INTEROPERABLE IMMERSIVE FASHION

VR IDEATION TO DIGITAL PATTERN PROTOTYPES

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Abstract

This paper addresses the limited integration of virtual reality (VR) within fashion design workflows, where it is typically used for visualisation rather than creation. Through a practice-led methodology, the study develops and tests a hybrid digital workflow that connects immersive sketching in VR with technical refinement in 3D CAD (Computer Aided Design) software. By translating sculptural garment designs into flat patterns, the workflow enables a streamlined transition from early ideation to production preparation. The method was validated through cross-platform experiments and the creation of physical garments, revealing its potential to improve efficiency, reduce sampling and support more intuitive collaboration. The findings suggest VR's functionality as a real-time design tool, one that enhances spatial judgement, accelerates feedback and supports sustainable garment development. This paper contributes a scalable, practice-based model for hybrid digital fashion design that addresses current inefficiencies in design-to-production pipelines.

Keywords: *Virtual reality; Digital fashion workflows; 3D CAD; Immersive design; Garment development*

INTRODUCTION

Digital technologies are transforming the fashion industry, however it remains tied to traditional workflows. Conventionally, early design remains anchored in flat, 2D processes, while digital 3D tools can demand technical precision too early in the cycle. This misalignment slows development and limits collaboration. The fashion industry requires more agile and digitally fluent fashion practices (Karell & Niinimäki, 2020).

The potential for virtual reality (VR) as a creative design tool remains underutilised. While VR platforms such as Gravity Sketch and CAD packages like Clo3D are gaining traction, they often serve separate functions: VR for visual exploration and CAD for technical sampling.

This research explores how the fashion industry can adopt digital workflows and demonstrate a coherent design-to-production pipeline answering the following research questions:

- Can VR function as a tool for spatial garment ideation?
- What adaptations are needed to convert VR outputs into simulation-ready CAD patterns?
- How can this improve design efficiency and sustainability?

The project aims to create a scalable workflow that begins with VR sketching and ends with functional pattern outputs.

FRAGMENTED DIGITAL WORKFLOWS IN FASHION

Although digital tools are now embedded in many parts of the fashion industry, core design workflows remain fragmented. Digital sampling and visualisation tools in current workflows are persistently inefficient (Papachristou & Bilalis, 2017). Misalignment between conceptual and technical stages lead to redundancy and waste which create negative environmental impacts.

Digital garment development in the fashion industry often begins with manual 2D and 3D ideation. Often 2D digital design involves sketching via a tablet to visualise garment concepts and 3D development begins with draping sample fabrics. Translating freeform, unconstrained designs into more mature technical concepts relies on transitioning to CAD tools. The technical design is developed in CAD to produce a set of digital assets in the form of a 3D model and 2D digital patterns.

Digital fashion system challenges

Current digital workflows present several challenges that contribute to waste and inefficiency in the fashion industry. Transitioning freeform 2D designs into technical 3D CAD creates barriers within an iterative design process by demanding technical precision before creative ideas are fully resolved. These technical demands limit creative exploration and lead to inefficiencies through unnecessary sampling and revision cycles (Dumitrescu & Motta, 2022). Transitioning between digital tools also creates toolchain complexity navigating between platforms that do not share data fluently (Kumar et al., 2017). These barriers interrupt workflow and lack of integration reinforces linear design mentality despite the digital-first design environments. By contrast, integrated systems provide efficiencies through compressed development cycles and supporting the creative process by enabling earlier and faster decision-making.

In the current digital workflow, a number of sampling rounds are often required. There are several such as during pattern drafting, digital to physical discrepancies in the fabric selection, quality issues in construction.

Interoperability between digital design tools

One of the most consistent barriers to digital workflow integration is the technical incompatibility between digital design tools. Kumar et al., (2017) outline how unit misalignment, scale distortion and mesh fragmentation can create breakdowns in cross-platform workflows. In fashion design, these issues are especially disruptive, as CAD platforms rely on construction data (such as seam direction, grainlines and internal pressure points) that freeform VR models do not contain.

Most immersive design tools were initially created to facilitate artistic exploration, not the structural logic required for garment design (Dumitrescu & Motta, 2022). While they allow for fast, expressive form exploration, they lack an understanding of construction constraints. Without embedded rulesets for sewing logic or fabric behaviour, garments drawn in VR are conceptually rich but technically fragile.

VR IN FASHION

Although both VR and CAD tools exist, they are rarely used in sequence or with structured handover, creating disjointed pipelines where designers must choose between intuitive ideation and production viability (Gupta, 2024).

The use of VR in the fashion industry is predominantly for consumer experience as a communication or marketing tool (Sarakatsanos et al., 2024). Kim (2023) explores its use in immersive retail environments, where virtual spaces enhance emotional connection and brand engagement. Renault (2023) documents the rise of avatar dressing and virtual wardrobe curation across digital platforms. Similarly, (Jin et al., 2021) investigate the role of VR in virtual runway presentations, arguing that these settings support experiential storytelling. These studies position VR as a cultural interface rather than a working space for designers. The challenge is to integrate VR as a component of technical design and production workflows. Within educational contexts, VR has historically been used as an isolated visualisation tool, where immersive technologies are introduced separately from the technical systems, for interoperability more integrated teaching is required (Radianti et al., 2020; Rega et al., 2025) to align with industry 5.0 (see 1.4.1).

In creator-focused contexts, VR's offer great potential as a design environment, where form, proportion and silhouette can be explored spatially. By treating virtual space as an active design environment, real-time modelling and parametric adjustments can occur within the immersive setting (Coppens et al., 2019). However, existing studies rarely address how such immersive ideation environments can be systematically translated into CAD-based garment development, leaving a critical gap between spatial creativity and production viability.

FASHION INDUSTRY FUTURES

The future of fashion is being increasingly shaped by the convergence of digital technology and systemic sustainability, prompting a fundamental shift in how garments are designed, produced and consumed (Gupta, 2024). Across the industry, emerging technologies such as 3D simulation, artificial intelligence (AI), and VR are reshaping workflows, whilst more circular design principles and lifecycle thinking are becoming embedded in both education and production strategy (Aakko & Niinimäki, 2018). As these tools evolve, so too does the role of the designer, requiring not only technical creative skill, but the ability to navigate complex systems and ethical decision-making. This transformation signals a move from aesthetic output to an integrated, digitally fluent and environmentally responsive fashion system (Miah & Salgado, 2024)

FASHION INDUSTRY 5.0

Industrial development is commonly framed through models such as Industry 4.0 and 5.0, which help contextualise technological shifts and align practices with wider economic and societal aims. Traditional pattern cutting aligns with Industry 2.0-3.0 due to its reliance on manual tools and basic machinery, while digital fashion reflects Industry 4.0 through the use of CAD systems and simulation technologies (Grice, 2019). As immersive platforms and AI enter mainstream use, parts of the sector are now moving toward Industry 5.0, which re-centres human creativity within digital workflows (López, 2024).

Unlike the automation-driven ethos of Industry 4.0, Industry 5.0 promotes collaboration between people and machines, valuing adaptability, sustainability and personalised design (Donmezer et al., 2023).

Specifically, Industry 5.0 within a fashion context involves integrating technologies into design and production (Donmezer et al., 2023). 3D body scanning can be used to aid fit analysis and pattern cutting (Casciani & Bertolini, 2025) while digital twins enable improved digital accuracy and iterative garment evaluation across physical and virtual contexts, streamlining development timelines (Papacharalampopoulos et al., 2025). Case studies of mass customisation platforms like Future Fashion (Grosso & Boselli, 2022) demonstrate how digital platforms enable designers to adjust fit and materials in response to user inputs while maintaining control over manufacturing. It is also recognised how AI will play an increasing role is mass customisation (Nain & Samal, 2026). This collaboration between human individuality and digital systems in the fashion industry exemplifies Industry 5.0’s focus on enhancing creativity and responsiveness in an increasingly digital market.

Immersive tools such as VR and digital twins are expected to facilitate real-time decision-making without compromising creative autonomy (Donmezer et al., 2023).

From an educational standpoint, this shift calls for educational models that emphasise workflow understanding and decision-making in interconnected systems. Hartmann et al. (2023) stress the importance of hands-on learning environments that foster human-machine collaboration and improved digital literacy. Immersive tools embedded in production workflows help learners connect design intent with production strategies, reinforcing Industry 5.0 as a human-centred paradigm (Martínez-Gutiérrez et al., 2024; Rega et al., 2025; Tóth et al., 2023).

Sustainable workflows

Digital fashion provides an sustainable alternative with accurate 3D simulation reducing the need for sample rounds. Black (2012) and Nahid-Ull-Islam et al., (2025) both document how virtual prototyping can reduce waste, accelerate development, and limit dead stock. However, these studies focus primarily on substituting physical steps with digital equivalents. Transforming the workflow to an industry 5.0 model may further improve sustainability, with as much as 80% of a product's environmental impact is determined during the conceptual design stage (Karell & Niinimäki, 2020), early decision-making is critical to sustainable outcomes. However, most digital workflows still embed sustainability only at the sampling or manufacturing level.

METHODOLOGY

This pilot study adopts a practice-led research methodology conducted through design of immersive garment workflows. designer-led enquiry provides insights that are difficult to access through theory alone (Nimkulrat, 2012; Rust, 2007). This study uses direct experimentation to surface problems and test solutions to establish protocol for transferring spatial VR designs into production-ready patterns.

The study progressed through four distinct phases, based on the Lewinian experimental learning model (Kolb, 1984), to ensure the development was both technically and practically viable.

ITERATIVE EXPERIMENTS

Tool calibration focused on identifying compatibility between platforms, testing data formats and resolving early-stage interoperability issues.

Reflection focused on assessing the outcome from each experiment and making informed decisions based on findings.

Workflow refinement involved iterative testing of methods to create a structured, repeatable pipeline from VR sketching to simulation-ready patterns informed by reflection.

Physical validation assessed the accuracy and production potential of the outputs through: garment sampling measured against two representative industry quality assurance (Amrod, 2019; TFG, 2012) tolerance charts. Additionally real-time client collaboration was used to assess and evaluate the garments. These two methods ground the digital process in tangible outcomes.

DIGITAL FASHION TOOLS

Three tools were selected for their complementary roles and relevance to current or emerging industry practice:

- **Gravity Sketch (GS)**: widely adopted in 3D concept design for its intuitive spatial modelling interface, making it suitable for immersive garment sketching. Gravity Sketch offers volumetric freedom without precision.

- **Blender**: initially used for UV unwrapping and scale checking; while not yet a fashion industry standard, it is increasingly being explored by companies such as Adidas and offers accessible, open-source functionality ideal for pipeline experimentation.

- **Clo3D**: a recognised industry standard in digital garment simulation and pattern development, enabling accurate testing of fit, structure and material behaviour.

REFLEXIVITY AND RESEARCHER POSITIONALITY

This practice-led study was conducted by a designer-researcher with prior familiarity with the tools used, which may introduce bias through tool preference and tacit skill. To mitigate this, decisions were documented across Tests A–D (including unsuccessful outcomes), supported by notes recorded after each phase. Outputs were evaluated using garment measurement checks reported in the Results, and a co-viewed session with an external stakeholder (SCIMM) to broaden judgement of fit and silhouette during live iteration.

RESULTS

This section outlines the outcomes of an iterative testing process designed to evaluate the technical viability of a VR-to-CAD garment workflow.

ITERATIVE WORKFLOW EXPLORATION

A series of structured tests were conducted using Gravity Sketch (GS), Blender and Clo3D to assess interoperability and traceability.

Test A: Direct Interoperability
Geometry exported from Gravity Sketch (.FBX/.OBJ) was imported directly into Clo3D. The geometry appeared intact but failed to produce editable patterns. Mesh structures were fragmented and the files lacked seam logic, resulting in simulation failure.

Test B: UV Mapping via Blender
VR garments were passed through Blender to generate UV layouts. These were imported into Clo3D as graphic overlays and manually traced using internal lines. Pattern traceability improved, but UV distortion and scale inconsistencies were observed.

Test C: Scaffold-Based Sketching
Test C introduced skeletal scaffolding, defined here as the use of a simplified 3D garment exported from Clo3D to serve as a proportionally accurate reference within Gravity Sketch. Simplified garments were exported from Clo3D and used in Gravity Sketch as proportionally accurate scaffolds. The designer drew new VR forms around these scaffolds, which were reimported into Clo3D for manual tracing using UV mapping from test B. Alignment improved and traced shapes more closely resembled the intended fit.

Test D: Avatar-Based Tracing
VR garments designed using scaffolding for fit were imported into Clo3D as avatars. Designers traced internal lines directly over these forms using the "3D Pen (Avatar)" tool followed by the "Flatten" tool to create 2D pattern pieces (Fig. 01). The resulting patterns were editable and compatible with full simulation.

EXPERIMENTAL RESULTS

The results of the four tests are summarised in Table 01, which compares import methods, traceability, simulation support and overall technical viability.

Across tests, several recurring technical issues were observed:

- Geometry from Gravity Sketch lacked construction-aware data, preventing pattern generation in Clo3D.
- UV mapping introduced scale distortion and required advanced cleanup in Blender.
- Manual tracing remained necessary in all methods except avatar-based tracing.
- Clo3D's native avatar tool provided the most consistent results for generating editable, simulation-ready patterns.

PILOT STUDY: VR-TO-CAD WORKFLOW

This pilot study documents the development of a garment workflow connecting immersive VR sketching with CAD-based pattern generation (Fig. 02). The objective was to create a pipeline that retained the spatial creativity of VR while producing structured outputs suitable for simulation and manufacturing. Through staged experimentation, the system evolved from initial object imports to a refined, replicable method based on avatar tracing.

WORKFLOW VALIDATION

The final workflow was validated through physical construction and live client testing. Two garments created using the avatar-based tracing method were successfully printed and assembled using standard garment production techniques (Fig. 03). No additional sampling rounds were required beyond the first prototype for either garment, confirming the accuracy of the pattern logic and reducing material waste.

Client testing took place in a live session with SCIMM (Fig. 04), where the VR garment was reviewed via screen share. Edits to colour, branding and fit were requested and applied in real time. Minor adjustments were finalised in Clo3D, and no further revisions were needed. The session

Summary of workflow testing across three development phases

Test Phase	Tools Used	Import Method	Pattern Traceability	Simulation Support	Technical Viability
A: Direct Interoperability	GS + Clo3D	Object import	Poor	No	Not Viable
B: UV Workflow	GS + Blender + Clo3D	Graphic overlay + manual trace	Moderate	Yes (with errors)	Partial
C: Scaffold Based Sketching	GS + Blender + Clo3D	Graphic overlay + manual trace	Moderate	Yes	Viable
C: Avatar Trace	GS + Clo3D	Avatar import + internal trace	High	Yes	Viable & Scalable

Tab. 01

Fig. 01

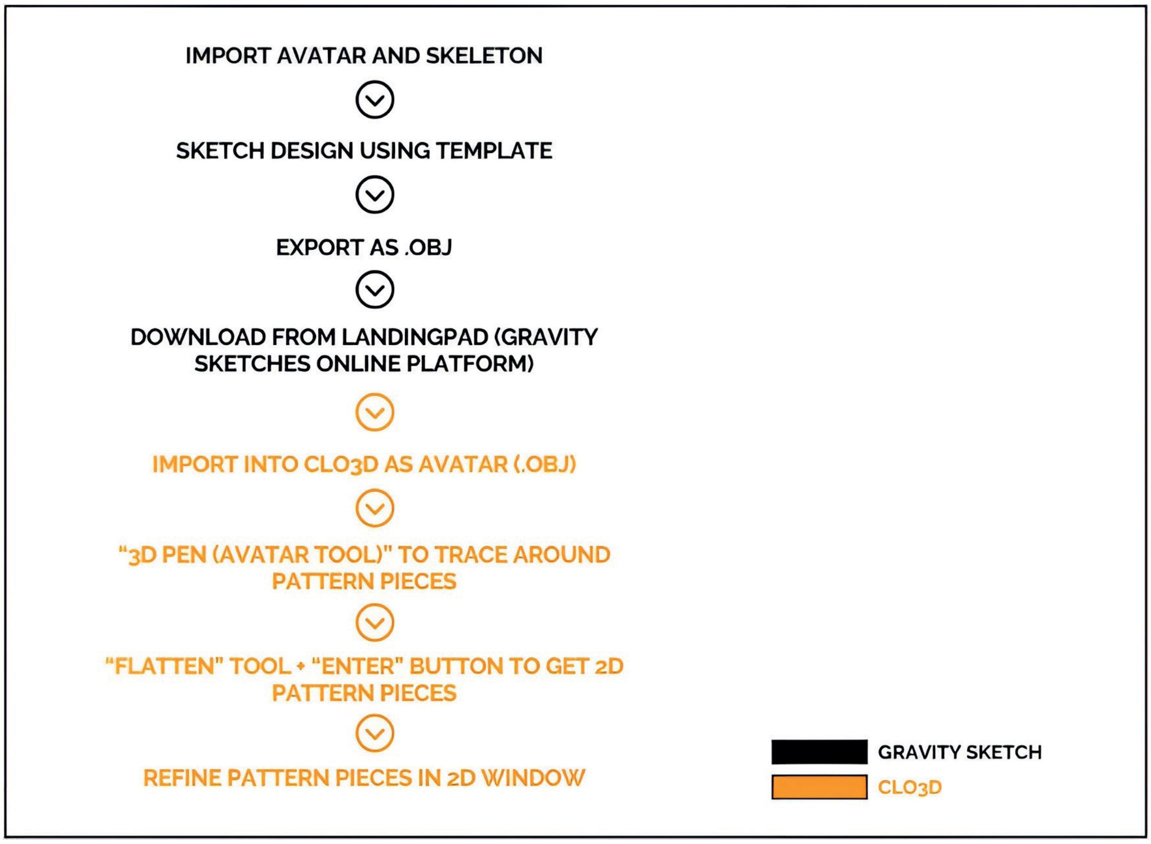
IMPORT AVATAR AND SKELETON
SKETCH DESIGN USING TEMPLATE
EXPORT AS .OBJ
DOWNLOAD FROM LANDINGPAD (GRAVITY SKETCHES ONLINE PLATFORM)
IMPORT INTO CLO3D AS AVATAR (.OBJ)
"3D PEN (AVATAR TOOL)" TO TRACE AROUND PATTERN PIECES
"FLATTEN" TOOL + "ENTER" BUTTON TO GET 2D PATTERN PIECES
REFINE PATTERN PIECES IN 2D WINDOW
GRAVITY SKETCH
CLO3D

Fig. 02


FdA Fashion 19

Fig. 03


Proportiee
Typn
Basic
Tentom
Material setting

Fig. 04

Results from tolerance test comparing digital sample vs physical outcome for garments 1 and 2

Shirt Measurement	**Nominal Digital measure** (cm)	**Tollerance** (cm)	**Garment 1**			**Garment 2**		
			Physical measure (cm)	Difference (cm)	Accept / Reject	Physical measure (cm)	Difference (cm)	Accept / Reject
Back Shoulder Length		0.5	46.1	0.3	A	46.2	0.2	A
Back Neck Rib Band	16	0.5	16.2	0.2	A	16.1	0.1	A
Full Back Length	130	1	129.7	0.3	A	130.1	0.1	A
Sleeve Length	18.3	1	18.5	0.2	A	18.3	0	A
Cuff Length (1/2)	18.5	0.5	18.5	0	A	18.2	0.3	A
Chest Circumference	46.5	1	47.2	0.3	A	46.5	0	A
Back Middle Circumference	48.2	1	48.6	0.4	A	48.3	0.1	A
Underarm To Cuff	5.8	0.5	6	0.2	A	6	0.2	A
Opening Back Under Rib	21.5	0.5	21.5	0	A	21.5	0	A
Hem	48.9	1	49.4	0.5	A	49.2	0.3	A

Tab. 02

confirmed the workflow's ability to support direct design feedback without relying on static presentations or asynchronous communication.

Whilst a virtual garment is built to a nominal size, a physical garment requires technical specifications to incorporate defined tolerances that account for material behaviour, machine variation and human execution during construction. Industry-standard tech packs for the T-shirt garment type in this study typically specify acceptable measurement deviations between ±0.5 cm and ±1 cm depending on style, fabric and construction complexity (TFG, 2012) (Tab. 02).

Sample vs physical outcome for garments 1 and 2

The measurements of the physical garments created during this workflow are shown in Table 02, all measurements are well within the specification with a maximum deviation of 0.5cm. Within this context, the constructed garment in this study demonstrate the viability of the VR-to-CAD workflow for physical sample production. In this study, the refined digital pattern outputs produced through the spatial-to-CAD workflow were assessed against predicted specification measurements and found to fall within accepted industry tolerances (Table 2). This alignment indicates that the proposed workflow supports production-ready pattern accuracy comparable to standard digital and physical sampling processes, reinforcing its reliability for technical garment development.

ANALYSIS

The results of this study demonstrate how a layered VR-to-CAD workflow can address critical inefficiencies in digital fashion development. Traditional digital workflows often rely on material-specific simulation too early in the process, limiting creative freedom and increasing sample iterations. This study presents an alternative: a pipeline that enables early spatial judgement in VR and structured refinement in CAD, maintaining creative agility while reducing waste. Rather than correcting the limitations of VR tools, the workflow embraces their strengths, using sketches as guides for pattern development. By enabling co-viewed, real-time design sessions, it also replaces asynchronous revisions with live iteration, significantly reducing feedback cycles.

REAL-TIME FEEDBACK AND COMPRESSED ITERATION

This study demonstrates that immersive workflows enable earlier and more collaborative decision-making, reducing repeated sampling and accelerating refinement cycles. Rather than relying on static sketches or asynchronous reviews, design decisions were made live as the garment was developed in VR, streamlining feedback and minimising iteration. Compared to traditional digital workflows, which separate ideation and sampling into linear steps, this approach compresses the cycle into a single collaborative session.

This efficiency has significant sustainability implications. As McFall-Johnsen, (2020) highlights, the fashion industry is responsible for immense environmental damage, contributing to high carbon emissions, material waste and water consumption. Garment overproduction has become routine, with billions of unsold items discarded annually (WRAP, 2022). While digital tools are often promoted as sustainable, they are increasingly used to speed up production rather than reduce waste (Pucker, 2024). In contrast, the immersive approach proposed here allows for earlier judgement and reduces the need for physical prototypes, offering a genuinely sustainable alternative.

At scale, this workflow could increase transparency and responsiveness across distributed teams. By reducing reliance on static decks and bridging creative and technical phases, it not only improves communication but also supports more sustainable practices. Designers shift from generating static outputs to facilitating real-time co-creation.

IMMERSIVE SPACE AS A SITE OF DESIGN JUDGEMENT

This study shows that VR can act as a practical site for structural garment evaluation, not just a space for visualisation. Designers working within immersive spaces are able to assess silhouette and proportion volumetrically, forming judgments typically reserved for later stages in CAD. Because design and judgement happened in parallel, decisions can be made earlier and with greater confidence. In contrast, conventional CAD systems require precision early on, discouraging intuitive exploration. By combining immersive sketching with later CAD refinement, this approach supports spatial judgement without sacrificing technical rigour. This hybrid mode may be particularly valuable for complex silhouettes or bespoke garments, where proportion is difficult to visualise flat.

INCLUSIVE ACCESS FOR NON-TECHNICAL STAKEHOLDERS

This study demonstrates that immersive workflows can be structured to include collaborators without technical expertise or access to specialist software. By separating authorship (designing in VR) from feedback (observing via screen share), the process enabled meaningful input from clients who might otherwise be excluded from digital design workflows.

In the SCIMM testing session, the client observed the design process via video call and provided live feedback on fit, silhouette, and branding. They did not require a headset or any direct interaction with the software. The designer made real-time adjustments in response, collapsing what is typically a multi-step review process into a single collaborative exchange. This approach removed the need for formal presentations or post-session revisions and allowed the client's perspective to shape the garment as it was being created.

This structure responds directly to accessibility critiques in the literature. Creed et al., (2024) highlight how many immersive pipelines embed high technical thresholds, excluding non-specialists from participating meaningfully. By reducing the interaction requirement to observation and verbal feedback, the workflow lowers barriers and supports co-creation across technical divides.

The broader significance lies in its adaptability. For clients with mobility or cognitive impairments, or for distributed teams working across time zones, this format reduces friction. It eliminates the need for platform onboarding or file exchange while increasing transparency and speed. In doing so, it promotes a more democratic design process, one where insight is not limited by software fluency but enabled through shared visibility and live communication.

SPATIAL-TO-PRECISION INTEGRATION

Rather than treating VR sketching and CAD pattern development as separate phases, the process demonstrates how form and function can be developed in parallel, bridging intuitive design with simulation-ready output. Tests B and C revealed that direct geometry exported from Gravity Sketch lacked the structural logic required for CAD interpretation. However, when used as an ideation tool through garment scaffolds and imported into Clo3D, the resulting silhouettes aligned closely with the avatar and could be traced into accurate, editable 2D patterns. This allowed the designer to preserve spatial intent while working within the parameters of garment construction software. Crucially, the final method did not require post-processing steps such as UV mapping or mesh repair. Instead, the tracing was done directly in Clo3D using its native tools, enabling rapid pattern creation without technical overhead. The efficiency and accessibility of this approach improved overall workflow speed while maintaining fidelity to the designer's original vision.

This finding supports Sarakatsanos et al., (2024), who note the potential for VR tools to enable meaningful garment evaluation before physical sampling. While many systems support visualisation, few offer a seamless bridge between immersive ideation and technical execution. The avatar-trace method fills this gap by creating a viable pathway from volumetric design to functional garment data. This highlights VR's potential to unify creative and technical tools. By reducing friction between stages, the method encourages early spatial design without compromising production logic. For freelancers, small teams, or educational contexts, this means a faster, more accurate route from concept to prototype, supporting cost estimation, design communication and sustainability.

LIMITATIONS AND STRUCTURAL GAPS

Gravity Sketch is a spatial modelling tool, not a garment design environment, it lacks built-in logic for drape, stretch, seams, or gravity. This limits the designer's ability to judge how a garment will behave in real-world conditions, making early-stage material decisions difficult. Yet, this absence also provides creative freedom. Without embedded constraints, designers can explore exaggerated volumes and sculptural forms unconstrained by physical limitations. In this context, VR becomes a space for ideation rather than prediction.

However, the lack of garment-aware functionality means all structural information must be reconstructed in CAD. Designers are required to interpret and translate their work between platforms, a process that adds friction and reduces scalability, especially for less technically experienced users.

These limitations reflect wider interoperability issues across fashion technology. Kumar et al., (2017) highlight how exchanging files between CAD systems can significantly alter part accuracy and compromise integrity. Until VR platforms incorporate garment logic or standardised export and import protocols are adopted, these hybrid workflows will remain partially improvised. In educational contexts, this lack of interoperability has direct implications for how digital fashion workflows are taught, as students must rely on informal workarounds rather than stable, repeatable processes, making it difficult to develop consistent technical understanding across platforms.

A final constraint lies in the perception of VR itself. It is still widely viewed as a visualisation tool, not a developmental one. This limits industry adoption and slows platform evolution. However, this study demonstrates that with the right workflow, immersive sketching can move beyond spectacle and serve as a credible stage in garment development.

KEY FINDINGS

This research demonstrates how VR enables early volumetric judgement of silhouette and proportion. The workflow moves beyond visualisation, supporting fluid early exploration and collaboration before concepts are introduced to the precision constraints of CAD. It also supports meaningful input from non-technical stakeholders through observation and live feedback, without requiring headset access.

This study proposes a novel workflow logic rather than a new tool or interface. VR is used deliberately for 3D ideation and a space to make design decisions, while CAD is used for garment logic, construction and refinement. The pipeline formalises VR sketches as scaffolds that can be interpreted and resolved downstream in CAD, creating a clear digital 3D workflow pathway from ideation to pattern production.

The study shows this approach can reduce development time by enabling key decisions to be made in real time during co-viewed VR sessions, reducing the traditional cycles of reviews and repeated sampling. It also shows that viable, editable patterns can be produced when VR sketches are processed through avatar-based tracing in Clo3D.

CONCLUSION

This pilot study has developed and tested a hybrid digital workflow that positions immersive sketching as a credible and practical tool within garment development. By connecting spatial ideation in VR with technical refinement in 3D CAD, the workflow offers a clear alternative to the fragmented processes still common across much of the fashion industry. It enables designers to move fluidly between creative exploration and production logic, producing simulation-ready outputs that are suitable for manufacturing. By reducing the number of physical sampling rounds and enabling earlier, real-time feedback, the method offers a more responsive and resource-efficient pathway that aligns closely with broader sustainability aims across fashion design and production.

The research confirms that VR can be used as a legitimate environment for spatial ideation. It allows designers to shape form, proportion and silhouette directly in scale and in volume, accelerating early decision-making compared to conventional 2D sketching and digital refinement workflows. In this context, immersive tools become more than just aesthetic platforms; they offer a practical contribution to both design speed and sampling efficiency. Through physical prototyping and real-time industry testing, it demonstrated its functionality across educational and commercial contexts.

The framework developed is deliberately modular and adaptable. While it requires a base level of technical fluency and access to specific platforms, it reduces process complexity by using in-platform features and avoids additional technical steps such as UV mapping, preserving creative freedom during early-stage design. Through structured testing, the workflow was refined into a clear and repeatable process, avatar-based tracing within Clo3D, that effectively bridges expressive VR sketching with the pattern logic needed for 3D garment construction.

The workflow created during this research depends on the designer's garment-making knowledge and digital literacy to successfully translate immersive design intent into viable pattern data. To educate designers in these industry 5.0 skills, they require expertise in technical skills, reinforcing the role of embodied knowledge in digitally mediated fashion practice. Taken together, the findings suggest a need for a pedagogical shift from teaching immersive technologies as isolated digital skills towards cultivating workflow fluency. Aligning with Industry 5.0, designers should be trained on continuity, translation and decision-making across connected design workflows.

FURTHER WORK

In the future, this workflow could inform the development of garment-aware VR platforms that embed construction logic directly into spatial modelling environments, reducing the need for manual reconstruction in CAD software's. As demand grows for more sustainable, collaborative and agile design systems, industry adoption of immersive workflows like this could become part of standard digital practice. Ultimately, the framework offers a foundation for building infrastructure that links creativity and construction within a single, adaptable pipeline.

CAPTIONS

[Fig. 01] 3D Avatar Pen Tool and results in Clo3D.

[Fig. 02] Novel VR to CAD Digital fashion 5.0 workflow.

[Fig. 03] Worlds first VR created garments made physically through VR-to-CAD workflow.

[Fig. 04] Screenshot from live session with SCIMM exploring colour wheel in Gravity Sketch for pocket colour.

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