Digitisation of Body Modification Garments to Ensure Silhouette Accuracy in Historical Costume

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Abstract

Body modification undergarments - that alter, accentuate and create desirable silhouettes by applying force to the body or through structured wearable enhancements - have been used to throughout history. In costume, historical body modification garments are important symbols for portraying wealth, position and historical context.

Garments that modify the body present a challenge for digital historical pattern creation as digital avatars are commonly solid 3D objects which are unable to 'realistically respond to external forces' e.g. 3D constructed/simulated garments. This study investigates harnessing body scanning and digital processes to create silhouetted avatars, to permit the digital production of historically accurate patterns that are accurate of an actor's biometric data.

The research takes an empirical approach to test four experimental digital workflow methods and develops a specific process for body modification avatars. The processes are then applied and assessed through production of a digital 16th century historical costume garment. The results offer metric and observational insights into workflow consistency, dimension accuracy, and mesh usability.

The generation of 'silhouetted period avatars' using 3D body scans and historical body modification garments supports the digital creation of costumes with increased efficiency and historical accuracy.

Keywords: Digital Fitting, Costume Design, Historical Silhouette, CLO3D, Digital Body Modification, Bespoke Avatar, Theatre, Digital Pattern Drafting

1. Introduction

3D Body scanning and digital workflows can offer an effective alternative to traditional garment production [1]. There has been growing recognition of vital links between 3D body scanning and garment pattern production in the fashion industry [2]. Comparatively, little research has investigated how to apply these methods to costume processes, particularly for bespoke complex garments such as period costumes. These intricate garments present a particular challenge due to the use of body modification undergarments such as corsets and their influence on form and silhouette.

This study investigates how 3D body scanning and digital construction can cooperate with existing hard skin avatar technology to produce 'silhouetted period avatars', allowing the creation of digital, historical costume patterns which require body modification undergarments. The term 'hard skin avatar' refers to avatars which are solid objects and unable to respond to external pressure applied to their surface. This research seeks to develop a workflow for digital, historical pattern production which can be used in the historical costume making process. To ensure the production of a successful workflow, this paper compares different body scanning and construction techniques, evaluating their performance throughout.

1.1. Costume Realisation Process

Known to be complex [3], the costume making/realisation process consistently encounters challenges such as tight budgets, short turn arounds, and traditional, time intensive methods of making garments [4]. Consequently, experimental and innovative approaches [5] to traditional production methods are required to ensure ease of working and to preserve the industries iterative rather than linear production process [4]. Existing alternative production methods include padding out a dress form and cutting on the stand [5], second skin pattern cutting (ibid), and creating digital twins of individuals utilising historical body dimensions [6]

The ongoing evolution of technology and digital tools permits exploration of further alternatives. This paper aims to contribute to this exploration and produce a valuable framework for digital, historical pattern production in the costume industry as it continues to adopt digital processes into its practices.

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1.2. 3D Body Scanning and Digital Processes in Costume

While fashion and apparel industries have widely adopted 3D body scanning and digital garment workflows, their integration into the costume industry has been more gradual [7]. For costume designers, the most advanced examples of digital processes are evident in high-budget blockbuster films. Costume designers collaborate with digital departments or specialist workshops to combine traditional craft with advanced technologies [8]. Current digital practices in film costume include:

- *3D Body scanning of actors*: Now standard in many blockbuster productions (e.g., Marvel, DC, and Disney franchises), actors are digitally scanned, producing highly accurate digital doubles that inform both physical costume builds and CGI integration [9]. Another practice used is 3D printing scans of actors to produce a physical dress form precise to the measurements of their bodies [10]. This method enables practitioners to construct and adjust the costume to an actor's body without them being present.
- *Digital pattern-making and fabrication*: Tools like Clo3D and Marvelous Designer are used by some costume illustrators and pattern-cutters to create and simulate garments digitally before committing to expensive or time-intensive builds [8]. These digital garments can be exported directly for 3D printing or laser cutting.
- *3D printing and CNC milling*: Hard-surface costume components (e.g. armour, helmets, corsetry elements) are frequently modelled in ZBrush or Maya and then printed or milled, before being finished by hand [11].
- *Digital doubles*: In cases where costumes are fully digital, physical costume teams often create reference garments or partial builds that are scanned to inform VFX workflows [9].

Despite this, widespread adoption of digital technologies remains uneven. Large-budget productions increasingly depend on these tools, while smaller productions often lack access due to cost. Costume departments have been slower than fashion houses to adopt end-to-end digital workflows, relying instead on selective integration where digital tools support, but do not replace, traditional craft.

The film industry's hybrid adoption of scanning, digital fabrication, and 3D design underscores both the opportunities and challenges of digitisation in costume practice.

1.3. Digitisation of Body Modification Undergarments

The term body modification undergarments refers to garments such as corsets, and/or structured skirts. These garments alter the body's silhouette, either by applying an external force and compressing the body or through the addition of structured wearable enhancements. They are used in costume to support the wider performance, complimenting the narrative and its wider contexts such as location, period, activity, and class. Usually worn beneath the main costume, they are commonly heavily structured to impact the shape of the over garment and provide the illusion of a different silhouette.

Current hard skin avatars are unable to realistically respond to external forces [12]. This lack of soft skin means they do not interact with 3D constructed/simulated garments correctly. Where the purpose of the garment is to modify the form and silhouette of the body, it prevents the accurate and practical use of body modification undergarments from altering the shape of the body in 3D apparel CAD software. Soft skin avatars [13] are available however, this paper has focused on cooperating with hard skin avatars as these are more commonly used in 3D apparel CAD software [13].

There is little research on digitising body modification undergarments however, perhaps the most detailed account is to be found in the work of Kang [14] and Kang et al. [15], [16]. Through a series of papers, Kang et al investigated methods for the digital recreation of historical costumes for exhibition in a museum, experimenting with different photo scan software's to obtain an accurate digital silhouette. Agisoft PhotoScan was chosen to produce the digital body modification objects. Photographs were taken of the torso of a historical mannequin and crinoline skirt and processed to create digital objects. To create a virtual figure, the objects were 3D modelled together in the software 3DS Max alongside a head and limbs generated in MakeHuman. This method of scanning and modelling proved successful for producing a historically accurate silhouette and figure. It permitted the creation of a digital historical costume replica which was pattern drafted in 3D apparel CAD software. Kang's research is an example of how the digitisation of body modification undergarments can be used to create accurate period garments as museum exhibits in the heritage sector.

Historical accuracy is also important within historical period costume design, however fitting is a key aspect that needs to be considered in terms of a digital process. The bespoke measurements of an undergarment on a performer's body combined with historical accuracy provide a specific challenge for this study.

2. Methodology

This research uses an empirical approach by evaluating multiple 3D body scanning methods and processes to create silhouetted period avatars. This was conducted in two stages:

- Stage 1, Period costume digital workflow trials - Four different workflow methods to create viable period costume patterns were trialled. Quantitative metrics were used to compare different scanning technologies and processes [17]
- Stage 2, Proof of process study - full trial of a new workflow process to create a 3D design of a historical late Tudor period costume originally designed for a theatre production [18].

This enabled the proposal of a viable workflow to create complex outfits using body modification undergarments.

2.1. Digital workflows

Two separate 3D body scanning technologies were used to scan and create avatars.

1. Infrared 3D body scanning with Sizestream SS20 booth scanner.
2. Structured-light scanning using a handheld PEEL 3 3D scanner.

Four experimental digital workflow methods described in table 1 were explored in this study.

Table 1: Digital Workflow Methods

Digital Workflow methods	*Scanning technology*	*Avatar creation*	*Pattern production*
Workflow 1	N/A	Clo3D used to 3D model undergarments, then added to a standard avatar from Clo3D library	Clo3D 2D window Pattern drafting
Workflow 2	Sizestream SS20 booth scanner	.obj file imported into Clo3D and 'autoconvert to avatar' tool	
Workflow 3	Peel 3D with tracking points and turntable		
Workflow 4	Peel 3D with tracking points.		

Four different workflow methods were trialled in this study to create a 3D representation of the participant wearing body modification undergarments. Workflow 1 used a standard avatar and digitally constructed the undergarments within 3D pattern drafting and garment simulation software CLO3D. Workflows 2, 3 and 4 involved 3D body scanning a participant wearing the body modification undergarments to create an avatar.

A mixture of quantitative and qualitative methods was used to assess and compare the workflows and determine if the trialled methods functioned as required. The study collected primary data in the form of scans and digital garments, as well as time metrics from the Sizestream manufacturers guide. An assessment of layer interference, method consistency, and pattern fit accuracy provided an evaluation for each workflow.

2.2. Body scan participants

Criterion based sampling [19] was used to select participants for this study. Primary inclusion criteria for the participants were adult female, comfortable with the idea of being scanned and identify between a size 6-12. This parameter was set to ensure the participant was able to fit in the undergarments being used in the trial without disrupting their consistently measurable structure. This allowed comparison across the workflow; however, it does not allow participants measurements to evaluate accuracy. Prior to scanning, the participants received an explanation of the project and were asked to fill out a consent form regarding their involvement which described in detail how their data may be processed and used. Two individual participants were used in the scanning process; one participant was scanned using the Sizestream SS20 and the other was scanned using the Peel 3. The choice to use two participants was due to the scanner/participants availability and did not affect any results as the same undergarments were used for both participants. Both participants were required to stand in an 'A' pose for the duration of their scans and tracking dots were applied during the Peel 3 3D scans to aid with tracking.

Once the participants had been scanned, their scan data was converted into an avatar using CLO3D and a typical CLO3D process was used to create a digital 16th century dress pattern. The pattern was chosen as a real-world example of a garment for production and was adapted from two pattern drafting books [20] [21]The patterns were iteratively altered in relation to the fit of the digital historical costume on the avatar.

2.3. 3D Digital Undergarment Construction

Workflow 1 used a stock avatar from CLO3D's avatar library, a 16th century farthingale undergarment was digitally pattern drafted to fit the body and resemble a traditional physical undergarment. Once the patterns were completed the corresponding 3D garments were frozen (become solid objects that do not respond to external pressure), and a standardised Clo3D process was used to create digital patterns. The patterns were iteratively altered in relation to the fit of the digital historical costume on the avatar and the frozen digitally constructed undergarments.

2.4. Evaluation Process

The physical historical body modification undergarments used in the scans were measured against their digitally constructed/scanned counterparts using a physical tape measure and the basic circumference measurement tool in CLO3D. The same positioning of the measurements was ensured by utilising the garments structured hoops which were prominent in real life as well as digitally; they allowed consistent measuring of the circumference of the undergarment across all methods. Due to its structure, the size and shape of the hoops of the physical undergarment measured did not change between each participant permitting consistency between both scans.

Observations were manually recorded throughout the trials in relation to layer interference and manual data input/editing process. Layer interference refers to obvious abnormalities in scans where the avatar may cause tension on the digital garment or in severe cases the avatar protrudes through the garment. Evidence of this can be seen in Figure 6: 1. And 2. Furthermore, to collect time metrics, videos with time stamps and secondary data sources in the form of manufacturers guides were used. These mixed methods of data collection were adopted to allow for a comprehensive evaluation and measurable comparison of each trial production method.

Table 2: Evaluation metrics and Operational Definitions

Scan Capture Time	Referring to scan capture only. Not including set-up time, calibration or obj processing time.
Undergarment Dimensions	• The first hoop below the waist of the farthingale was measured to compare the circumference between physical and digital. (Hoop one). • A single measurement was taken. • Tolerance within measurement resolution (<0.5cm).
Fit Accuracy to Traditional Garment	Accuracy of silhouette created by undergarments was determined by comparing the silhouette to reliable references.
Layer Interference	Visual inspection was carried out to assess issues.
Mesh Usability	• No mesh was altered in post clean-up. • 'Gaps' in the mesh refer to holes/missing surface of the scan.

2.5. Proof of process study

Once the variety of 3D body scanning options were explored in stage 1, the trial processes were tested as a completed workstream for the creation of a digital dress pattern of the late Tudor dress fitted to the participant in the appropriate body modification undergarments. Notes and data collected from this proof of process stage provided an assessment of the viability of the workflow for producing historical garments [18] utilising existing hard skin avatar technology.

3. Results

The following results provide an overview of the data and outcomes from the stage 1 experimental workflow trials and the stage 2 proof of process.

3.1. Period costume digital workflow trials

The exploration of using digital technologies to create period costume was an iterative process. Only after 3D modelling was trialled were 3D body scanning options tested. During all body scanning trials, the participants wore the same body modification undergarments: A corset, farthingale and Bumroll.

3.1.1. Option1, Modelling undergarments in 3D Pattern Drafting Software

Digitally constructing body modification undergarments onto a standard hard skin avatar was conducted using 3D pattern drafting and garment simulation software Clo3D. Figure 1 provides an outline of the workflow that was followed.

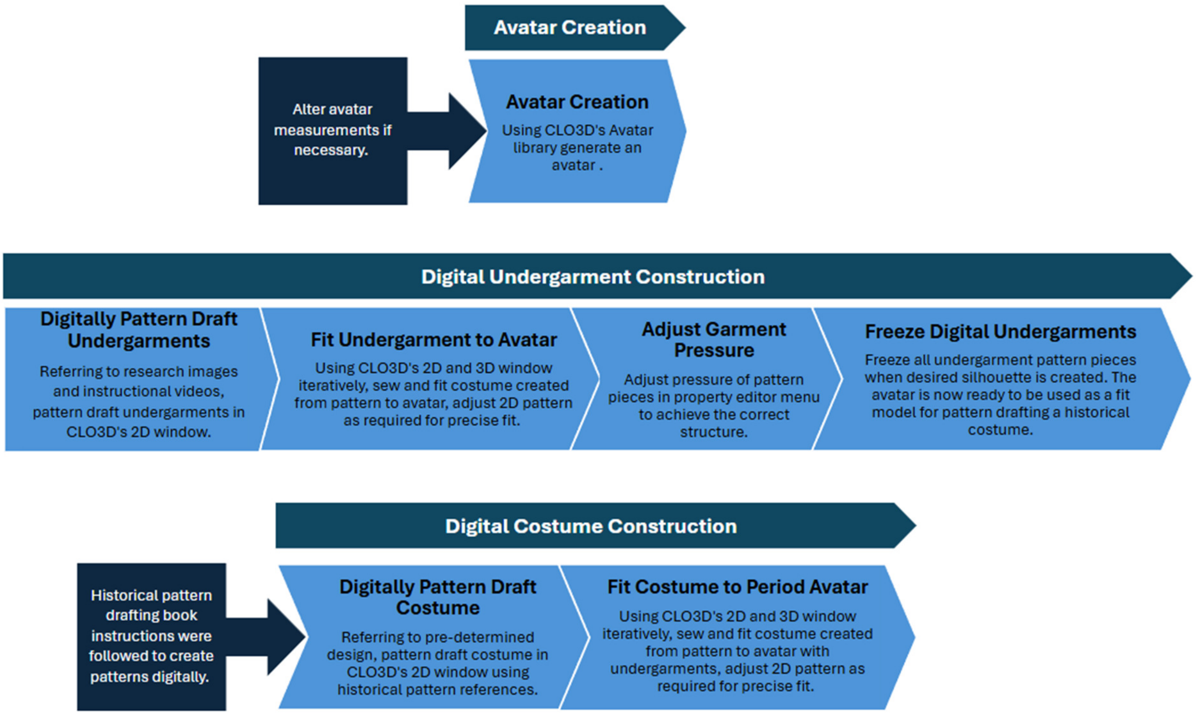

Fig. 1. Workflow 1 process flow diagram

The digital construction of undergarments in CLO3D was complex and inefficient. Typical digital garment processes were used to create the undergarments in the software however, due to the necessity of producing a structure that represented a traditional farthingale as well as imitate the effects of a corset, the process was prolonged, lasting many hours.

A core problem involved with digitally constructing the body modification undergarments was how they cooperated with the hard skin avatar. A hard skin avatar does not distort in response to a garments pressure on the body [12]. Figure 2 clearly demonstrates this in the 'corset's' inability to flatten and mask the shape of the breasts giving the appearance of a flat chest as it would in real life. Additional issues arose from the construction method of the farthingale undergarment; the construction was influenced by reference images and videos as well as interacting with the software's capabilities rather than converting manual measurements. Consequently, while the garment looked aesthetically correct the size did not reflect the traditional undergarment. Both issues affected the fit of the digital overgarment and as a result the final pattern. Manual measurements such as the circumference of the farthingale at different points could have been adapted from the physical undergarment and modeled in the software for a more accurate depiction of the garment; however, as the process was already both labor intensive and time consuming due to its many components and iterative construction in order to achieve a representation of the desired shape, continuing the process to produce a more accurate version proved to be fruitless. Specifically, as the process would have to be meticulously altered to change the size.

Furthermore, due to the number of layers caused by having garments sit on top of each other, there was interference with the fabric/structure of the undergarment and the over dresses. This issue was partially resolved by freezing the undergarment.

Fig 2: Undergarment digitally constructed in CLO3D

3.1.2. Option 2, Sizestream SS20 3D body scan converted to avatar

Figure 3 shows the Sizestream SS20 trial process flow - scanning a participant in historical body modification undergarments using a fashion industry booth 3D body scanner.

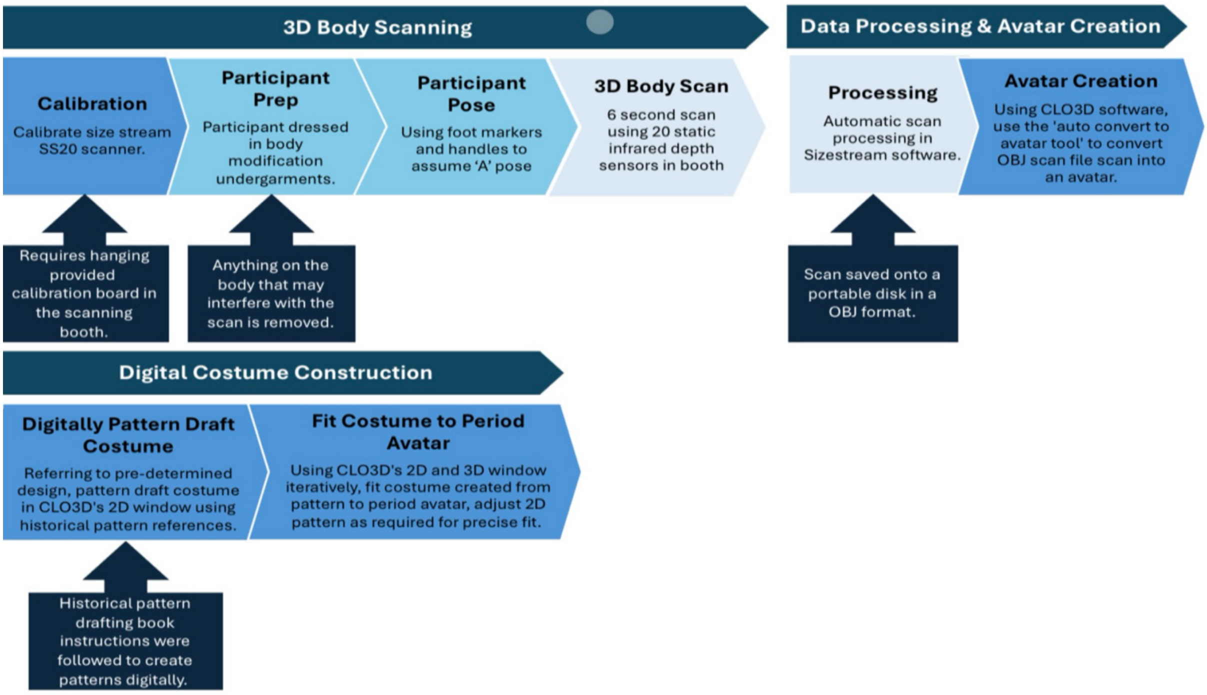

Fig. 3. Workflow 2 (SizeStream SS20) process flow diagram

The Sizestream SS20 scanning process as shown in figure 3, was simple to calibrate and run, the scan took only six seconds to capture and could be operated independently. Occasional issues occurred in relation to the processing of the scan in the Sizestream software. The scanner demonstrated limited ability to recognise objects that strayed severely from a standard body, in some cases preventing the archiving of the scan. This issue was intermittent and did not interfere too greatly with the production of a scan file to be converted into a bespoke avatar.

An issue with the Sizestream SS20 more generally is the line of sight for each sensor and the limiting size of the booth. Blind spots occurred in the scan where the sensors were obscured by the volume of the farthingale. This resulted in gaps in the farthingale when the avatar was processed. The farthingale in this case was still useable however, larger undergarments such as panniers or crinolines may cause complications. This calls attention to the method’s consistency and whether it is robust enough to be considered as a viable option for historical costume making practices.

In this trial, the process performed as desired and permitted the production of a historical dress pattern that was considerate of body modification undergarments and bespoke to the participant body measurements.

3.1.3. Option 3, Peel 3D with turntable 3D body scan converted to avatar

The Peel 3 3D scanning process using the turntable is described in figure 4. This involved- scanning a participant in historical body modification undergarments using a handheld, structured white light 3D object scanner and a turntable. This process was simple to set up, calibrate and execute. The handheld scanner was connected via a cable to a laptop displaying real time scan imagery throughout the process. The participant stood still on a turntable as it slowly rotated them; this allowed the scanner operator to single-handedly adjust the height they held the scanner to capture the entire body. The operator was able to utilise the real-time imagery on the laptop to identify missing mesh sections and aid in capturing a complete scan. A minimum of two people (participant and operator) is required for the capture process; the scanner cannot be used independently due to the motions required to record a full body scan.

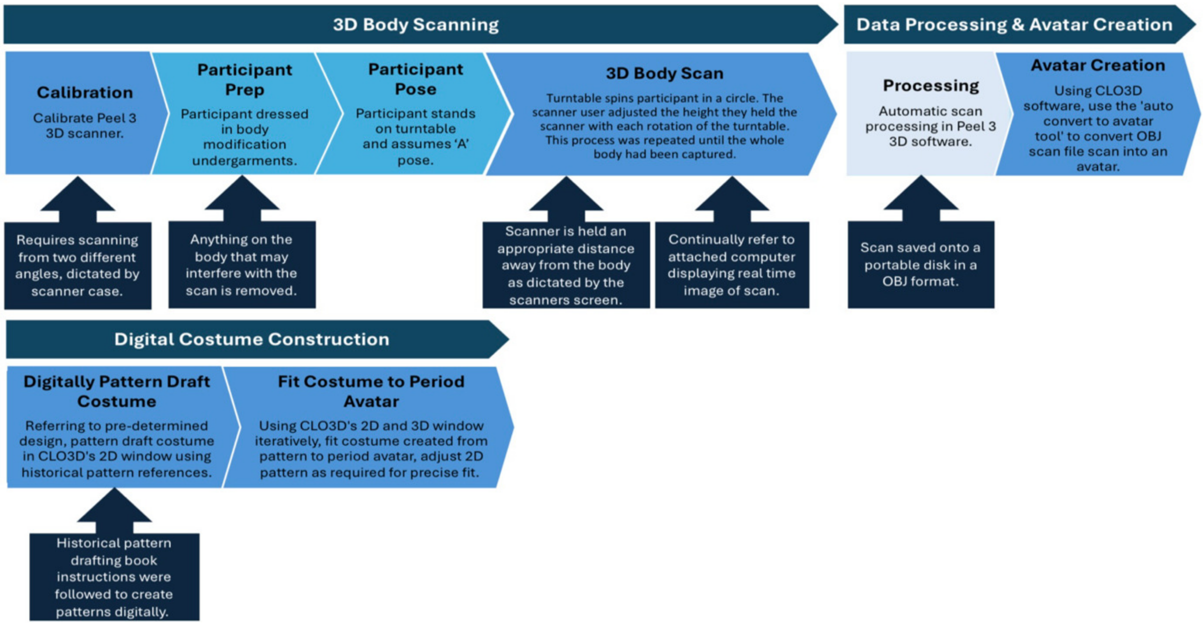

Fig. 4. Workflow 3 process flow diagram

An important feature of the Peel 3 3D that prevents compromising the scans mesh was the scanners tolerance of slight natural human motion. This feature was necessary during the scanning of the participant due to its long scanning time. On average, the scans taken using the Peel 3 3D were 5-10 minutes in duration, the participant was instructed to remain as still as possible during this time to help prevent the scanner from losing tracking. Tracking dots were also applied to the body, undergarments and the floor as reference points to aid the tracking further.

Using this method, the scans would start off clean but would lose tracking as the scan progressed, this was often when the scanner user attempted to scan areas such as the arms from the same, original position. As the scanner lost tracking, it would often produce a new scan that conjoined with the original making it unusable as an avatar. This method was inconsistent and unpredictable, making it unsuitable for the costume industry's already complex practices. Consequently, a decision was made to not proceed with the scans conversion and consequently the pattern drafting process.

3.1.4. Option 4, Peel 3D without turntable 3D body scan converted to avatar

Option 4 as shown in figure 5 involved scanning the participant dressed in the undergarments as they stood on the ground. This method required the participant to stand still in the centre of the room while the scanner operator circled the participant at different levels to ensure that the whole body had been scanned. These scans were far more consistent than option 3 and tracking was not lost as often. If tracking was lost it was often easy to rectify using the guide on the scanner.

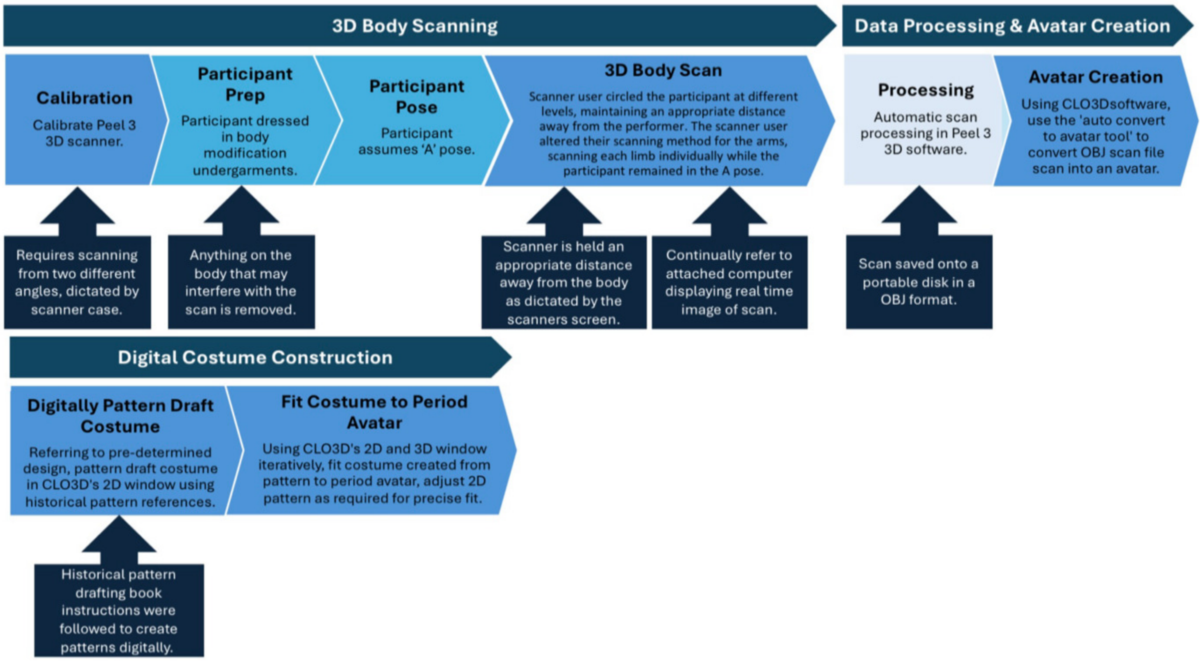

Fig. 5. Workflow 4 process flow diagram

Two issues emerged in the Peel 3 3D scanning process without a turntable, firstly, the areas of loss of tracking/performer movement where a second skin has formed, in this paper, this refers to the scanner registering another layer on top of the existing scanned surface giving the appearance of a second layer of skin. This was most commonly on areas such as the hands, arms and legs which were significantly more difficult to scan; this was due to having to navigate around the limbs without the participant moving. The second issue was, the cable between the scanner and the laptop restricted the flow of movement while scanning which occasionally led to gaps in the mesh.

Despite these issues, the scanning process was successful, and the scans produced were highly detailed and accurate to the traditional physical undergarments.

3.2. Experimental Overview

Table 3 provides an overview of the individual processes results, the metrics and definitions for these results can be found in Table 2.

Table 3: Experimental Overview

	Digital Undergarment Construction	*SS20 Sizestream Booth Scanner*	*Peel 3 3D with Turntable*	*Peel 3 3D without Turntable*
Scan Capture Time	N/A	6 Seconds	300-600 Seconds Approx	300-600 Seconds Approx
Layer Interference	Yes	No	N/A	Yes
Mesh Usability	N/A	Yes	N/A	Somewhat.
Undergarment Dimensions Difference(<0.5cm) (Hoop one: 134cm)	N/A	-2.31cm Hoop one: 131.69cm	N/A	0 cm Hoop one: 134.07cm
Accuracy to Traditional Garment	Somewhat	Somewhat	N/A	Yes

In all 3D body scanning trials, the scan data was imported as a .obj file. This format allowed CLO3D to convert the raw scan data into a digital avatar.

3.3. Additional Observations

- *Workflow consistency*: a further theme that emerged from observations throughout the process was the unexpected outcomes related to the consistency of the different workflows. All process demonstrated issues regarding consistency, some issues were rectifiable, however others demonstrated their workflows to be unusable.
  - *3D digital undergarment construction* – multiple iterative changes, unique to each size and body shape would be necessary to produce close to consistent and repeatable results.
  - *SS20 Sizestream booth scanner* – This method does not consistently perform; the software sometimes fails to recognise a body and therefore the scan does not finish processing. This could prevent the scanning of more obscure body modification undergarments.
  - *Peel 3 3D with turntable* - Turntable prevented the quality scanning of insides of limbs, this resulted in unusable scans due to the inability to draft and fit a garment to the body and consequently an unusable workflow.
  - *Peel 3 3D without turntable* – This method was somewhat consistent, occasionally the scanner would lose tracking, and the scan process would have to be restarted.
- *Layer interference:* Follow-up from table 3.
  - *3D digital undergarment construction* – Freezing the undergarments did not prevent the overgarment from interference evidenced in Figure 7 – Avatar 1 where the undergarment protrudes through the dress and causes tension on the fabric.
  - *SS20 Sizestream booth scanner* – There is no layer interference as the Peel 3 3D software produces a full mesh which prevents issues such as the over garment getting caught in gaps. It provides a solid surface similar to a mannequin, allowing the dress to sit atop of the avatar and be influenced by its shape.
  - *Peel 3 3D with turntable* – N/A
  - *Peel 3 3D without turntable* – There is slight layer interference as evidence in Figure.7 - Avatar 2. There are gaps in the mesh which have caused the overgarment to get caught on the digital costume, where a second skin has formed, you can also see the scan protruding through the garment at the shoulder. Both issues could be resolved by cleaning up the scan.
- *Physical Limitations:*
  - *3D digital undergarment construction* – N/A
  - *SS20 Sizestream booth scanner* – The size of the scanning booth limits the use of larger undergarments which limits this workflow.
  - *Peel 3 3D with and without turntable* – The scanner struggles to scan dark colours – any undergarments worn would have to be light in colour to achieve an effective scan without excessive gaps in the mesh.

3.4. Workflow trial - Historical Digital Pattern Making

Figure 6 shows the undergarments results without the overgarments. Figure 6. Avatar 1: Digitally constructed undergarments; Avatar 2: Peel 3 3D body scan without turntable; Avatar 3: Sizestream SS20.

The results were tested by creating a digital historical garment pattern, the results are shown in figure 7. Avatar 1: Digitally constructed undergarments; Avatar 2: Peel 3 3D body scan without turntable; Avatar 3: Sizestream SS20.

A 16th century historical dress pattern was drafted and sewn together in the CLO3D’s 2D window. The pattern and sewing were translated into 3D elements in the 3D window which permitted the fitting of the dresses onto the avatars. The patterns used were taken from historical pattern drafting books, this was to ensure their period accuracy [20] [21]. Additionally, these books were used to quantify and evaluate the fit and accuracy of the silhouettes created. Images in both books were used to determine whether the fit identified as acceptable as stated in Table 2. The Peel 3 3D and Sizestream avatars performed as desired, providing not only the actors measurement data but also the silhouette created by the body modification undergarments. The digitally constructed avatar's silhouette is less accurate due to the lack of structure and compression around the chest.

Fig 6: Avatars wearing undergarments

Fig 7: Avatars wearing 16th century digitally constructed dress

Occasionally, issues emerged during the Peel 3 3D process such as, when a measurement was required for pattern drafting, it was sometimes difficult to use the measurement tools in the software due to holes in the scan's mesh preventing the tools from taking full measurements. There was also difficulty fitting the garments to the Peel 3 3D and digitally constructed avatars at times as they would get stuck on the avatar where there were holes in the mesh or in the case of the digitally constructed undergarment in between the garment layers. Layer interference is evident in both the Peel 3 3D avatar and digitally constructed avatar in fig 7, noticeable by its stark white appearance against the purple of the dress.

All avatars were successfully used to pattern draft and create period accurate historical costume patterns that were considerate of body modification undergarments.

4. Discussion

4.1. Implications of Processes Tested

Considering the results in their entirety, there are indications that the Peel 3 3D scanner method without the turntable demonstrated the greatest potential as a digital historical pattern process. Fundamental to an effective process, the method is consistent, and the results are accurate. Naturally, there were also drawbacks to this approach such as the long scan time, layer interference and difficulty scanning dark colours, where the Sizestream SS20 proved superior. Nevertheless, this method retains its practical applicability and some of these issues may be resolved through additional scanning practice and cleaning up of the scan prior to avatar conversion.

In comparison, the Sizestream SS20, despite having a quick scan time, does not have a consistent and dependable method for scanning historical undergarments due to its limiting booth size. Similarly, the Sizestream is not easily transportable due to its size/set-up particularly when compared to the handheld Peel 3 3D scanner; this could play a significant role in determining its adoption in the industry. A notable feature of the process that would render this process equally as effective were it not for the size limitation, is its ability to be used independently while still providing clean and accurate scans. This adds to the efficiency of the process, allowing participants to scan themselves enabling focus to be elsewhere and could lead to faster turnarounds. Ultimately, both scanning methods proved valuable to the digital creation of historical patterns utilising existing hard skin avatar technology and have the potential as alternative historical costume making processes.

By contrast, the digitally constructed undergarments process did not demonstrate the same potential, the inaccuracy and long process time makes the process unappealing as an alternative historical costume method. Furthermore, unlike the scanning methods, the patterns produced from this process are not accurate to specific measurements, instead they rely on the measurements of a stock avatar – this does not measure up to the expectations surrounding bespoke garments in the costume industry. A solution to this could be to input physically gathered measurements to alter the stock avatars bodily dimensions, however even with these alterations, the issue still remains regarding the hard skins avatars inability to conform to the pressures exerted by 3D constructed garments making it clear why Kang [14]chose to scan the torso of a historical mannequin in order to create a period accurate upper body silhouette.

4.2. Utilising Current Hard Skin Avatar Technology

The present results are significant in at least two major aspects. Firstly, the application of body scanning body modification undergarments in conjunction with current hard skin avatar technology permits the creation of silhouetted period avatars for historical pattern drafting. The integration of 3D body scanning may also have applications when creating replicas for the heritage sector. [6] Additionally, it could conceivably hypothesise that this research is not limited to historical body modification undergarments. Adapting current hard skin avatar technology using body scanning could also be used to costume more obscure body modifications such as mythical/fantasy silhouettes or extreme haute couture garments for the fashion industry. Body scanning using the Peel 3 3D method affords opportunities to push the boundaries of pattern drafting simply by wearing body modification garments while being scanned. The 3D avatar pen tool in CLO3D works similarly to second skin pattern drafting [5] and could work with converted scans to permit the creation of obscure patterns that are bespoke to that silhouette. It could serve as a catalyst for the wider adoption and standardisation of 3D body scanning and digital processes in costume.

Secondly, the present study raises the possibility of an alternative to the traditional methods of working in the costume industry. Prior studies have noted the complexity of the traditional costume realisation process [3], these results offer a substitute approach permitting the proposal of an innovative workflow.

4.3. Proposal of an Innovative Workflow

The workflow shown in figure 8 offers a digitally focused alternative to traditional costume fitting and making practices and illustrates the potential of the processes discussed in this paper. Although centred around historical costume in relation to the core theme of this paper, the workflow can also be applied to non-specialised areas of costume. The patterns created using the 3D body scanning/body modification undergarments workflows are not confined to a digital space but instead can be applied for real world making and application.

The Peel 3 3D scanner lends itself well to a virtual costume fitting process for the same reasons as discussed previously in this paper (accuracy/consistency), however, it also offers advantages such as providing a resemblance to participants faces due to the detail it can capture. This feature would mean that the visualisation of a 3D costume on the avatar would be more effective and truer to real life costume fittings.

Ultimately, the proposal of this workflow aims to support the complex costume making/realisation process using digital tools while honoring the industry’s traditional craft.

4.4. Limitations

It is possible that these results may not be applicable to all historical costumes produced using the processes proposed. The accurate construction of some historical costumes in 3D garment simulation software such as CLO3D can be unattainable as the sewing techniques available in the software are developed for the construction and realisation of modern-day clothing, rather than historical. An implication of this is, careful consideration must be taken when digitally fitting a historical costume on the avatar as modern techniques placeholders/workarounds may affect the costumes pattern so that when it comes to using historical techniques on the physical garment it does not translate effectively.

A further limitation of this study is, that it is unproven on a physical garment for a theatre or film production. This validation of 3D body scanning for this application would be required for introducing this as an industry workflow.

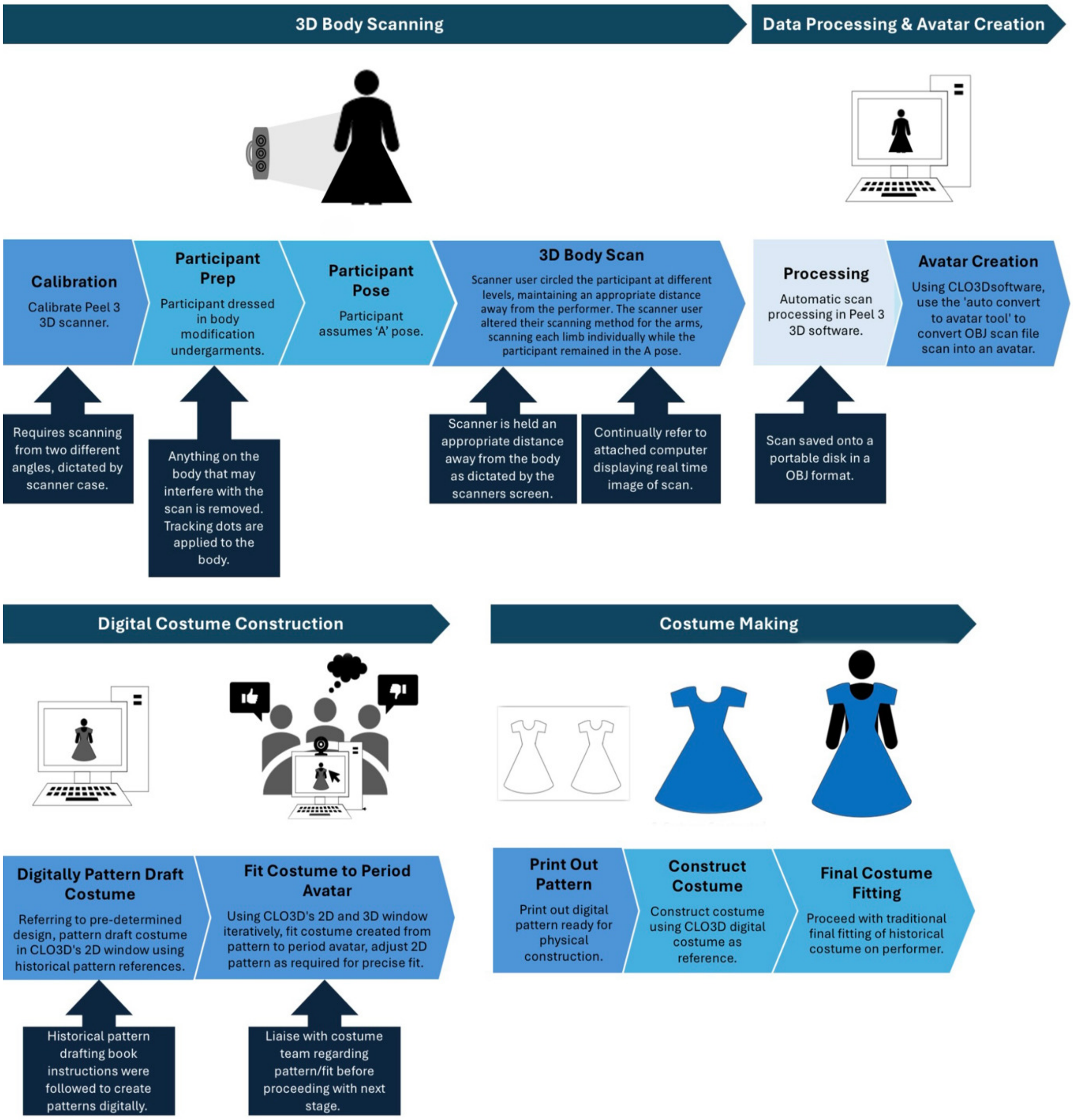

Fig 8: Innovative workflow flow diagram

5. Conclusion and Further Work

In this investigation, the aim was to assess how 3D body scanning and digital workflows could be used in the costume industry for the creation of digital patterns, of historically accurate costumes which require body modification undergarments. The study has shown that body scanning is a viable and effective way to utilise existing hard skin avatar technology to achieve silhouetted period avatars. Furthermore, it has proved that the avatars created permit the creation of historical, digital patterns in 3D garment simulation software. This study focuses on the costume industry, additionally the findings can be used for the historical preservation of garments as well as commercial body modification garments such as those in the fashion industry.

The understanding gained here should help to make decisions regarding body scanner compatibility as well as demonstrate the potential for digital workflows and body scanning implementation in the costume industry. A natural progression of this work is to test the proposed novel workflow and construct a physical historical garment that's fit can be analysed on the body of a participant. This would validate further the potential for digital workflows and body scanning in the costume industry as well as advocate for greater efforts to promote and conduct research.

Additionally, future work addressing the lack of historical sewing techniques in 3D garment simulation software would be worthwhile. Conversations between software developers and costume industry practitioners to discuss the integration of costume specific tools within these digital platforms are essential. The integration of digital tools to support costume practices is gradual but on-going; to successfully adopt these tools and software as standard practices in the costume industry, traditional, costume focused sewing and construction techniques need to be made available/possible via industry specific tabs or optional plug ins.

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