Building Novel Dynamic Pattern Theory via 3D Body Scanning Data

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Abstract

Is it possible to build a well-fitting and functional pair of pants “from the ground up” via a 3D scan of a human? Body scanning provides opportunities to build more robust body-to-pattern drafting and product design theories. The practices provided can allow garment pattern blocks to be defined with much clearer relationships to the body, using body regions and understanding of body shape and fit requirements. However, the current technology for body scanning merely replicates existing practices for sizing or product development measurement, with little focus on how this technology can significantly and accurately evolve computer pattern drafting practices. This research explores how enhanced data coming from body scanning can support pattern blocks for trousers which are developed more uniquely to the body, enhancing both ready-to-wear and made-to-measure market needs.

Body measurement files and OBJ scan files were collected using multiple leading mobile scan brands. The challenges of validating and verifying the measurements utilizing the OBJs are discussed. The issues fell into two main categories: variance of measurement definitions and techniques, and the geometry of the mesh itself. The geometry of mesh can lead to approximations of measurement locations which have an impact on pattern drafting. The uses of the OBJs beyond visual representations are presented.

Applying novel measurement extraction techniques to OBJ scan files, this research uses Rhino and Grasshopper software to extract measurements that drive a parameterized trouser pattern. Clearly-defined requirements were set for extraction, and the parametric block was established in Seamly2D® open-source pattern cutting software.

This research illustrates the advantages of using novel approaches and enhanced measurement techniques to develop pattern theory that uniquely reflects the body size, shape, and proportion of the wearer. By identifying novel usage of data to drive the pattern, it is possible to address fit requirements, illustrate clear benefits of body scanning, and define how the application of technology can evolve pattern drafting practice to allow better engineered garment fit.

This research reflects the work of members of Open Circle Apparel Coalition, an ad hoc working group whose mission is to enable more efficient and effective garment manufacturing through standardization, integration, and open-source methodologies. There is a clear need for greater interdisciplinary approaches to harness technology more effectively.

Keywords: 3D Body Scanning, Measurement Approximations, Pattern Drafting, Garment Manufacturing, Fashion Technology, Body Morphology, Mass Customization, Pattern Customization, Artificial Intelligence, Generative AI, Digital Fashion, 3D Design.

1. Introduction

As body scanning becomes more popular and normalized within the retail shopping experience, there is an assumption that body data can be easily used to improve the fit outcomes for all body shapes. This is, unfortunately, not the reality in the current garment production environment.

The process for generating bespoke clothing products requires the alignment of multiple stages, from measurement collection, extraction, pattern creation or adjustment, and ultimately to manufacture. This research seeks to explore a pathway from mobile body scan to digital bespoke pattern, through virtual and ultimately physical fitting for trouser block patterns. The content of this paper will focus primarily on the development of the digital pattern and its application in garment fit and development.

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The research will identify key stages of the process and provide a foundation to make recommendations for areas of development that ensure a good outcome. Addressing the engineering of patterns from mobile scans contributes towards developments in scaling production of customized, bespoke, and made to measure garments. It also offers clear benefits for addressing fit in a more engineered manner for ready to wear garments, and the application of technology in the process of garment development.

Whilst research has illustrated that scan to pattern is possible [1]–[3], there remain necessary areas of practice and knowledge development to ensure it can be realised more widely by those involved in garment development.

For garment product development approaches to be more sustainable and address fit criteria of wearers more explicitly, it is necessary to further develop body-to-pattern theories. This includes identification of key body parts and how they inform explicit decisions in the creation of the garment pattern. This work builds on exploration of McKinney et al., [4] where crotch extension was identified as being possible to drive directly from depths of the body, rather than determined by a calculation of hip circumference.

2. Methodology

This research adopts a multistage mixed methodology in the capture, processing, analysis, and application of body scan data to drive products. Challenges were observed and documented in validating and verifying the measurements, e.g. determining consistent definitions for obtaining measurements, verifying algorithms would work for every scan, and understanding how the avatars (OBJ files) varied from the person scanned (i.e., height).

Data was captured and anonymised from 12 female participants of varying age, body mass index, and skin tone, using four mobile scanning applications. Working in conjunction with participating scanning app companies, 48 measurement profiles were created and data exported as CSV (comma separate values) and OBJ (3D mesh avatar) files. The scanning companies used different methods for measurement extraction and extrapolation, including still photos, LIDAR, and video capture.

It should be noted that all scans were done in 2022, and the products utilised may have changed or improved since then. The purpose of this research was not to critique any company, but rather to understand better the differences between technologies and production stages to identify issues and system interoperability impediments.

Variance in the resulting measurements from each scanner made it necessary to apply more localised consistent measurement extraction; this was done using Grasshopper® graphical algorithm editor within Rhinoceros® 3D software, commonly called Grasshopper/Rhino (Figure 1). Standardised measurement method definitions and data labels were applied to key body measurements for the lower body, in order to facilitate mapping of data directly to a novel trouser draft. [Some data were not computed due to lack of unsupported data requirements, specifically posture and its relation to crotch point, hip, and waist.]

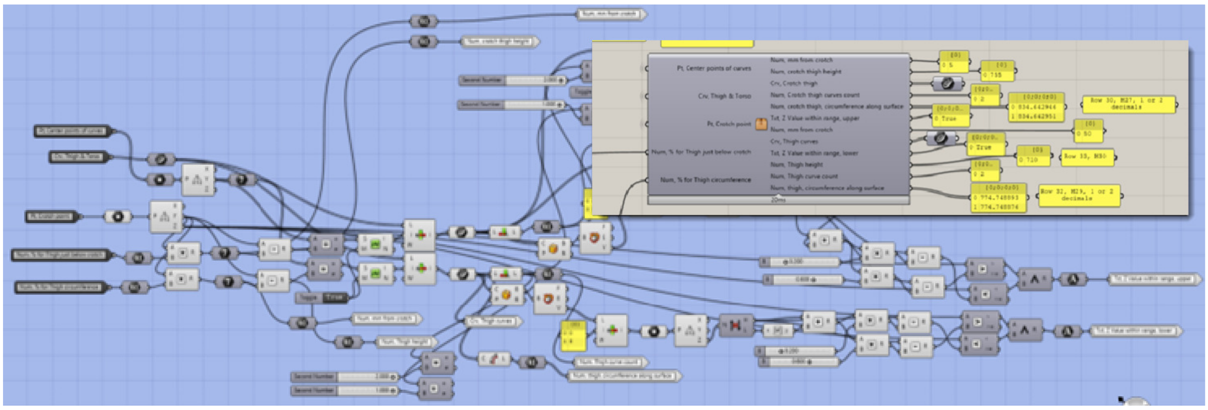


Figure 1: A cluster is set up in visual programming software to find the thigh curves based on the location of the crotch point

The trouser pattern draft process utilised extracted heights and circumferences via the Grasshopper/ Rhino software to frame out the pattern, allow visualisation, and control of "ease" (gap between clothing and body) at key locations. Further development of the extraction allowed for two key elements to be determined: firstly the crotch point, which is the lowest point of the torso on the midsagittal plane. Secondly, front and back crotch curves were projected from the pattern guided by the seat depth with a division between front and back guided by general outcomes from current pattern drafting methods.

Next, using open-source software from Seamly® [5] a parametric pattern draft was framed out which allowed for measurements from each participant to drive the resulting pattern shape. The application of Seamly allowed for pattern measurement files to be written from the extracted data of each scan, input manually from Excel exported from Grasshopper/Rhino. Measurements were used to resize the parametric trouser block for each individual and small adjustment were made to true lines and angles for each participant's pattern. The truing of seamlines is a typical final step in the development of a pattern.

Lastly, a "virtual try-on" was staged between each data-driven garment and the digital twins of each participant as modelled from their measurements. The Seamly trouser patterns were extracted as industry standard DXF format and imported into CLO3D/Style3D® and virtually fitted to the mesh avatars (3D scans) obtained from mobile scanning. The retention of key pattern lines like crotchline and knee line aided the virtual fitting process.

Outcomes were observed and documented as to the perceived accuracy of the garment fit, and likelihood to be considered a success by the wearer.

3. Results and Discussion

Whilst the research did illustrate the possibility of integration from mobile scan to bespoke pattern and virtual fitting, there were considerable issues that required manual intervention and expertise to overcome in the process. Fundamentally the overall process relied heavily on key specificity to ensure the success of each stage, and to allow the stages to link together successfully. This has implication for workflow for these processes and how they develop.

Mobile scanning provides an efficient means to capture and render the human body into a 3D CAD environment. However, it was observed that each scan technology provided different measurements in terms of both data values and naming protocols, and not all were explicit as to how values were derived or aligned to body landmarks. Further the same participant was rendered differently in each interface (Figure 2), which complicated the outcomes that would drive the resulting pattern.

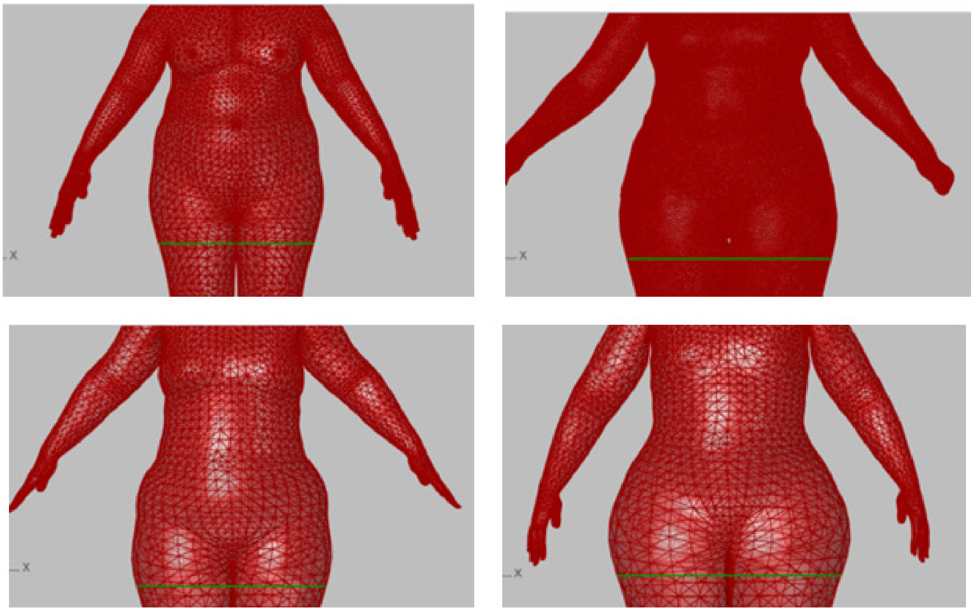


Figure 2: Four scans of a single participant. Note the dramatic differences in surface topology and body shape interpretation. Moreover, it was observed that some scanners removed body mass or smoothed areas, possibly a result of incorporating external data from large scanning databases. Some scanners replaced body parts with "stock" extremities such as heads, hands, and feet. In some, body posture was adjusted.

To avoid the difficulties of having to use similarly named but different measurement data, a common issue [6], [7], it was necessary to use the Grasshopper/ Rhino software and follow each series to measurement definitions which were defined specifically to generate the trouser block [8].

The process was further frustrated by differing surface geometry from the scans, plus bridging and other “noise” in the 3D files. It was necessary to develop and refine the algorithms in Grasshopper/Rhino to ensure a consistent and appropriate output for each individual scan of the 12 participants by each scanner type. This process illustrates the complexity of scan data analysis and its use in automated systems, and the importance of incorporating standard and robust definitions to extract and utilise measurement data.

To narrow scope, it was determined the most important area of concern in the research was the issue of consistently plotting accurate crotch points and crotch curves, which are a critical element of making trousers. Because there is no standard methodology for calculating crotch curves from a limited set of points and landmarks, and because the key value of Crotch Point was sometimes missing or incorrect in the scan data, each pattern had to be manually corrected and adjusted. In a fully automated system, this creates inefficient workflows and opportunities for error.

There are two main factors we found in our research that affected the availability and accuracy of crotch measurements: thigh bridging and posture/pelvic tilt.

3.1. Bridging created significant errors on scanned humanoids

It should be noted that in many of the 3D avatars exported by mobile scanning technologies, the visual topology representation is smoothed or adjusted based on algorithms and other secondary processes. In some cases, the heads, feet and hands are replaced by a generic appendage. However, the exported point cloud data in the OBJ file or body measurement data in the CSV file often reflect a different set of values.

Mesh triangulation issues frequently occur close to the crotch or if the legs are close together above the knee, especially on certain body shapes. The issue of deriving an incorrect crotch point measurement is shown in the following illustrations (Figures 3-5), which show how thighs touching creates a fusing or “bridging” of the mesh. It shows up as an extension of the torso shape, and crotch point is predicted to be at a false location. Each thigh is also thus not fully separated, and in some cases the mesh fusing creates overlapping surface data.

Figure 3: When thighs are touching during a scan, the result can be an incorrect projection of crotch point. Shown on left are uncorrected and overlaid outputs of the four mobile scans for one individual, participant 1002. The "bridging" of thigh data is evident. The right illustration shows corrected crotch points and crotch curves.

Below, the vertices on the right leg in the mesh are not only part of mesh faces on the right leg but also part of the mesh faces on the left leg (Figure 4). This must be cleaned up for any product design or animation for apparel. However, simply removing tissue to create an artificial thigh gap is problematic. A recommended solution is not to impose an arbitrary thigh gap of a fixed width but instead look in detail at the triangulation within this area.

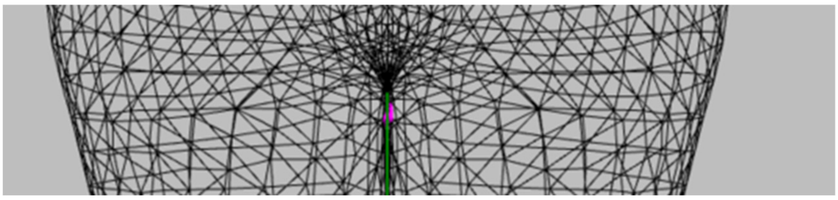


Figure 4: Bridging or fusing creates sharing of mesh between right and left leg, impacting animation movement and accurate garment production. Vertical green line is superimposed to indicate where mesh separation should occur. An example of mesh triangles of concern is shown in pink.

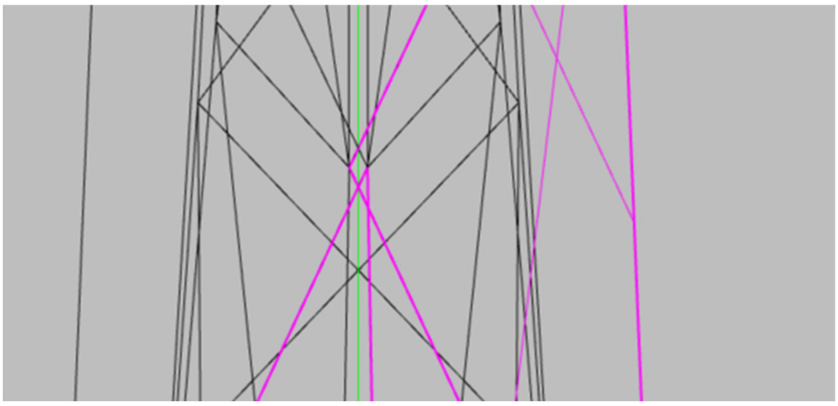


Figure 5: Closeup of vertex with mesh fusing/bridging

In Figure 5, the overlapping mesh triangles are shown in pink with a vertical superimposed green line to indicate what should be separation of thighs. The left leg and right leg mesh triangles are intertwined. The proper separation of the leg meshes from the knees to the crotch can be determined with proper evaluation.

Because of this issue, there is a high probability that if used as-is, the body data will yield incorrect patterns. Thus, a method for “cleaning” the mesh as well as predicting an accurate crotch curve is required. Accurate data of the crotch currently requires manual intervention and can allow for more points along the curve to be generated (Figure 6).

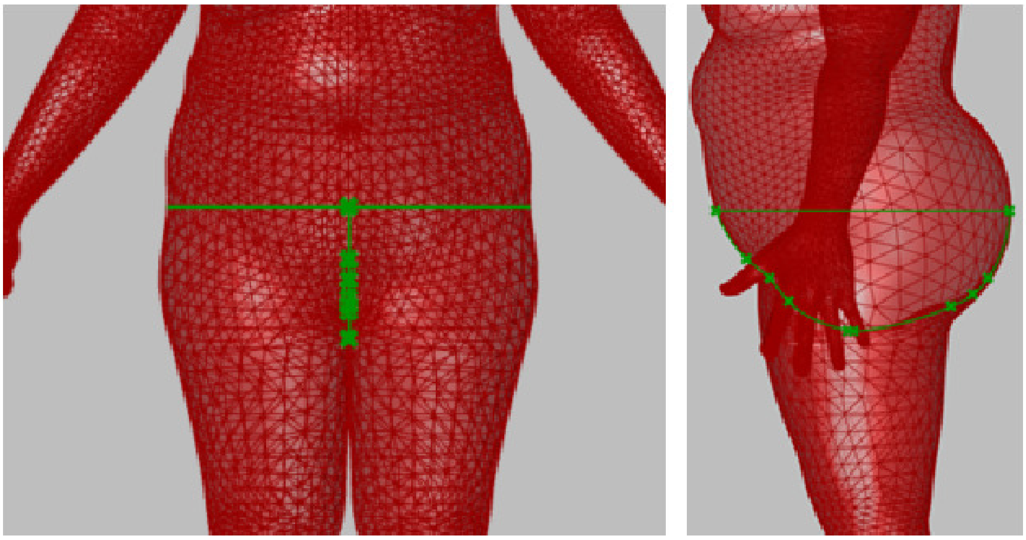


Figure 6: Curves and crotch points manually plotted on mesh of participant 1002, after correcting for bridged thigh mesh. This will become a key part of the trouser pattern draft.

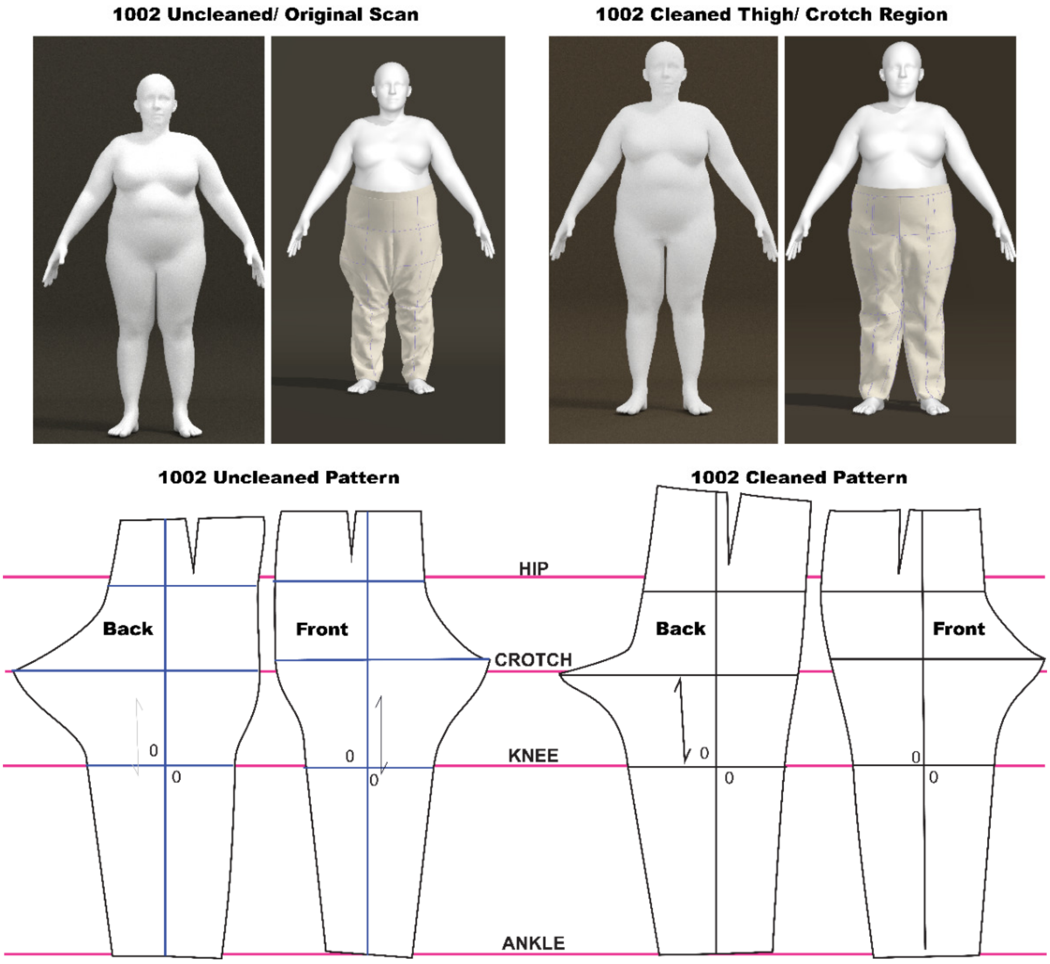
3.2. Virtual fitting provided helpful visualization of poor or mixed results

The research group chose a larger body from amongst the participants to analyse first, due to the number of challenges these forms present in digital applications. Body measurements from each OBJ "raw" (uncorrected) were used to draft a pattern block purely from data. The resulting trousers, when rendered and put onto a 3D model of the participant, were not a desired product outcome because of the thigh bridging and measurement miscalculations which occurred. The body scan data output drove the hip and crotch to be lower on the body than expected, sometimes dramatically so.

In Grasshopper/Rhino, it was discovered the bridging not only caused a drop to the crotch, but also mixed or swapped the references for point location and mesh triangulation as shown in Figure 5. To solve the issue, the leg zone was cleaned and corrected, while maintaining the thigh circumference measure. This allowed the crotch points on the figure to be isolated (via Grasshopper/ Rhino) for use of consistent data across software platforms.

After the humanoid scans were corrected to remove thigh bridging, the height and sagittal plane of the crotch point was used to generate points at 22.5, 45 and 67.5 degrees along a curve to assist with trouser design for both rear and front curves. It also allowed the fabric to have more room for drape assembly. This was done for all four scans of each participant.

The example below in Figure 7 shows the differences between the hip lines, crotch levels and other major landmark lines. The 0/0 (datum) point used was the knee, based solely on the stable nature of the knee point across all the body scans. Neither the ankle nor the waist could be used as 0/0 due to posture changes and foot placement changes.


1002 Uncleaned/ Original Scan

1002 Cleaned Thigh/ Crotch Region

1002 Uncleaned Pattern

1002 Cleaned Pattern

Figure 7:Pattern and trousers generated from default raw scan measurement data, for participant 1002. After correcting crotch region bridging and calculating crotch point and curve, a much better fitting virtual garment was created.

3.3. Artificial posture can affect pelvic tilt

The research team also tested the data-driven programming and theory on a smaller body that didn't have bridging issues (Figure 8 and 9). The result generated more successful outcomes for a body pattern that could be further adapted for fit and overall improvement. However, challenges for the pelvic tilt fit were still present, assumed to be related to developing further mapping and data from the 3D form. This issue will impact pattern generation and ultimate garment fit.

Many body scanners will utilize "stock" body parts to represent extremities, and others will adjust the posture to be more upright, or smooth the overall shape (perhaps to make a more pleasing avatar). We determined that auto re-posture, neck replacement, and even foot replacement impacted the pattern shaping and logic (ref. figures 7, 8 & 9). Pattern logic requires the knowledge of full crotch formation and its relationship to thigh shape. Pelvis rotation is related to the front rise length and back rise length. Any reformation of the spine will incur a varied level of inaccurate data or measures based on the overall shape considerations. From a programming perspective, the mesh data needs clearly defined quadrants on the XYZ right-handed axis system. This can be a consideration for aspects of interoperability needs between software systems.

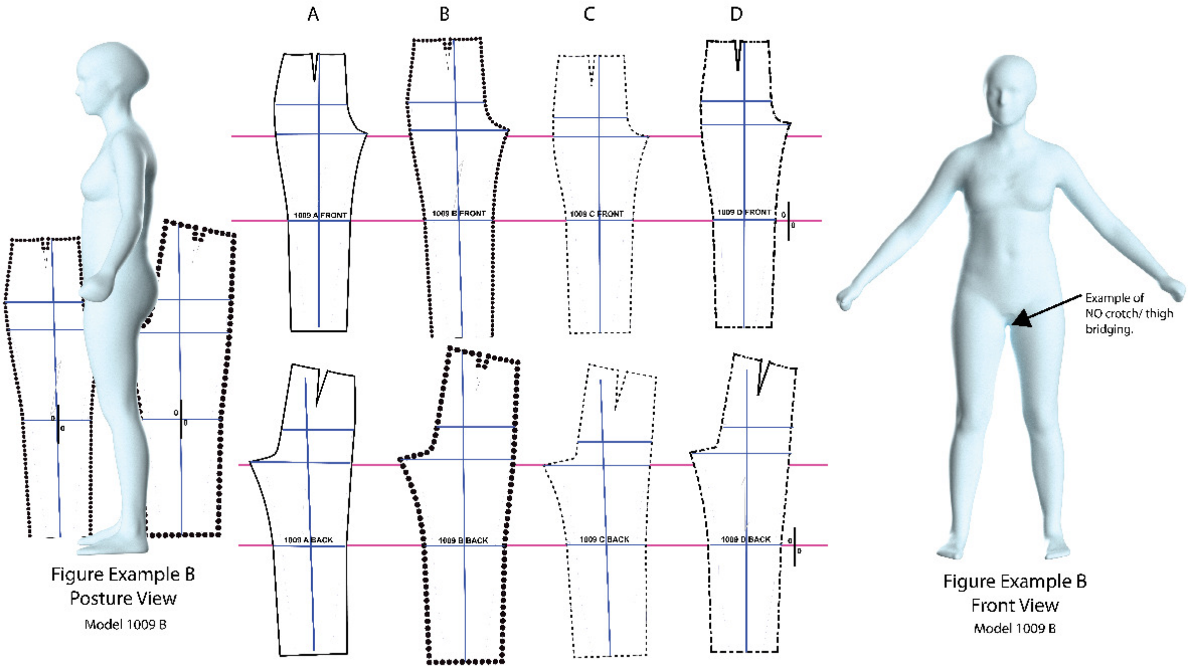


Figure 8: Patterns for participant 1009 as scanned with four different apps. Front, side, and back views of each pattern are the same views. Note the smaller body has a clear crotch and thigh region capture. This is the ideal capture of crotch region for all size ranges if possible. Compare with Figure 7 where thighs were touching.

With the knee as the common datum (0/0), the patterns can be shown for the slimmer figure based upon measurements from the four different interfaces. It is evident that the pattern will differ by key parts in terms of shape and length that would require more consistency between suppliers to better control for fit. Alternately, further optionality could be exercised in the draft pattern stage to foster consistent outcomes from more divergent data. Both approaches require theory development to better control the body-to-pattern interaction.

Allowing for the requirements for skilled operators at each stage it is possible to take a body from scan to virtual fit with some degree of success (Figure 9). Without the issue of thigh bridging, the smaller body (Figure 8) seemed more suited to consistency between the mobile scanners. Clearly this raises an issue for more divergent customers and requires more research for realizing bespoke products for full populations.

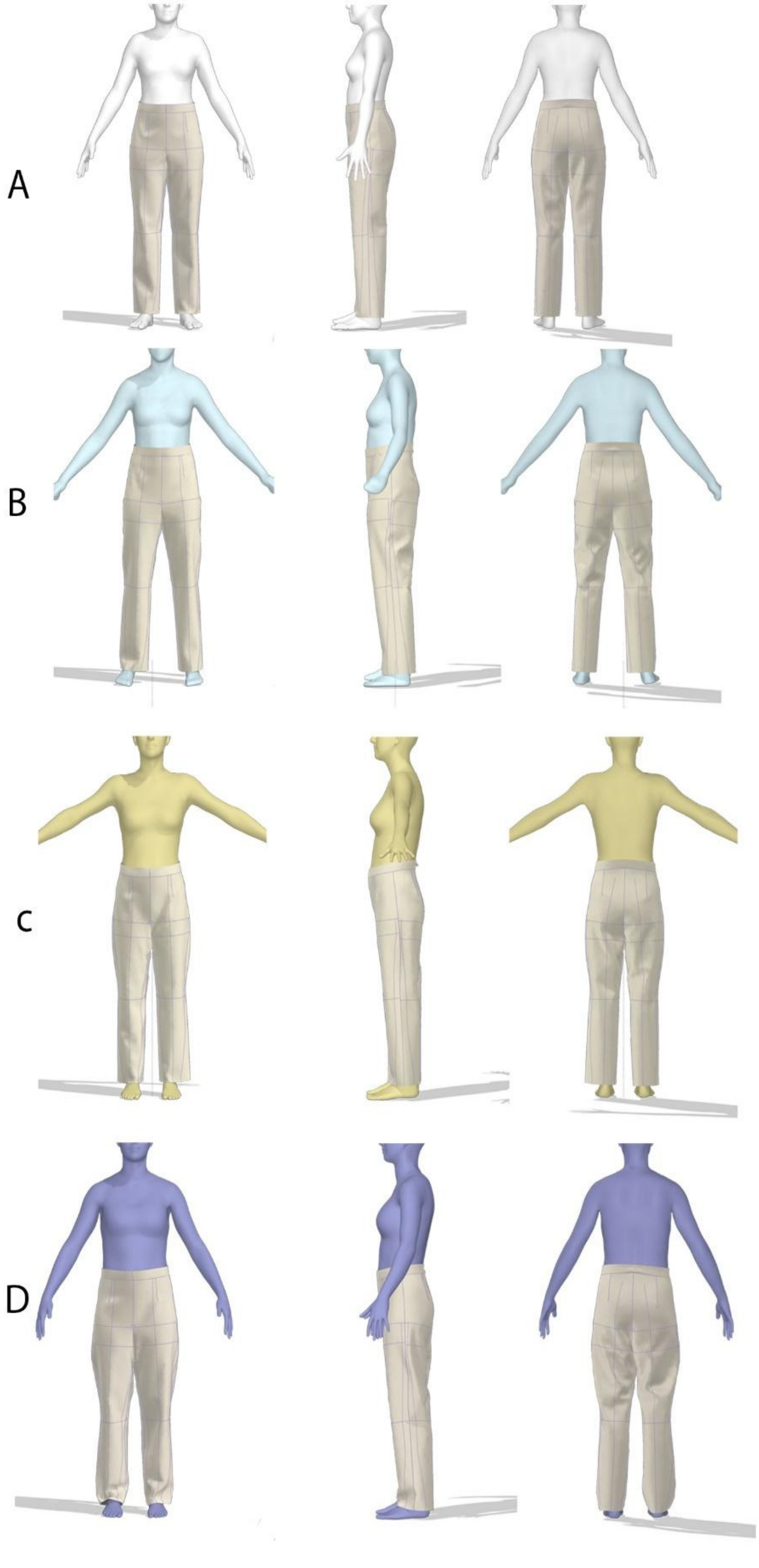


Figure 9: Virtual try-on for participant 1009 yielded mixed results. Trousers were generated from four scans and resulting patterns; front, side and back views are shown for each pattern. Note the varied pelvic tilts and how this impacts front and back sides of the waist.

4. Conclusions

The crotch point and the crotch curve are critical elements of pattern generation for trousers, and these elements are not currently available in scanning technology in a way that enables them to engineer the pattern. Much discussion has focused on waist and hips, but there has been less attention paid to delivering accurate crotch data to drive the components that generate comfort in the product and positive visual outcomes in the virtual fitting. There is a need for a clear definition of the crotch respecting the need to define it relative to a virtual scan environment, something which has begun but requires development [9].

The fashion industry and patternmaking experts need to provide more guidance to the scanning industry, particularly as it relates to fitting larger bodies or those with leg areas that touch. Simply asking participants to change their poses for wider leg spread is not the solution. Rather, there should be an application of logic in generating the mesh to determine the crotch points and curves and clear theory to support the different actors at each stage of collecting and applying the data.

We were able to establish how this research has contributed to theoretically and practically.

4.1. Theoretical contribution

There is a need to better define the crotch position, which requires a robust theory of the crotch point in X, Y and Z space suitable for measurement in a scan environment. This is not only necessary to begin creating better novel pattern methods, but also for the programming of figure data that maybe used in various areas of the supply chain, such as 3D modelling for dress forms.

This research clearly establishes the opportunity to link the body and the pattern block and sets a trajectory for development that allows clear linkages to be more explicit.

4.2. Practical Implications

This paper illustrates it is possible to develop bespoke patterns directly from body scan data, however for a more linear process the definitions of measurements extracted need to be more consistent between body scan providers. Parametric patterns using software such as Seamly allow for the quick development of individual pattern blocks and for the application and development of pattern theories to engineer patterns based on individual user input.

The process of pattern development to virtual fitting can be applied, however a consistent body outline is required and clearer body-to-pattern links maintained during the virtual fit process. Consider how these might be programmed as “if/then” software statements, for example, or imagine how body landmarks would automatically drive adjustments to the pattern and remain within the digital file for virtual try-on.

It is imperative to appreciate the implication of lack of consistency between body scan providers. If a body scan fails to accurately capture the size and contours of the body, any garment based on the information gathered from that scan will not fit properly. With a lack of consistency between scan providers, scalability is severely limited, since garments made with information from one provider will fit differently than garments made with information from another provider.

In addition, current methods of clothing patternmaking were developed long before the development of scanning technology. At that time, it was impractical to obtain anything other than surface measurements. “Measurement extraction” and other scan processing generally attempts to re-create the experience of an experienced tailor measuring the body, paying little if any attention to the actual three-dimensionality of the body. Due to the limitation of information available in the past, existing patternmaking methods make assumptions about the shape of bodies. To move forward, a fundamentally different method of pattern making must be developed; one that embraces the three-dimensionality of the data available from body scans.

Furthermore, to enable any such new pattern making methodology to be scalable, it is imperative that the scanning technology be separated from the processing technology. Such new patternmaking methodology would require fundamentally different information from the body scans, some of which might be proprietary. Standardization of measurements is not enough. To move forward with such new technologies, it is necessary to be able to automatically extract the required information from output scans from many different providers.

Limitations and Further Research

Further research requires more accuracy of the person's posture to aid in the research on body circumference depths in relation to crotch point. Evaluations such as lighting, camera, depth of field and other program controls may also be evaluated.

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