

Cross-Platform 3D Workflow for Developing Asymmetric Dress Forms for Wheelchair Users

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Abstract

This study investigates the development of custom, full-scale dress forms for wheelchair users using a combination of 3D body scanning and 3D modeling technologies. Four wheelchair users were recruited, and two data acquisition methods were employed based on participants' physical conditions: full-body 3D scanning and creating customized digital avatars. Both methods enabled the generation of usable body data; however, avatar-based modeling presented limitations, including restricted representation of asymmetrical body shapes and unrealistic soft-tissue deformation in seated postures, such as abdominal volume redistribution between the thighs. Additional technical challenges were identified, particularly inconsistencies in cross-platform scaling when transferring data between software applications, which required manual correction. Despite these limitations, the proposed 3D workflow demonstrates the feasibility of producing customized foam dress forms that reflect seated and standing postures relevant to wheelchair users. The final foam dress forms were evaluated in an educational setting by fashion design students, who used them for garment design, pattern development, and fitting. Feedback indicated that the custom dress forms enhanced students' understanding of non-standard body shapes, reduced apprehension when designing for individuals with disabilities, and improved efficiency in the pattern development and fitting process.

Keywords: 3D body scanning, Custom dress forms, Inclusive fashion, Wheelchair users

1. Introduction

A dress form is a three-dimensional replica of the human body used in fashion design and garment construction to create, fit, and alter clothing without the need for a live model. Conventional dress forms are designed for mass-market consumers, utilizing standard body measurements and symmetrical body types. This approach often fails to accommodate individuals with divergent body types or disabilities, particularly wheelchair users. Young designers or students are often encouraged to think critically about inclusivity in their designs; however, they may lack direct experience with the unique needs of diverse body types and the unavailability of "real-size" dress forms.

Wheelchair users and individuals with conditions such as scoliosis, cerebral palsy, or muscular dystrophy present notable deviations from standard body proportions, necessitating custom-fitting approaches [1]. The conventional clothing in the mainstream market often lacks designs that accommodate a seated posture, which requires garments tailored to eliminate tightness and excess fabric while incorporating features such as open waistlines and flexible structures for easier wear. Many wheelchair users opt for garments with stretch materials to meet these requirements.

Research has focused on using 3D body scans to create innovative body forms, including a woman's half-scale dress form in standing poses [2–4] and in active poses, such as cycling [5] and sitting poses [6]. Research highlights that incorporating posture-specific metrics into adaptive clothing design is crucial for achieving functional comfort, which includes reducing pressure points, accommodating various seated postures, and facilitating ease of dressing [7–8].

Advances in 3D body scanning and modeling technology allow designers to capture precise postural and asymmetrical features, creating customized dress forms and digital prototypes that more accurately represent diverse body shapes [2,9–10].

The gap in fashion education regarding accurate representation of diverse body types poses challenges for young designers, particularly in patternmaking courses [10]. Without appropriate dress forms, young designers struggle to create well-fitted garments for individuals with disabilities. Previous studies have developed various types of foam dress forms or 3D-printed forms using 3D scanning technologies [4, 10] and employed 3D modeling software to create customized avatars [11].

This exploratory study aims to develop and evaluate a practical workflow using 3D technologies to produce full-scale, custom foam dress forms for wheelchair users. The study addresses constraints posed by scanner accessibility, posture requirements, and software limitations, while providing

pedagogical value for fashion design education. By integrating these technological advancements, the project aims to cultivate a new generation of designers capable of creating inclusive and functional fashion for diverse body types.

2. Method

2.1 Participants

For this study, four wheelchair users were recruited to provide insights into their specific fitting needs. The conditions of the four participants are as follows: Model 1 can stand and walk for a short time if needed but relies on a wheelchair. Model 2 has paraplegia but is independent and can take care of herself. Models 3 and 4 have limited arm mobility and require 24-hour care for daily activities. The participants were informed that they would each serve as a model for students in an introductory flat pattern class and would participate in the design process for creating custom dress forms.

2.2 Body scanner selection and scanning protocol

The Vitus Smart XXL 3D body scanner (by VITRONIC) was selected for this study because it was the only full-body scanning system available in-house at the institution and had been previously validated in related apparel research projects. The scanner provides high-resolution, full-body point cloud data suitable for generating accurate cross-sectional slices for dress form construction. Due to project time constraints, budget limitations, and limited institutional access, it was not feasible to conduct a search for alternative scanning systems during the study period.

Hand-held 3D scanners were considered; however, they were not adopted for this study for several reasons. Full-body hand-held scanning requires subjects to remain static for extended periods, which can be particularly challenging for individuals with limited balance or muscle control. Additionally, capturing a complete standing scan using a hand-held device is challenging due to surface occlusion, alignment drift, and prolonged scanning time, which could compromise participant safety and data quality. For subjects who were able to stand (Model 1), a standing scan was prioritized when possible because standing posture provides a more stable anatomical reference for creating vertically aligned dress forms used in traditional pattern development and garment balance assessment.

To address these challenges, the original plan was modified to prioritize participant safety and data accuracy. Only Model 1 could enter the scanner chamber and be scanned independently. Model 2 was scanned with assistance; three individuals supported her body during the scan to maintain a seated posture. While this approach enabled data capture, it introduced potential inaccuracies due to external contact and constrained posture. Figures 1 and 2 show the 3D scanned images of Models 1 and 2.

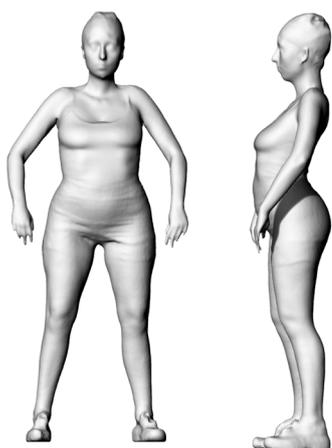


Fig. 1. 3D Scanned Image of Model 1

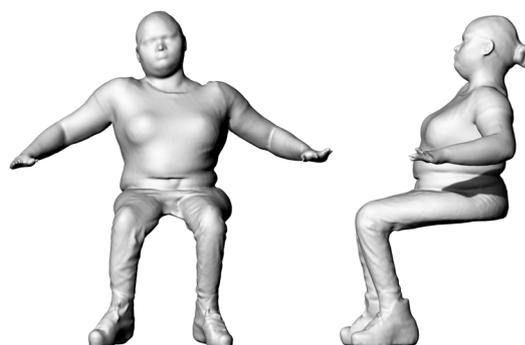


Fig. 2. 3D Scanned Image of Model 2

For participants who must remain seated in wheelchairs, hand-held 3D scanning presents a promising alternative and should be explored in future studies. Portable scanners may allow scanning in familiar seating systems, reducing postural distortion and participant discomfort. Evaluating the accuracy and usability of hand-held scanning systems for seated body scanning will be an important direction for future work.

2.3 3D avatar development

The original plan was to 3D scan all four participants using the Vitus Smart XXL 3D Body Scanner and then perform one-inch cross-section slicing to create foam dress forms. After reevaluating the scanner chamber capacity and the participants' conditions, several limitations were encountered. First, the chamber doorway was not wide enough to accommodate a wheelchair. Second, the scanning platform required participants to step up, which some could not navigate independently. Third, the scanning process required maintaining specific postures, either standing or seated, without back support, which was challenging for individuals with limited mobility or trunk stability.

Models 3 and 4 were not scanned due to their mobility and health restrictions; therefore, alternative methods were used to acquire 3D body images. To capture their body shapes and measurements accurately, a combination of manual measurements and 3D modeling techniques was employed. First, the body measurements, including various circumferences and lengths, were manually taken using a measuring tape while the participants were seated. Additional measurements from traditional standard body measurement points were taken to ensure body data accuracy, for example, upper and lower chest circumferences, waist-to-hip depths of front and back, waist-to-hip-to-back of knee length, center front length to top of thigh, center back length to the top of the seat, ranges of arm movement to possible pocket placement, etc. Since the participants had unique body sizes, the images of the nearest-sized avatars in seated pose in front, back, and side views were created and marked to assist designers in visualizing where to measure. Measurements were input into CLO3D to create customized avatars (Figures 3–4), which were then exported as OBJ files for further processing. Using CLO3D's avatar customization functionality in CLO3D version 7, approximately 7-10 body measurements were input to generate each customized avatar.

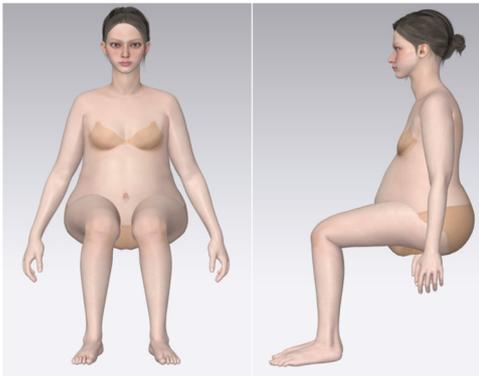


Fig. 3. Custom Avatar of Model 3



Fig. 4. Custom Avatar of Model 4

2.4 Cross-section slices and dress form assembly

After the avatar files were created and modified to ensure an accurate representation of each participant's body measurements, the software Anthroscan (by Humanetics) was employed to create 1-inch cross-sectional slices from under the chin down. These steps followed previous studies [4, 10], except that the present study used 1-inch slices to build a full-scale dress form, whereas previous studies used slices of 1/4 or 1/2 inch to create half-scale forms. The rationale for developing full-scale dress forms was two-fold. First, they provide a more accurate representation of individuals with irregular body shapes, allowing young designers to better visualize the figures of their models to better develop designs and patterns, particularly during 2D pattern development. Second, full-scale forms are essential for fitting sessions, as they more closely replicate the actual model's proportions and enable more precise assessment of muslin fittings and garment fit.

In each cross-section slice image, two reference measurements of height and width were marked before being screen captured and saved. Each sliced image was labeled in order from top to bottom. Adobe Illustrator was used to scale the image to full scale, ensuring that the cross-section image had the correct measurements. This step was time-consuming due to a minimum of 30 images for each participant. Figure 5 summarizes the workflow steps.

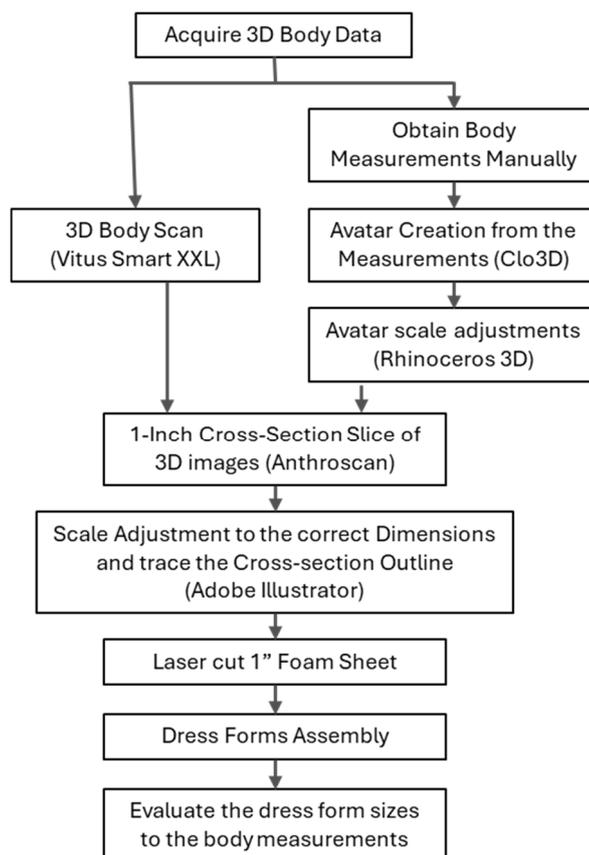


Fig.5. Summary of the Workflow

One-inch Polyethylene foam sheets were laser cut and glued together to assemble the dress forms. The final steps were to confirm that the foam dress forms' measurements were accurate and accurately reflected the participants' body sizes and shapes, as well as to reference and add landmarks critical for pattern development to the dress. For example, bust points, center front and center back lines, necklines, waistlines, and hip levels were clarified to help guide students in creating well-fitted patterns.

Two poses were selected for the dress forms to represent: a seated position (Models 2 and 3) and a standing position (Models 1 and 4). Diverse postures were chosen for each model based on their anatomical configuration and daily activities. For instance, although Model 4 remains in a wheelchair throughout the day, she engages in a daily stretching regimen that necessitates standing for a specified duration. Model 3 is restricted to the use of a wheelchair; consequently, a seated dress form is more necessary to design for her than an upright dress form. In the end, the dress forms were built from below the chin to four inches below the crotch. Figure 6 shows the final custom foam dress forms of all four participants.

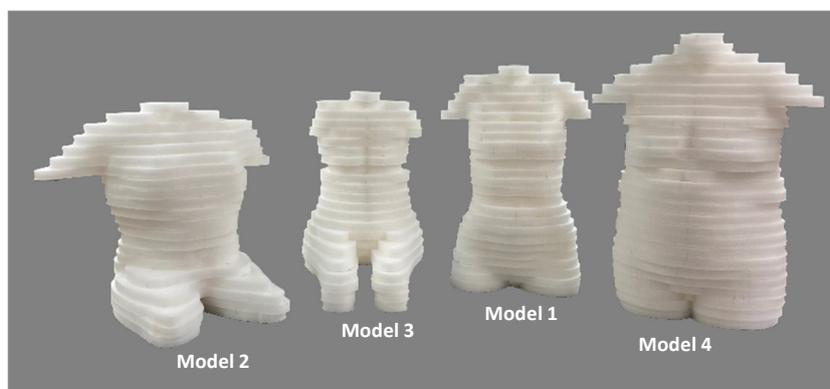


Fig. 6. Finished foam dress forms

2.5 CLO3D avatar limitations

While CLO3D offers an accessible and efficient platform for avatar customization, the software presents several limitations when applied to individuals with disabilities. The avatar system primarily supports symmetrical body modeling, restricting its ability to represent the asymmetries commonly observed in wheelchair users, such as uneven shoulders, pelvic obliquity, or spinal curvature. Additionally, the number of customizable measurement parameters is limited, preventing the full representation of complex body geometries and posture-induced volume redistribution.

Another limitation is that pose transformations in CLO3D rely on algorithmic deformation rather than biomechanical simulation. As a result, when transitioning avatars from standing to seated poses, body mass, particularly in the abdomen and hips, was redistributed in an unrealistic manner, resulting in discrepancies in circumferential measurements and surface contours.

Future research could explore alternative avatar systems or 3D modeling applications that allow for asymmetrical inputs and posture-specific morphing, enabling higher levels of control over body shape customization. Integrating such systems could significantly improve the accuracy of digital-to-physical translation in adaptive apparel design.

3. Results and Discussion

3.1 Comparison of the 3D body scan data and the customized avatar data

The data obtained from a 3D body scanner is generally more accurate than the customized avatar data, as the scanning process captures surface geometry directly from the participants' bodies. However, the accuracy of 3D body scan data is highly dependent on the participant's ability to maintain a stable and natural posture during the scanning process. If a participant cannot maintain the required posture independently, localized inaccuracies may be introduced.

For example, in this study, Model 2 required physical assistance to remain stable during the scan process. The presence of supporting hands and partial obstruction of the body surface likely introduced localized distortions and shadowed regions that were later interpolated during post-processing. In addition, the seated posture adopted during scanning differed from the participant's typical wheelchair posture, which may have influenced the distribution of soft tissue in certain areas (Figure 7).

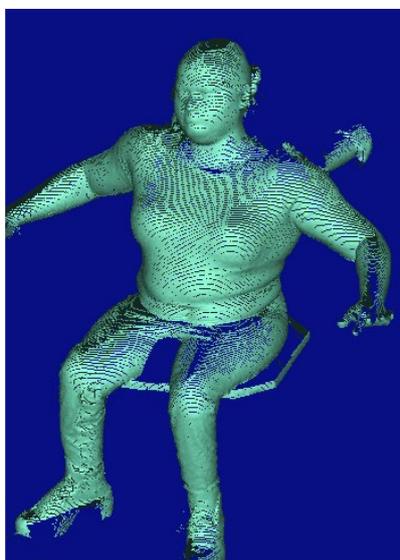


Fig. 7. Model 2 scanned image with the extra hands of the assistants

The ability to customize avatars provides an alternative method when 3D body scanning is not feasible. In this study, the application used for avatar creation is limited to generating symmetrical body shapes, which may limit the representation of the unique asymmetries found in individuals with disabilities. Furthermore, the number of body measurement parameters that can be directly input is limited, restricting the representation of complex body geometries, posture-induced asymmetry, and soft-tissue redistribution. As a result, customized avatars should be understood as simplified geometric approximations rather than precise anatomical replicas.

To estimate the overall accuracy of the resulting foam dress forms, key circumferences (e.g., bust/chest, waist, hip), vertical lengths, and depth measurements were re-measured on the completed dress forms and compared against the participants' original body measurements. Minor deviations were observed, particularly in areas influenced by seated posture and soft-tissue compression, such as the abdomen, upper thighs, and hip regions. These deviations were generally within approximately 0.5–1 inch, which is consistent with variations reported in previous studies involving seated body measurement and soft-tissue deformation.

Importantly, the magnitude of these scanning- and modeling-related inaccuracies is small relative to the coarse spatial resolution of the one-inch sliced polyethylene foam construction used to fabricate the dress forms. Given the educational intent of the project, the foam slicing process itself represents the dominant source of dimensional abstraction. Consequently, minor inaccuracies introduced during scanning, post-processing, or avatar generation did not meaningfully impact the functional utility of the dress forms for draping, pattern development, or fit evaluation.

Despite these limitations, the overall body proportions, posture characteristics, and key landmark relationships were successfully preserved in the final dress forms. This level of accuracy proved sufficient for instructional use, as evidenced by the reduced number of live fitting sessions required and the ability of student designers to achieve acceptable garment fit prior to final model fittings. These findings suggest that, for pedagogical applications, the developed workflow provides an effective balance between technical accuracy, accessibility, and practical usability.

3.2 Comparison of the standing pose and the seated pose

In comparing the standing and seated poses, the seated position is crucial for accurately addressing the fitting needs of wheelchair users, as it reflects their everyday posture and the fit of the patterns. While the 3D body scan accurately captured the interaction between the participant's soft tissue and the seat surface, the resulting bottom geometry reflects a chair-dependent deformation rather than an abstracted anatomical form. The flattened appearance is therefore not a scanning object but a realistic representation of the combined effects of body tissue compliance and seat material rigidity.

From a garment design and patternmaking perspective, however, such chair-specific deformation may limit the generalizability of the dress form when garments are intended to accommodate seated postures across different seating systems. This distinction is important when translating scanned data into reusable physical dress forms for educational use.

Although the CLO3D avatar presented a smoother and more visually continuous seated surface, it may not represent a biomechanically realistic seated human body. CLO3D avatars do not deform soft tissue in response to gravity or collision with rigid objects, nor do they dynamically adjust spinal curvature to reflect natural seated postures. As a result, the avatar should be understood as an abstracted geometric approximation rather than a realistic simulation of seated body anatomy. The perceived visual regularity of the avatar may support pattern development workflows, particularly by providing a simplified and repeatable reference surface; however, it does not accurately reflect the physical deformation experienced by living bodies composed of soft tissue.

This study found that a custom avatar can provide a simplified geometric representation of seated posture that is useful for initial pattern visualization, rather than an anatomically accurate depiction of the seated body. However, if the model has large waist measurements or a prominent abdomen, when changing the pose from standing to sitting, the computer algorithm may pull part of the abdomen between the legs, compressing and suspending soft tissue unrealistically, as shown in Figure 3 (side view). The circumferences of the high waist, diagonal waist-to-hip measurements, and thigh regions may therefore deviate from actual body measurements.

This may be due to limitations in pose-based deformation algorithms. While the human body redistributes mass differently when seated, depending on the muscle-to-fat ratio and tissue compliance, the computer model applies generalized transformations that may not accurately reflect individual body behavior. Realistically, the abdomen may drape over the thighs, and the hips may expand onto the seat surface more than represented in the avatar. Consequently, addressing these discrepancies is essential for improving the accuracy of digital representations and ensuring that the resulting garments fit comfortably for the models.

Future work may benefit from incorporating more advanced biomechanical or skeletal-based rigging approaches that allow for posture-dependent spinal curvature and soft-tissue deformation, thereby improving the fidelity of seated digital body representations.

3.3 Technical challenges and limitations

This study employed different 3D scanning and 3D modeling technologies, such as Vitus Smart XXL 3D Body Scanner (VITRONIC), Anthroscan (Humanetics), CLO3D, Rhinoceros 3D (Robert McNeel & Associates), and Adobe Illustrator. While no issues were found when viewing the scanned data on Anthroscan, obtaining cross-section slicing images took several steps. First, the measurements were marked on each of the cross-section images and screen captured. Then, Adobe Illustrator was used to trace the outline and scale it to the correct measurements. These steps were time-consuming and required careful attention to detail to ensure accuracy. Additionally, the integration of various software tools presented challenges in maintaining consistency across the design process.

Once the custom avatar was created, the data file was sent to get the 1-inch cross-section slices. After opening in Anthroscan and Rhinoceros 3D, the avatar files were not opened in the correct scale. The 3D figures were only 3 mm tall. This caused much confusion as different settings were applied to all three programs to correct the errors, but the problems persisted. In the end, to troubleshoot the scaling issues, we performed manual adjustments, which delayed the overall workflow and required additional validation to ensure accurate representations of the participants' body shapes and sizes. These challenges underscored the necessity for improved compatibility between different 3D modeling software and scanning technologies. Better compatibility between programs can streamline workflow and enhance accuracy in fashion designs for individuals with disabilities.

3.4 Perceptions and applications of the custom dress form

Overall, the comparisons of the participants and dress forms are accurate. The participants were surprised and happy to see themselves in a custom dress form. The young designers found the dress forms to be very beneficial in the design process, pattern construction, and fitting. As some of them have only met the participants virtually or on the phone, the dress forms served as accurate physical visualizations of the participants. These dress forms helped students create a design that complements the model's body and enhances the comfort and function of the garment, fitting the model's needs. In the pattern construction phase, the first and second draft patterns were quickly draped on the dress form and modified to fit the body before students created the fitting muslin. The fitting muslin was tried on the dress form, marked, and adjusted. These steps are crucial not only for the designers but also for the models. At least two adjustments of the muslin fitting with the dress form were done before a real fitting session with the models. In the end, only one fitting session was needed before final pattern adjustments. Some of the patterns did not require any adjustments. The feedback from the young designers was very positive, with some describing this project as fun. Feedback also addressed how students liked to work with a real client who diverges from the norm, with some describing how they would like to design for those with disabilities in the future. The participants were also pleased that they did not have to travel for several fittings, and described being able to see their custom dress form as a great experience.

4. Conclusion

This study presents a feasible cross-platform workflow for generating custom asymmetric dress forms using commercially available 3D technologies, despite existing software constraints related to accessibility, handling asymmetry, and posture representation. The findings underscore the importance of carefully selecting scanning technologies based on participant abilities and project objectives. The interdisciplinary collaboration combined expertise from fashion design, special education, and digital modeling, demonstrating the value of cross-disciplinary partnerships in inclusive design education.

Future research directions include the systematic evaluation of handheld 3D scanning systems for seated wheelchair users, refining avatar creation pipelines to better represent asymmetrical and posture-dependent body shapes, and developing more efficient and interoperable methods for generating sliced images and constructing full-scale dress forms.

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