

Adopting 3D Body Scanning in Customized Apparel Design: Cultural, Technical, and Perceptual Barriers of Fashion Designers, Pattern Makers, and Final Users

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Abstract

This study examines the technical, operational, and socio-cultural aspects of 3D body scanning, investigating consumer perceptions and the experiences of fashion operators in integrating 3D body scanning into digital fashion workflows. A mixed-methods approach was adopted, with approximately twenty-three participants completing surveys before and after scanning sessions using the We Wear (Prisma Tech) cabin, assessing their emotional responses, trust, and usability. In parallel, eight fashion operators, including designers and patternmakers, participated in semi-structured interviews to examine digital measurement extraction, avatar generation, digital-to-analog conversion, and parametric pattern making. Consumers reported that the 3D body scanning experience was generally positive, describing it as fast, intuitive, and non-invasive, with increased confidence in its ease of use after the session. However, some concerns remained about body image discomfort and the perceived loss of a fashion craftsmanship touch. Fashion operators valued body scanning for enhancing fit, reducing waste, and enabling visualization and pre-prototyping; however, they noted challenges, including measurement and landmarking inconsistencies, misalignment with manual methods, mesh quality issues in converting digital avatars, and limited software interoperability. This highlights the need for streamlined digital processes and more effective training. A revised workflow framework is proposed to bridge gaps between analog and digital practices across fashion design workflows.

1. Introduction

3D body scanning technologies could become central to the advancement of mass personalization in fashion [1, 2], providing a promising foundation for the development of custom-fitted garments using available digital tools [3, 4, 5]. These systems are known to enable the capture of a broader and more precise set of anthropometric data than traditional manual measurement acquisition, thereby facilitating the creation of garments tailored to an individual's unique shape and proportions [6, 7]. This approach not only enhances fit and comfort but also increases user satisfaction and garment longevity, contributing to sustainability by reducing overproduction and waste associated with ready-to-wear models. As highlighted by [5, 8], scanatars, such as digital avatars derived from scan data, can be directly linked with parametric garment design software, enabling rapid prototyping and virtual fitting of personalized garments without the need for physical samples.

Recent advancements have integrated 3D scanning with AI and machine learning to automate measurement extraction and predict fit preferences [9], while mobile scanning platforms are increasingly democratizing access, albeit with limitations in accuracy and environmental control [10]. Despite the technology's maturity, its adoption in mass customization for fashion remains limited due to both operational and technical integration challenges, as well as socio-cultural barriers faced by fashion operators. The latest refers to the set of culturally embedded beliefs, values, and practices within fashion ecosystems that hinder the integration of Industry 4.0 tools. They include a deep-rooted resistance to change, fear of job displacement and loss of artisanal identity due to automation, skepticism toward the perceived quality and authenticity of digitally mediated production, and a pronounced generational and knowledge digital divide [11]. Unlike [12], who emphasize system capabilities, emerging studies increasingly consider users' perceptions and behavioral responses to scanning technologies. Understanding how individuals interact with these systems and how such interaction reshapes their expectations, self-perception, and purchasing behavior is crucial for unlocking the full potential of body scanning in consumer-centric design. As such, 3D scanning is not just a technical enabler but a socio-technological interface with transformative potential for fashion design, production, and consumption.

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This exploratory study investigates the adoption of 3D body scanning technologies within the fashion industry. While such tools are increasingly available and could be integrated into digital fashion workflows, significant gaps remain regarding their technical accuracy, user experience, and compatibility with existing fashion design and production practices. By examining the perceptual dimension, this research aims to assess user expectations, emotional responses, and potential barriers to consumer acceptance of body scanning in the context of fashion mass personalization. At the same time, it considers the operational challenges faced by professionals in translating scan data into digital avatars, patterns, and virtual prototypes. The study provides insight into the socio-cultural readiness of the fashion industry, offering an understanding of the opportunities and limitations of 3D body scanning to support improved fit, pre-production visualization, and scalable digital transitions across design, prototyping, and production phases.

2. State of the Art

2.1. 3D body scanning for fashion mass personalization

Fashion Mass Personalization could be supported through the integration of advanced digital technologies and user-centered design approaches in the fashion industry, with the goal of creating garments tailored to the individual needs, preferences, and body dimensions of consumers at scale. It lies at the intersection of industrial efficiency and custom-fit uniqueness, enabled by innovations such as 3D body scanning, parametric pattern-making, and AI-driven systems. Recent literature underscores how digital transformation in fashion has made personalization technically feasible and increasingly desirable. 3D body scanning technologies enable the capture of detailed anthropometric data, allowing brands to generate clothing patterns tailored to individual body shapes, thereby improving fit and comfort [5,6]. [2] further define mass personalization as the strategic evolution of mass customization, in which product variants are automatically tailored via configurators or co-design platforms to suit user preferences, without disrupting the economics of scale. The distinction lies in the use of body data, user behavior, style preferences, and purchase histories integrated through AI and machine learning algorithms to generate highly customized offerings. As [1] points out in a review of digital fashion practices, mass personalization is now increasingly embedded in user experience design, where digital avatars, virtual try-ons, and recommendation systems contribute to seamless co-design processes between consumer and brand. Yet, cultural, operational, and technological challenges [11] still hinder wide adoption, despite its potential to reduce overproduction, improve resource efficiency in the industry, and enhance body inclusivity in fashion garment design and production.

2.2. 3D body scanning and parametric pattern-making technological readiness level

In the apparel sector, emerging 3D body scanning technologies include cabin-based or portable 3D body scanners, as well as smartphone-based applications [13]. The first category enables the affordable capture of high-resolution surface data, still facing limitations in measurement accuracy and consistency, often failing to meet ISO standards for anthropometric precision [14,15,16,17,18,19]. Studies comparing handheld scanners show acceptable accuracy at easily identifiable landmarks but less reliability in complex body regions [20,4]. Smartphone-based HBDTs represent the latest evolution in body scanning, exploiting integrated LiDAR sensors, computer vision, and deep learning to estimate body measurements from 2D images or 3D reconstructions [10]. These mobile applications enable real-time, user-friendly scanning and avatar generation. Despite their accessibility, challenges remain regarding landmark detection accuracy, background interference, and body diversity representation [21]. Measurement deviations (20–30 mm) from benchmark data raise concerns for made-to-measure fashion [22]. Recent research is advancing the integration of autoencoders, GANs, and 3D recurrent neural networks to enhance scanning accuracy and shape estimation [23, 24, 25]. However, limitations in training data diversity and computational constraints on mobile platforms continue to restrict generalizability and real-time performance [26]. In custom garment design and patternmaking applications, these tools continue to struggle to consistently achieve accurate fits, underscoring the need for further research and development in both technology and user education [27]. The literature confirms that while 3D body scanning has matured technically, its operational and organizational integration into fashion design and production workflows remains underdeveloped [28,29].

Traditional pattern-making techniques remain prevalent in both education and professional practice, and are largely paper-based or sketch-driven in CAD. They have been criticized for inefficiency and their inability to support customization and sustainable innovation [5,32]. These methods result in static

patterns that consume considerable time and resources for creation, alteration, and correction since they rely on trial-and-error processes. By contrast, parametric sewing pattern-making connects outputs (digital drawings) with variable inputs, such as body measurements, ease allowances, style/design alterations, and preferences, thereby generating adaptable and reusable patterns that can be automatically adjusted through software [4]. This approach could reduce material and energy waste but also enhance precision, fit, and design flexibility. Despite these advantages and several attempts to integrate digital parametric workflows into CAD systems for fashion pattern-making [4, 31, 32], their adoption remains limited due to persistent reliance on traditional pedagogy and practice, accompanied by the lack of shared theoretical, conceptual, and technical frameworks and educational methodologies to be tested by fashion operators [30].

2.3. Perception about technologies for body scanning from users

To study consumers' acceptance of scanning technologies, various paradigms and models have been employed in the literature over the years. One of the most popular models is the Technology Acceptance Model (TAM), which was theorized in the 1990s by Davis, resulting from the integration of previous research from various fields, including Human-Computer Interaction, Management Information Systems, and laboratory research [33]. The theory was initially applied to test consumers' intention to adopt information technologies (such as text editing or calculation software), but it has since been applied to many other technologies. According to the TAM, individuals' intention to use a new technology is predicted by their beliefs and attitudes toward the system. In turn, attitudes are predicted by the perceived usefulness of the system and its ease of use, which are also correlated with each other. Davis defined perceived usefulness as the extent to which the new technology helps consumers perform a specific task. Nevertheless, even if the consumer finds the technology useful, they may not use it if the costs associated with it are too high (in terms of ease of use, complexity and effort).

The theory has been extended with various modifications, and one of the revised versions also included the construct of enjoyment [34]. They found that people's intentions to use the program were strongly influenced by their perceptions of how useful and enjoyable it was. When individuals engage with a new technology, perceiving the experience as enjoyable, in addition to useful and functional, enhances their willingness to use it again. This appears to be important for fashion consumers as well, whose choices to shop online or in traditional stores often depend not only on practical reasons (e.g., making the best purchase decision) but also on hedonic motivations related to the enjoyment of the shopping experience [35]. Some companies are indeed beginning to provide consumers with visualization technologies, such as body scanners or virtual try-on tools, which could reduce the risk of returns (and the consequent environmental impact) while also offering novelty and entertainment [36].

Several studies have explored consumers' attitudes toward these technologies to understand whether they would be willing to use and integrate them into their shopping habits. For example, in an exploratory study [37] asked consumers to rate the Me-Ality 3D body scanner used in shopping malls. Results showed that the perceived ease of use was very positive: 94.2% judged the scanning process as clear and understandable, and 82.4% said it was also very easy to use. In 2011, [38] investigated young people's attitudes toward body scanners in Saudi Arabia and found that 94.3% of consumers were very interested in using 3D body scanners to obtain accurate measurements and simplify the shopping process. .

A recent study by [39] identified trust and satisfaction with 3D body scanning technology as fundamental predictors of their intention to use it. The authors further explain that for consumers to be willing to adopt these technologies in their consumption practices, it is important that the user experience aligns with the consumers' expectations. Trust and satisfaction are particularly salient in this context, as these technologies entail structural features that may cause resistance to adoption among consumers. Specifically, these technologies use image modeling and can create privacy concerns, since they process both shared body images and a large amount of body measurement data generated through 3D modeling [40]

In addition, another potential barrier to adoption stems from the exposure of individuals to highly detailed pictures of their bodies, which may lead to negative psychological outcomes, such as body dissatisfaction. For instance, [41] found that the majority of the participants experienced some negative reactions, such as stress or frustration, after the scanning experience. Consequently, as argued by [39], trust in the technology is insufficient alone; it is essential to investigate and enhance both the reliability of the technology and the consumers' overall satisfaction with its use.

3. Methodology

3.1. Research aim from research gaps

The study employs a mixed-methods approach, incorporating both fashion consumer and industry perspectives. Data were collected between May and July 2025 at the Circular Fashion-Tech Lab, located within the Department of Design at the Politecnico di Milano. On the professional side, the study addresses a lack of empirical research into how fashion operators, particularly fashion designers and pattern makers, engage with digital measurement and fashion digital design workflows. On the consumer side, the study examines user expectations, affective reactions, and potential barriers to consumer acceptance of body scanning technologies in the context of fashion personalization. Together, these research strands aim to evaluate the socio-cultural readiness of integrating 3D body scanning and parametric design into the fashion design, prototyping, and production workflow, thereby contributing to a more comprehensive understanding of its applicability in fashion mass customization.

3.2. Participants and research protocols for fashion operators

Participants

This study involved eight participants ($n = 8$) working in the fashion industry, specifically professionals with expertise in fashion design, pattern making, and digital garment development. They were identified through professional networks and selected to ensure diversity in both role and digital expertise, reflecting the evolving technological landscape of the apparel industry. They encompass complementary expertise across the fashion design and production pipeline, representing both creative and technical roles. Pure fashion designers ($n = 2$) present expertise in conceptual design, garment development, and creative direction, while pure pattern makers ($n = 3$) were specialized in translating design concepts into technical patterns, including one participant integrating tailoring skills, specifically focused on garment assembly and finishing, overlapping with pattern-making expertise. One participant combines both expertise. Additionally, there was one fashion product developer ($n = 1$) responsible for coordinating design, technical specifications, and production workflows, as well as two laboratory technicians ($n = 2$) specialized in knitwear technologies and tailored garment construction. Besides, two participants have been working extensively with parametric pattern design ($n = 2$).

Materials and procedure

The research was conducted using semi-structured interviews, designed to elicit both descriptive and reflective insights into participants' experiences and perceptions regarding human body digital twin technologies (HBDTs). Their experience with measurement extraction, scanatar generation, scanatar conversion, and parametric pattern-making was assessed in the context of designing made-to-measure garments through digital technologies. Interviews were conducted either in person or online, depending on participant availability and geographical location. The average duration of each session was between 45 to 60 minutes. The interview protocol was developed to assess familiarity with 3D body scanning hardware (e.g. We Wear by Prisma Tech), their experience and/or perception with measurement definition, extraction tools and methods, the view and use of scanatars in garment visualization and fitting software (e.g. CLO3D), the engagement with parametric pattern-making software (e.g. Seamly2D), while finally reflecting on perceived benefits and limitations of digital tools for made-to-measure fashion production. The semi-structured interview included sections on professional background, use of digital tools, design workflows, perceived barriers to adoption, and future outlooks. Questions were open-ended and aimed to capture both workflow-specific practices and attitudinal dimensions, such as digital literacy, tool reliability, and integration into existing production pipelines. Responses were coded thematically to identify patterns across participants' experiences, challenges, and expectations regarding the use of HBDTs in fashion workflows related to personalization. The research protocol adhered to ethical standards, ensuring participant anonymity, informed consent, and the voluntary nature of participation.

3.3. Participants and research protocols for consumers

Participants

Participants were recruited on a voluntary basis from students and collaborators of Politecnico di Milano, as well as acquaintances of the researchers, using a snowball sampling method. 23 subjects participated in the pre-scanning survey (47.8% female; Mage = 31.28 ± 10.82 , ranging from 22 to 58) and 22 in the post-scanning survey. Some participants completed the pre-scanning survey but not the post-scanning survey. For the analyses, we used all the information provided in the surveys, even though not every participant completed all sections of the pre- and post-scanning surveys.

Materials and procedure

Participants completed two online surveys implemented on Qualtrics, one before the scanning experience and one after. They were involved in five scanning sessions using the 3D body scanning cabin (We-wear by Prisma Tech) to assess system consistency, aligning with evaluation methods by [15]. Manual measurements were also used to compare and validate the accuracy of digital data (these measurements are not discussed in this paper). In the pre-scanning survey, after the informed consent form, participants were presented with an open-ended question about their general expectations of the scanning experience. Subsequently, they had to report their expectations about three phases of the scanning process: the preparation phase, the scanning process, and the manual measurement phase. For each phase, they rated adjectives (slow, embarrassing, complex, easy, intuitive, precise) on a scale from 1 to 5. The list of adjectives varied slightly depending on the phase. Afterwards, participants rated their expectations regarding the accuracy of the avatar's face and physical appearance on a scale from 1 to 5. Next, they indicated the extent to which they were experiencing a list of emotions before starting the scanning experience (interested, excited, fearful, hostile, enthusiastic, alert, confused, inspired, worried, attentive, nervous, active, scared). Finally, they were asked to complete the Attitudes Toward General Technology Scale [42] and answer some questions regarding their interest in the field of fashion personalization, their intention to purchase made-to-measure clothing, and their previous experience with fashion personalization. At the end of the questionnaire, participants reported demographic information regarding their age, gender, education, and income. After the scanning experience, participants were shown their digital avatar on a screen, without being informed about its specific body measurements. In the post-scanning survey, after the informed consent form, participants were presented with a similar set of questions to those in the first survey, assessing the preparation phase, scanning experience, precision of the avatar, and their feelings during the experiment. However, in this case, participants were asked to make a retrospective assessment, while in the pre-test, they were evaluating their expectations. Unlike the pre-scanning survey, this questionnaire also included a question about their intentions to use the body scanner in the future. Lastly, participants were asked to answer three open-ended questions, each requiring a minimum of 30 words, regarding their overall experience with the body scanner, the pros and cons of the experience, and aspects of the scanning process that could be improved.

4. Results and findings

4.1. The perspective of fashion operators

Background and expertise

The group of participants involved in the study reflects a diverse range of professional backgrounds and expertise within the fashion industry, spanning creative, technical, and educational domains. Their roles encompassed fashion design, pattern making, tailoring, product development, and technical expertise in knitwear and tailoring, thereby covering the key stages of the fashion production pipeline. In terms of experience, the participants ranged from emerging professionals (0–3 years) to senior experts with more than 15 years in the field, allowing for a cross-generational perspective on design practices, digital workflows, and production methodologies (Table 1).

Table 1 – Participants' background and working experience in the fashion industry

Role(s)	Years of Experience	Company Type	Market Segment(s)
Fashion designer	4–7	R&D	Smart sportswear
Fashion designer	0–3	Not working yet	–
Pattern maker	15+	Freelance / Consultancy	Haute couture, ready-to-wear
Fashion designer/ pattern maker	8–15	Medium-sized company	Sportswear, technical garments
Pattern maker, tailor	8–15	Large-scale company	Haute couture, luxury, high RTW
Product developer	0–3	Large-scale company	Ready-to-wear
Knitwear & tailoring technician	8–15	University	Design education
Cut&Sew tailoring technician	4–7	University	Design education

Early-career participants were represented by a recent graduate of fashion design and a young product developer in a large-scale ready-to-wear brand, highlighting the perspectives of younger professionals entering the industry. Mid-career professionals (4–15 years of experience) included a couple of fashion designers/pattern makers in a medium-sized company focused on sportswear and technical garments, a pattern maker/tailor working in haute couture and luxury segments within a large-scale corporation, and two tailoring technicians engaged in design education within a university context. Senior expertise

(15+ years) was represented by a freelance pattern maker with consultancy activities spanning haute couture and ready-to-wear. The participants' market segments ranged from haute couture and luxury to ready-to-wear and sportswear / technical garments, as well as design education in academia.

Current use, familiarity, and expectations from 3D body scanning technologies

Participants demonstrated a heterogeneous level of familiarity with 3D body scanning technologies, ranging from direct hands-on experience in research and academic contexts to little or no integration within professional workflows. Early-career designers reported initial but growing exposure to 3D modeling, parametric pattern-making, and 3D body scanning, primarily through academic or research projects. Conversely, experienced pattern makers and technicians noted that they used such tools infrequently, with concerns also centered on the skills required to incorporate these tools into their usual practices. Hybrid participants described their use of scanning as applied to pattern making or prototyping, but it had not yet been established as a routine practice. Across all groups, the technology was widely recognized as promising, although it had not yet been fully integrated into their own practices. Differences also emerged in the perceptions of 3D body scanning among various roles within the fashion industry. Fashion designers primarily focused their expectations on creativity, conceptualization, and product development, expressing a strong interest in how body scanning could influence design prototyping and personalization. Pattern makers, by contrast, emphasized issues of precision, fit, and measurement accuracy, often articulating skepticism about the readiness of current scanning tools for reliable integration into their workflows. Hybrid professionals, who combine design and technical expertise, consistently emphasize the importance of collaboration between creative and technical domains to maximize the value of scanning technologies.

Experienced/perceived advantages and challenges of 3D body scanning

Operational advantages were frequently highlighted, albeit from different perspectives: fashion designers valued the technology's potential for early/fast prototyping, aiming to achieve time savings; pattern makers focused on its potential to streamline measurement-taking and reduce errors in custom tailoring; hybrid professionals emphasized the role of scanning in enabling integration of body data into digital workflows, smoothing design and production phases. Economic benefits were most often associated with improved efficiency. Fashion designers stressed the prospect of cost savings through reduced physical prototyping, whereas pattern makers linked the technology to greater efficiency within made-to-measure production processes. Social and cultural benefits were also acknowledged: several participants regarded scanning as a means of supporting diversity in body representation and fostering inclusive sizing, with early-career designers highlighting the potential for engaging consumers more directly through the use of personalized avatars. Despite these advantages, participants expressed a range of technical, practical, and systemic concerns related to integrating 3D body scanning into the fashion design workflow. Technical integration was frequently described as poor/inconsistent across existing fashion-related tools, particularly in CAD and pattern-making software. Challenges were noted in the back-end data management and in the complex workflow to convert raw scan data into industry-ready files, such as 2D sewing patterns. Scan data often requires reformatting before it becomes compatible with pattern-making software, noting that this not only complicates the workflow but also limits the efficiency gains that scanning technologies could otherwise provide. Measurement discrepancies between digital and traditional manual methods further increased workflow complexity. In relation to parametric pattern-making practices, fashion designers who have practiced with Seamly2D described initial difficulties in drawing patterns compared with the traditional ones, thus requiring practice and a change in mindset. They raised questions about whether scanning could be seamlessly integrated into creative processes and highlighted the inadequacy of avatars generated by the scanning systems, which were *"not suitable for working in CLO3D"*, thus requiring adjustments and further study for better results. Measurement accuracy emerged as a significant concern among experienced pattern makers with no experience in 3D body scanning, as they attributed technical immaturity to current scanning systems. Some economic barriers were finally raised due to the perceived high costs of the equipment (both hardware and software).

Design applications and process implications

Participants identified a range of garment typologies and user needs where 3D body scanning technologies could have the most significant impact, with a recurring emphasis on contexts that require precision in fit *"such as underwear, and tailored clothing,"* while also highlighting their importance for *"users with non-standard body types or specific functional needs, such as people with disabilities, elderly users, or gender non-conforming people."* Sportswear and technical garments were frequently mentioned, focusing on *"daily sports, high performance sports, [and] extreme sport... or other technical*

clothing areas outside the fashion system” and emphasizing their value for “competitive sportspeople... as much as all the fields where precision is important (science, space).” Beyond performance-oriented apparel, other perspectives included the potential use for “ceremony dresses and formalwear” or even “streetwear and urban wear, where a good fit is important but the garments are not too tight.” Still, some expressed reservations about its suitability for highly elastic garments, which could limit the direct usefulness of scan data in those contexts. Additionally, in luxury and haute couture contexts, the customer experience of in-person interaction with tailors and sales staff was emphasized as a core value, rendering digital approaches less attractive due to their perceived impersonality

Participants also reflected on the potential implications for the broader design process, expressing a variety of perspectives on where 3D body scanning fits within the fashion design workflow and what problems arise when moving from scanning to parametric pattern implementation. A recurring theme among fashion designers was that body scanning is *“most useful in the early design and prototyping phase”*, particularly for capturing accurate measurements quickly and creating more precise garment patterns. One fashion designer extended the usefulness of scanning beyond design and prototyping, suggesting potential in *“the retail phase, showing to the customer all the possibilities and fitting of the garments they’re looking at and guiding them through the most correct purchase.”* Hybrid professionals envisioned new forms of cross-disciplinary collaboration, in which creative innovation and technical precision could converge around shared access to body data.

Future prospects of the application of 3D body scanning in the fashion industry

Participants described several conditions that should be met for 3D body scanning technologies, as well as parametric pattern design, to fully implement mass personalization in the fashion industry. The first technology-related issue was identified in the broken collaboration between technology providers and fashion practitioners, highlighting a lack of mutual understanding and insufficient alignment between tools and real-world needs. This disconnect often results in digital tools that fail to adequately support garment production processes. Therefore, they presented recurring demands for *“better integration between scanning tools, pattern software, and production”*, *“clear guidelines to understand the right positions for each measurement”*, additional data points currently missing from scans, alongside workflow adjustments. Technology companies often fail to anticipate how designers and pattern makers work, while at the same time, *“fashion people may not fully understand how the technology works,”* reinforcing the cyclical nature of the gap. Beyond tool development, participants also emphasized the importance of the acquisition of *“new skills or roles in the team,”* and the practical exposure: *“to try more and more 3D scanner systems to have the possibility to choose the one they think is more efficient for them.”*

The impression of readiness in approaching new digital design processes, encompassing 3D body scanning and parametric pattern making, was mixed: fashion designers considered their organizations to be ready, but still waiting for improvements in integration between tools and current workflows; pattern makers and freelancers were more likely to describe the industry as not yet ready, citing persistent issues of reliability and cost as significant barriers to the adoption of technology. The cultural distance of companies and fashion designers was also raised as an obstacle: *“Many fashion practitioners feel technology is distant; they can’t relate because they are maybe more familiar with crafting tools and procedures. Manual work and digital work should be more related.”* On the side of consumer-facing aspects of body scanning, fashion designers generally expected positive consumer reactions, provided the process was quick and intuitive. Some suggested that consumers would place trust in the accuracy of scans, but also recognized potential cultural hesitation regarding the collection of body data. These results underline that both systemic improvements and cultural acceptance are necessary prerequisites for industry uptake.

The potential sustainability impact of 3D body scanning was widely acknowledged, particularly in terms of reducing material waste, lowering return rates, and enabling on-demand production. Participants expressed mixed but generally optimistic views on how 3D body scanning could contribute to sustainability in the fashion industry. However, not all participants were equally convinced, expressing skepticism and suggesting that sustainability benefits would remain *“possible but unproven”* until adoption of the technology became broader and more systematic.

The participants expressed diverse perspectives on how the role of designers may evolve in a future where body data and digital tools become central to the fashion production process. The majority of participants (7/8) envisioned a shift towards a more hybrid technologically integrated role, requiring new skills (*“the designer must become a more digital figure with technology-related expertise and at the same time learn basic notions of pattern making, therefore disconnect [ing] from the figure of the artist.”*) suggesting a stronger connection with the consumer, while also considering the possibility that *“the user*

[may] become the designer themselves by using these digital tools.” Participants highlighted the ways in which digital prototyping could allow designers to increase body inclusivity and creativity, thereby enhancing rather than replacing their role and functions. To achieve this future role, participants agreed that training and support are crucial for the wider adoption of 3D body scanning in the fashion industry. While the tools are not inherently difficult for those with a fashion background, clearer operational guidance (e.g., posing for scanning, measurement points, and preparing parametric pattern making) is needed. Dedicated education was also required through scaffolding teaching, video tutorials, and opportunities for hands-on experimentation and comparative testing between human and 3D measurements, to fully leverage body scanning across design and production.

4.2. The perspective of consumers

Expectations preparation phase, scanning phase, measurements phase

Given the limited sample size, these results from the pre- and post-scanning surveys should be considered descriptive and exploratory. To investigate how participants perceived the scanning process before and after the scan, we compared the mean ratings participants gave for the three phases of the scanning process: the preparation phase, the scanning process, and the manual measurement phase. We also conducted a qualitative text analysis to understand how participants evaluated the scanning experience.

Preparation phase

As Table 2 suggests, the negative attributes (slow, embarrassing, complex) associated with the expectations regarding the preparation phase already received low scores in the pre-scanning survey. These scores decrease even further in the post-scanning survey. Conversely, the positive attributes rated by participants about the preparation phase (easy, intuitive, precise) increase from the pre-scanning survey to the post-scanning survey. Some of the values reported in Table 2 are also visualized in Figure 1.

Scanning phase

Similarly, in the pre-scanning survey (Table 2), participants reported low scores for the negative attributes (slow, embarrassing, complex) related to the scanning process, which were even lower than the post-scanning survey ratings. As with the preparation phase, the scores for the positive attributes (precise, safe, intuitive) of the scanning process increase from the pre- to the post-scanning survey. Some of the values reported in Table 2 are also visualized in Figure 2.

Manual measurement phase

Comparable results are also observed for the manual measurement phase (Table 2), where the scores for the negative attributes (slow, embarrassing, complex) decrease from the pre-scanning survey to the post-scanning survey, while the scores for the positive attributes increase from the pre-scanning survey to the post-scanning survey. Some of the values reported in Table 2 are also visualized in Figure 3.

Accuracy of the body measurements

The participants' ratings of the expectations regarding the accuracy of the avatar's face and body shapes decrease from the pre-scanning survey to the post-scanning survey (see Table 3). The values reported in Table 3 are also visualized in Figure 4.

Emotions

Consistent with the ratings of expectations in the pre- and post-scanning surveys, (Table 4), the values attributed to emotions also result in better evaluations after the scanning experience. The scores of most positive emotions (interested, excited, enthusiastic, inspired, attentive) increase, while the scores of the negative emotions (fearful, hostile, confused, worried) decrease after testing the scanning booth.

Pre-Open-ended question

In the first open-ended question of the pre-scanning survey, regarding expectations about the scanning booth, participants reported being generally curious and open to the scanning experience. The most recurring topic concerned the precision of the body measurements, which were described by 6/18 participants (33%), as particularly useful for reducing human errors during body measurements, useful for purchasing clothes on demand, tailored to consumers for 3D modelling, and useful for fashion design software, as for instance CLO3D. The digital avatar was also mentioned by 7/18 participants (38%) with different labels, such as “digital twin”, “digital version of my body,” or “3D model of the body”. The idea of having one’s own digital twin was particularly appreciated by participants who reported working with virtual reality environments, by students in their design courses at the university, and by participants

Table 2 - Means and standard deviations of ratings for the preparation, scanning, and measurement phase in the pre-scanning and post-scanning surveys. Participants rated adjectives on a scale from 1 to 5 for each of the three phases of the process, where 1 indicated "not at all" and 5 indicated "very much". The list of adjectives varied slightly depending on the phase.

Adjective	Mean Pre	(SD)	Mean Post	(SD)	Mean Pre	(SD)	Mean Post	(SD)	Mean Pre	(SD)	Mean Post	(SD)
Preparation phase				Scanning phase				Measurements phase				
Slow	3.06	0.80	2.00	1.14	3.00	1.08	2.17	1.04	3.17	1.11	2.50	0.99
Embarrassing	2.61	1.38	1.50	0.79	2.61	1.42	1.83	0.99	2.67	1.19	1.83	0.92
Complex	2.78	1.11	1.22	0.55	2.89	1.41	1.67	0.97	2.89	1.26	2.11	1.34
Easy	3.44	1.20	4.61	0.70	3.78	1.11	4.39	1.39	2.22	1.68	2.56	1.38
Intuitive	3.72	1.23	4.44	0.78	3.39	1.04	4.17	1.33	3.50	1.19	4.11	1.20
Precise	4.17	0.86	4.39	0.78	4.06	0.94	4.17	1.15	3.56	1.27	3.89	1.40
Safe					4.56	0.78	4.78	0.92				
Innovative					4.44	0.86	4.11	1.42				

Table 3 - Means and standard deviations of ratings for perceptions of the avatar's accuracy in the pre-scanning survey and post-scanning survey. Participants rated the accuracy of the body measurements on a scale from 1 to 5, where 1 indicated "not accurate at all" and 5 indicated "very accurate". The list of adjectives varied slightly depending on the phase.

	Mean Pre	(SD)	Mean Post	(SD)
Accuracy of the body measurements				
Avatar's face	3.06	0.80	2.00	1.14
Avatar's body shapes	2.61	1.38	1.50	0.79

Table 4 - Means and standard deviations of ratings for emotions toward the experience in the pre-scanning survey and in the post-scanning survey. Participants rated emotions on a scale from 1 to 5, where 1 indicated "not at all" and 5 indicated "very much".

Adjective	Mean Pre	(SD)	Mean Post	(SD)
Emotions				
Interested	4.56	0.62	4.53	0.62
Excited	3.11	0.83	3.53	0.87
Fearful	2.00	1.14	1.24	0.44
Hostile	1.44	0.62	1.18	0.39
Enthusiastic	3.83	0.86	3.88	0.86
Alert	3.00	1.08	3.29	1.05
Confused	2.11	1.23	1.41	0.62
Inspired	3.11	1.02	3.24	1.09
Worried	1.67	1.08	1.47	0.62
Attentive	3.67	0.97	3.82	0.88

seeking to improve the fit of the clothes they purchase. Another topic that emerged from this question was the interest in technology, as a facilitator for participants who reported being intrigued by the scanning booth because of its innovative and sometimes even futuristic aspects, *“as it happens in the movies in which they get your biometric measurements”*. Another mental image that participants mentioned when describing their expectations was the body scanner used in airport security checks. Even in cases where participants reported not being familiar with technology or scanning booths (3/18 participants, 16%), they still expressed curiosity about trying something outside their comfort zone. Regarding the technical expectations of the scanning process, it often emerged that participants anticipated the precision of the scanning booth, the speed of the process, the need for a small box to be scanned, the requirement to wear a specific tight-fitting suit, and the need to stand still. Finally, some of the participants (3/18 participants, 16%) mentioned the topic of body image, saying that they hoped the scanning experience would also have improved their relationship with their body, or that they were curious about how the technology could have helped them find their precise body measurements, to use when purchasing custom-made garments.

Post - Open-ended question 1

After the scanning experience, participants answered three open-ended questions. The first question asked them how they found the experience with the body scanner. Generally, they evaluated the technology as positive, innovative, and surprisingly easy to use. Some of them (5/16 participants, 31%) even highlighted the speed and fluidity of the process (*“I didn’t even realize I was being scanned”, “It lasted 15 seconds”*). The non-invasive aspect of the scanning was appreciated for avoiding the need to be measured and touched by other human beings, which could sometimes result in embarrassing experiences. Another topic was also the future, in which participants envisioned the possibility of purchasing customized clothes (*“It would be a revolution in the way I approach clothes”*), or using the technology for their research work (mentioned by 3/16 participants, 18%). Nevertheless, alongside the enthusiasm for the development of technology, a sense of fear toward it was also mentioned (*“I am a little bit scared of a “too” technological future”*).

Post - Open-ended question 2 - Pros and cons

In the second open-ended question, we asked participants to list the pros and cons of the experience. Participants reported on average 2 pros and 1 con. The general assessment yielded positive findings, with a prevalence of pros including intuitiveness, speed of the process, and precision of the measurements. Several participants (7/16 participants, 43%) appreciated the short time required for the scanning process, which allowed them *“to have in a few seconds a whole picture of their body measurements”*. Participants also cited the opportunity to personalize clothes and adapt them to personal needs, which could even reduce the *“time and costs needed for the clothes prototyping”*, and therefore also minimize textile waste. This feature was described as something that could help people during the often stressful shopping process of finding the right size in both fast-fashion and non-fast-fashion stores. Along with the positive aspects, participants also listed cons, such as the *“relative precision”* of the measurements, which were not *“identical”* to one’s own body (mentioned by 3 participants, 18%). In other cases, it emerged that the subjective experience of being exposed to one’s body image could be an obstacle (mentioned by 3 participants, 18%), and the scanning process might not be pleasant for everyone (*“It didn’t help to boost my self-confidence”*). Finally, we collected differing opinions about the technological innovation of the scanning booth, which might replace years of artisanal tradition. Specifically, it was noted that removing any form of physical touch and humanness from the process could jeopardize a historical tradition and *“action”*, reducing it to a process in which the customer *“just needs to stand still for a few seconds”*. Nevertheless, another participant highlighted among the pros the positive contribution of this technology to a shift in the *“custom-made”* clothing sector, from a traditionally artisanal and slow approach to a more technological one.

Post - Open-ended question 3

Finally, we asked participants about aspects of the scanning process that could be improved. The answers indicate general satisfaction, with the majority of participants reporting that they wouldn’t change anything about the experience. Nevertheless, some suggestions highlighted minor aspects that could be optimized. For instance, some mentioned that for precise results, it is necessary to wear very tight technical clothing, and minor imperfections in the garments might influence the accuracy of the measurements. Another participant highlighted the need for an auditory feedback system to signal the start and end of the scanning process to the person being scanned, as well as some visual indications, such as a body shape silhouette, to suggest the correct posture to maintain during the scanning process. The experience was described as generally fluid, intuitive, and well structured, as was the interaction with the people in charge of the manual body measurements, which contributed to a welcoming and reassuring environment.

Differences in evaluations of preparation for the scan pre vs. post

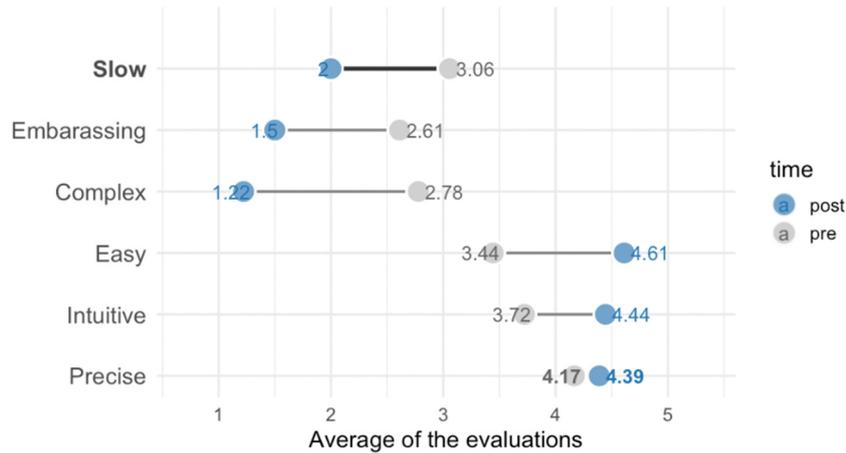


Figure 1 - Means of ratings of the preparation phase in the pre-scanning and post-scanning surveys. Participants rated adjectives on a scale from 1 to 5, where 1 indicated "not at all" and 5 indicated "very much".

Differences in evaluations of the scan pre vs. post

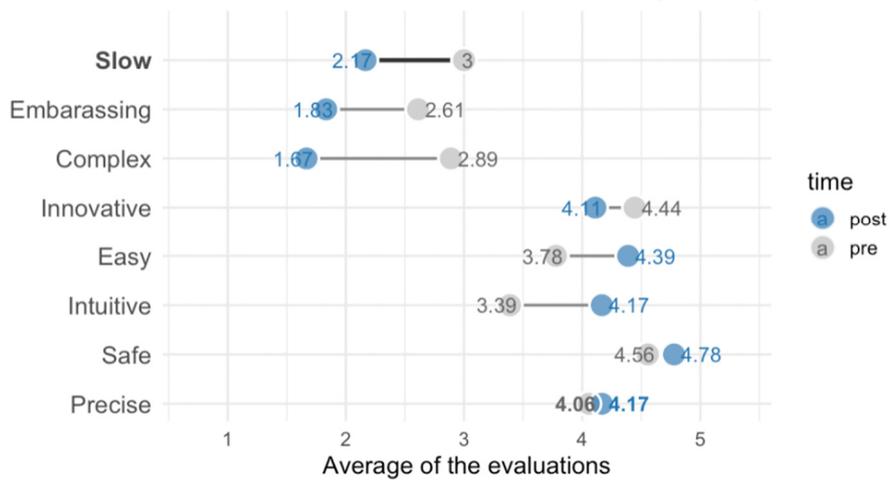


Figure 2 - Means of ratings of the scanning phase in the pre-scanning and post-scanning surveys. Participants rated adjectives on a scale from 1 to 5, where 1 indicated "not at all" and 5 indicated "very much".

Differences in evaluations manual measurements pre vs. post

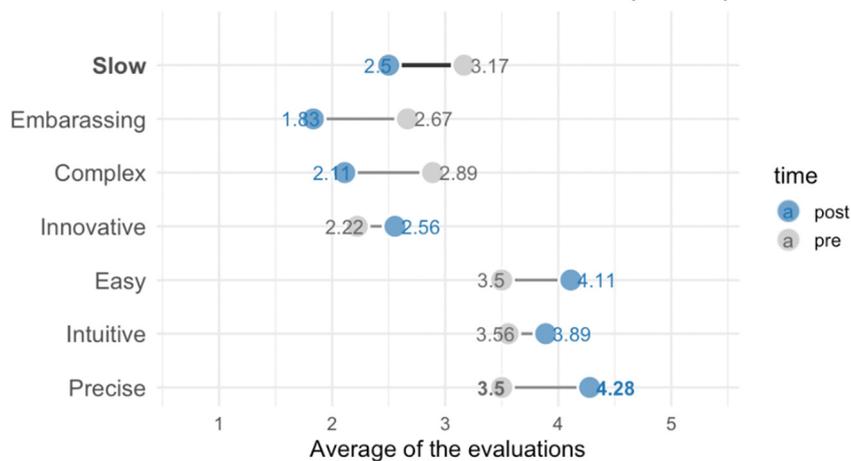


Figure 3 - Means of ratings of the measurements phase in the pre-scanning and post-scanning surveys. Participants rated adjectives on a scale from 1 to 5, where 1 indicated "not at all" and 5 indicated "very much".

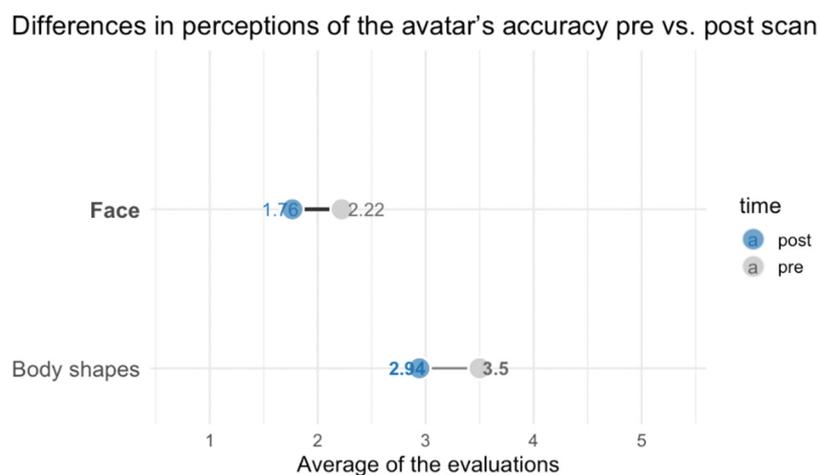


Figure 4 - Means of ratings for perceptions of the avatar's accuracy in the pre-scanning survey and post-scanning surveys. Participants rated the accuracy of the body measurements on a scale from 1 to 5, where 1 indicated "not accurate at all," and 5 indicated "very accurate".

5. Discussion

5.1. Bridging Readiness and Application: Reflections from the Fashion Operators' Perspective

Within the exploratory sample of this pilot study, the findings highlight varied user attitudes toward 3D body scanning, shaped by differing levels of trust in technology and concerns over usability. The findings suggest that while 3D body scanning is increasingly recognized as a promising enabler of personalization and sustainability in fashion, its adoption remains constrained by technical, economic, and socio-cultural factors, with current use primarily concentrated in research and experimental settings rather than mainstream industry workflows. While participants across career stages and professional roles acknowledged its potential to improve garment fit, personalization, and sustainability, they also identified significant challenges in current digital workflows. These included measurement inconsistencies, limited interoperability between scanning and pattern-making software, difficulties in aligning digital measurements with established fashion industry protocols, and the need for training in shifting toward parametric pattern making using digital measurements. In this pilot research, the challenges fashion operators face in adopting 3D body scanning for mass personalization include organizational inertia, training needs, cost, and integration with existing workflows. The need for designed mediation between tech providers and fashion operators is accompanied by the view of a hybrid figure of creative-technical designer able to translate capabilities into meaningful use cases. In this new transition, opportunities emerge for design methodologies to support the transition from experimental use to systemic integration in the fashion design and prototyping pipeline.

Fashion operators' concerns underscore that the transition from analog to digital practices is not a straightforward substitution but rather a reconfiguration of workflows, roles, and expectations. Designers saw opportunities in embedding scanning into their prototyping and creative processes, whereas pattern makers stressed the importance of accuracy and reliability as prerequisites for meaningful adoption. These tensions reveal both the opportunities and constraints of digital integration, pointing to gaps in the alignment between technological capabilities and professional needs. To address these emerging frictions, we propose a revised framework (Figure 5), adapted and expanded from [43]. The presented framework extends the amplitude of the workflow, doubling the number of the steps toward fashion mass personalization, clarifying sub activities of main phases of the previous pipeline [43], highlighting used hardware and software, and including the use of 3D modeling software to simulate and visually verify the correct fitting of personalized garments, while also encompassing the necessity of translating the scanatars into workable digital avatars for fashion design and prototyping. In addition to this, this framework highlights gaps and points of friction between analog and digital practices, particularly in technical and procedural issues such as scanning protocol and landmark definition, mesh quality in crucial areas of the digital avatar (which creates problems of compatibility with avatar conversion in CLO3D), measurement accuracy due to the misalignment between manual and digital measurement acquisition protocols in several points, and reliable interoperability across the fashion workflow. At the same time, the framework identifies opportunities for innovation toward improved garment fit, customization, and sustainability, particularly focusing on new methodologies for sewing pattern design

and development based on digital measurements, enhanced visualization and simulation tools that allow for pre-production and pre-prototyping assessments, and more efficient communication of fit and style across design, production, and retail stages. The framework acknowledges systemic challenges, such as the technological integration of different software used in the fashion design workflow, which requires specific training and practice-based experiences to decrease cultural resistance to technological adoption among fashion operators and the industry as a whole. If 3D body scanning can function as a mediating technology that bridges analog craft knowledge with emerging digital ecosystems toward customization and inclusivity, it foregrounds the necessity of aligning software choices and measurement standards with fashion design workflows, from measurement capture to design, prototyping, simulation, and rendering. The framework provides a basis for more effective digital transitions, highlighting the importance of bridging the cultural and technical divide that continues to shape the fashion industry's engagement with body scanning technologies. From an educational perspective, it highlights the necessity of designing educational tools to support the widespread adoption of innovations in digital measurement applications for fashion pattern construction, specifically within the context of customized design approaches, as mentioned by [44,30].

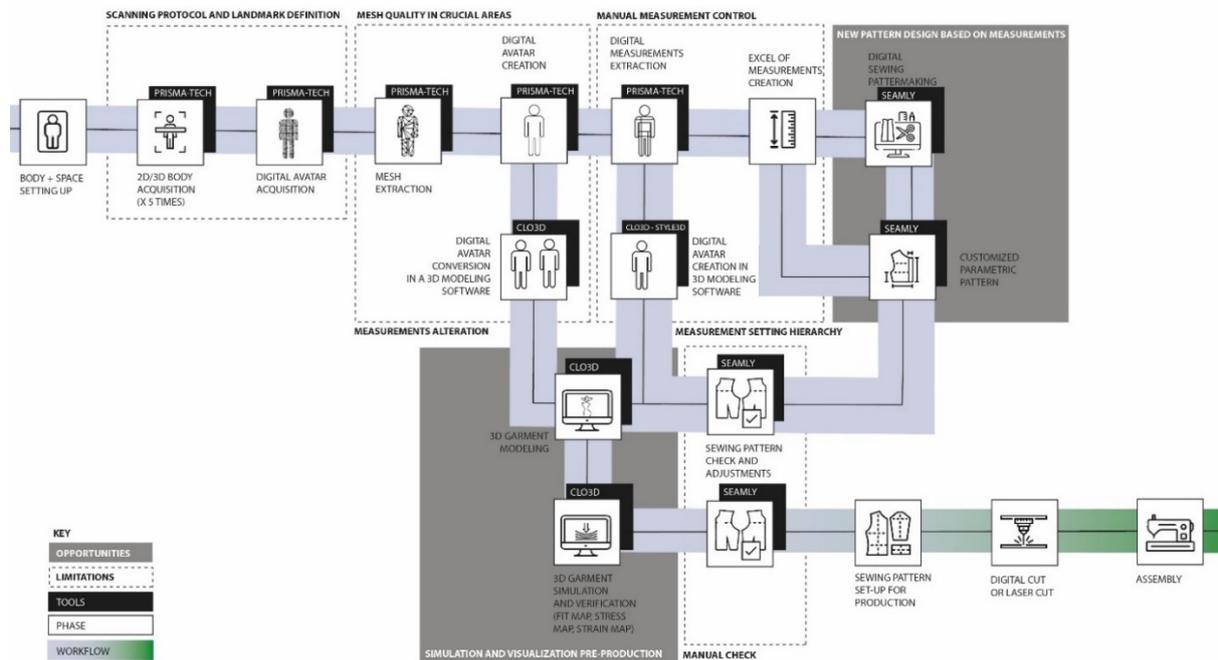


Figure 5 – Framework for 3D body scanning integration into fashion design workflows, updated from [43].

By making limitations and opportunities visible, the framework supports a clearer understanding of where investment in tool development, education, and cross-disciplinary collaboration is most urgently required to enable smoother transitions from analog to digital workflows.

5.2. User Perception and the Socio-Cultural Dimension of Digital Fashion Innovation

The analysis within this exploratory sample of participants revealed a general improvement in the perception of the body scanning experience from the pre- to the post-scanning survey. Although the negative expectations regarding the slowness, embarrassment, and complexity of the experience were already low in the initial ratings of the participants, they decreased further after they experienced the scanning booth. The scores for the positive attributes, such as ease, intuitiveness, and precision, were already high in the pre-scanning survey and increased across all three phases in the post-scanning survey. This phenomenon shows that participants were already optimistic about the scanning booth technology before trying it, and their positive experience further increased their enthusiasm afterward, confirming their positive expectations. As previous literature suggests [45], this may be due to participants particularly appreciating the speed, non-invasiveness, and fluidity of the process.

Nevertheless, it is important to consider, for future technological development, the critical aspects that emerged from the study. Among the technical issues noted by participants, many answers drew attention to the avatar's inaccuracy in representing the face and body shapes of the participants, as documented in earlier research [45]. Expectations toward its precision actually declined after the

scanning experience. This suggests that, although the overall experience was positively rated, the expectations for high precision in the avatar's representation of one's own body image were not fully met in this pilot study. Additionally, participants emphasized that auditory cues indicating the start and end of the process, as well as visual indications on how to position oneself in the scanning booth, would make the scanning process even more intuitive. More complex and broader concerns were also pointed out: for instance, the influence that the introduction of this technology in the custom-made field would have on the humanness of the artisanal tradition. Finally, it is worth noting the participants' reflections on the implications of exposure to their own body image, which align with previous findings [41]. This exposure could have positive effects on the consumers, such as boosting self-confidence and body awareness, but also lead to discomfort due to inaccuracies in the digital avatar's representation.

6. Conclusions

6.1. Limitations and future research steps

This exploratory study aims to understand the socio-perceptual impact of integrating 3D body scanning technologies and parametric pattern-making in the design of customized apparel. By providing an integrative framework (Figure 5), the research aims to support fashion operators, including designers, researchers, patternmakers, and digital and physical tailors, in identifying the current challenges and opportunities associated with embarking on this technological shift. Although the results were very promising, the research presents limitations. Firstly, the small and non-representative sample of consumers, who may already be familiar with or interested in the technology, might have influenced their positive approach to the technology compared to the average population. Such a factor could limit the generalizability of the results to less informed consumer groups. Conversely, the group of fashion operators reflects a balance between early-career and highly experienced professionals, working across haute couture, luxury, ready-to-wear, and sportswear markets, while also being employed in the education field as laboratory technicians. This diversity provides valuable insights into both artisanal craftsmanship and industrial-scale production, as well as the integration of emerging digital tools within different segments of the fashion sector. However, this sample size could be enlarged to ensure a more varied reflection on the topic of investigation, particularly by including fashion operators that are currently using 3D scanning technologies within the fashion industry in the group.

The sample size was also negatively affected by the fact that participants had to reach the Circular Fashion-Tech Lab, where the scanning booth was located, in order to participate in the study. This may represent a broader issue for this type of technology, which, for now, is only available in specific locations. Further research should investigate the willingness to travel to these locations to use the technology, as well as their attitudes toward it. Another related limitation is that the scanning process was conducted in a controlled laboratory environment, which is not an ecologically realistic setting, unlike, for instance, a fashion retail store or a tailoring workshop, where many other external factors might influence the perception of the technology. Finally, we did not assess participants' long-term evaluations and actual adoption of the scanning booth in real-life contexts. Future research should involve a larger sample, include participants with varying levels of technological knowledge, and plan a follow-up study to assess how acceptance and actual behaviors may evolve over time.

Certain limitations observed in this study are closely tied to the specific hardware and software employed in the 3D scanning process, digital avatar conversion, 2D block pattern-making, and 3D modeling of garments. These include challenges related to landmark definition for measurement acquisition and extraction in the back-end software, as well as issues with generating and converting digital avatars within fashion-oriented 3D modeling tools. Such limitations are technology-dependent and may not occur, or may present differently, with alternative systems, making the findings not fully generalizable. Future research should therefore compare different tools to identify shared challenges and areas of divergence. Parametric sewing patterns were developed using Seamly2D, as other commercially available software currently used in the fashion design practice did not provide automated pattern adjustments. Further studies could explore the limitations and opportunities of this digital framework in practice, for example, by assessing feedback from fashion design students after digital scanning and parametric pattern-making training, and providing instructions and tutorials to follow. Besides, future studies should address how scanatars could add value for small, medium and large fashion companies where standardized avatars and grading systems are already embedded, for example testing hybrid workflows such as fit validation, premium personalization services, customer data enrichment, or limited made-to-measure offerings, while adopting comparative, longitudinal, and multi-stakeholder methodologies, integrating technical evaluation with user-centered and organizational perspectives toward individualized, on-demand, and more sustainable production models.

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