine the quantity of material used for individual printed components, production waste generated during printing, support-material requirements, and the relationship between digital garment geometry and material efficiency.

E. Technical Limitations & Practical Implications

The experiments revealed practical limitations arising from the different physical properties of PLA, TPU, and wood-based filament. These materials were not interchangeable, as structurally defined materials were less suitable for areas requiring flexibility and movement. Integrating 3D-printed elements with conventional textiles also requires consideration of attachment, movement, scale, and garment construction. The hinged panel approach provided one method for connecting articulated structures, while alternative attachment methods could be explored in future research.

The study was limited to 10 material experiments and 6 final garments, providing practical evidence of

feasibility but not covering the full range of materials, textile combinations, or garment applications. As controlled mechanical testing was not conducted, observations of flexibility, durability, and material behaviour should be considered practice-based observations rather than laboratory measurements.

F. Implications for Future Research

The findings provide several directions for further research. Future studies could investigate a wider range of biodegradable, recyclable, and bio-based printing materials, including their mechanical and environmental performance under controlled conditions. Quantitative comparisons between 3D-printed and conventional garment components could also examine material consumption, production energy, waste generation, durability, and end-of-life treatment, supported by life-cycle assessment (LCA). Further research could explore zero-waste integration, mass customization, digitally controlled production, wearer comfort, washing performance, and long-term durability. These investigations would provide a stronger understanding of the practical and environmental implications of integrating additive manufacturing with conventional textile garment production.

V. CONCLUSION

This study investigated the feasibility of integrating FDM 3D-printed elements with conventional textiles for innovative ready-to-wear garments. Ten experiments were conducted using PLA, TPU, and wood-based filament, leading to the development of six designs and six final garment prototypes.

The findings showed that filament properties influenced the design and application of the printed components. TPU provided greater flexibility, while PLA and wood-based filament produced more structurally defined forms. Hinged panels also demonstrated an approach for connecting 3D-printed components while allowing movement within the garment structure. The study demonstrates that 3D printing can complement conventional garment construction by integrating selected three-dimensional elements into textile-based garments.

However, the findings primarily demonstrate design and material feasibility rather than environmental superiority. Material research should investigate material efficiency, mechanical and long-term durability, energy consumption, environmental impacts, and end-of-life treatment through controlled material testing and quantitative environmental assessment.

A. Research Limitation

The study was limited to three filament categories PLA, TPU, and wood-based filament and ten material tests, limiting the generalizability of the findings. Material behaviour was evaluated through practice-based observation rather than controlled mechanical, washing, or durability testing. The study also did not include life-cycle assessment, energy analysis, waste quantification, or controlled biodegradation testing. Finally, due to time and resource constraints, the research focused on demonstrating design and material feasibility through six garment prototypes rather than large-scale production or consumer evaluation.

VI. ACKNOWLEDGMENT

I sincerely thank the Department of Textile and Apparel Technology, Faculty of Engineering Technology, The Open University of Sri Lanka, for the opportunity, guidance, support, and facilities provided throughout this research and design development process.

VII. REFERENCES

|1| Berman, B. (2012). 3-D printing: The new industrial revolution. Business Horizons, 55(2), 155–162.

|2| Marić, J., Rodhain, F., & Barlette, Y. (2016). Frugal innovations and 3D printing: Insights from the field. Journal of Innovation Economics \& Management, 21(3), 57–76.

|3| Michalik, J., Joyce, J., Barney, R., & McCune, G. (2015). 3D opportunity for product design: Additive manufacturing and the early stage. Deloitte University Press.

|4| Tao, X., & Bruniaux, P. (2013). Toward advanced three-dimensional modeling of garment prototype from draping technique. International Journal of Clothing Science and Technology, 25(4), 266–283.

|5| Vanderploeg, A., Lee, S.-E., & Mamp, M. (2017). The application of 3D printing technology in the fashion industry. International Journal of Fashion Design, Technology and Education, 10(2), 170–179.

|6| Wang, B. Z., & Chen, Y. (2014). The effect of 3D printing technology on the future fashion design and manufacturing. Applied Mechanics and Materials, 496–500, 2687–2691.

|7| Weller, C., Kleer, R., & Piller, F. T. (2015). Economic implications of 3D printing: Market structure models in light of additive manufacturing revisited. International Journal of Production Economics, 164, 43–56.

|8| Walk Free. (2023). Global slavery index 2023.

|9| TAFE Queensland. (2022).

|10| The Economist. (2012, April 21). *A third industrial revolution*.

|11| The rise of 3D printing: Opportunities for entrepreneurs: Hearing before the Committee on Small Business, House of Representatives, 113th Cong. 1 (2014). U.S. Government Publishing Office.