Fashion Design Empowered by Digital Technology

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Lyu Shenhao

Student name: Shenhao Lyu
Student ID: 10756510
Supervisor: Daria Casciani
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Abstract

Currently, in the era of digital transformation, digital technology has received unprecedented attention across various industries. As a result, the fashion industry has entered the 4.0 era, profoundly impacting aspects such as design, production, and dissemination.

Numerous design software, such as CAD, Clo3D, and Marvelous Designer, have emerged to meet this demand. They enable designers to quickly complete design, modification, and prototyping on computers, discarding the cumbersome process of traditional manual drawing and prototyping, saving a significant amount of time and cost. Additionally, these software programs allow designers to create 3D models based on patterns, showcasing every detail of the clothing and displaying dynamic effects through simulated actions. These advantages eliminate errors generated by communication factors in the traditional design process, help designers collaborate better with other departments and suppliers, and enable consumers to understand the material and details of the clothing more intuitively. In design promotion, these software programs also play a unique role while avoiding environmental pollution caused by sample production.

Digital technology not only improves design efficiency and accuracy but also brings more opportunities for innovation and sustainable development. Unfortunately, many clothing companies are still in the early stages of implementing digital technology. Apart from using CAD for pattern making, digital modeling and display have not been well-integrated into the design and production process. Reasons for these issues include technical barriers in software usage and a lack of understanding of the potential value of digital technology in fashion design, as well as a lack of reference points to evaluate the pros and cons of digital technology, causing temporary suspension of digital transformation plans.

Therefore, this thesis uses case analysis, based on Clo3D and Blender software, to guide readers to understand and learn the digital process of prototyping, fabric and hardware making, shooting production; and comparing the digital process with traditional production. Finally, this thesis will summarize the entire operation process and discuss some issues that digital fashion still faces based on the practical operations in the previous sections, analyzing its advantages and disadvantages.

This thesis aims to help relevant personnel solve technical problems, provide readers with inspiration and ideas, and explore digital clothing technology in various aspects of the design process, as well as how to optimize the traditional fashion industry.

Keywords: **Digital Fashion**, **Clo3D**, **Blender**.

Sommario

Attualmente, nell'era della trasformazione digitale, la tecnologia digitale ha ricevuto un'attenzione senza precedenti in vari settori. Di conseguenza, l'industria della moda è entrata nell'era 4.0, influenzando profondamente aspetti come il design, la produzione e la diffusione.

Numerosi software di progettazione, come CAD, Clo3D e Marvelous Designer, sono emersi per soddisfare questa domanda. Essi consentono ai designer di completare rapidamente progettazione, modifica e prototipazione sui computer, eliminando il laborioso processo di disegno e prototipazione manuale tradizionale, risparmiando così notevole tempo e costi. Inoltre, questi programmi software consentono ai designer di creare modelli 3D basati su pattern, mettendo in mostra ogni dettaglio dei capi e mostrando effetti dinamici attraverso azioni simulate. Questi vantaggi eliminano gli errori generati dai fattori di comunicazione nel processo di progettazione tradizionale, aiutano i designer a collaborare meglio con altri reparti e fornitori e consentono ai consumatori di comprendere il materiale e i dettagli degli indumenti in modo più intuitivo. Nella promozione del design, questi software svolgono anche un ruolo unico evitando l'inquinamento ambientale causato dalla produzione di campioni.

La tecnologia digitale non solo migliora l'efficienza e l'accuratezza del design, ma offre anche maggiori opportunità per l'innovazione e lo sviluppo sostenibile. Sfortunatamente, molte aziende di abbigliamento si trovano ancora nelle prime fasi dell'implementazione della tecnologia digitale. Oltre all'utilizzo di CAD per la creazione di modelli, la modellazione e la visualizzazione digitale non sono state ben integrate nel processo di progettazione e produzione. Le ragioni di questi problemi includono barriere tecniche nell'uso del software e una scarsa comprensione del valore potenziale della tecnologia digitale nella progettazione della moda, nonché una mancanza di punti di riferimento per valutare i pro e i contro della tecnologia digitale, causando una sospensione temporanea dei piani di trasformazione digitale.

Pertanto, questa tesi utilizza l'analisi dei casi, basata sui software Clo3D e Blender, per guidare i lettori a comprendere e apprendere il processo digitale di prototipazione, realizzazione di tessuti e componenti hardware, produzione fotografica; e confrontando il processo digitale con la produzione tradizionale. Infine, questa tesi riassumerà l'intero processo operativo e discuterà alcune questioni che la moda digitale deve ancora affrontare sulla base delle operazioni pratiche nelle sezioni precedenti, analizzandone vantaggi e svantaggi.

Questa tesi mira ad aiutare il personale pertinente a risolvere problemi tecnici, fornire ai lettori ispirazione e idee, ed esplorare la tecnologia dell'abbigliamento digitale in vari aspetti del processo di progettazione, nonché come ottimizzare l'industria della moda tradizionale.

Parole chiave: Moda Digitale, Clo3D, Blender

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Personal motivation

The progress of technology often brings revolutionary changes to the way of production. In recent years, digital technology has been developing at an incredible speed, with 3D technology, holographic projection, AR, VR, and other technologies that were once only in science fiction novels now becoming accessible.

All of this is first and foremost thanks to the progress of hardware, such as this year's graphics cards, which have computing power that is tens of thousands of times greater than that of graphics cards from ten years ago (Chen, J. X., 2016), allowing for a significant improvement in the precision of 3D models and more delicate graphic representations. This transformation has had the most significant impact on the gaming and film industries, which make the most use of graphic technology.

Thanks to more powerful computer processing capabilities, many new computer algorithms have emerged, such as the **mass-spring system**, which is a simulation algorithm focused on the simulation of elastic soft materials (Jiang, Liu & Chen, 2012). Its emergence allows computers to better simulate 'soft' models, such as the fluttering of fabrics and the undulating waves of the ocean.

Ray tracing algorithms encode real-time, more realistic lighting effects on objects, greatly improving the realism of lighting, shortening the rendering time required to achieve the same level of realism, and reducing production costs.

As someone who has been passionate about video games since childhood, I have personally experienced the evolution of graphics in video games. I believe that these developments will eventual have a significante impact on the fashion industry.

Fig 1. Screenshot from the game *German Headquarters* (1992)

Fig 2. Screenshot from the game *Red Dead Redemption 2* (2018)

1.

2.

When I first entered the fashion industry in 2014, the influence of digital technology on the fashion industry was not as significant as it is today. Few fashion brands or designers integrated digital technology into fashion shows, and the use of digital technology was limited by various factors and was not yet widespread. However, with the innovation of these digital technologies mentioned above, the cost of creating delicate 3D models is gradually decreasing, and many software programs specifically designed for 3D fashion production have emerged, such as **Clo3D**, **Style3D**, and **MD**, along with many free 3D modeling and rendering software programs such as **Blender**. These programs greatly reduce the distance between 3D digital technology, which used to be inaccessible, and ordinary designers, making it possible for graphic designers or fashion designers to create 3D models on their own without requiring a large amount of manpower and resources.

This is a significant opportunity and challenge for fashion designers like me.

Industry motivation

The impact and optimization of 3D digital technology on the traditional fashion design industry is not limited to simply creating a 3D model to show to clients. It has a comprehensive impact, from clothing production to media communication and sales models.

1. For designers and design departments
Digital technology greatly changes and optimizes the process of clothing design, reducing the cost of design and production. Based on excellent clothing simulation software such as Clo3D, many processes and steps of traditional clothing design will be influenced and changed to a certain extent.

- Digitization of design process:
In the future, designers may communicate with clients directly through 3D models instead of effect drawings. Computer-aided design software enables designers to quickly model, modify and render, accelerating the design process.

Fig 3. Digital sample garment production process and display images for *Call of Cthulhu*. From left to right: first version prototype, second version prototype, fabric addition, and final prototype display.

- Better communication and optimized production:
3D technology can also enable designers to communicate with pattern makers and clients more intuitively, allowing them to better understand the designer's ideas. Therefore, the production of samples may only require the first pattern, rather than the re-sewing of second or third samples, greatly reducing the time and cost of this process. Digitizing the entire clothing design process can shorten the design cycle from the traditional 30-60 days to about 5 days (Mu & Cao, 2015).

- 3D clothing is easier to store:
Due to the digital nature of 3D clothing, even if many 3D samples are produced, they can be easily stored in a 10-centimeter hard disk, avoiding the occupation of storage rooms by a large number of physical samples. The sales model can be transformed into customers browsing 3D samples first, then placing orders, and then putting the clothing into actual production. In this case, 3D clothing serves as a preview of real clothing, further solving the inventory problem that troubles most clothing companies.

- Easy transportation and unified management:
Due to the digital nature of 3D clothing, it is easier to spread between different departments of clothing design. This advantage is more significant in cross-regional or cross-national companies, saving a lot of transportation costs. Moreover, as digital fashion is essentially 'data', it is easier to summarize and edit its information compared to physical clothing, improving its traceability.

2. For fashion promotion and consumers
More and more clothing brands are using digital technology to simulate and showcase their clothing, and to package and promote their brand image through digital technology. As mentioned earlier, technological advancements have made it possible to create highly realistic 3D models of clothing, such as the ***Afterworld: The age of tomorrow*** clothing collection by Balenciaga, which is entirely presented digitally, using high-precision rendering of clothing and science-fiction scene construction, as well as electronic games as an interactive way to engage with customers, providing them with a great sense of novelty. Similarly, more and more brands are using digital technology and futuristic styles to package themselves, and more and more consumers are being attracted to clothing brands with similar tones in the concept of the metaverse. This may become a major trend in the near future (Arribas, V., & Alfaro, J. A. (2018)).


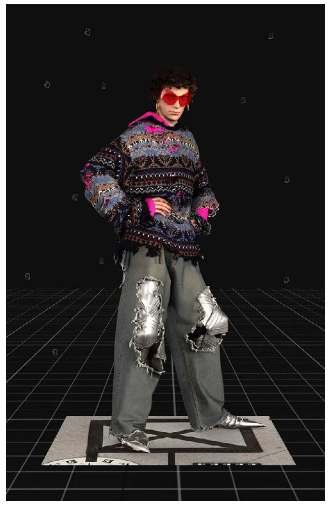

Fig 4. Balenciaga *Afterworld: The age of tomorrow* screenshot.

In terms of sales models, we can see that clothing sales are gradually shifting from offline physical retail to online sales. As someone who has been living in China for a long time, I can clearly feel that online shopping has almost replaced offline shopping in recent years. In Europe, more and more people are starting to sell their own clothing through online channels. Clothing brands are also increasingly valuing this sales channel. Thanks to the popularity of large-screen smartphones and 4G transmission technology, the image quality is getting higher and the transmission speed is getting faster, so what customers see on their phones is often almost identical to the actual product. Online shopping is also very time-saving, so customers prefer this convenient way of shopping. In the next few years, with the replacement of mobile devices and the popularization of AR and VR technology, customers may be able to directly view holographic projections of goods on their portable devices, which may become a newer and more popular shopping mode (Chen & Wang, 2022) (Bulović, V., & Čović, Z. 2020, September).

3. For environmental protection and sustainable development
- Digital technology can significantly reduce waste output and conserve resources.:
As mentioned above, traditional clothing production methods require a large amount of raw materials and manufacturing processes, and the produced clothing usually requires multiple modifications and trials before it can be formed, resulting in a lot of waste and waste. However, using 3D clothing technology, the design can be directly converted into a digital model, reducing the steps of sample making and adjustment, saving the consumption of raw materials and energy, and reducing waste output.

- Reduce carbon emissions:
Traditional clothing production requires a lot of logistics, processing, and manufacturing, which produces a large amount of carbon emissions. However, using 3D clothing technology, remote collaboration and digital manufacturing can be achieved, reducing the processes of logistics and processing, and reducing carbon emissions. (Huynh, P. H., 2021).

Fig 5. *No Man's Land*, by French artist Christain Boltanski, composed of 30 tons of discarded clothing, on display at the Park Avenue Armory in New York City, May 2010.

However, despite the importance of digital technology and 3D fashion to the fashion industry, most clothing companies or enterprises only focus on the concept hype and gimmicks of digital fashion, rather than applying digital fashion technology to optimize the clothing design and production process, leading to a lack of attention to this aspect.

3. For environmental protection and sustainable development
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Current research status of the topic

Research Status

The author conducted some research and reviewed some theses related to how digital technology can be applied to the clothing design process, which are either theoretical or practical. Based on these theses, the main issues and processes related to 3D clothing production can be divided into three categories: digital sewing techniques and related issues, digital fabric simulation calculations, digital clothing runway rendering and digital clothing display forms.

1. How to use Clo3D for digital clothing production
For example, Ma Chenjie briefly introduced the use of digital model customization and sewing tools in Clo3D (Ma, 2020) and analyzed how to optimize the clothing customization process using Clo3D. Mu Shuhua and Cao Weiqun used a formal dress as an example and briefly introduced the process of making digital clothing using Clo3D (Mu & Cao, 2015). Song Ying et al. discussed the method of generating and exporting patterns using CLO3D and produced physical samples to verify its feasibility (Song, Xiang & Sun, 2022). Duan Ting (Duan, Shi, Liu & Dong, 2023), Chen Xin (Chen, Yi, Ren & Zhu, 2022), and others used CLO3D as a tool to model and produce some Chinese ethnic clothing in their own theses.

2. Digital fabric simulation of digital clothing
Wang Huiwei and Zhang Hui used a group experiment to discuss the effect of CLO3D's bending and density parameters on the drape of fabric (Wang & Zhang, 2015). Ashmaw, Hassouna, and others used the drape of a fishtail skirt as the object of observation, and through adjusting multiple sets of data, compared and experimented with the drape difference between the fishtail skirt in Clo3D and the real world (Ashmawi, B., Hassouna, A., Nasr Eldine, N., & El-Newashy, R. (2021).

3. Digital clothing runways and rendering
For example, Yu Hongting discussed the innovative and necessary role of digital technology in clothing exhibitions and classified and analyzed existing digital technology cases for clothing exhibitions (Chen, 2018). Wu Sehee and Kang Yeonkyung analyzed the technical aspects of major digital fashion shows in recent years and attempted to produce them (Wu, S., Kang, Y., Ko, Y., Kim, A., Kim, N., & Ko, H. (2013)).

Research Question

After consulting related materials, it was found that current online theses about digital technology, 3D fashion production, or 3D clothing displays use relatively simple case studies. Therefore, the production steps and comparisons with traditional clothing design steps are not in-depth enough.
For example, taking a dress as an example, it may not cover the explanation of the **down filling** feature in CLO3D. Simplified examples also do not explain how to customize zippers, buckles, and other accessories. Therefore, the reference value provided is limited.

In addition, existing theses mostly focus on only one aspect of the design process, such as sewing clothes or rendering fashion shows. This, to some extent, requires readers to consult multiple theses to understand the entire process, and the examples between these theses do not match, thereby increasing the reading difficulty.
Moreover (and also due to the overall limitations of fashion design professional education), existing theses on digital clothing mostly focus on the design software **CLO3D**.

The advantage of **CLO3D** lies in digital clothing modeling, but it is relatively weak when it comes to digital shooting that requires a themed scene. To achieve better rendering effects, it is necessary to involve software such as **3DS Max**, **Cinema 4D**, **Blender**, and methods for simulating character catwalk actions in Maya or MixMao. The mixed use of multiple software and platforms is precisely what existing theses overlook.

This makes the examples that readers learn from when consulting information not deep enough, when learning about clothing modeling, accessory modeling, scene rendering, etc., it often requires consulting different theses, literature and video materials, resulting in a sense of fragmentation of learning and increasing the difficulty of learning.

Therefore, in order to help relevant practitioners better understand **the whole progress of digital fashion design** and provide valuable references, the author has written this thesis. This thesis elaborates on the digital garments modeling process and rendering methods in detail and organically connects the entire process to facilitate smoother learning.

In the process of achieving the best effect, this thesis uses **multiple software** for different steps and introduces the problems that may arise when mixing these software based on the author's experience, helping readers better understand the usage of different software while avoiding possible problems and risks that may arise from mixed usage.

In addition, this thesis compares the **traditional fashion design process** with the digital design process in the relevant chapters, analyzes the different operation modes between them, and their respective advantages and disadvantages. Through these case studies, we hope to provide some inspiration for optimizing the design process, compare the differences between digital fashion design and traditional fashion design, and bring better reference value to relevant practitioners.

Research methods and structure of the Thesis

The methods and structure of this study are mainly based on three research methods: **Research**, **Reflection-in-action**, and **Reflection-on-action**. These three methods are applied progressively in the research of this thesis.

Readers can see the application of these methods in each individual chapter.
For example, in Chapter 2, this thesis first uses the Research method to investigate and compare the differences between digital and actual samples. Then, using the Reflection-in-action method, with Clo3D and Blender software as the main tools, each step of the digital sample making process is experimentally explored in detail, to better understand the differences between the digital design process and the traditional design process, and to detail and compare the advantages and limitations of the digital design process. Finally, using the Reflection-on-action method, based on the results of the experimental cases, the digital sample making process is further summarized and discussed in a reflective manner, including summarizing the strengths and weaknesses of digital samples, issues with software that need to be improved, and difficulties faced in its application.

At the same time, the overall structure of this thesis is also set according to these methods.
For example, the preface and Chapter 1 are more biased towards Research; Chapters 2 to 5 are generally based on the previous Research, using the Reflection-in-action method to experiment with the clothing design process; the discussion section in Chapter 6 is based on the previous experimental results, using the Reflection-on-action method for a deeper summary and discussion.

Chapter 1 - Introduction:
development and challenges of digital fashion design

Differences and similarities between digital and traditional fashion design

Digital fashion design and traditional fashion design have similarities and differences in various aspects of the design process. This section roughly divides the fashion design process into four parts: **design**, **pattern making** and **prototype making**, **fabric**, and **photography**, for brief comparison. The comparison of the differences and similarities between the two also sets the stage for the experimental structure of the case study in the following sections.

Design Stage

Firstly, in the design stage, the design thinking of traditional fashion design and digital fashion design **is similar**.

Generally, the process of collecting inspiration and drawing sketches is highly unique to each designer and is therefore not significantly influenced by digital technology. The differences in the key lies in the tools used between traditional sketching and digital sketching.

However, digital design allows for rapid prototyping and iteration through the use of computer software, providing richer visual effects and unlimited creative possibilities (Smith, 2020). Nonetheless, this does not mean that traditional design is entirely abandoned as it usually involves hand-drawn sketches and hand-made creations. Although this process may take longer in certain aspects, it can better reflect the designer's personality and artistic style (Johnson, 2018).
Therefore, in the design stage, there is not much difference between traditional fashion design and digital fashion design. Instead, they are highly complementary to each other, and both can learn from each other to achieve the best design results.

Pattern Making and Prototype Making Stage

In the pattern making and prototype making stage, the digital design process **differs significantly** from the traditional design process.

Digital design uses **CAD** pattern making, 3D modeling, and digital fitting technologies, which can quickly preview the final product and make adjustments, reducing trial and error costs and increasing production efficiency (Lee, 2019). Digital pattern making technology also helps to precisely control garment sizes and cuts, avoiding repeated pattern making and sample production adjustments, reducing waste, and increasing sustainability in the production process.

However, in **digital prototype making**, designers not only require fashion design knowledge but also need knowledge of pattern making, prototype making techniques, and other relevant skills. Therefore, high personal qualities are required for the designer. Additionally, the digital skills. Therefore, high personal qualities are required for the designer. Additionally, the digital pattern making and prototype making process may lose a part of the inspiration source in the design and production process due to not being in contact with actual fabrics and patterns, which is a downside of digital technology.

In contrast, the **traditional method** requires hand-drawn pattern making, fabric cutting, and prototype sewing. This process is more time-consuming compared to digital pattern making and prototype making. Also, since pattern making and prototype sewing are two separate steps, it is easy to make mistakes, and repeated adjustments are often necessary, making the design adjustment process more time-consuming. Furthermore, traditional methods require repeated prototype production, which may not be as eco-friendly as digital pattern making and prototype making.

Nevertheless, it is worth mentioning that the attention to detail and sensitivity to materials in the hand-made process are difficult for digital technology to completely simulate. Although traditional methods may not be as efficient as digital design in terms of time and efficiency, it still has irreplaceable value in providing unique tactile sensations and maintaining artistic qualities.

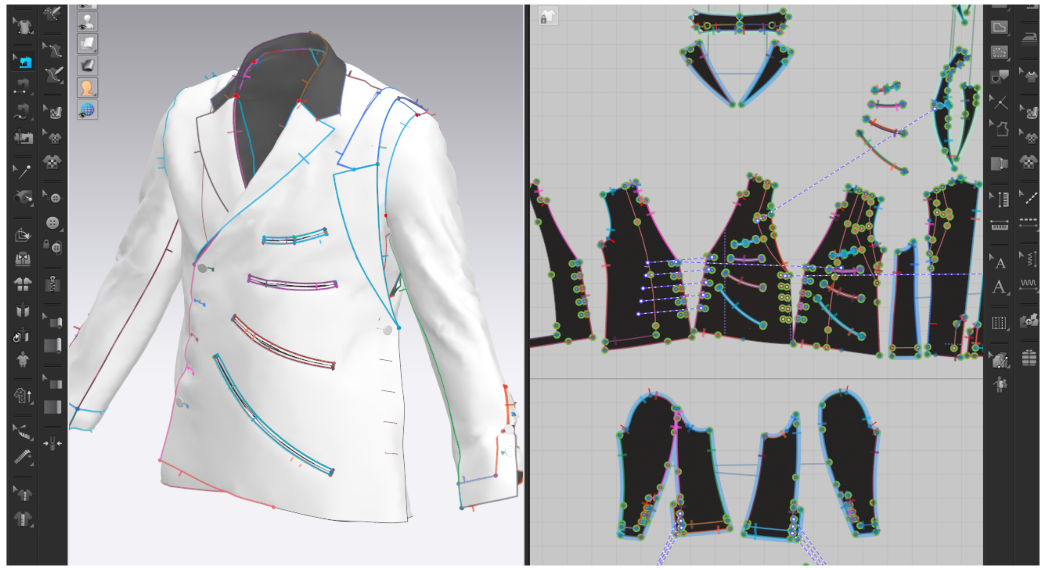


Fig 6. The digital suit and digital pattern files created in Clo3D

Fabric selection

In terms of fabric selection and application, there are **significant differences** between traditional and digital fashion design.

Regarding fabric selection, digital fabrics consist of different **texture mapping** and are virtual, and designers can select the desired fabric from a rich digital fabric library (Kim, 2020). In contrast, traditional fabric selection requires designers to physically examine fabrics, which is time-consuming.

However, it is precisely because of the virtual nature of digital fabrics that their **perceptibility**

during the selection process is poor. Although digital fabrics can have some physical properties such as elasticity, stiffness, and drape, and can simulate real wearing effects through the algorithms of relevant software, their simulation effects are still difficult to compare with actual fabrics (Wang, 2019). In this regard, the texture, gloss, and color of actual fabrics can provide more intuitive reference for designers.

Moreover, during the process of cooperating with digital modeling, digital fabrics can be changed quickly, thereby increasing design efficiency and possibilities. Designers can try different fabric combinations in a short time to find the best design solution. However, in traditional fashion design, changing actual fabrics usually requires re-cutting and sewing, which is time-consuming and costly.

Photography

In the shooting stage, there are **significant differences** between digital and traditional fashion photography.

Digital photography allows designers to build **virtual scenes** in the computer, freely match various elements, and create endless possibilities for backgrounds, saving the cost and time of actual scene setting (Sullivan, 2021). Although traditional photography can present more realistic and vivid visual effects (Brown, 2018), it requires significant human, material, and financial resources and is greatly limited by on-site conditions, such as the inability of the studio to provide relevant shooting props and significant weather interference in outdoor scenes.

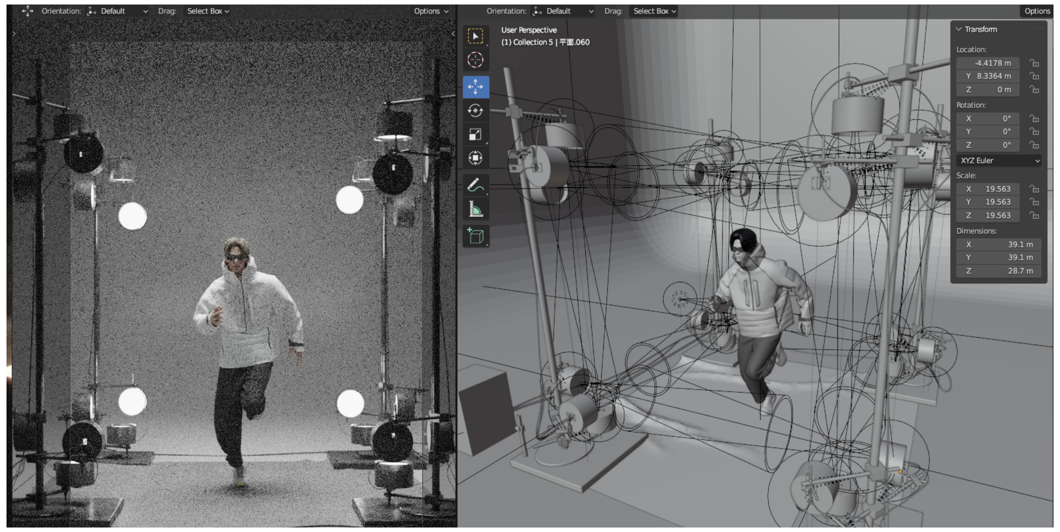


Fig 7. Digital photography in Blender

Light settings in digital photography can be finely adjusted through software, which helps to better show the texture and details of clothing. In contrast, traditional photography needs to rely on professional lighting equipment to adjust the lighting, which may be limited by on-site conditions. Digital photography can also use virtual try-on and dynamic demonstration technology to display the visual effects of clothing under different scenes and actions, saving model fitting time and quickly previewing the effects of different design schemes. Although **digital models** may appear relatively stiff and inflexible in terms of dynamics and expressions compared to actual models, their expressive power will continue to improve with the continuous development of technology, gradually compensating for this shortcoming. In addition, digital models can greatly save fitting time, improve designers' work efficiency, and allow them to explore more design possibilities in a short time.

Traditional photography requires models to wear actual clothing for fitting and shooting, which may be time-consuming and limited by the models' body shape and movements. However, at present, the realism and texture of the models are still difficult to replicate with digital technology.

Comparison of clothing prototype making processes:

Comparison chart of digital sample garment production and actual sample garment production processes

Challenges Faced by the Popularization and Application of Digital Fashion Technology

Based on the comparative analysis above, we can see that digital fashion design has significant differences from traditional fashion design in terms of process and technology, except for the design inspiration stage. Digital fashion design has the advantages of precision, efficiency, easy modification, cost-saving, and eco-friendliness. Although there are many disadvantages, it is still a good design tool that can complement traditional fashion design to some extent.

However, as mentioned earlier, the popularization of digital fashion technology still faces many challenges, such as immature technology and insufficient knowledge dissemination:

For fashion designer

Digital design requires designers to have a certain knowledge of pattern making and garment construction, as well as proficiency in various 3D software, which puts higher demands on the comprehensive quality of fashion designers. Traditional fashion designers may not have the basic skills and experience in 3D modeling, which means they need to spend a lot of time and energy learning and adapting to new technologies. In addition, designers need to constantly update their skills to keep up with the development of digital technology, which also puts higher demands on their career development.

For digital fabric

Although the digital fabric library provides designers with a wealth of choices, the simulation effect of digital fabric is still difficult to compare with that of actual fabric, which may affect the design effect. For example, it is difficult to simulate the folds, texture, and some damaged details of fabric in a digital environment. This means that in some cases, designers may need to rely on actual fabric for experimentation and creation, which reduces the application efficiency of digital technology.

At the same time, when it comes to digital fabric scanning, designers usually do not have a professional fabric scanner, and the quality of scanning with a mobile device may not reach a professional level. Post-processing, such as 'seamless' processing or generating corresponding textures, is also time-consuming and labor-intensive.

For digital photography

In the process of digital photography, designers need to have relevant modeling and lighting knowledge, but usually, designers do not have this professional skill. This means that designers need to work closely with other professionals during the shooting stage, which increases communication costs.

In addition, the expressive power of digital models in terms of dynamics and expressions is limited, and compared to actual models, they may appear stiff. This limits the creative expression of designers in the shooting process. Although the technology of digital models has improved in it still needs more time and research to make up for this shortcoming.

Although digital technology has the above limitations, its advantages in improving efficiency, saving costs, and other aspects are unmatched by the traditional fashion design production process. Therefore, in order to better analyze the advantages and disadvantages of digital fashion technology in these aspects, this thesis will use relevant chapters to conduct more in-depth research on it and conduct related case studies, in order to have a more in-depth understanding and reflection of its advantages and disadvantages compared to the traditional fashion design process.

Introduction to 3D clothing modeling and rendering software and why choose CLO3D and Blender

Comparison of 3D software

There are many 3D modeling software options available on the market, such as Maya, 3ds Max, Cinema 4D, and Blender. In the realm of clothing modeling, Marvelous Designer (MD), Clo3D, VSTITCHER, and Style 3D stand out for their distinctive features.

Among these programs, Marvelous Designer (MD) is more suitable for animation and CG production, while Clo3D is better suited for clothing design professionals due to its improved compatibility with certain DXF format pattern files. Style 3D has similar functionality to Clo3D, and VSTITCHER excels in terms of fabric simulation realism and rendering quality, but is slightly inferior to Clo3D in model dynamics and animation production. Additionally, VSTITCHER has a more complicated interface, making it more difficult for beginners.

Overall, these four software options share the same basic logic, utilizing 2D pattern files for 3D modeling, with similar workflows. Taking various factors into account, this article chooses Clo3D for case demonstrations as it performs well throughout the entire design process, from pattern creation to rendering.

However, these four software options excel at creating digital clothing models and simple rendering. When it comes to complex scenes, lighting, and professional photography, their performance can be somewhat lacking. In particular, the 'mass-spring model' algorithm used by Clo3D is more suitable for modeling "soft body" fabrics but falls short in modeling rigid objects like clothing accessories and hardware.

To address this issue, other software is needed to assist in photography and rigid modeling. Currently, mainstream 3D rendering software includes Blender, Cinema 4D, Maya, and 3ds Max. Cinema 4D, Maya, and 3ds Max are powerful, easy-to-learn software widely used in the film, television, and gaming industries. Cinema 4D supports third-party plugins, offering even more functionality, while Maya and 3ds Max, as Autodesk products, can be used seamlessly together.

In comparison, Blender is a younger software, but its capabilities are on par with other programs. As a full-process open-source software, it can handle tasks from modeling, sculpting, and animation to rendering. More importantly, Blender is free, saving subscription costs and making it more user-friendly for individual designers and small studios.

Therefore, the author chooses to use **Blender** in combination with **Clo3D**. In clothing modeling, Blender can assist in creating hardware, and during clothing rendering, Blender can quickly and efficiently build scenes for digital fashion models, set up more professional lighting, and camera parameters, significantly improving the final rendering outcome (Zhang, 2022).

Fig 8. Comparison table based on clothing production and rendering functions. Maya, 3ds Max, Cinema 4D, and Blender do not support importing clothing pattern files, so related functions are not discussed here

	3D Modeling	Supports importing garment patterns	Garment Modeling Accuracy	Garment Dynamic Simulation	Digital Model Animation Editing	Rendering function	Ease of Operation
Clo3d	☆	✓	☆☆☆	☆☆☆	☆☆	☆	☆☆☆
Marvelous Designer	☆	✓	☆	☆☆☆☆	☆☆	☆	☆☆☆
VSTITCHER	☆	✓	☆☆☆☆	☆☆	☆	☆	☆☆
Style 3D	☆	✓	☆☆☆	☆☆	☆	☆	☆☆☆
Maya	☆☆☆				☆☆☆☆	☆☆☆	☆
3ds Max	☆☆☆				☆☆☆	☆☆☆	☆
Cinema 4D	☆☆☆				☆☆☆	☆☆☆	☆☆
Blender	☆☆☆				☆☆☆	☆☆☆	☆☆

Clo3D Introduction

Clo3D is a 3D modeling software with a different basic operating method than "non-clothing" modeling software, which tends to focus on industrial modeling. The latter often starts with a cube or polyhedron and slowly adjusts it to the final shape. However, for clothing modeling software, it is a process of **'sewing'** using pre-drawn clothing patterns (which can be imported or drawn within the software) on an existing human model.

In Clo3D, the operating interface is mainly divided into two windows: one is a **2D window**, where users adjust the clothing flat patterns, and the other is a **3D window**, where users can see the 3D effect of the garment. Any changes made in the 2D window will be updated in real-time in the 3D window. This not only facilitates designers to make major modifications to the pattern when designing clothing, but also allows pattern makers to see the slight changes in the 3D garment when making minor adjustments to the pattern.

In addition to the digital sewing capabilities, Clo3D can also customize the size of the 3D model to better meet customer needs or satisfy the designer's requirements. After sewing, the clothing can be rendered with simple lighting and camera settings.

However, the downside is that when designers are doing digital rendering, especially for complex scenes and professional camera shots, Clo3D software may be slightly inadequate. Also, all the modeling algorithms in Clo3D are based on the 'mass-spring model' algorithm, which is more suitable for modeling "soft" fabrics. However, for hard objects such as various clothing accessories and hardware parts, "hard" modeling is slightly inadequate.

Therefore, to compensate for the shortcomings of Clo3D in shooting clothing or modeling "hard" clothing accessories, Blender can be used.

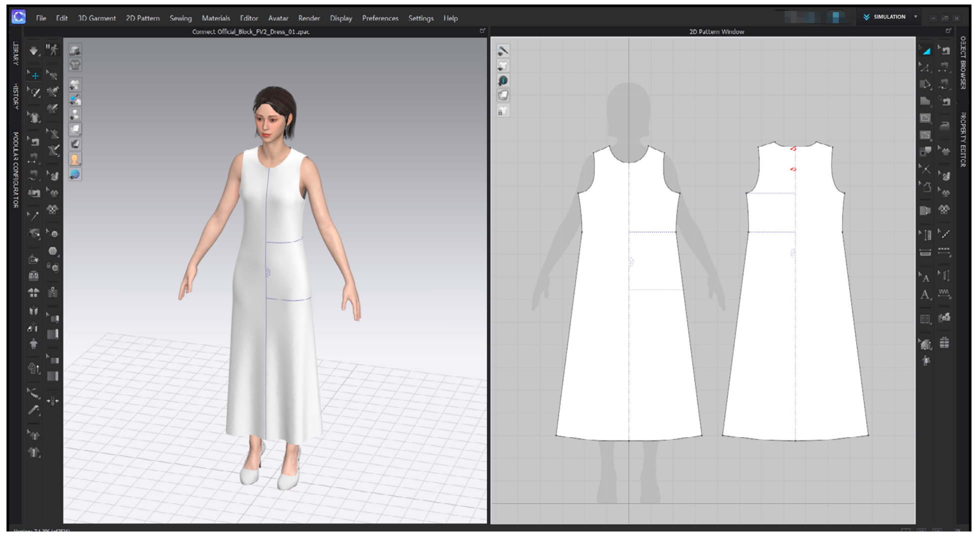


Fig 9. Clo3D main interface screenshot

Blender Introduction

Blender is a powerful 3D modeling software that is full-featured, from modeling to texture mapping, motion simulation, and animation rendering. It can be said to be a very powerful software.

After completing the clothing modeling in Clo3D, we can import it into Blender and use Blender's modeling functions to build the scene. Usually, the scenes for clothing displays are not complicated, so mastering Blender modeling is not difficult for clothing designers with simple learning.

Also, its **camera** is quite professional, and users can adjust all the parameters of a professional camera, such as depth of field, aperture, manual exposure, etc. When shooting short films, users can also add slider or simulated focus effects to the lens through keyframes.

However, it is worth noting that although Blender has cloth simulation capabilities, it is not as accurate as Clo3D in precisely calculating the physical properties of fabrics such as warp and weft strength and tension. Regarding texture calculations such as drape, wrinkles, and thickness of non-textured fabrics, it is not as accurate as Clo3D, so overall, the author still recommends using Clo3D for clothing modeling.

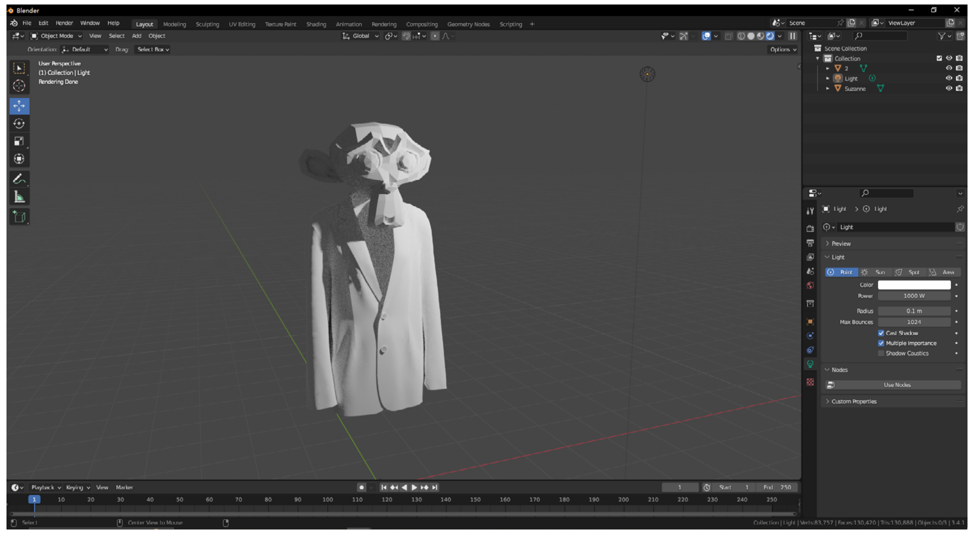


Fig 10. Blender main interface screenshot

In summary, using **Clo3D** for clothing modeling and **Blender** for clothing display scene construction and rendering can achieve very good rendering effects.

As a side note, Clo3D is personally considered to be the easiest software to learn (with clothing-related knowledge) compared to other modeling software such as MAYA or Blender because of its simple and beautiful overall UI design. All functions are also focused on 3D clothing making, and it can basically complete digital clothing modeling and simple rendering.

Blender, as a full-process software, has a complete range of functions, so it is relatively difficult to learn and use compared to Clo3D. However, compared to Clo3D, it can better build rendering scenes and set up cameras. Therefore, if there is a demand for photographic scenes and pursuit of more interesting photographic angles, in addition to learning Clo3D, it is also necessary to learn and research Blender.

Chapter 2
Comparison between digital clothing prototype making on Clo3D and real-life clothing production

As mentioned earlier, the creation of digital clothing samples is the first step where there is a significant difference between traditional design processes and digital design processes. Following the overall comparison of traditional clothing design and digital clothing design, this chapter will provide a more detailed comparative analysis of the single aspect of creating digital clothing samples. It will also include corresponding case experiments, and ultimately, provide more in-depth analysis and reflection based on the results of the experiments.

Introduction: advantages and limitations of clothing prototype making on Clo3D

The overall logic for creating traditional clothing samples and digital clothing samples remains unchanged. The process involves creating a pattern for the clothing and then making the prototype based on the pattern. Based on the effect of the clothing sample, the pattern is then modified repeatedly until the final effect is determined. Although the logic between the two is the same, the actual operations are significantly different. Digital prototype making is completed on a computer, which makes it faster, more accurate, and offers more possibilities than traditional prototype making. This section will highlight the differences between traditional and digital prototype making, analyze their advantages and limitations.

Comparison of Digital Patterns and Actual Patterns

The process for creating digital CAD patterns and actual patterns is not significantly different. Similar to sketching, the difference lies mainly in the tools used. Traditional clothing pattern makers use and pen, while CAD pattern making is done on a computer. However, unlike sketching, CAD helps significantly with pattern making.

The main reason for this is that CAD pattern making is simple, making it **time-saving**. Compared to traditional clothing pattern making, which is laborious and not easy to operate, CAD pattern making is much simpler. Pattern makers can complete the work on the computer, sitting down and using the mouse and keyboard to adjust the pattern size, copy and paste elements, thereby improving work efficiency (Hwang, J. Y., & Hahn, K. H. 2017).

CAD computerized pattern making also has the advantages of **high precision** and **easy preservation**. First, CAD software can automatically calculate and align patterns. Designers can control the proportion and size of the pattern more easily, thereby achieving highly precise results in a short time, greatly improving the accuracy and consistency of pattern making compared to traditional hand-drawn pattern making. Second, CAD pattern files can be permanently saved on a computer or in the cloud, not affected by external factors such as moisture, pollution, and wear and tear, making it easy for designers to find and modify them at any time.

Finally, CAD pattern files are **highly compatible** with digital clothing design software such as

Clo3D, Marvelous Designer, and others. The files produced by CAD pattern making can be directly imported into the software, enabling rapid 3D modeling and effect display. Designers can preview the final product effect in the early stages, providing a more intuitive reference for subsequent prototype making, modification, and adjustment.
It is worth noting that most clothing companies have adopted CAD software for pattern making, as Zhang and Zhang (2018) pointed out.

The **widespread** use of digital pattern making has paved the way for digital clothing. As mentioned earlier, digital fashion modeling software is based on clothing patterns, so digital CAD patterns can be directly imported into relevant software for modeling, while patterns need to be scanned and processed before they can be imported into clothing modeling software. This is another significant advantage of CAD pattern making.

Comparison of the advantages and disadvantages between digital prototype sewing and actual prototype sewing

Advantages
When it comes to comparing the advantages and disadvantages of digital and physical clothing prototype making, the biggest advantage of digital prototype making is **time-saving** and **environmentally friendly**.

Digital prototype making is faster than traditional handmade prototype making when it comes to tasks such as fusing, ironing, sewing, adding zippers or buttons, and other details. This is because digital sewing can complete all steps directly in the software, avoiding many cumbersome processes in handmade sewing and improving overall work efficiency.

Due to **real-time display capabilities** (such as CLO3D), designers can detect errors in the design process and make adjustments in a timely manner. This helps to evaluate the effect of digital clothing and reduces the number of modifications and rework, further saving time. At the same time, this ability to discover and correct errors in real-time also improves design quality and reduces the rework rate of finished products in later stages (Sayem, Kennon, & Clarke, 2010).

For the same reason, digital prototype making **can reduce communication barriers** between pattern makers and designers. Under this premise, pattern makers can directly create patterns on relevant software, or designers can modify patterns on relevant software and explain them to pattern makers. This direct and efficient communication method helps to improve the collaboration efficiency of the entire team, reduce the frequency of prototype making, and shorten the design cycle (Puri, 2013).

In terms of **environmental friendliness**, the virtual nature of digital clothing samples does not require the production of actual clothing samples, saving a lot of fabric and manpower resources. Secondly, since errors can be discovered and corrected in real-time during the digital sewing process, the number of modifications required for clothing samples is reduced, further reducing unnecessary waste generated during the actual clothing production process. In addition, since digital sewing is completed on a computer and does not require the consumption of actual fabric, it is more environmentally friendly.

Disadvantages
Although digital prototype making has many advantages, it also has some disadvantages and limitations due to computer algorithms and high computer power requirements. Therefore, it may lack realism and detail texture compared to physical clothing samples. In contrast, physical prototype making still has certain advantages despite the potential drawbacks of repeated modifications and time-consuming processes.

Physical clothing samples have more accurate fabric expressions, as actual fabric can be used directly in physical prototype making. This allows designers and pattern makers to more accurately perceive the texture of the fabric, which is helpful for making subtle adjustments to the design or pattern.

Moreover, the handling of details in physical clothing samples is also more outstanding. For example, when creating pleats or handling special stitching techniques for some clothing, physical clothing samples are more accurate than digital clothing samples. This is because the latter usually has to be "simplified" due to the large amount of calculations required to handle these details, which may cause distortion.

Finally, the most important point is that physical clothing is more convenient to connect to traditional production lines. Currently, due to technical or traditional concept reasons, digital clothing samples have not been widely used in the clothing design process, making it difficult to connect with existing equipment and technicians. On the other hand, physical clothing samples are more easily integrated into existing production processes, making it more convenient for designers and technicians to communicate and collaborate.

In conclusion, both digital and physical clothing samples have their advantages and disadvantages. In the future, digital clothing samples will be used more widely in clothing design to improve prototype production efficiency and take advantage of their benefits in terms of efficiency, precision, easy modification, and environmental friendliness. However, physical clothing samples will not completely disappear from view. Ideally, designers could use digital clothing samples for trial and error, and then create physical clothing samples for final verification of fabric and detail effects.

Case study and analysis: Creating a prototype using Clo3D

In this section, a digital prototype will be created using the Clo3D software, from importing the digital pattern to completing the sewing of the clothing sample. Through case analysis, the differences between digital and traditional patterns, the sewing process of digital clothing samples, and the addition of details will be explored. Finally, the technical difficulties and challenges encountered in the case study will be summarized.

Patterns

Importing clothing pattern

Clo3D software can import pre-made digital pattern files in three different formats:

DXF format, the most widely used and universally compatible digital pattern format, usually made with professional clothing pattern CAD software.
AI/PDF format, a single image format created in AI or other drawing software.
MYU format, a format exported from the Alpha My pattern-making software.
Among these three formats, DXF is the most commonly used and precise digital pattern format, and is the most popular in various clothing companies.

In this thesis, the pattern-making software used by the author is **ET System (China)**, and the exported file format is DXF. The pattern file is provided by ISPO.

Fig 11. *ET System* software window screenshot location change

Once we have the relevant clothing pattern files, we can import them into the Clo3D software. The specific operation is: File ➡ Import ➡ DXF, which can import our pre-drawn pattern. After a successful import, the pattern will appear in the 2D and 3D windows on both sides of CLO3D

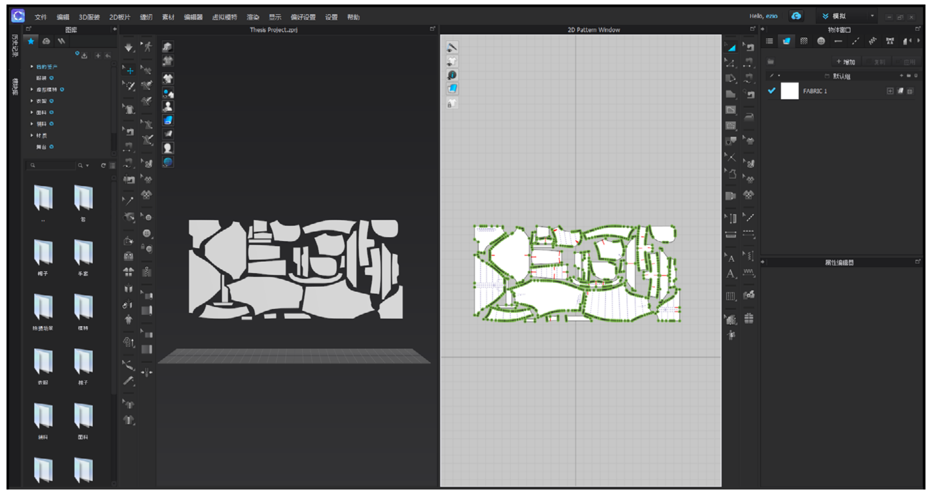


Fig 12. Clo3D window screenshots after importing patterns

Digital clothing modeling is different from traditional prototype production processes. Traditional prototype production involves **cutting** the fabric according to the clothing patterns and then sewing the pieces together. However, digital clothing modeling directly generates patterns based on the pattern files, without the need for pre-cutting of the fabric.

This logical difference in the production process results in some **differences** between the pattern files suitable for digital clothing modeling and those for actual prototype production:

In traditional prototype production, fabric cutting is required, so the pattern files require a high degree of completeness. In addition to the main body pieces, other fabric pieces such as pocket fabrics or pocket edge fabrics, and hem edge fabrics cannot be missing.

However, in the process of making digital clothing, personnel can use its digital virtuality to freely copy and add clothing pattern pieces or modify them symmetrically. Therefore, the emphasis is not on the completeness of all the patterns, but mainly on some main body pieces.

Therefore, after importing the clothing pattern, we need to perform corresponding **deletion** and optimization operations on it according to the characteristics of digital software sewing, and delete these '**redundant**' pattern pieces, which can greatly reduce the overall volume of the 3D file, reduce the computer load, and reduce the occurrence of software lag or even crashes during the sewing process.

Fig 13. Screenshot of the pattern, with the orange pattern being the unnecessary ones

Method for Optimizing Patterns in Clo3D

For pattern pieces that are symmetrical on the left and right sides, we can use the symmetry function in Clo3D. The symmetry function will symmetrical copy the target pattern piece.
Specific steps: Right-click on the target pattern piece in the 2D window and select 'Symmetric pattern with sewing' (selecting 'Symmetric pattern' alone will not symmetrical the subsequent sewing and related operations).

The marked symmetrical pattern pieces will be automatically associated with all subsequent operations, which can greatly save the time of our model making. Of course, if you need to make individual modifications to symmetrical pattern pieces later, you can cancel the symmetry association at any time.

For pattern pieces that are symmetrical along a central line, such as the back piece and collar, such as the pocket fabric in the clothing interlayer and the double-sided sewing pattern pieces like the bottom collar, we can use the Unfold tool to flip them over the centerline.
Specific steps: In the 2D window, use the 'Edit Pattern' tool, right-click on the central line that needs to be folded, and select 'Unfold Symmetric Edit with Sewing' (selecting "Unfold Symmetric Edit" alone will not affect subsequent sewing and related operations).

Finally, as mentioned above, delete the "unnecessary" pattern pieces; these pieces either do not affect the overall sewing effect (such as the lining pocket fabric) or can be added more quickly through shape duplication (such as edge sticking and other clothing details).

Digital prototype case study: ISPO windbreaker down jacket

Sewing Thread Addition and Simulated Sewing

After importing the pattern, we can place it on the digital mannequin. Similar to sewing real clothing, we can use the sewing tools in CLO3D to add and simulate sewing threads.

The main tools used are the Segment Sewing tool, the Free Sewing tool, and their MN sewing mode.

Fig 14. Illustration of virtual sewing in Clo3D

After completing the basic clothing assembly, I used a special feature of digital sewing that differs from physical sewing, namely the cloning function, to quickly add clothing details:

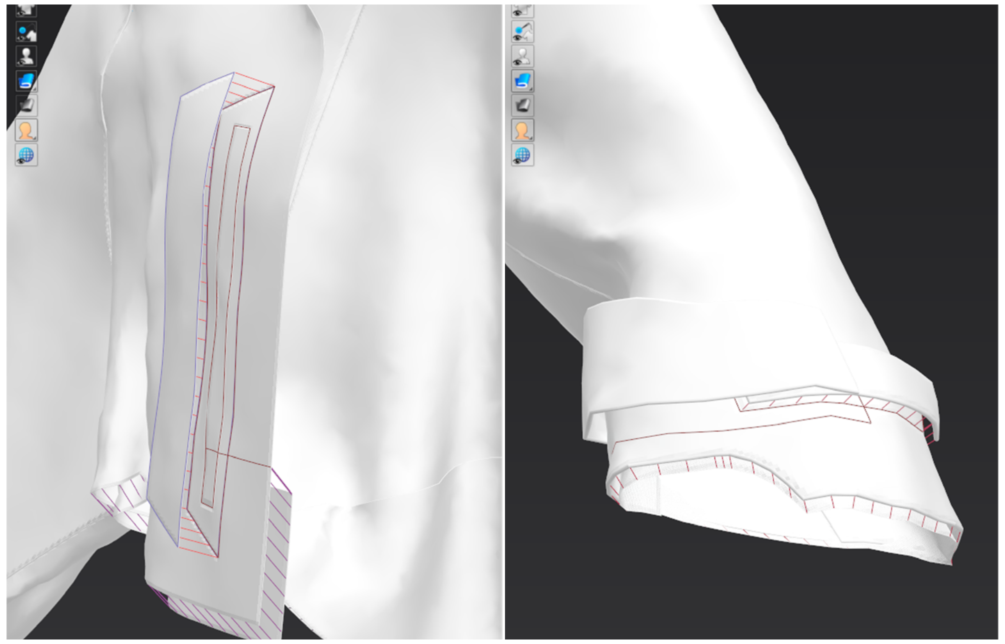


Fig 16. Illustration of detail addition

Layer Clone Over (or Under):
In the 2D panel, select the pattern piece selection tool, then right-click the pattern piece and select 'Layer Clone Over (or Under)'.
According to the auxiliary lines for pockets (or edge pasting) that were previously left on the main pattern pieces (or can be directly drawn and adjusted), cut the new pattern pieces.
Delete the cut pattern pieces and keep the needed ones.
Adjust the editing sewing lines to the correct position or directly delete the sewing lines and sew them again.

Superimpose (Over, Under, Side):
First, we need to add sewing lines to the target pattern piece. Then, select the target pattern piece, right-click on it in the 2D or 3D window, and select 'Superimpose (Over, Under, Side)'. The target pattern piece will automatically snap onto the pattern piece we added the sewing line to according to the sewing line we added.

Completing the sewing of the down layer and adding the zipper

To simulate the digital down filling effect, I used the **pressure function** in Clo3D. The **'Fill'** tool can also be used for this purpose, and this part will be shown in the "Technical difficulties and challenges in practical cases" section of this chapter.

After completing the down filling effect, I used the Layer tool to "insert" it into the previously sewn garment.

Fig 17. Illustration of Down Filling and Layered Stitching

Pressure function:
Use the "Clone Outside (Inside)" tool to duplicate the plate that needs to be filled with down. Apply pressure to the plate facing outward and reduce pressure on the plate facing inward to simulate the effect of down filling.

Layer function:
Import two sewn garment files (here, I sewed the inner and outer layers separately and saved them as different files) into the same file. Select all the inner layer fabric plates and set their layer to 1 (less than the outer layer), then select all the outer layer fabric plates and set their layer to 2. Then simulate the sewing. All inner layer plates will automatically be inserted into the outer layer plates.

For the **zipper** details on the garment, I used the zipper tool in Clo3D to add them. To ensure the stability of the zipper sewing, I used fabric simulation for the side two zippers, and the difference between them will be explained in more detail in the 'Technical Difficulties and Challenges in Practical Cases' section.

Fig 18. Illustration of zipper addition.
The middle zipper is added by tools, and the zippers on both sides are added manually

Zipper tool:
By using the Zipper tool in the 3D window, clicking on the starting and ending points of the two zippers in either the 3D or 2D window, the zipper can be added.

Manual zipper addition:
Create a fabric pattern according to the desired length and width, and apply the zipper's material and texture maps, and then sew it directly as a zipper

Details and Textures: the relationship between Stitching Thread Display, Rendering Thickness, and Puckering

After completing the basic modeling of the garment, in order to enhance its texture and emphasize the stacking relationship between panels, we can adjust two parameters of the sewing lines and panels in Clo3D.

The first method is to adjust the display of 3D sewing lines from **Plain Seam to Derictional**.

The second method is to increase the **thickness** of certain panels to create the stacking effect visually.

It is worth noting that the first method uses texture mapping to create the stacking effect visually, while the second method directly increases the thickness of the panel to create the stacking effect, which can increase the GPU computation pressure on the computer.

By using a combination of the above two functions, I set the stacking relationship of the garment panel sewing and further enhanced the texture of the garment model.

To simulate more realistic sewing effects, especially when making garments with prominent washing effects such as jeans, we can use the puckering tool to add folds to the edges of the sewn garment.

The process of adding folds is similar to that of adding stitching lines, and can be done either by adding line segments or by freehand drawing. After adding the folds, we can further edit them in the physical window, such as adjusting their texture, normal map, width, density, opacity, etc.

After adding the folds, we can use the selection edit puckering tool to further edit them. In the 2D window, we can select the fold we want to edit, and then move it or adjust its distance from the edge.

The puckering added using the puckering tool are essentially textures and do not physically stretch the edges of the pattern pieces. Since they are textures, they do not add much load to the computer's GPU, making them a cost-effective way to add realistic details to the model.

Fig 19. Before(left) and after(right) comparison of thickness addition

Adjust thickness:
Click on the panel that needs to be thickened, and in the 'simulation properties' column of the property editor on the right side, find the "Add thickness-rendering" parameter and adjust it higher. Usually, adding 1mm to thinner fabrics is enough to see the stacking effect.

Adjust 3D Sewing lines display and Puckering Too:
Using the sewing line editing tool, select the sewing line segment that needs to be changed to folding in the 3D or 2D window, and then change the mode from 'Plain Seam' to ' Derictional' in the 'display 3D sewing lines' column of the property editor.

To simulate more realistic sewing effects, especially when making garments with prominent washing effects such as jeans, we can use the puckering tool to add folds to the edges of the sewn garment.

Fig 20. Before(left) and after(right) comparison of puckering addition

Technical Difficulties and Challenges in Actual Cases

During the experiments, I found that there are certain difficulties and techniques to achieve certain effects while sewing clothing in Clo3D. Understanding these difficulties and techniques can help users simulate sewing more effectively and stably. In this section, I will summarize these contents.

Comparison between pressure function filling and Fill tool filling in the simulation of down jacket

There are two tools in Clo3D that can be used to create the filling effect of a down jacket. The first is to use the built-in filling tool of Clo3D, which is more suitable for industrial 3D modeling. That is, when the specific filling amount and related data of the down jacket or other filled clothing are known, inputting these data will result in a relatively realistic effect. However, the disadvantage is that it requires professional numerical values to be input, and the effect of changing them is not intuitive.

The advantage of using the pressure function is that it is more flexible and can change the 'filling amount' more intuitively. Therefore, it is still more suitable for creative clothing modeling. Therefore, in this thesis, I chose to use the pressure function to simulate the filling effect.

Note: When filling, if there are stay-stitches inside the plate, you need to set the internal lines inside the plate first, and then use the filling tool or the 'add to outside (inside)' tool for filling simulation. This way, Clo3D will automatically fold the internal lines inside the plate, which is more time-saving.

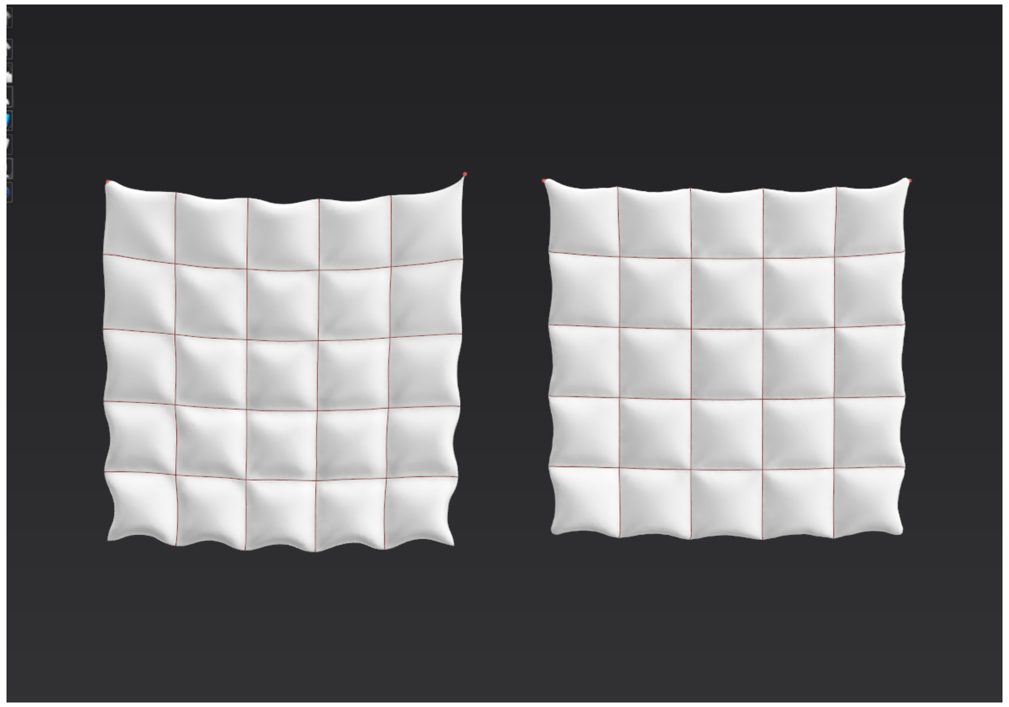


Fig 21. Comparison of Pressure function and Fill Tool on the left and right respectively

Zipper Tool vs. Manual Zipper

As mentioned earlier, there are two ways to add zippers in Clo3D, and in some specific situations, it is best to use the manual method to ensure the stability of the model. However, in terms of final display effects, there is not much difference between the three methods. The manual method is more time-consuming because it involves some adjustments to the texture and the addition of the Zipper Puller OBJ file. But in some cases (such as when the zipper tape is invisible, showing only 1mm), manual addition of the zipper will be more stable in the subsequent simulation process. The advantage of using the Zipper Tool is that it is faster and can convert the zipper teeth into OBJ entities (which greatly increases CPU usage). However, in some cases, the simulation is not stable. Therefore, a combination of both methods should be used depending on the specific situation.

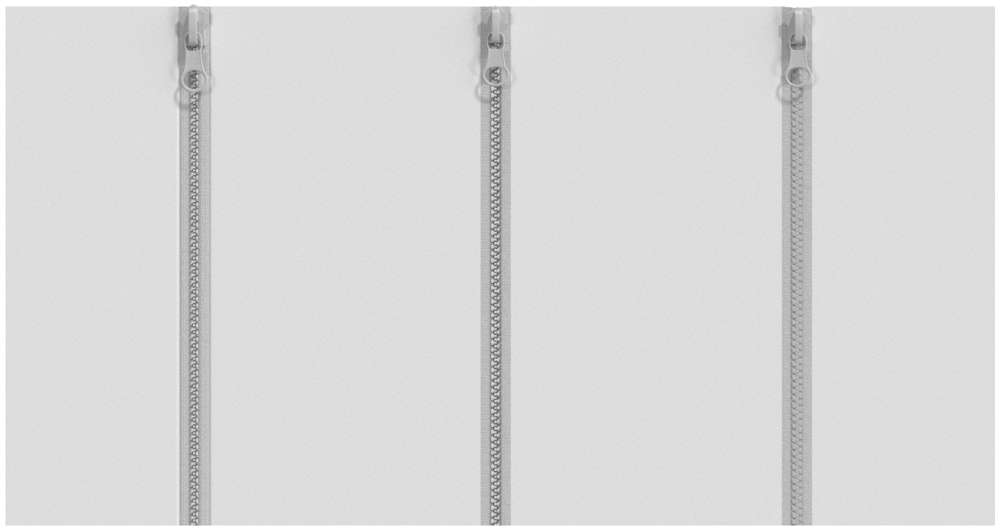


Fig 22. Comparison of three methods for adding zippers. From left to right: manually added zipper, zipper added with zipper tool, zipper added with zipper tool (OBJ teeth type)

Setting different particle distances between different fabric panels

Clo3D fabric algorithm

Before setting different particle distances for fabric panels, users need to understand the Clo3D fabric algorithm.
The basic algorithm of Clo3D is Mass-Spring Model To simulate the effect of real fabric, Clo3D increases the "triangle surface number" per unit interval. This can be achieved by adjusting the internal particle distance parameter.

The default value for particle distance is 20, which means that the distance between the endpoints of internal triangles is 20mm. The smaller the value of this parameter, the more triangle surfaces per unit area, and the more realistic the fabric simulation. However, this also increases the software and computer load. Conversely, a larger value means fewer triangle surfaces per unit area, resulting in less realistic fabric simulation and lower software and computer load.

Therefore, in order to improve the realism of digital clothing, we usually set the particle distance as small as possible. However, this is often limited by computer performance. Pursuing overly realistic simulation effects may cause software to become slow or even crash.

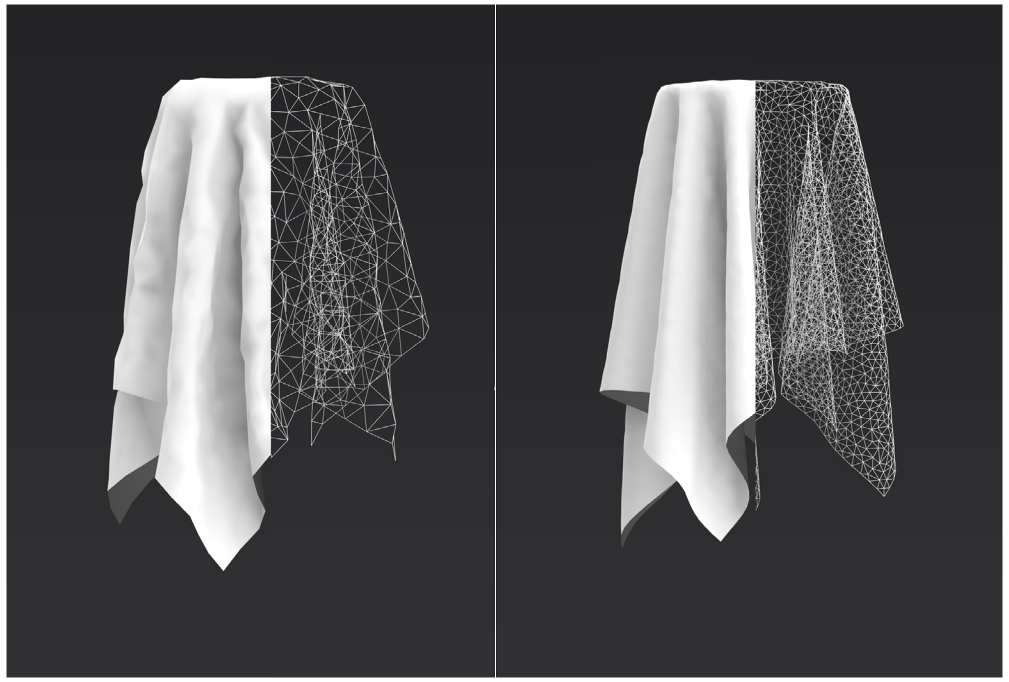


Fig 23. Particle distance comparison:
The fabric size in the image is 50*50cm, with particle distances set to 20 (left) and 8 (right)

Optimization of particle distance:

Just like optimizing invisible panels mentioned earlier, to improve the smoothness of our software operation, we can optimize the particle distance of different panels. We can increase the particle distance of panels in inconspicuous locations (such as the inside seam of cuffs, hem seam, inner pocket fabric, facing, etc.), and decrease the particle distance of panels in prominent locations, in order to minimize the number of model faces, optimize software performance, and improve the overall simulation effect.

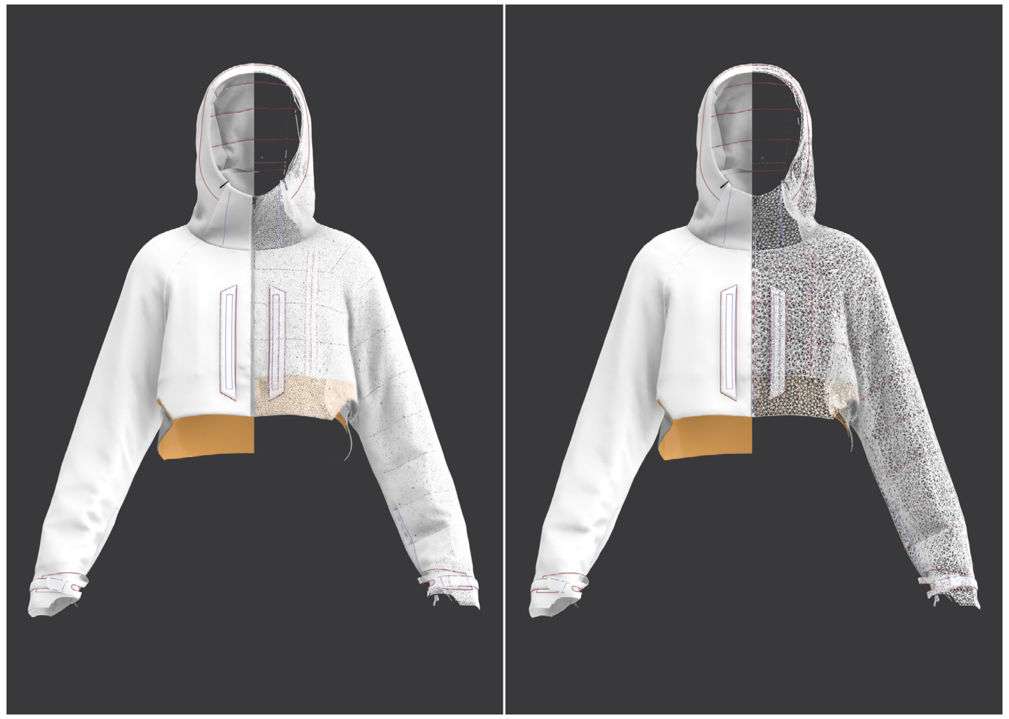


Fig 24. Comparison of particle spacing before and after optimization:
The left image has a total of 1,359,186 faces, and the particle spacing of all panels in the left image is set to 5mm;
The right image has a total of 382,858 faces, and the particle spacing of different panels is set between 5-20mm based on their weight.

Summary and Reflection

In this chapter, we first introduced the knowledge of CAD pattern making, compared the advantages and disadvantages of traditional garment pattern making and digital modeling, and analyzed their differences in the production process.

Then, through the modeling process of a down jacket, we analyzed the entire modeling process from pattern import, optimization, sewing, to detail adding. During this process, the author discussed the possible issues, compared the effects of different methods on filling and zipper adding, and explained how to adjust the particle spacing of panels more reasonably to reduce computer CPU resource consumption while ensuring the realism of the clothing model.

Based on these experiments, the author reflected on the following:

The difference between digital pattern and traditional pattern

As mentioned above, the garment pattern required for digital garment making is different from that of traditional garment making. In the traditional garment making process, the **internal lines** of the panels are usually deleted for visual simplicity. For example, a garment panel with pockets may only indicate the pocket opening position, and the pocket shape is not directly drawn on the main body pattern. Similarly, the width of the hem stitching is not directly drawn on the body panel, but is drawn on a separate panel on to facilitate cutting and production.

However, in digital modeling, internal lines are crucial for adding details because most garment details can be directly added by **copying and pasting**. Therefore, compared to actual garment production, garment patterns in digital modeling need to clearly draw internal lines on the main body panels.
Therefore, in the case of digital pattern making, all garment internal structures can be drawn on the main body panel as internal lines without being drawn as separate panels.

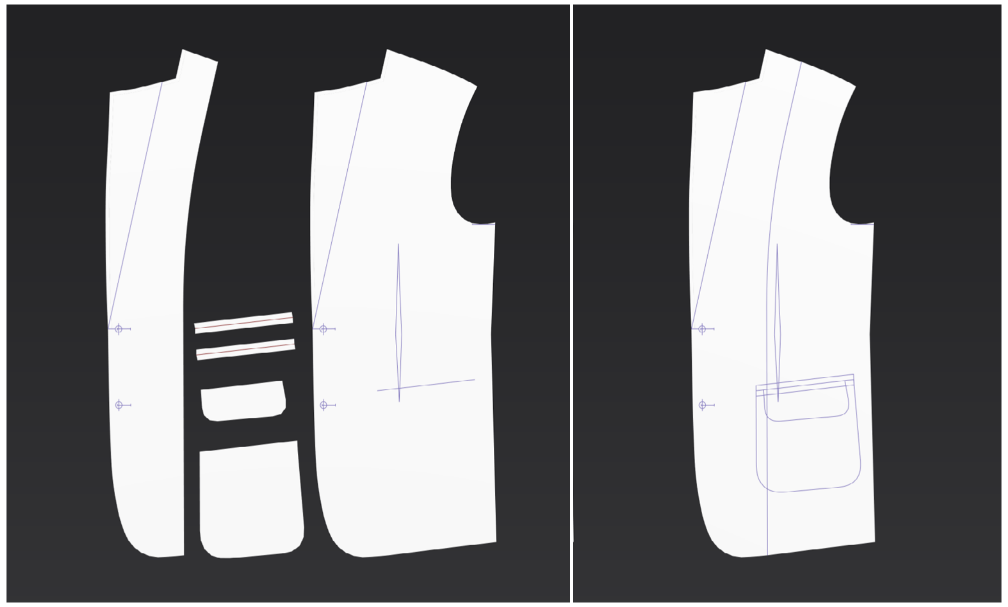


Fig 25. Comparison of required pattern pieces in actual carment production(-left) and digital garment(ri-ght) production

Advantages of digital prototype based on experimental results

In software such as Clo3D (and similar software), the sewing of digital garments is similar to actual garment sewing in many ways. Both involve sewing 2D panels of the garment together based on sewing techniques.

It is worth noting that when using software like Clo3D, users can easily simulate the sewing process, such as adding zippers, with just a few clicks, saving a lot of time compared to using an actual sewing machine. In addition, adding details such as pockets and patches is faster and more efficient in Clo3D using the "copy and paste" function, while it is more laborious and time-consuming in traditional garment production.

Based on the experiments, the author found that after spending approximately **three hours** modeling, the digital garment already had a rough effect of an actual garment. However, it takes at least ten hours to make an actual garment up to this point (excluding the stuffing process). For independent designers who do not have their own studio, if they need to outsource to another studio for production, the waiting time may be even longer.

In addition, the virtual nature of digital fashion means that the entire production process can be completed with just **one computer**, saving time, money, and reducing waste of materials such as fabric and accessories. Compared with traditional garment production, this method avoids the cost of purchasing sewing equipment, reduces the initial investment cost, and the cost of equipment maintenance and updates. At the same time, the digital storage method reduces storage space costs and eliminates the need to pay extra rent and management fees for physical garments and raw materials.

Disadvantages of digital prototype based on experimental results

First, digital fashion modeling requires designers to have a certain level of **professional knowledge** and **interdisciplinary knowledge**. Designers not only need to master knowledge of garment pattern making, but also have a deep understanding of relevant techniques and structures. In the traditional garment industry, designers, pattern makers, and prototype makers are usually separate professions. However, when using software such as CLO3D, designers need to have the relevant skills of all three professions, which is a considerable challenge for them.

As I mentioned optimizing the spacing of panel particles at the end of the experiment. This is not only for operation in Clo3D but also to ensure a smoother rendering when importing into Blender for scene shooting. However, why set different particle spacings for different panels, how model face count affects model accuracy, and the use of UV maps and hardware modeling are not directly related to garment production. Therefore, this further raises the requirements for the designer's skills.

In addition, due to current limitations in software technology, digital garment models cannot fully replicate the texture and feel of real clothing samples. For example, although it is possible to simulate the stacking effect between panels by setting different fabric thicknesses or overlapping relationships between seams, or simulate realistic sewing effects by adding sewing thread wrinkles, there are still differences in detail between the simulation and the real garment.

Chapter 3
Digital Fabric Experiment Based on Clo3D

Introduction: Differences in Composition between Digital and Real Fabric

The differences in composition between digital and real fabric can mainly be divided into two points:
Firstly, unlike real fabric which is woven from **yarn**, digital fabric is made up of individual triangles and simulated using a mass-spring model **algorithm** to mimic the physical properties of real fabric.

Secondly, digital fabric is essentially a **texture map**. Its appearance is primarily influenced by the texture map, and is presented with different concave-convex, reflective, and transparent effects based on normal maps, bump maps, roughness maps, and opacity maps.

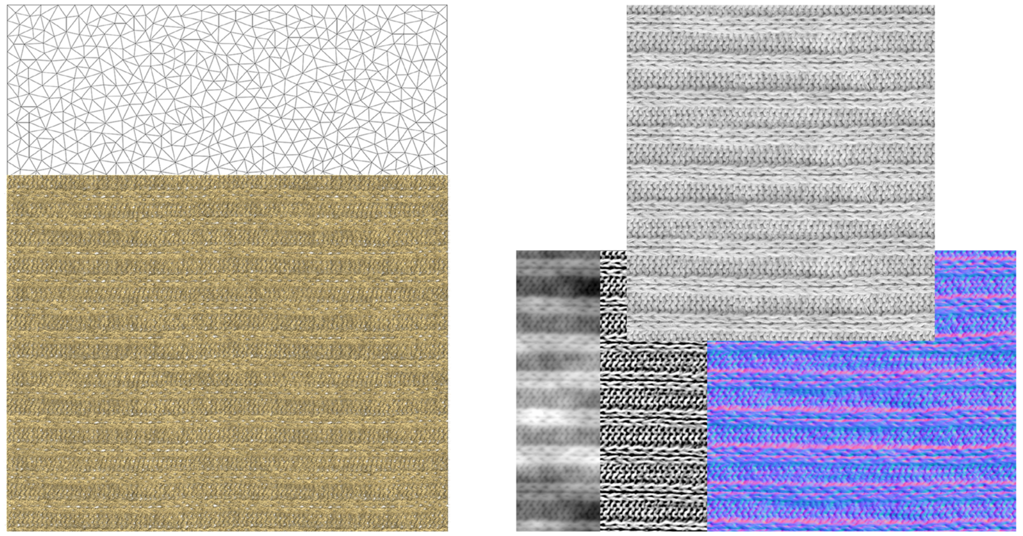


Fig 27. Illustration of digital fabric composition

Case study: Digitizing fabrics

This section will focus on the comparison between digital fabrics and real fabrics through a case study, and use Clo3D as the basis to **scan fabrics** and generate relevant textures to verify the authenticity of digital fabrics. In addition, **physical property** adjustments will be made on Clo3D. Taking ISPO down jacket as an example, the differences in fabric texture between the digital sample and the real sample will be compared.

Fabric scanning process and seamless processing

In the process of fabric digitization, the first thing to do is to obtain the basic texture pattern of the fabric. This can be done by using a professional scanner, such as **Vizoo's xTex**, or by using mobile devices such as phones or cameras for shooting or scanning. Regardless of the method used, at least one complete continuous square pattern in the fabric composition needs to be scanned. After obtaining the basic four-square continuous pattern, we can generate a normal map using this pattern.

The best way to scan fabrics is to use a professional fabric scanner. There are many professional fabric scanners on the market, such as Laser Design's SURVEYOR Scan Head, Shima Seiki's SDS-ONE APEX3, Optitex's O/Cloud 3D, Artec's Eva Lite, and so on. The most suitable fabric scanner for Clo3D is Vizoo's xTex, which is a high-precision fabric scanner based on camera technology. It can quickly scan various types of fabrics and **automatically** generate a series of maps that are compatible with Clo3D, which can be directly imported into the Clo3D software as a package file.

For individual designers or small studios, **mobile devices** such as phones or cameras can also be used to scan fabrics. When scanning, it is necessary to pay attention to the uniformity of the light, the same background color, and the overall flatness of the fabric. When shooting fabrics, some apps such as Google's "Google Camera" and "3D Scanner" can be used to assist in obtaining better scanning results.

When using mobile devices for scanning, there may be size deviations, so it is necessary to check the image size in third-party software such as PS. When adjusting the texture size of the fabric map in Clo3D, all maps need to be imported before adjustment, otherwise there may be a situation where the texture map does not correspond to the normal map, bump map, and transparency map.

Generating seamless texture with Photoshop

Next, we need to process the texture image we captured to make it **seamless**. Here are two methods: using **Photoshop** to generate a seamless texture image and using Clo3D's **fabric Generator** to generate a seamless texture image.

In Photoshop, import the images we need, select the four continuous squares, and then deselect other areas for deletion to make the texture seamless.
During this process, we can also open the PS **pattern preview function** (View ➡ Pattern Preview, this function requires a PS version of at least 2022) to help us lock and correct the four continuous patterns.

The Photoshop method is relatively simple and easy to operate, but due to the errors caused by the scanning patterns, the seamless patterns produced using this method often have unnatural transitions. More time may be needed to adjust the edges of the pattern to make the transition smoother and more natural.

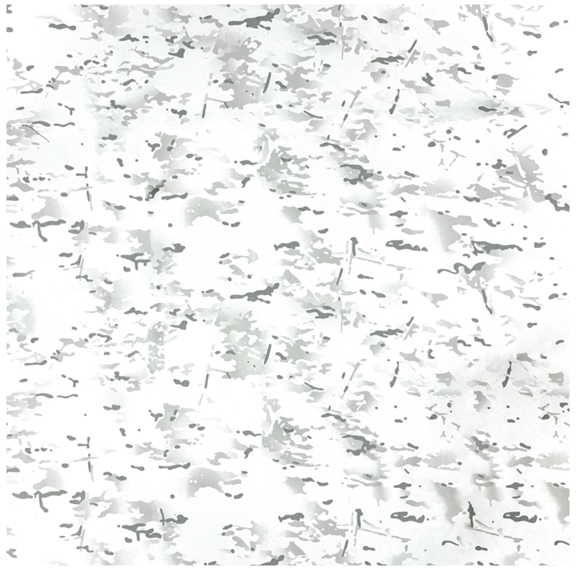


Fig 28. Fabric shooting by phone camera
Asset belong to ISPO

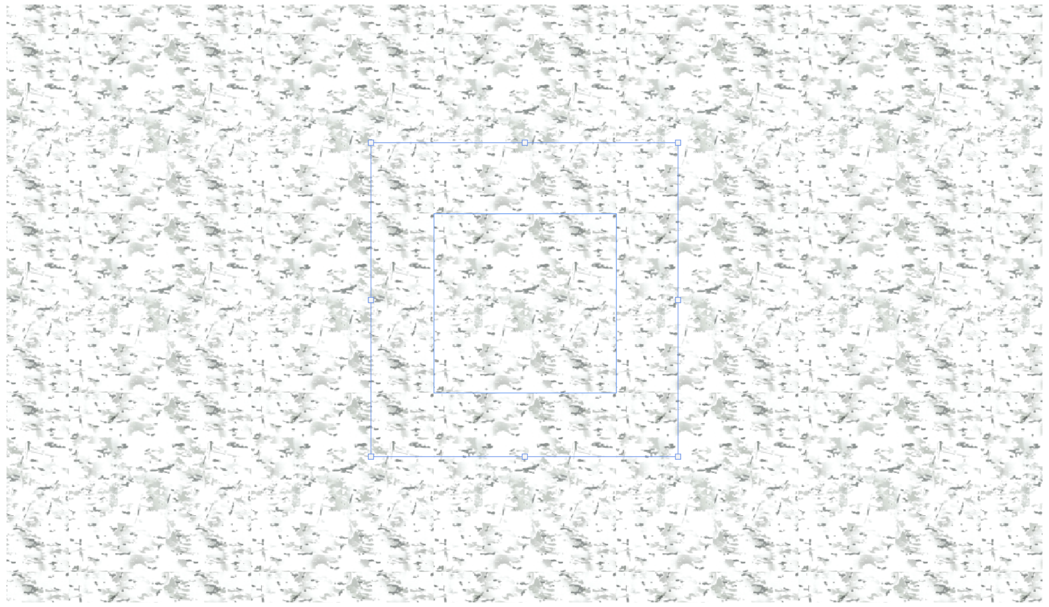


Fig 29. Creating seamless patterns using Ps, with the Pattern Preview window shown in the picture
Asset belong to ISPO

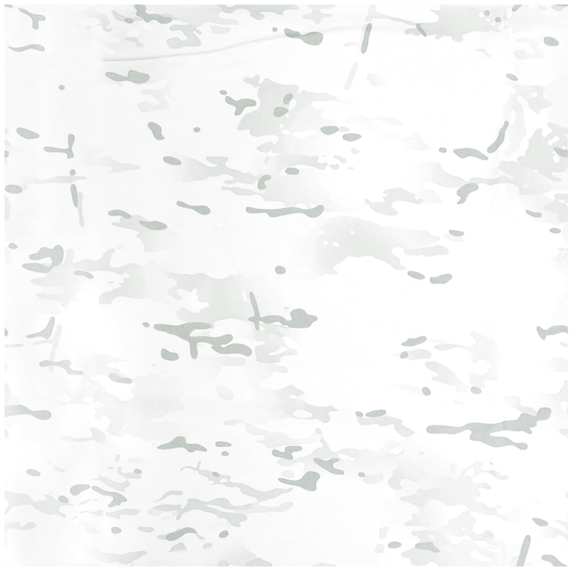


Fig 30. Seamless texture pattern created using Photoshop
Asset belong to ISPO

Using Clo3D to generate seamless textures

Using Clo3D's Fabric Editor to generate seamless textures has a significant advantage in terms of **time savings**, especially when processing plain fabrics without patterns.

Clo3D will use intelligent algorithms to calculate the edge connection of the seamless pattern based on the boundary range of the pattern we select, making it smoother. However, this method may not be able to accurately identify the pattern boundaries when dealing with more complex fabric patterns, so more adjustments and optimizations may be needed in later stages.

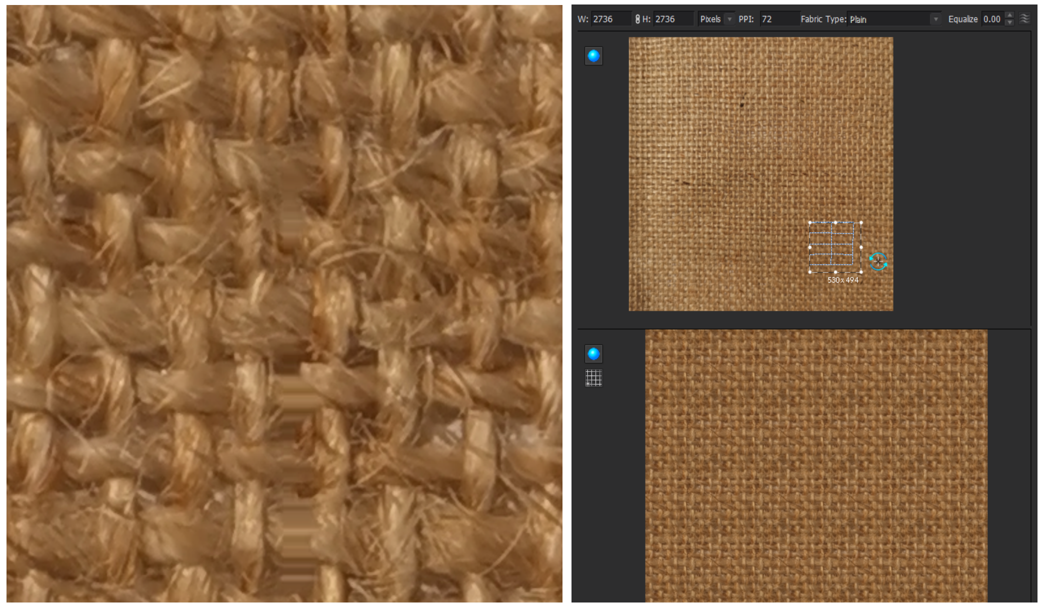


Fig 31. Clo3D's seamless texture editor (right) and automatically generated seamless texture (left)

Operation:
In the Fabric window, click on the "+" sign to enter the seamless texture creation interface.
Click "Open" at the bottom to open the image needed to create the seamless texture. Select the pattern in the upper window, and the seamless texture will be generated automatically in the lower window.

Note:
The scanned texture pattern can be appropriately reduced in size when making the fabric's seamless texture. This can help reduce file size, making computer work more efficient.

Texture map generation:

After obtaining the fabric's basic pattern, third-party software such as Photoshop, Substance Designer, or Clo3D's built-in fabric pattern editor can be used to generate texture maps such as normal maps, displacement maps, opacity maps, reflection maps, etc.

Normal maps and bump maps:

Normal maps can further **enhance** the texture of the fabric. Clo3D provides us with many basic fabric texture maps, including their corresponding normal maps. In most cases, we can observe the weave texture of the desired fabric and directly find the corresponding normal map in the CLO3D fabric library and apply it to the fabric. However, in the absence of a well-matching normal map, we can also use the 'Generate Normal Map' filter in Photoshop to generate a normal map based on the created seamless texture map.

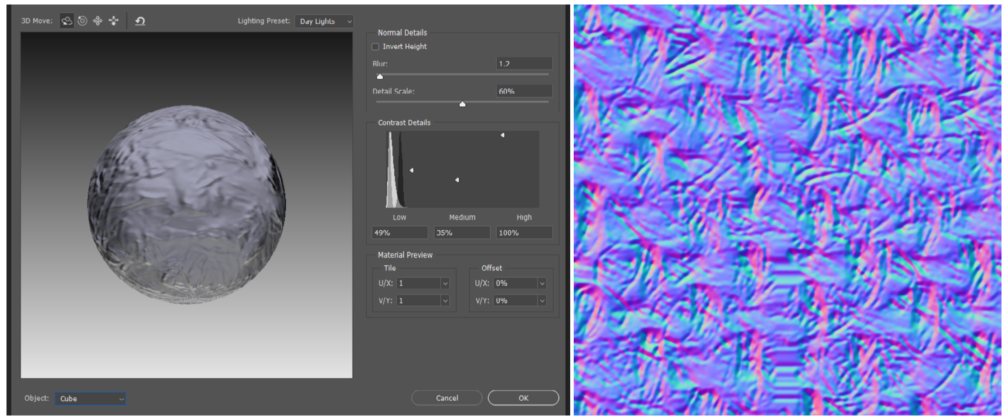


Fig 32. Photoshop window for generating Normal Maps (left) and the generated Normal Map (right)

For fabrics with strong texture, besides normal maps, **bump maps (displacement map)** are also used to enhance the surface's concave and convex texture. The generation method is similar to that of normal maps. Import the seamless texture map into Photoshop and use the bump map function in the 3D filter function to generate

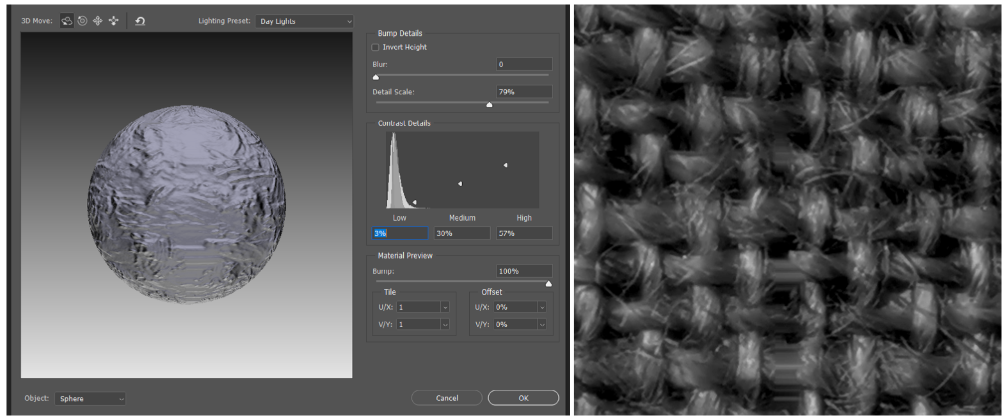


Fig 33. Photoshop window for generating Displacement Maps (left) and the generated Displacement Map (right)

Note:
The Displacement Map in Clo3D can only be viewed in the rendering window.
Compared to the Normal Map, the Displacement Map changes the actual shape of the fabric mesh model, while the Normal Map only changes the grayscale of the fabric texture to simulate the 3D effect. Therefore, the 3D effect simulated by the Displacement Map is more realistic, but it also consumes more computer memory compared to the Normal Map.

Fig 34. Illustration of texture without map (right), after applying Normal Map (middle), after applying Normal and Displacement Map(left)

Opacity Map and Reflection Map

Lace and other fabrics with hollow patterns often use **Opacity Maps** to simulate the hollow effect. When scanning these types of fabrics, we can place a piece of paper or fabric with a significantly different color and brightness under the fabric to make it easier to create the Opacity Map using third-party software later on.
(Refer to the picture on the left)

When the fabric has partial reflection or metallic decoration, **Roughness Map** or **Metalness Map** can be used to control the local reflection of the fabric. Both of these maps are grayscale images. In the Roughness Map, the darker the area, the smoother the surface and the stronger the reflection; the whiter the area, the rougher the surface and the weaker the reflection. In the Metalness Map, the darker the area, the weaker the metal and the weaker the reflection, and the whiter the area, the stronger the metal and the stronger the reflection.
(Refer to the picture on the left)

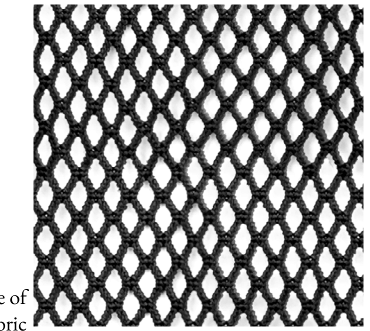


Fig 35. Seamless texture of mesh fabric

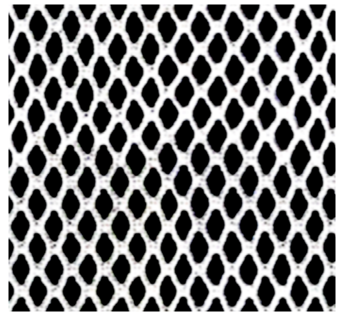


Fig 36. The Opacity Map

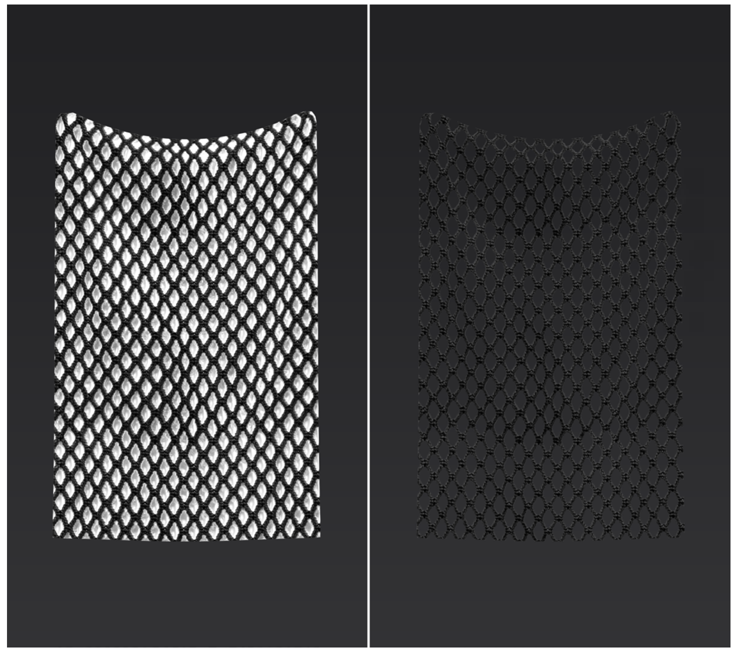


Fig 37. Before applying the Opacity Map (left) and after applying the Opacity Map (right)

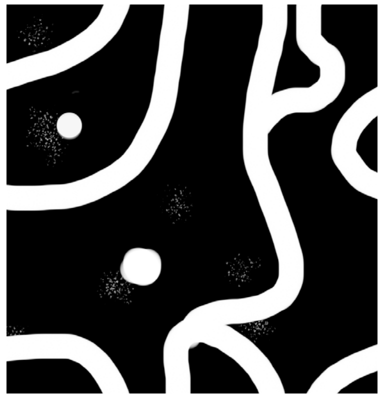


Fig 38. The Roughness Map. Textures created in Photoshop

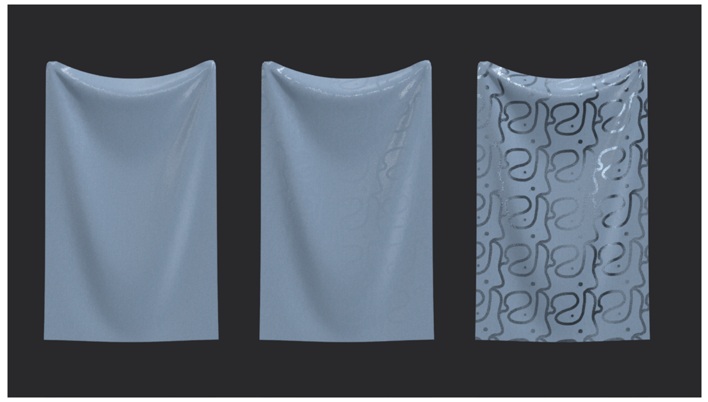


Fig 39. From left to right: no Map applied, texture image applied as Roughness Map, texture image applied as Metalness Map

Graphic Tool: Adding Texture Details

In Clo3D, in addition to adjusting the fabric texture to edit clothing patterns, you can also use the Graphic Tool to add local patterns. The former is more suitable for adding continuous patterns, while the latter is more suitable for adding individual non-continuous patterns.

We can also supplement the texture of fabric **wear effects**. Taking a pair of jeans as an example, by scanning and combining with Photoshop, PNG images with washed-out effects and worn edges were obtained. The Graphic Tool was used to apply them to the corresponding fabric pieces, apply the same normal map as the fabric, and adjust their transparency. Finally, a more realistic effect was achieved.

Fig 40. Comparison of Graphic texture before (left) and after (right) application.
The designer of the pants in the picture is Giovanni Fazzini

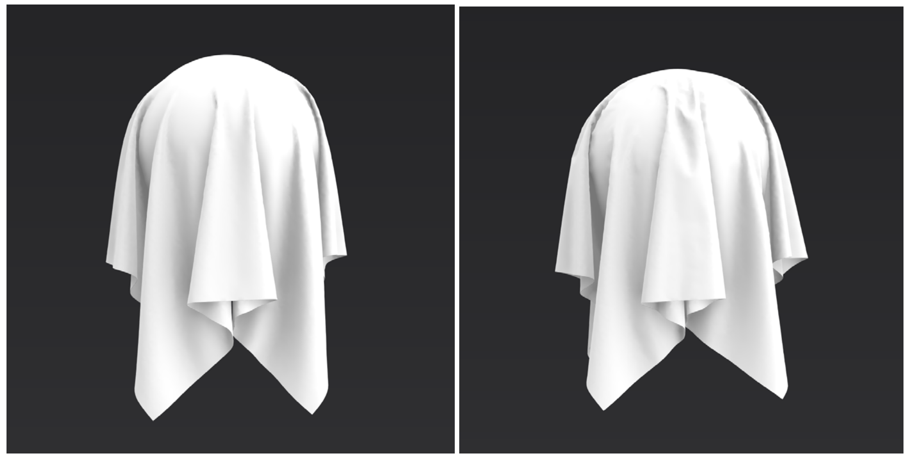
Fig 41. The processed texture, with the upper half being the worn effect and the lower half being the washed-out texture
Note that for better image display, the transparent texture background has been replaced with black

Based on Clo3D's fabric physical property testing

In order to adjust the physical properties and shape of fabrics, Clo3D provides a series of adjustable parameters. These properties are divided into 15 groups, which can be roughly divided into five groups. The first four groups of variables are based on the yarn direction of the fabric: warp, weft, diagonal-left, and diagonal-right.

The first group of variables controls the strength of the yarn (Stretch-Weft, Stretch-Warp, Shear), which determines the fabric's hardness. The larger the value, the stiffer the fabric, the sharper the folds, and the less stretchy it becomes; conversely, the smaller the value, the softer the fabric, the softer the folds, and the more stretchy it becomes.

Fig 42. Illustration of fabric physical property experiment.
Left: Default fabric physical properties (version 5.2)
Right: Based on the default fabric properties, the first set of variables are increased by 40



The second group of variables controls the bending strength of the yarn, which determines the stiffness of the fabric. The larger the value, the stiffer the fabric and the less drape it has; the smaller the value, the softer the fabric and the more drape it has.

Fig 43. Illustration of fabric physical property experiment.
Left: Default fabric physical properties (version 5.2)
Right: Based on the default fabric properties, the second set of variables are increased by 40

The third group of variables controls the deformation rate of the yarn, which determines the tension of the fabric. The larger the value, the stronger the tension of the fabric; the smaller the value, the weaker the tension of the fabric.

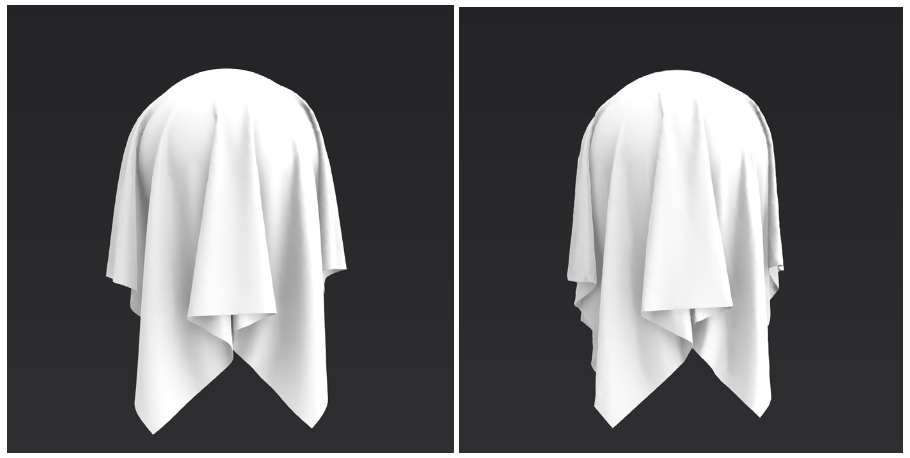


Fig 44. Illustration of fabric physical property experiment.
Left: Default fabric physical properties (version 5.2)
Right: Based on the default fabric properties, the third group of variables are increased by 40

The fourth group of variables controls the deformation strength of the yarn, which determines the bending strength of the fabric in the folds. The larger the value, the sharper the folds of the fabric; the smaller the value, the softer the folds of the fabric. These variables are usually adjusted simultaneously with the third group of variables.

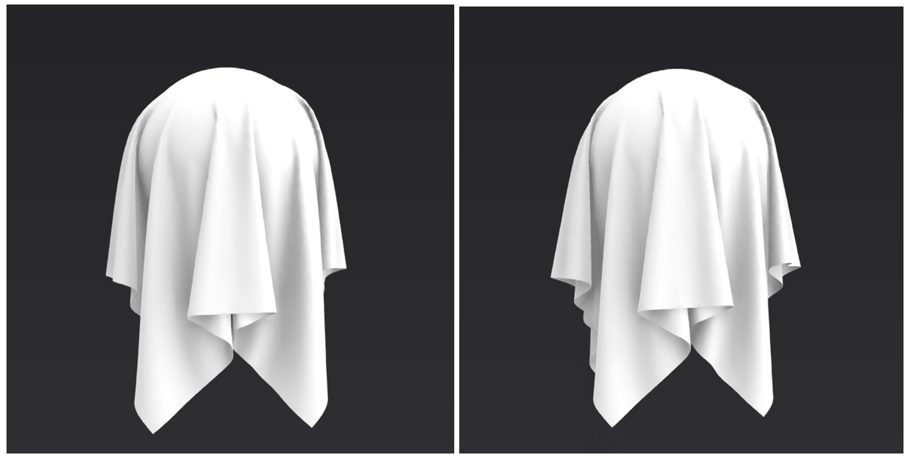


Fig 45. Illustration of fabric physical property experiment.
Left: Default fabric physical properties (version 5.2)
Right: Based on the default fabric properties, the fourth group of variables are increased by 40

The fifth group of variables sets the overall properties of the fabric, including the internal resistance, density, and friction coefficient.

Comparison of texture between virtual and physical garment

Furthermore, based on the above knowledge, I set the physical properties of the fabric for my research project in Clo3D, and through comparison, it can be observed that the fabric of the virtual garment (static) can essentially reproduce the texture of the real garment fabric.

Fig 46. Comparison of ISPO windbreaker digital and physical samples

Challenges and problems encountered in the experiment

The time-consuming scanning process

Since the author did not have a professional scanner, all fabric scanning and texture map generation were done using relatively simple methods. The author used a smartphone camera (iPhone 14) for scanning fabrics and Photoshop for generating texture maps. However, even with these simple methods, a satisfactory result was achieved in the end, which is encouraging for small studios and independent designers.

The issue with this approach is that the entire digital fabric creation process takes a long time, especially when generating related texture maps, which requires repeated adjustments. Therefore, it is not suitable for large-scale fabric scanning.

Distortion of fabric pattern size

When using mobile devices to scan fabrics, factors such as the distance between the device's camera and the actual fabric, shooting angle, and image resolution can cause the scanned size to be inaccurate. In this case, after scanning, we need to use related software to correct the size to be closer to the actual fabric size. However, this step will increase the time needed for fabric digitization, thus affecting the efficiency of the entire process.

Unrealistic fabric physical property parameters

The fabric in Clo3D is based on a particle-spring model algorithm, which is completely different from the physical parameters of real fabrics. As mentioned earlier, the physical adjustment parameters of fabrics in Clo3D are the strength of the yarn, bending strength, deformation rate, and deformation strength. In reality, fabric physical parameters include yarn density, thickness of warp and weft yarns, fabric weight, and fabric composition. These cannot be directly matched with the parameters in Clo3D, so designers have a vague reference system when setting fabrics and can only approach the real fabric texture through repeated experimentation.

Summary and Reflection

This chapter mainly explores the methods of **fabric digitization** and compares the **differences** between digital fabrics and real fabrics in composition. The experiment results show that digital fabrics can achieve quite realistic effects in appearance through texture maps (such as normal maps and displacement maps). Also, in Clo3D, designers can use the Graphic Tool to simulate garments with washed or worn textures like jeans.

In Clo3D, designers can adjust the physical property parameters of fabrics to simulate their physical texture. However, the author found that the fabric's physical simulation effect is quite good in static situations, but in dynamic simulation, due to the limitations of the base algorithm, the realism of fabric texture still needs improvement.

The visualization and storage advantages of digital fabrics

During the digital fabric creation process, the highly visual nature of the process makes it superior to traditional printing processes in terms of fabric pattern placement and size adjustment. Traditional printing processes usually require multiple sample productions and print tests to determine the pattern size, repetition, and position. This process is often time-consuming and laborious, potentially leading to fabric waste and product rework. In contrast, when using Clo3D's Graphic Tool for fabric pattern placement and size adjustment, designers can make multiple adjustments and tests on the computer, allowing for a faster, more accurate, and flexible way to determine the best pattern layout and size.

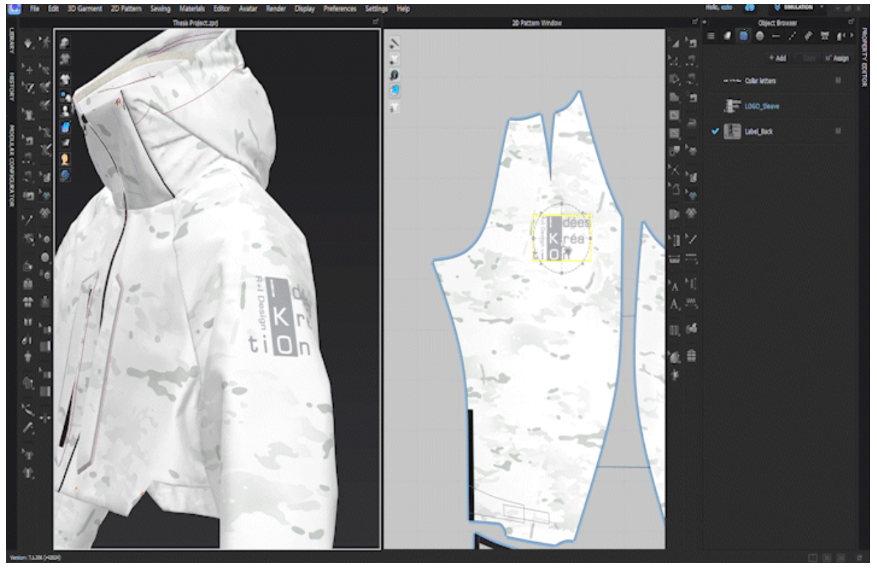


Fig 47. Adjustment of sleeve print (only in the presentation)

Digital fabrics have significant advantages in **storage**, saving designers a lot of time in fabric selection and application. For example, digital fabrics created in Clo3D can be saved as assets on a computer or in the cloud, and the resulting digital fabric library can be used directly by designers in their subsequent creative work. The concept of **digital fabric libraries** has become increasingly popular in recent years, with many digital fabric libraries or digital fabric "bookstores" appearing online, providing designers with a wealth of fabric resources.

For instance, in CLO3D's **CONNET community**, designers can directly select and download (possibly paid) fabric files and seamlessly apply them to CONNET project files. Designers can easily change fabric properties, test, and optimize design solutions on the computer, which helps save time, reduce costs, and improve design efficiency.

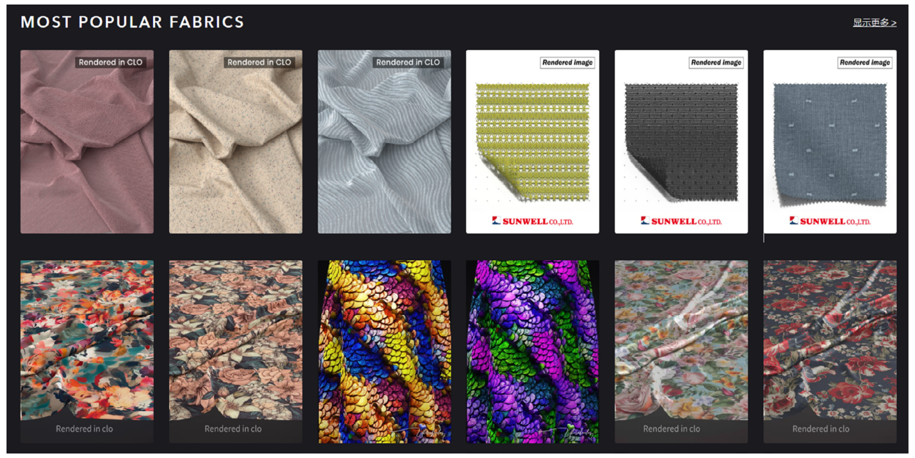


Fig 48. Screenshot of Closet - CONNET store

Weaker perceptibility of digital fabrics

When selecting digital fabrics, designers mainly rely on **visual perception**, focusing on the texture, color, and gloss of the texture maps, but cannot fully replace the multi-sensory experience of real fabrics. When selecting actual fabrics, designers can perceive the fabric's texture, elasticity, breathability, and sound through various senses such as touch, smell, and even hearing, making a more comprehensive and accurate choice.

Fortunately, there are some technical experiments actively trying to bridge the perceptual gap in digital fabrics. For example, simulating the touch of fabric texture by sliding fingers on a **touch screen** (Atkinson, D., Orzechowski, P., Petreca, B., Bianchi-Berthouze, N., Watkins, P., Baurley, S., ... & Chantler, M. 2013, April) or sliding digital fabrics with a stylus and experiencing the roughness and friction of fabric through **sound feedback** (Huang, G., Metaxas, D., & Govindaraj, M., 2003).

However, most of these experiments are still in the exploratory stage and have not been widely disseminated and applied. There is currently no mutually supportive ecosystem with 3D clothing modeling software or digital fabric museums.

Therefore, to make digital fabrics play a more significant role in designers' daily work, designers, engineers, and researchers need to strengthen interdisciplinary cooperation, jointly promote the practical application of these technologies, and bring digital fabrics from the laboratory research stage to a wide range of market applications. This way, these experimental results can be genuinely applied to existing 3D clothing modeling software and digital fabric museums, forming a more complete ecosystem.

Mechanical feel of digital fabrics

Lastly, we need to note that digital samples often have an "overly neat mechanical feel" lacking liveliness and realism. This is because, in the actual garment sample production process, the fabric placement may have a certain degree of irregularity due to the artisan's operational defects (such as uneven cutting, ironing, and shrinkage). This **randomness of human factors** is challenging to reflect in digital fabric physical property settings.

Therefore, before actual industrial production of clothing, designers still need to create samples to adjust the design according to subtle differences in fabric texture.

Chapter 4
Hardware customization - A comparative experiment between Clo3D and Blender

In this chapter, I will discuss the advantages and disadvantages of digital hardware and physical hardware, and based on the customizability of digital hardware, I will use Clo3D and Blender to create digital hardware. I will then compare the similarities and differences between the digital hardware created in the two software programs and discuss the strengths and weaknesses of Clo3D and Blender for designing digital hardware. This will provide designers with more ideas when creating digital hardware.

A brief analysis of the similarities and differences between digital and physical hardware accessories

Digital accessories have smaller perceptual barriers:
Digital hardware accessories and physical hardware accessories share many similarities, such as appearance, shape, color, and texture. Unlike digital fabrics, digital hardware generally has a rigid texture, which does not involve complex digital simulation algorithms such as softness or drape. The digital simulation of color and reflectivity is relatively simple, so digital accessories and actual accessories are essentially 1:1 reproductions. Therefore, the perceptual barrier for digital accessories is smaller, and it is easier for designers to choose digital hardware compared to digital fabrics.

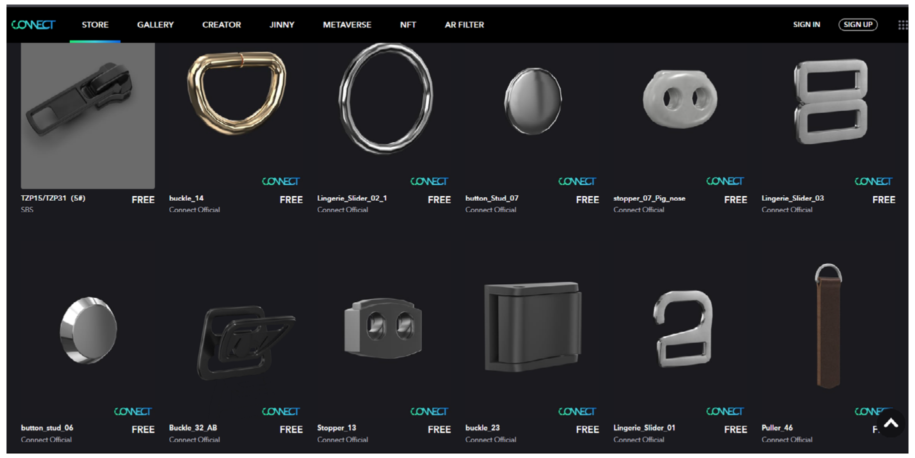


Fig 49. Screen shot from Closet-Connet website

Moreover, digital accessories have high customizability:
Digital accessories have high customizability and flexibility. In addition to selecting hardware on related websites, designers can use software like CLO3D and Blender to change the shape and material of accessories, perform operations like punching or embossing, and more. This

makes digital accessories highly valuable in digital displays or preliminary versions, meeting the needs of designers and enabling rapid concept verification and design iteration. However, digital accessories are virtual and need to be converted into physical objects through technologies like 3D printing, which may increase additional costs when not mass-customized.

Case Study

In this chapter, I will discuss the advantages and disadvantages of digital hardware and physical hardware, and based on the customizability of digital hardware, I will use **Clo3D** and **Blender** to create digital hardware. I will then compare the similarities and **differences** between the digital hardware created in the two software programs and discuss the **strengths** and **weaknesses** of Clo3D and Blender for designing digital hardware. This will provide designers with more ideas when creating digital hardware.

Customizing accessories in Clo3D

Button

First, we will import the scan of the button lettering into the pattern tool and create a panel. We will then use the internal line tool to trace the edges of the button lettering, converting any holes into hole shapes with internal lines. Next, we will add thickness to the button lettering, which can be done by adjusting the fabric properties or the rendering thickness in the panel's physical properties. The edge curvature parameter can also be adjusted to change the sharpness of the edges of the button lettering. Finally, we will use the pin tool to deform the button panel to some extent.

Zipper Puller

For customizing a zipper puller, we can modify the built-in zipper OBJ file in Clo3D. First, import a basic zipper OBJ file with a satisfactory shape. To demonstrate an example of engraving,

we will use texture maps and normal maps to modify the existing OBJ file. Apply the edited images to the corresponding positions of the zipper material and observe the final effect. If the engraving effect is not clear, a displacement map can be used for correction.

In addition to texture map modifications, we can also add decorations. For example, we can add a fabric strip decoration to the end of the zipper puller. Use the Polygon tool to create a fabric strip, and the Move tool to pass it through the hole at the end of the zipper puller. Add the necessary seams and topstitching, and apply the desired pattern to the panel.

Buckle

In Clo3D, besides buttons and zippers, other hardware accessories such as buckles can also be created. Taking the buckle as an example, first apply the buckle shape to the plate, then use the 'Cut' function to obtain the required part and delete the unnecessary parts. Then use 'Layer

Clone' to clone another plate. Use the move tool to move the two plates apart, creating a long rectangular plate to act as the thickness of the buckle. Use the internal line tool to draw the buckle hole, and after adding thickness, create a strip of fabric according to the width of the hole and sew it through the hole. Finally, apply the fabric texture and the buckle is complete.

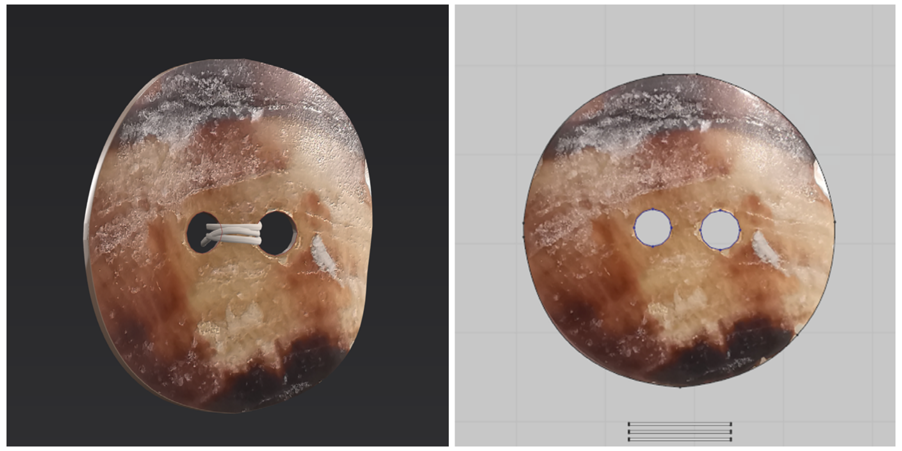


Fig 50. Button made by Clo3d

Fig 51. Puller modification display image

Fig 52. Buckle Made inside Clo3D

Customizing accessories in Blender

Button

First, create the basic shape and thickness of the button. Click Shift+A ➡ Mesh ➡ Add Circle and adjust the size. In 'Edit Mode,' select all the points of the model and form a solid circular surface. Extrude the button thickness upwards to complete the basic shape creation. Then, create two cylinders, scale and move them to the button hole position, and use Ctrl+- to complete the punching.

Next, add some Bezier curves, move them to the button hole, adjust the chamfer depth, and duplicate the curves to simulate real stitching effects. Finally, select the button model and create the material in the material property panel. Adjust the 'Principled BSDF' parameter to achieve the desired effect. Import texture and normal maps in the Shading panel to complete the texture import.

Button

First, to create and adjust the size of a cube, then use the Bool Tool to punch a hole. Then, use the text tool and Bool Tool to add carving effects: in the 3D window, add 'Text', enter the text, and convert it to a mesh. In 'Edit Mode,' add thickness and then use the Bool Tool to complete the button cutting.

Afterward, add a plane in the 3D window, adjust its size, and use 'Extrude Region' to pass through the Puller hole to add decorative strips. Finally, we can smooth the model edges: select the model, enter 'Edit Mode,' select the edges to be chamfered, use Ctrl+B and slide the mouse to complete the chamfer operation (the number of chamfer segments can also be adjusted by scrolling the mouse).

Buckle

First, we create a cube and adjust its shape for the buckle. Then, according to the shape of the hole to be punched, create a model, use the Bool Tool to complete the punching, and then use the chamfer function to process the edges. Finally, add the material and texture map following the button method.

When adding the buckle fabric, I used Blender's fabric simulation function to increase its realism. Like the Puller, create two flat meshes and make them pass through the upper and lower holes of the buckle. Then apply cloth simulation to these two meshes.

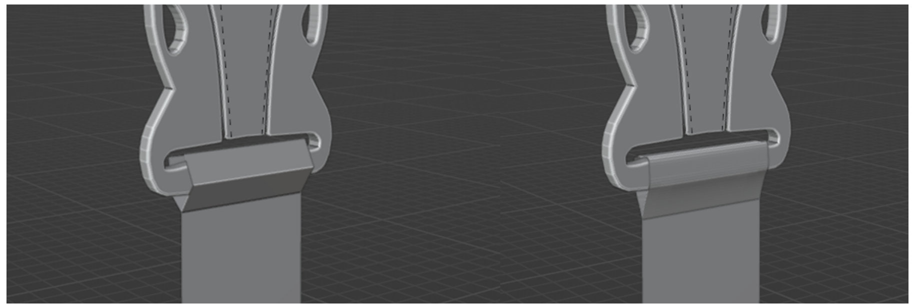


Fig 53. Comparison of Before (left) and After (right) Simulation of Fabric for Hardware

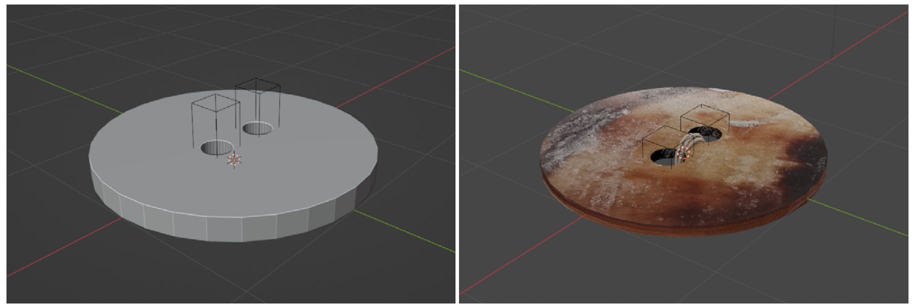


Fig 54. Button creation diagram in Blender

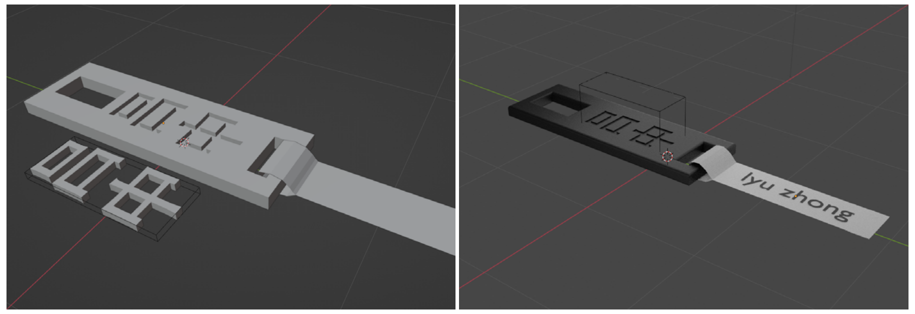


Fig 55. Puller creation diagram in Blender

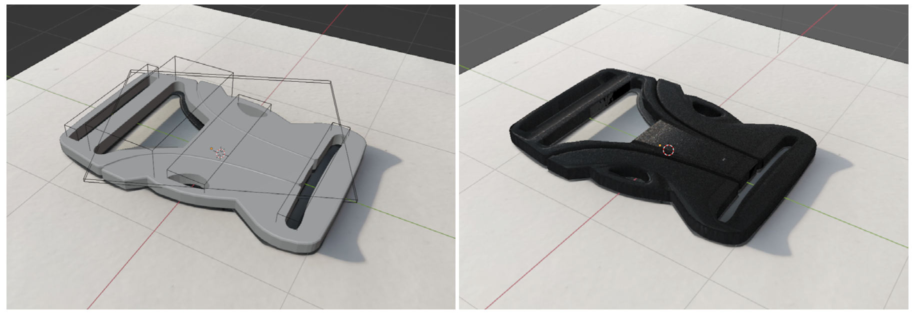


Fig 56. Buckle creation diagram in Blender

Comparison and Reflection on the Advantages and Disadvantages of Making Hardware in Clo3D and Blender:

In terms of model polygon count

Blender's Button has 534 faces, Puller has 2089 faces, and Buckle has 2210 faces.
Clo3D's Button has 12903 faces, Puller has 35794 faces, and Buckle has 97092 faces.

Clo3D does not have as good control over the number of faces as Blender does. When using Clo3D for hardware modeling, the **Practical Distance** parameter of the fabric is usually set to less than 3 to ensure the accuracy of the model, which often results in excessive face count and increased CPU usage. However, in Blender, the "**Decimate**" modifier can be used to reduce the number of faces in the model, so it is best to import the Clo3D-made model file into Blender for "Decimation" processing (usually reducing the face count to 1/10 without loss of quality).

In terms of modeling effects

Clo3D is more skilled in **soft modeling**, while Blender is more suitable for **hard modeling**. By comparing and observing, it is not difficult to find that when modeling a button, Clo3D can more easily '**bend**' it to achieve a better shell button texture, while Blender is more difficult to deform the model in a similar way (it can be achieved through sculpting tools, but it greatly increases the face count); when modeling a buckle, Clo3D's fabric simulation effect is slightly better than Blender's fabric simulation effect. However, for Puller modeling, Blender can use the Bool Tool to carve text on the Puller, while Clo3D does not have **carving** function, and can only simulate the concave-convex effect through Map. The same problem can also be found in the modeling of Buckle. Blender can achieve a more realistic model effect through carving and deformation of the Buckle model.

In terms of compatibility

The storage format of hardware is usually saved as OBJ or FBX, which can be well transmitted between Blender and Clo3D. In the above experiment, the OBJ format of Button and Zipper puller can be registered as assets for later use, but for Buckle, Clo3D currently does not support registering it as an asset, because it can only be imported into Clo3D in the form of Trim.

However, **Trim** in Clo3D can only be fixed on the clothing in a single point form, and in the case of this special Buckle with two ribbons on top and bottom, the two ends of the two ribbons cannot interact well with the clothing, especially in the dynamic simulation process. Therefore, in this special case, it seems that the Buckle made in Clo3D is better able to interact with the clothing due to its fabric composition, and can be better sewn with the clothing.

In terms of compatibility

Personally, I believe that Clo3D has a lower overall difficulty level than Blender. In general, Clo3D's UI design is much simpler compared to Blender. Blender has more modeling tools and functions for hardware, but as a result, it has a steeper learning curve and may not be very beginner-friendly. This can also be seen in the comparison between the fabric simulation functions of Blender and Clo3D. Blender's fabric simulation function requires the setting of multiple parameters, activation of multiple modifiers, and adjustment of gravity parameters, among others. On the other hand, Clo3D only requires the click of a button to simulate the fabric.

Overall, both Clo3D and Blender can complete hardware modeling work for clothing, but Blender is more suitable for hardware modeling work due to its more precise sculpting functions and control over the model's face count after becoming proficient.

However, because Clo3D is easier to learn, it can achieve quite good modeling results through

texture mapping when there are scanned images of real objects. Moreover, for some special trims, such as the buckle mentioned earlier, modeling in Clo3D may actually have better interaction with clothing than these professional software programs like Blender.

Furthermore, in the case of simple hardware structures with textures, the effects of using Clo3D for hardware modeling and using Blender for hardware modeling are similar.

However, for clothing designers who usually do not use Blender and are unfamiliar with the building of hard models, UV mapping, and material node usage, using Clo3D instead of Blender for hardware modeling is also a good option.

Therefore, it is still recommended that everyone try out and choose the most suitable method according to their different situations and needs

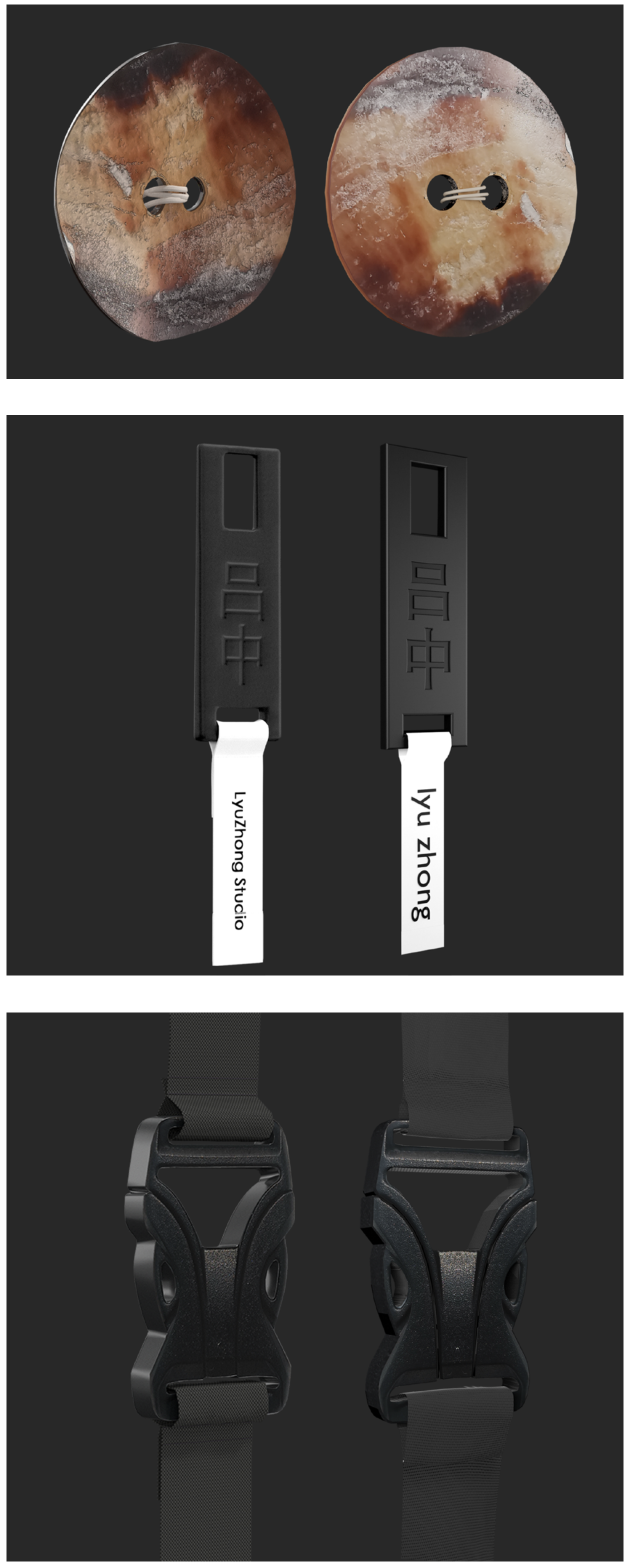


Fig 57. The resoult comparison
The left side is made in Clo3D, and the right side is made in Blender

Chapter 5
Photography - A Comparison of Digital and Traditional Photography

In recent years, although digital photography itself is not a new thing, the trend of incorporating digital clothing into digital photography for fashion promotion has just become popular. This is mainly due to the continuous evolution of digital models and digital clothing in terms of realism, making digital fashion photography increasingly popular. However, traditional photography still has certain advantages, such as more natural light performance, a stronger sense of realism in images, and irreplaceability in specific situations.

This chapter will first compare and analyze the processes of traditional fashion photography and digital fashion photography. Next, I will conduct a digital fashion photography experiment using a combination of Clo3D and Blender, comparing the advantages and disadvantages of using the two software, and explaining and analyzing some specific technical challenges of digital photography, such as importing model **animations**, and settings for **export** and **import** formats. Finally, I will summarize the entire **photography process** and conduct a more in-depth exploration of the advantages and disadvantages of digital fashion photography based on the experimental results.

Overview of the similarities, differences, advantages, and disadvantages of digital and traditional fashion photography processes

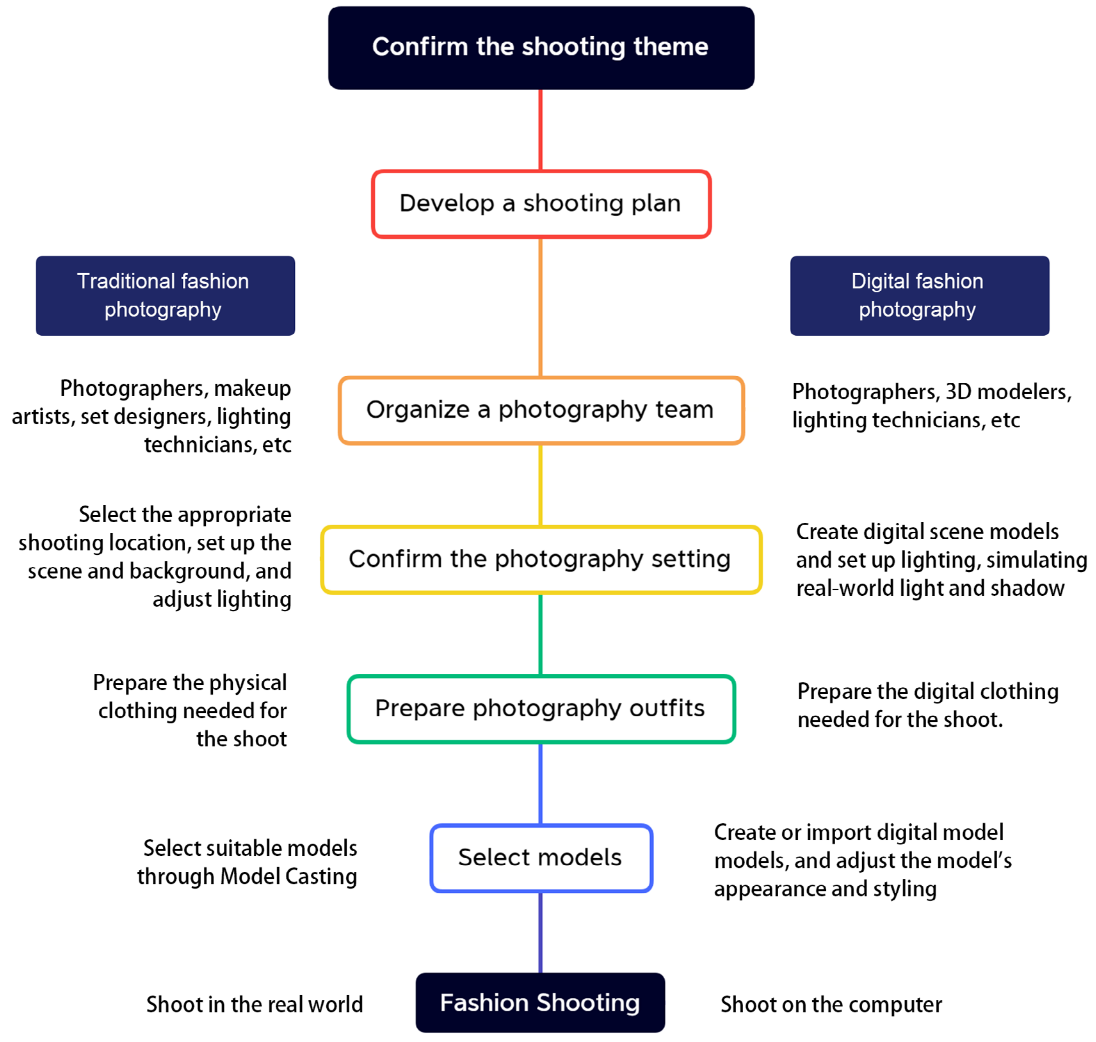
Overall, the digital photography process is similar to the traditional photography process and can be divided into the following steps: confirming the shooting theme, formulating a shooting plan, organizing the photography team, preparing photography clothing, selecting models, setting up photography scenes, taking photos, and retouching.

In the scene setup process, the digital fashion photography scene is built on the computer. Compared to the real-world setup of traditional fashion photography, it has less environmental impact and generates less waste during the shooting process. However, traditional photography can capture more natural light effects, giving the work a stronger sense of reality. Moreover, 3D photography has better operability, allowing for easy changes to environmental settings and lighting angles during the shooting process.

In terms of organizing the team and preparing clothing, due to the virtual nature of digital fashion photography, the clothing required is digital clothing, and the models are digital models. In physical fashion photography, preparations involve choosing real clothing and live models. Accordingly, the physical fashion photography team serves real clothing and models, including photographers, model makeup artists, stylists, set designers, and lighting technicians. In contrast, the digital fashion photography team differs from the traditional photography team, relying less on makeup artists and set designers, and more on **digital modelers** to set up photography scenes and adjust digital models.

During the actual shooting process, digital photography allows for **real-time previews**, making it easy for designers to quickly adjust scenes and angles, while traditional photography may require multiple attempts and adjustments. Additionally, digital photography has lower time and space requirements, allowing for shooting at any time and any place, while traditional photography needs to consider on-site conditions and scheduling. However, this also means that traditional photography can capture more natural light and scenes, resulting in stronger image texture and realism.

Comparison of traditional and digital fashion photography processes



Comparison chart of similarities and differences between traditional fashion photography and digital fashion photography workflows

Case Study

In this section, we will conduct experiments on the three steps of digital fashion photography: models, scene setup, and photographers. We will analyze the technical challenges during the experiment and finally compare the results with traditional fashion photography to gain a deeper understanding of their advantages and disadvantages.

Digital Model Section

Adjusting the model's pose

Clo3D allows designers to directly change the model's pose, and the operation is relatively simple.
First, Clo3D provides many preset model poses for designers, and designers can also download new model pose presets from the Closet website.

Another way is to use the '**X-Ray Joints**' tool to manually adjust the model's joints.
Click the 'X-Ray Joints' icon on the top toolbar (or Shift+X), and then click and drag the model's joints in the 3D window to make fine adjustments as needed.

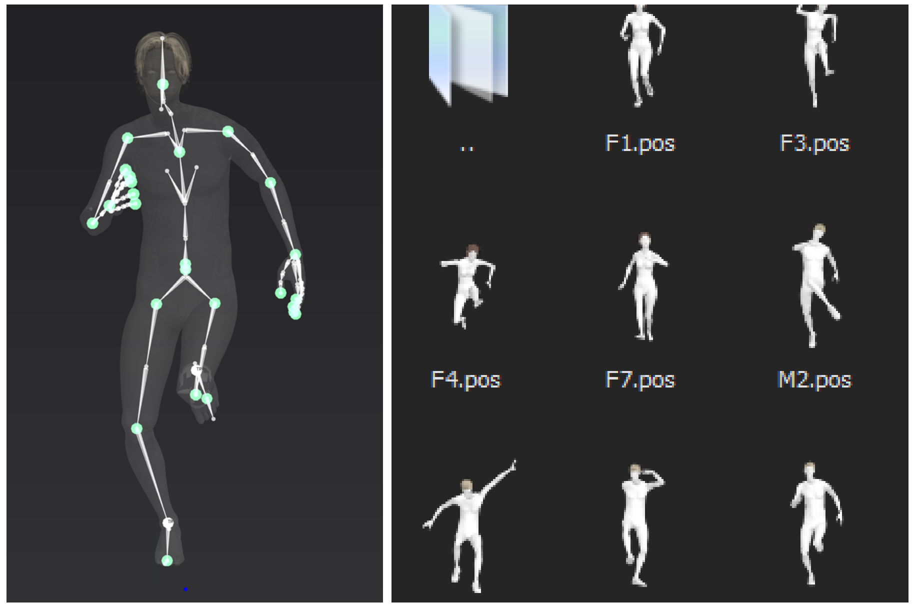


Fig 58. The adjustment window for the model's pose (left) and the saved model's pose (right)

Importing model animations with MIXAMO

Clo3D comes with an animation simulation editor and includes some runway animation files and runway scene model files.
Designers can conveniently complete animation rendering directly in Clo3D.

In addition to using Clo3D's built-in animation files, designers can also import animation files created in other software (such as **Maya**) into Clo3D and apply them to the Avatar.

We can also use third-party websites like **Mixamo** to directly perform joint binding and animation generation on the Avatar in Clo3D.
First, we will adjust the Clo3D model file to an A-pose and export it as an FBX file.
Note:
When exporting, we need to choose the texture image save path in the texture options according to your needs. In this case, the author chooses '**Embed**'.

Upload the file to the Mixamo website and follow the prompts to complete the skeleton binding and animation file selection binding.
Export the model file with the bound animation from the Mixamo website, and choose the **FBX** format for export.

Adjusting the model's dynamics in Mixamo. Then import the model animation file exported from Mixamo into Clo3D.

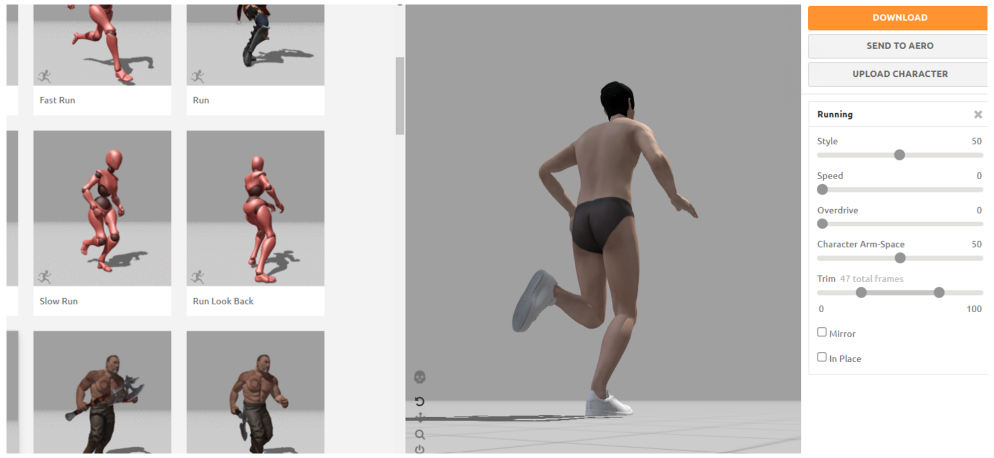


Fig 59. Adjusting character animation with Mixamo

In addition to directly import it into Clo3D, we can also import the downloaded file into Blender first. Use Blender's animation editing keyframes to further process the target animation.

Fig 60. Adjusting character animation with Blender

Then import the model file from Blender into Clo3D. Note that due to Blender's built-in algorithm, there may be issues with the model's joint binding when exporting the FBX file to Clo3D. If this happens, you can try exporting the animation file as an **Alembic (abc.)** format (a format that pre-bakes the model animation frame by frame) and then import the Alembic file into Clo3D to obtain a model file with animation.

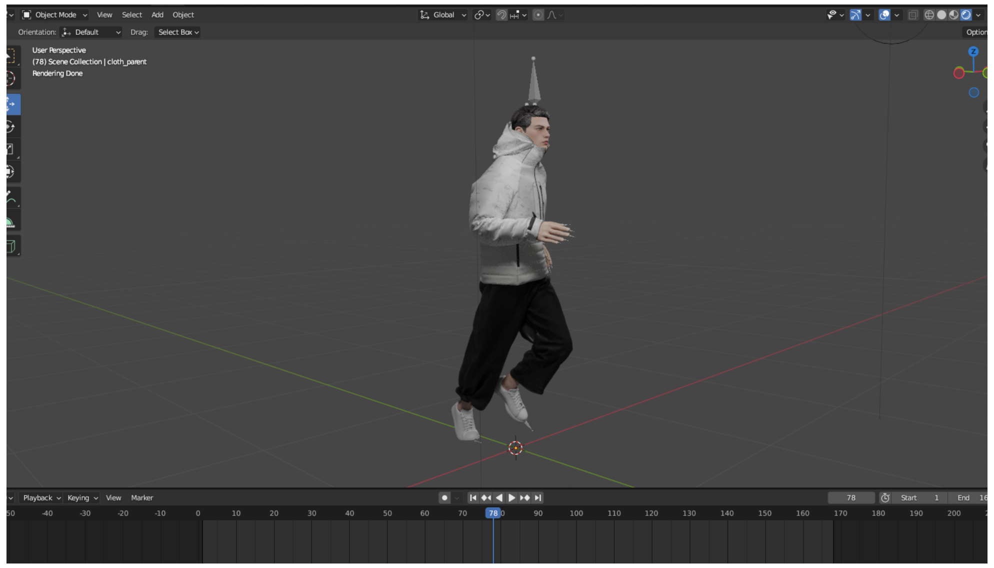


Fig 61. Importing Alembic animation files into Blender

Note: When importing an animated file directly from Mixamo into CLO3D, the **first frame** of the animation often does not match the previous clothing model file. Therefore, you need to manually adjust the model in the clothing project file to match the first frame of the FBX model's pose. Then delete the Avatar in the clothing file and apply the FBX Avatar with the animation file; or use Blender to preprocess the FBX animation, add an A-pose Avatar without animation at the beginning of the first frame, and select all the animation keyframes to drag them back about **30 frames** for easier simulation in Clo3D. Finally, import the processed file into Clo3D using the aforementioned method.

Using Clo3D for digitalw photography

Clo3D comes with its own rendering feature. Open the 'Render' option in the CLO menu bar to view the rendered results.

Customizing and saving the camera angle:

In Clo3D, the camera angle for rendering and the 3D window angle are tied together, allowing designers to adjust the angle and zoom with the mouse.
By choosing a custom camera angle (Attribute Editor ➡ Image/Video ➡ Camera Angle ➡Custom Camera Angle), designers can set multiple camera angles and render them together.

Custom camera angles can be saved for use in different projects, ensuring consistency and **professionalism** in the photographer's camera position across multiple clothing files.

Note: As for Clo3D's renderer, it does not support **multi-camera** angle rendering for videos. When rendering videos, the camera position is the current 3D window angle, and only one can be used at a time.

Clo3D lighting setup and HDRI environment lighting:

Clo3D's light source types include point light sources (rectangular light, spherical light, spotlight, IES light), parallel light sources (directional light), and environment light sources (skylight). Designers can create different lighting effects according to their needs.

Skylights, or **HDRI environment lights**, provide very realistic and complex lighting effects for scenes, including indirect lighting, reflections, and refractioWns. CLO3D provides designers with some HDRI environment light images suitable for clothing photography. Designers can also download and import HDRI images from third-party websites (such as hdri-haven.com).

Clo3D comes with a variety of lighting combinations suitable for clothing photography. Designers can directly use these combinations or modify them to achieve better lighting effects. The number of light sources is generally no more than five, or the lighting may become chaotic. Generally, using a skylight and an auxiliary side light source can achieve good results.

Fig 62. Clo3D rendering; Assets belong to ISPO

Using Blender for digitalw photography

Compared to Clo3D, Blender is more suitable for outdoor photography, and its camera is more professional.

As mentioned earlier, Blender has better "**hard**" modeling and sculpting capabilities compared to Clo3D, making it more suitable for scene construction. Although clothing designers are not animation designers and usually do not have scene modeling capabilities, the unique language of clothing **scene photography** does not require overly complex and detailed scene modeling, which greatly reduces the difficulty of scene construction in Blender.

Through some basic online tutorials, clothing designers can easily master scene modeling such as snow mountains, deserts, and underwater environments, greatly expanding the possibilities for clothing photography.

This section will briefly build a photography studio, using this example to give a basic explanation of modeling, lighting, camera, and rendering in Blender.
At the end of the chapter, we will use a snow mountain scene for photography and compare its strengths and weaknesses with photography in Clo3D.

Studio photography

Scene construction

I use Blender's modeling feature to build a simple clothing photography studio. The modeling process is similar to the Hardware production-related chapter, and will not be detailed here.

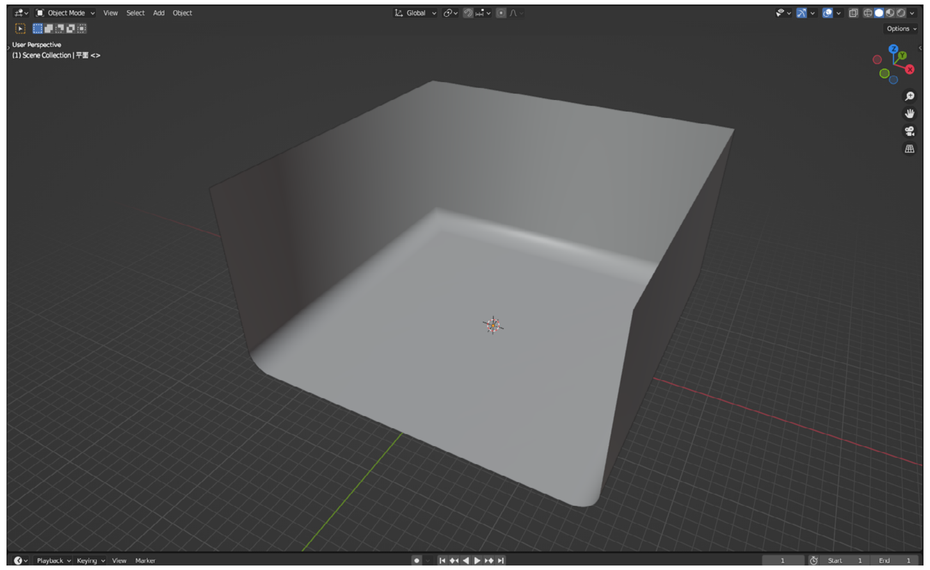


Fig 63. Basic Rendering Scene Setup

Lighting arrangement

Similar to Clo3D, Blender's light sources are also divided into point lights, sunlight (corresponding to the 'directional light' in Clo3D), spotlights, and area lights.

For general clothing photography, the commonly used lighting method is the '**three-point lighting technique**', which consists of a main light source (Key Light), an auxiliary light source (Fill Light), and a background light source (Back Light). This setup provides a good balance of light and shadow contrast, making the rendering more realistic.

In Blender, the main light source and the fill light source are usually point lights. The main light source has a stronger intensity and is located at the front-left or front-right of the camera, providing the primary lighting and shadow for the scene. The fill light source has a weaker intensity than the main light source, usually on the opposite side of the main light source, to balance the scene's lighting and soften shadows.

The background light source is usually an area light, placed behind the object to produce a rim light, making the object stand out from the background.

Note: In the three-point lighting technique, you can also set the main light source to be warmer (such as yellow or orange) and the fill light source to be cooler (such as blue or cyan). This can increase the color contrast and visual impact of the photo. This combination of warm and cool light sources can create a more three-dimensional and layered effect. Warm light sources can make certain areas of the object more prominent, while cool light sources can balance the strong shadows produced by warm light sources, making the image more harmonious.

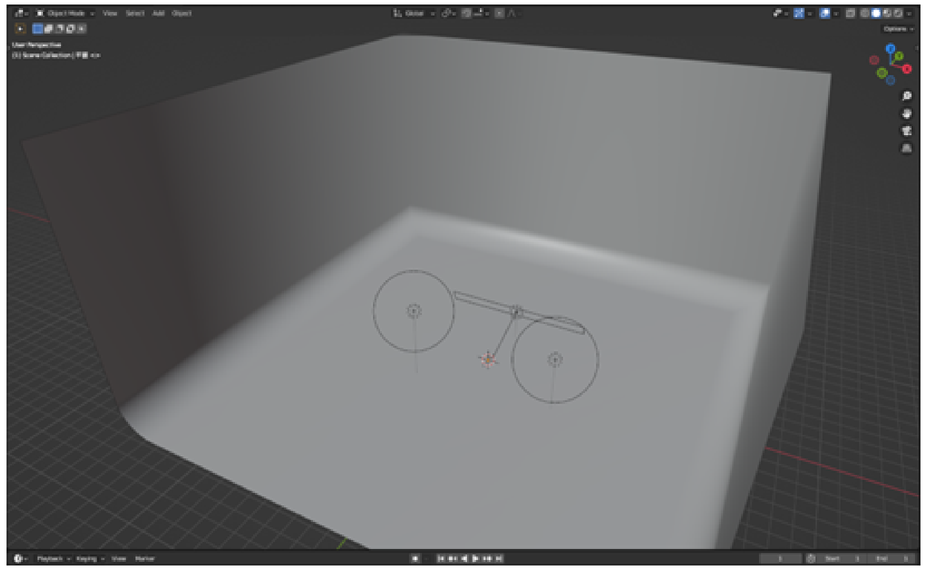


Fig 64. Three-Point Lighting Setup

Importing the shooting file

When importing pre-made clothing files from Clo3D and the clothing files are static, it is recommended to use the **FBX** format.

This format can better preserve the file's texture and normal maps, as well as save the pattern files in Clo3D, and prevent the textures from getting "lost" when importing into Blender later. By saving the clothing file as '**Thick**', you can also save it as 'multiple targets', which is convenient for adjusting individual parts later (Li, Lyu, Zhang, & Tian, 2022).

However, since Clo3D's built-in animation recording is multi-track, it will be saved as Joint Animation and Cache Animation (a pre-cached animation file), so when importing into Blender, animation files are often lost, or the Avatar has animation files (Joint Animation) but the clothing does not have animation files (Cache Animation).
Therefore, when exporting clothing **animations**, it is recommended to export **ALEMBIC (Alembic/OGAWA)** format files.

This format saves all animations as 'frame-by-frame caching' in the file, so the file size is usually larger, but the clothing animation is more complete, and the probability of errors during export and import is low.

The biggest problem with this format is that it cannot save file textures, so you need to adjust the UV layout of the clothing model file first and bake and save the corresponding UV textures. After exporting the ALEMBIC file from CLO3D and importing it into Blender, you can add the textures; however, once the UV layout is set correctly, adding textures in Blender is a relatively time-saving process.

Another issue with the ALEMBIC format in Clo3D is that it cannot save files as "thick" and "unmerged" simultaneously, so some material textures are lost in Blender.
In the appendix, this thesis will provide screenshots of the parameter settings for exporting FBX and ABC formats from Clo3D for reference.

Fig 65. The import of the shooting model (Since it is a static shoot, the export and import format is FBX)

Adding a camera

After importing the model and placing it appropriately, we can add a camera.

Before adding a camera, we can first split the main Blender window vertically into two and turn off the GIZMO and OverLayer Display in the left-side (camera viewfinder) window for better observation of the camera's viewfinder.

Press Shift+A, select the camexxra, and switch to the camera view in the auxiliary window by pressing the '0' key.

Then adjust the camera position to meet the shooting angle requirements. You can either drag the camera in the main window (not in the camera view) to adjust its position and rotation or set the camera to 'Lock Camera to view' in the auxiliary window (camera view window) and directly click the middle mouse button to drag the mouse to adjust the angle (pressing Shift at the same time allows for moving the camera position).

Adjust the lens

In the 'Camera' properties panel, find the 'Lens' section. By adjusting the 'Focal Length'

value, you can change the camera's view angle. Smaller focal length values will produce a wider view angle (12-42), while larger focal length values will produce a narrower view angle (100-180).(Budakov, P., Max, M., & Blender, R)

In the 'Camera' properties panel, under the Lens section, you can enable 'Depth of Field'and set the 'Focus Distance' and 'F-Stop' values to achieve depth of field effects. A smaller F-Stop value will create a shallower depth of field, making the background more blurred and the subject more prominent.
When setting the focus, you can also choose 'Focus on Object' and select the focus object to automatically focus.

That concludes the basic rendering scene setup, lighting arrangement, and camera adjustments for importing and working with clothing models in Blender. With these tips and techniques, you can create more realistic and visually appealing renders for your clothing projects.

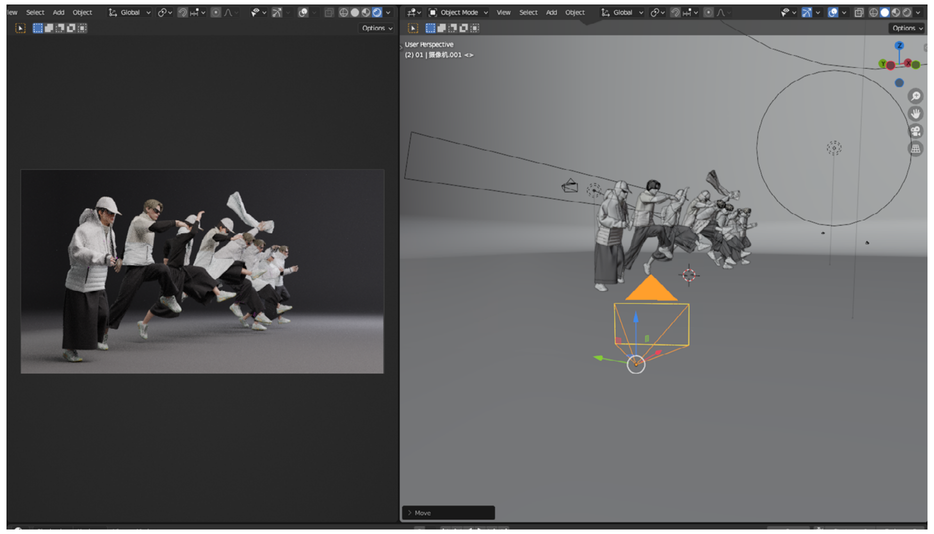


Fig 66. Rendering camera schematic
left image in the viewport is set to Shading

After completing the current camera lens settings, you can also add multiple cameras for different shots.
You can either duplicate the current camera (which will also copy the camera's settings) or repeat the process above to add more cameras.

Note: After adding a new camera, you can't directly enter the camera view. First, right-click on the new camera and select '**Set Active Camera**' to activate it.
When rendering from multiple camera positions, you need to bind each camera to different keyframes. Then set the start and end frames and click "Render Animation" to render multiple different camera angles at once.

Final renderin

Eevee Renderer and Cycles **Renderer**:
In the 'Output Properties' window, we can choose the renderer for the final rendering. The most commonly used renderers in Blender are the Eevee Renderer and the Cycles Renderer.

The Eevee Renderer has faster rendering speeds and better '**glow**' rendering effects, making it suitable for quickly and effectively rendering scenes or materials with many glowing objects and 'glow', such as night scenes.
The Cycles Renderer, although slower, renders materials with more realistic textures, and its light reflections are more true-to-life.
(Rao, G. R. K., Sgar, P. V., Bikku, T., Prasad, C., & Cherukuri, N. 2021, October).
Designers can choose the renderer according to their needs and set sampling parameters.
In this thesis, the Cycles Renderer is chosen.

Setting resolution and render output:
In the 'Output Properties' panel, set the 'Resolution' and 'Output' options. Choose an appropriate resolution according to your needs; generally, **1920x1080** or higher resolution can achieve better results. Also, ensure the output format is set to your desired image or video format.

Note:
In Blender, increasing the rendering resolution and sample rate can improve the final rendered image quality.
Generally, high-definition resolutions (such as 1920x1080) are suitable for most regular scenes.
In this thesis, the final rendering resolution is set to 3840 x 2160 (4K).
For low-quality preview renders, you can choose a lower resolution, such as 1280x720 or even lower, for quickly checking issues within the scene.
For sample rates, for preview renders, you can use lower sample rates (e.g., 32 to 128), which will reduce render time but may result in noisy images.
For final renders, higher sample rates are typically required (e.g., 500 to 2000 or higher). In this thesis, the sample rate used is 2000.
However, increasing the resolution and sample rate will increase the demand for rendering time and computational resources. Therefore, when setting up, please balance your hardware performance, time constraints, and quality requirements. You can also try rendering optimization techniques (e.g., denoising, photon mapping, etc.) to improve rendering effects and speed.

Fig 67 Case study final rendering preview

Scene rendering: Showcase

In addition to using Blender for basic rendering and shooting, it's more important to use Blender's own modeling features to create scenes for scene rendering.
In this section, we will showcase Blender's small and large scene rendering using two examples: 'Photography Studio' and 'Snowy Mountain'.
The "Photography Studio" scene was created by the author based on the shooting scene mentioned earlier - adding details such as light groups and shooting cloth, changing lighting effects, and adding 'volumetric fog'.
The 'Snowy Mountain' scene was created by referring to YouTuber Animatable's example (https://www.youtube.com/watch?v=393zz7KDa_c).

Photography studio shoot with scene

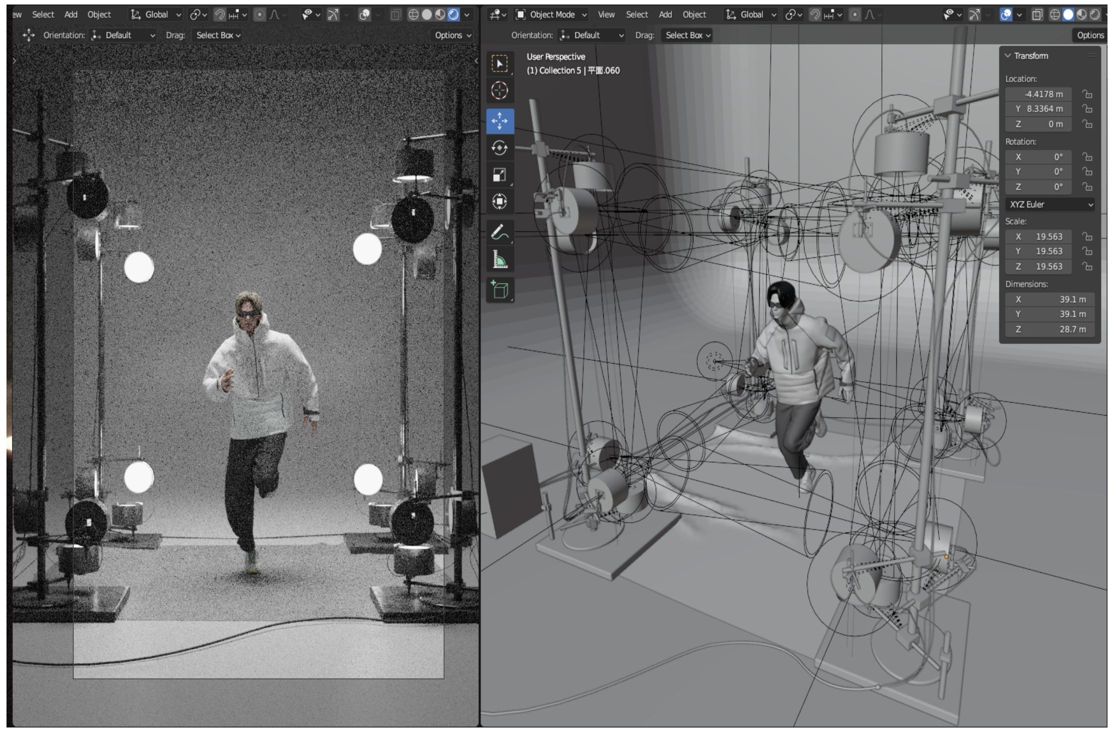


Fig 68. Studio photography screenshots

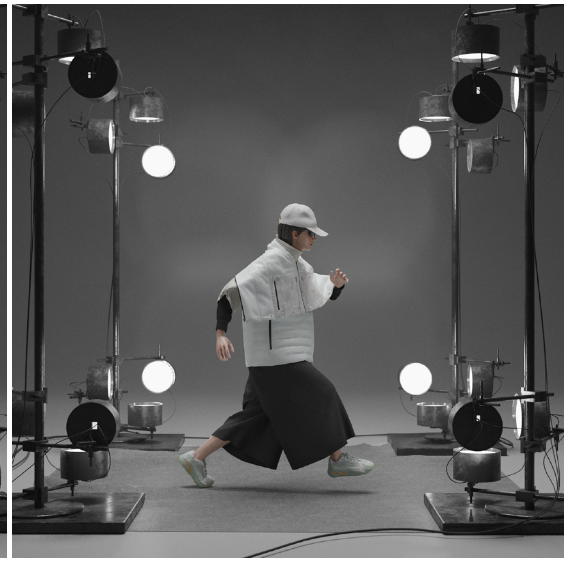


Fig 69. Studio photography Rendering

Fig 70. Studio photography Rendering

Fig 71. Studio photography Rendering

Snowy mountain photography

Fig 72. Snowy mountain photography screenshot

Fig 73. Snowy mountain photography Rendering

Fig 74. Snowy mountain photography Rendering

Fig 75. Snowy mountain photography Rendering

Difficulties and challenges in the case study

Different software formats are not fully compatible

During the experimentation process, the author noticed that when exporting model files from Clo3D to Blender, there were often **mismatches** in material **data** parameters (e.g., color loss or overly smooth appearance), or animation files could not be read.

While trying to search for related tutorials, the author found that there were **few tutorials** on the internet that combined Clo3D and Blender, making it difficult to find suitable references. After multiple attempts, it was discovered that the reason for the loss of animation files when importing FBX animation files from CLO3D to Blender may be due to the multi-track recording of Clo3D FBX animation files.

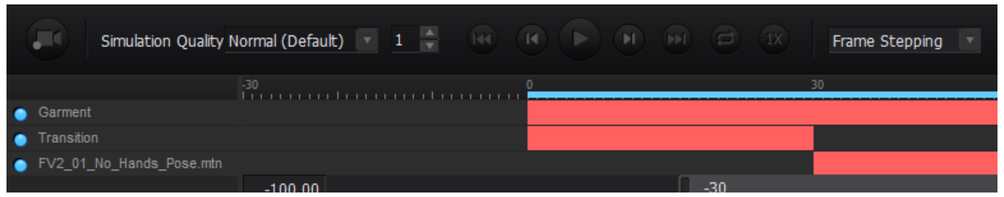


Fig 76. Screenshot of animation recording window in Clo3D

Following related tutorials, the author found that exporting in Alembic format seems to be the best choice for preserving animation files. However, the problem is that Alembic format files do not include texture information, so both exported and imported models will appear as "white models" and require reapplication of texture mapping.

Therefore, when exporting files, it is necessary to arrange and bake UVs in CLO3D and then reapply UV mapping in Blender.
This significantly increases the difficulty and time consumption of using multiple software.

Software crashes caused by excessively high model polygon counts

As mentioned earlier, some Clo3D models have a high polygon count. This drawback becomes more apparent when importing into Blender for photography.
Since photography in Blender typically involves scene photography or multiple model combinations, unlike Clo3D's rendering targeting individual clothing models and the model itself, Blender needs to render multiple clothing models and models simultaneously, along with the environment models and physical lighting settings such as volumetric fog, leading to frequent **CPU overloads**.

Therefore, when exporting models from Clo3D, it is essential to perform "polygon reduction" processes, such as deleting invisible panels (FBX format only) or adjusting Top Stitch and Zipper Teeth to Texture mapping mode.

However, because Clo3D's technology algorithm is based on high polygon count fabric simulation

reducing polygons often results in decreased model accuracy and poorer results. To truly solve this problem, relevant technical personnel need to optimize the model algorithm and fundamentally change this issue.

Summary and Reflection

Comparison between Clo3D rendering and Blender rendering

In this chapter, we have provided a detailed introduction to the rendering steps of digital fashion, discussing the rendering methods in Clo3D and Blender separately. We have also explained relevant knowledge points (such as adjusting model poses, export and import formats, etc.), analyzed potential problems and their solutions.

Through this chapter, we can clearly see that both Clo3D and Blender have their pros and cons when it comes to digital fashion rendering:

When using the built-in rendering function in Clo3D, its biggest advantage is convenience, avoiding the need to export the model file, thus eliminating problems that may be encountered during file export and import, such as missing textures. This saves production time and improves efficiency. Furthermore, Clo3D can render specific fabrics (e.g., fur-like materials) that cannot be imported into other software due to algorithmic differences and need to be remade in other software.

In comparison, Clo3D's rendering is relatively simpler than Blender's. As Clo3D's renderer is designed for single garment photography, it has fewer light and camera parameter settings and provides a variety of common HDRI lighting presets for garment photography. This makes it easier to learn and more suitable for single garment rendering.

However, the limitation of Clo3D's renderer lies in the fewer adjustable parameters for cameras and lights, making it less flexible in terms of camera angles and lighting arrangements compared to Blender.

Also, when it comes to composite photography (multiple garment models in the same scene), Blender is more convenient than Clo3D for importing garment model files and arranging positions.

In addition, Blender has a more comprehensive set of features, with richer and more professional camera settings, lighting, and built-in modeling functions, making it easier to create shooting scenes and props, resulting in more expressive camera language and "storytelling". Therefore, Blender is more suitable for multi-person and scene photography, but at the same time, it involves more complex knowledge points and has a steeper learning curve.

In summary, both software have their advantages and disadvantages in 3D garment rendering. The built-in renderer in Clo3D can complete rendering tasks well for single garment rendering and some detail shots. However, when it comes to multi-person shooting, scene shooting, and complex camera angles and lighting, Blender is the better choice.

The differences between traditional garment photography and digital photography, and their advantages and disadvantages

By observing the experiments in this thesis project, it is not difficult to find that there are significant differences between traditional garment photography and digital garment photography in terms of process and results:

First, let's talk about the disadvantages of digital fashion photography:
First of all, limited by computer computing power, it is difficult to replicate some of the details and camera textures in real shooting scenes:
For example, the dust in certain corners of the photography scene, or the "aged" feeling of the camera due to long-term use, are difficult to replicate in digital photography, or may take even longer to replicate than real shooting.
As a result, digital photography works often lack some charm compared to real photography and appear somewhat "distorted."

Secondly, there are still some technical issues to be resolved:
The interaction between digital models and digital garments is poor:
In the current Clo3D, when adjusting the pose of a model wearing a "more complicated style garment," the clothing material algorithm often relies heavily on "high-polygon" calculations, which can cause significant CPU load on the computer. Therefore, the process of adjusting poses is time-consuming and prone to errors.
This makes it a painful process to have a digital model wear clothes and pose for many shots.
In real garment photography, however, models can easily pose for many shots.

Digital models are not realistic enough:
Although the digital models in Clo3D have become increasingly realistic after numerous iterations, their facial expressions still appear stiff and their poses are not natural enough during the shooting process. Therefore, future digital fashion photography may increasingly adopt motion capture technology to improve the naturalness of model poses and the smoothness of model animations.

There are certain compatibility issues between different software:
For example, when importing clothing files from Clo3D to other software like Blender, some textures may be lost or material properties may need to be reset due to different material settings parameters in different software (such as materials imported from Clo3D to Blender often having too low roughness, making them appear overly reflective). Resetting the texture mapping and material parameters can be time-consuming.

Lastly, there are certain demands for interdisciplinary knowledge:
Whether it's modeling the photography scene, adjusting digital model poses, or dealing with file formats and parameter settings during export and import, these knowledge areas are far removed from what traditional fashion designers are familiar with and are closer to the field of computer animation. Although there are many online tutorials available, self-study can still be

quite challenging for fashion designers. As a result, the learning process may be difficult, and the learning curve steep.

To adapt to this trend, future fashion designers need to master modeling-related knowledge. Relevant universities also need to adjust their curriculum accordingly. This may include incorporating computer animation and modeling content into traditional fashion design courses to help students better adapt to the development of digital fashion design.

However, these shortcomings can hardly overshadow the advantages of digital fashion photography:

Firstly, with the mastery of relevant skills, digital fashion photography can save a considerable amount of photography expenses.
For example, the rental costs of photography studios and equipment, the expenses for setting up fashion scenes, and the fees for models. In digital photography scene construction, all work can be done on a single computer, saving a substantial amount of shooting costs.

Secondly, digital photography is time-saving to some extent.
Although scene construction and clothing model production take some time, once the photography scene is set up and the model poses are determined, they can be saved as assets on the computer and reused in future projects. Moreover, traditional fashion photography sometimes requires reshooting due to lighting issues, while adjusting the lighting and reshooting in digital fashion photography is relatively simple. Additionally, digital fashion photography can be done entirely on a computer, eliminating the need to coordinate venues and models, thus saving time.

Next, digital fashion photography is more environmentally friendly.
Traditional fashion photography sets are often dismantled after a single use (especially in fashion show sets), leading to some degree of material waste. In addition to materials, traditional fashion photography involves more people, from transporting clothes to flying models in and out, which generates a certain amount of carbon emissions. In contrast, the entire process of digital fashion photography mainly consumes electrical energy.

Lastly, and perhaps most importantly, the shooting scene is virtually unrestricted by space.
Thanks to the virtual nature of digital modeling, the adjustment of clothing models and digital clothing can somewhat ignore the limitations of physical laws, or the construction of clothing scenes is virtually unrestricted by space. For example, in the experiment described in this thesis, a snowy mountain scene can be created using Blender for a fashion shoot, or even underwater or outer space scenes can be set up. This level of variety in shooting scenes is difficult to achieve in traditional fashion photography.

Chapter 6
Discussion and Outlook

With the continuous development of electronic technology, we have seen that digital technology can assist the fashion design process in many ways, making it more efficient, flexible, and innovative, as well as more cost-effective and environmentally friendly.
This chapter will discuss the impact of digital technology on the fashion design process based on the case study presented in this thesis, and explore how to leverage the advantages of digital technology in fashion design.
Furthermore, it will discuss how digital fashion technology will further radiate into related industries and create opportunities and changes.
Finally, this chapter will summarize these issues and investigate the views of current fashion professionals on these existing or potential changes through interviews and questionnaires.

Through these discussions, the author hopes to understand the impact of digital fashion technology on the fashion industry, think about how to combine digital technology with traditional fashion design, make use of their respective strengths, and guide the development of digital fashion technology in a better and more useful direction.

The impact and optimization of digital technology on the fashion design process

After completing the digital fashion production experiment described above, it is not difficult to feel that digital software will have an impact on various aspects of the fashion design process. For example, digital patterns will become more popular due to the prevalence of digital prototypes, and the instant display of digital prototypes will in turn affect the design process. Designers can therefore more accurately express their design concepts or make changes more quickly. Digital prototypes will also replace some physical prototypes, reducing the time it takes to finalize a product from prototype to final production.

Digital patterns may replace paper patterns

For the fashion pattern-making industry, digital technology has already had a significant impact. CAD pattern-making is more precise in numerical calculations compared to traditional hand-drawn patterns, and the virtual nature of digital patterns makes storage, copying, and later modifications more convenient than traditional hand-drawn patterns. As a result, CAD pattern-making has largely replaced manual pattern-making, especially among large company pattern-makers.

Moreover, for digital fashion modeling, unlike traditional hand-drawn paper patterns that need to be scanned first to obtain DXF or AI pattern files, CAD digital patterns can be used directly for digital fashion modeling, seamlessly connecting to the "digital prototype production" stage. This will be one of

the reasons why digital patterns may replace paper patterns in the future fashion industry.

Both Fashion Designer and Modelist

From the case study presented earlier, we can see that when fashion designers use modeling software like Clo3D, pattern-making and model-making are parallel and mutually influential processes. This not only helps designers modify design schemes more quickly but also subtly improves their pattern-making and technical skills. Therefore, as designers continue to use this type of fashion software, their pattern-making and technical knowledge will continue to improve.

Conversely, to use this type of fashion software smoothly, designers need to have more pattern-making and technical knowledge. Therefore, in the future where digital fashion software becomes more and more popular, Fashion Designers may need more pattern-making and technical knowledge to be competent in their jobs. From this perspective, a Fashion Designer is not only a Fashion Designer but also a Modelist.

Digital prototypes replacing physical prototypes

In the traditional design process, prototype production is usually a time-consuming and labor-intensive step. This is because certain pattern errors or changes in clothing details often require multiple pattern or detail modifications after the "first edition prototype," resulting in repeated prototype production.

Based on the experimental results of this thesis, digital prototypes have a high degree of simulation. Although limited by current technology, they cannot reproduce the pattern and clothing details of real prototypes on a one-to-one basis. However, in the process of "first edition prototype" and subsequent modifications, the low trial-and-error cost and fast production of digital prototypes have absolute advantages compared to traditional prototype production.

At the same time, the production speed of digital prototypes is much faster than that of physical prototypes. In particular, as in the case mentioned above, when it comes to down-filled garment production, it only takes a few clicks on the computer to complete the simulation of the down-filling effect (although the down-filling effect may not be completely realistic). However, in the production of actual prototypes, the fabric needs to be sent to a relevant subcontractor first. After waiting for the subcontractor to complete the down-filling process, the finished product is sent back, and then sewn onto the prototype after receiving the package. This process consumes a lot of time and manpower.

Therefore, designers and related companies can first create digital prototypes for their designs, saving the costs of repeated modifications to prototypes during the process. Finally, before industrial production, they can produce a final version of the prototype to check some pattern and clothing details.

Opportunities and Challenges in the Digitization of Fashion Design for Related Industries

After conducting an experiment on the entire process of digital fashion creation, the author feels that some steps cannot be completed independently to achieve good results. In other words, these steps would be better completed with the assistance of other professionals. For example, when it comes to scanning fabrics, using mobile devices cannot achieve the precision and convenience of a scanner.

Additionally, the author lacks experience in animation production when editing the actions of digital fashion models. Therefore, only simple actions can be created, and it is not possible to produce or capture the entire dynamic animation or facial expressions of the model. In the final process of fashion photography, the author also feels that due to a lack of modeling experience, more detailed scene modeling cannot be completed, and the arrangement of photography lighting, camera parameter settings, and post-production retouching are quite amateurish.

Therefore, if digital fashion is widely used in the future fashion industry, these steps are likely to be delegated to more specialized professionals, thereby impacting related industries or giving rise to new ones.

Digital fabrics will play an increasingly important role in the fashion industry

As digital fashion is increasingly applied to design, production, and sales, the demand for digital fabrics will also grow.

From the cases mentioned above, we can observe that designers themselves can complete the scanning of digital fabrics using mobile devices in a relatively non-professional situation. However, this process is still relatively lengthy.

Firstly, without professional machines, each scanned fabric requires manual "seamless processing," generating related texture maps, and repeatedly adjusting physical parameters to make the physical texture more realistic. This process consumes time and cannot achieve the precision of professional scanners. Moreover, as fashion designers may lack knowledge about fabric physical parameters, there may be biases in the settings of fabric physical properties. Secondly, designers require actual fabric samples for scanning, which significantly limits the diversity of scanned fabrics.

For fashion companies, they can take advantage of their existing fabric libraries and purchase fabric scanning machines. They have significant advantages in the speed and professionalism of fabric scanning and the variety of fabrics provided.

Therefore, traditional fabric production companies may have a digital fabric department that digitizes existing fabrics, processes fabrics under development, or develops "highly demonstrative" digital fabrics.

The digital model industry may emerge

For fashion designers, choosing a suitable model for fashion display is essential because of the uniqueness

and particularity of fashion models. Each model has different static and dynamic poses, and these differences constitute the subtle differences in each model's temperament.

However, as far as Clo3D is concerned, there are still relatively few digital fashion models to choose from, and there are limited poses and dynamic animations available. Designers' adjustments are time-consuming and laborious, which severely restricts the possibilities for later digital fashion photography.

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Digital fashion photography may become a new trend

Similar to digital fabric scanning, the construction of photography scenes involves digital modeling and photography-related knowledge. Although fashion designers can accomplish simple setup and camera settings for fashion photography scenes through self-learning, they are not as professional as modelers and photographers.

Therefore, if digital fashion is applied more widely to fashion promotion in the future, it may give rise to industries related to the construction of digital fashion photography scenes or photography itself.

3D modelers may create and sell fashion photography scenes specifically for fashion shoots, uploading them to the cloud for sale. Fashion photography studios might hire 3D modelers to help create digital photography scenes and provide digital photography services. Fashion photographers may be commissioned to use digital software like Blender to photograph fashion pieces, in addition to using traditional cameras.

Designer Interview

Purpose of the interview

The main purposes of this interview are twofold. First, to survey fashion designers on the usage of digital fashion design software, investigating the prevalence of digital software, and the difficulties faced by designers when using digital tools.

Second, to explore the attitude of fashion designers towards the application of digital technology in fashion design, determining whether the majority view is positive or negative, and to inquire about their specific opinions on digital technology.

Third, to investigate the attitudes of fashion models and fashion photographers towards digital fashion. While verifying the viewpoints in the thesis, it is also important to hear different voices and supplement any unmentioned aspects in the thesis.

Interview format

There are two parts to this research: one is a **questionnaire**, which involved 20 participants and targeted fashion designers only. The other part is a **one-on-one Q & A interview**, with the interviewees divided into **fashion designers** (6 people), **fashion models** (6 people), and **fashion photographers** (3 people).

Please refer to the appendix of this thesis for the questions and the results collected from both the questionnaire and the interviews.

Questionnaire summary:

The interviewees consisted of 20 fashion designers, with most having around 3 years of work experience. Among them, 7 are from Europe and 13 are from Asia

Challenges of widespread application of digital technology in fashion design

Through the summary of the questionnaire results, the author found that the popularity of digital fashion design software among fashion designers is quite high. All interviewees had used digital fashion design software, with a 100% usage rate for Clo3D, and only one person (the author) having used MD.

The main difficulty when using Clo3D is the high requirement for computer performance, and optimization is needed in fabric simulation algorithms. The most frequently mentioned positive aspect of digital fashion technology is its ability to quickly generate visual effects, making it easier to optimize and improve designs. In terms of difficulties in promoting digital technology, the most frequently mentioned issue is the difficulty in changing traditional mindsets. This result is predictable, as the traditional fashion industry has many branches and involves a large number of personnel. Therefore, the application of digital fashion technology would involve changes or even revolutions in many branches, so the resistance to popularization may not come from the barriers of digital technology itself, but from traditional mindsets.

Subconscious concerns about the rapid iteration of digital technology

Regarding whether digital technology will change the traditional fashion design process, 16 of the 20 designers gave positive answers, holding a generally positive attitude towards the application of digital technology in the fashion field. The most frequently mentioned benefits were improved communication efficiency, reduced sample production, and reduced pollution. However, most designers held a neutral attitude towards the overall pros and cons of digital technology in the fashion industry. The main reason, as derived from the questions, is the concern about the rapid iteration of digital technology.

Q & A summary:

Q & A 1 targeted 6 emerging fashion designers with approximately 2 years of work experience. Four of them are from China and two are from Italy.

Please describe the specific role of digital technology in the fashion design process?

- Widely used in the fashion industry, such as early CAD drawing and current 3D garment generation software
- Involves the front end (inspiration source) and back end (market sales strategy) of the fashion industry chain
- Improves technology and provides unique creative ideas
- Assists non-creative activities (such as drafting, optimizing sustainable development chains) and provides AI-generated creative concepts
- Simplifies the design process and quickly obtains results
- Digital display, prototyping, texture application, saving time and materials

Do you think digital technology can help reduce the cost of fashion design?

- Depends on the operation model of the fashion studio or company and the personnel using digital technology
- Some costs are still unavoidable, and random variables in actual operation cannot be replicated in computer programs
- May reduce costs: avoiding labor costs in actual production, scene building, shooting, etc.
- Reduces material consumption, improves iterative efficiency, and strengthens the connection between businesses and the market
- Considering the cost of talent, technology, equipment, and adapting to the original production mode
- The popularity of digital technology needs to be improved, and consumer acceptance affects efficiency conversion
- Reduces material costs but has other costs: training, software, internet connection, dedicated computers, and their environmental impact
- May reduce the cost of the production process and reduce the number of physical prototypes needed for product industrialization

What challenges do you think the popularization and application of digital technology in fashion design still faces?

- High costs to adapt to the new work rhythm, and the current digital technology is not yet mature
- A shortage of professional talent, high recruitment costs; excellent digital works require high-level professional skills
- Need to invest in introducing various software for technical connections, difficult for small businesses to truly get started
- Huge gaps between companies and brands, low barriers (everyone can self-learn) and high barriers
- Rapid updates of digital technology, making it difficult to keep up and fully utilize its potential

- Important challenges to be resolved: introducing new sensory levels, such as touch and texture, to truly change industry rules

Do you support the increased use of digital garment technology in fashion design?

- Support, can save a lot of time in some processes
- Support, digital technology can effectively solve problems or improve drawbacks of traditional production modes by providing visualization and sustainability
- Support, the diversity of information language helps effective communication within the industry
- Support, can improve product quality, reduce «useless production,» and enhance market competitiveness
- Support, helps reduce risks
- Support, promotes sustainable development in the fashion industry
- Neutral, supports the application of digital technology, but it must be used consciously

Please share your expectations on the future trends of digital technology in fashion design, including potential development directions and impacts.

- Development and improvement: improving output quality, reducing costs, making it more easily accepted by consumers and businesses
- Promoting technology popularization: cultivating talent, building infrastructure
- Diversified visual expression and information transmission: improving the diversity and convenience of clothing products
- Digital technology application scenarios: used for communication and feedback, iteration, digital consumer experiences (such as virtual fitting, virtual stores, virtual films, etc.)
- Promoting sustainability: reducing material participation, helping the clothing industry transition to sustainable development
- Lowering costs and improving economic conversion rates: helping companies reduce costs and improve economic conversion rates
- Improving consumer experience: helping consumers obtain higher consumer experiences
- Creating new branches and opportunities: generating new branches and development opportunities for the fashion industry
- Predicting customer needs: making digital technology closer to user needs
- Improving the realism of digital renders: reducing production time and increasing realism

Q & A 2, the respondents are 6 fashion models working in Milan, aged between 22-28, from all over the world.Four of them are from China and two are from Italy.

Are you familiar with digital fashion technology?

- Heard a little bit, but still prefer the feeling of real clothes
- Understand the development of the fashion industry and believe that digital fashion technology is changing the fashion industry
- Curious about new technology, but personally prefer traditional fashion methods

- Interested in digital fashion technology but concerned about its impact on the modeling industry
- Not very familiar, know that it has to do with virtual clothing and fashion
- Very familiar, believe that technology is becoming more and more popular and interesting in the fashion world

What impact do you think digital fashion technology will have on the modeling industry?

- Work may change, but still like the feeling of actually wearing clothes
- Believes technology will bring significant changes to the industry, improving efficiency and reducing waste, but real models still have an advantage
- Thinks brands might prefer to use digital models, but real models still have unique value
- Concerned that brands might prefer to use digital models, leading to competition for real models and changes in the industry's way of working
- Thinks technology might make brands lean towards using virtual models, but real models have something unique in showcasing emotions and connecting with audiences
- Believes technology has an impact on the industry, but real models have an advantage in conveying emotions and connecting with audiences

Have you ever thought about scanning yourself and creating your own digital model?

- Interesting attempt, willing to try
- Can improve work flexibility, but concerned about privacy issues
- Prefer to stick to traditional methods
- Worried about the future, cautious attitude
- Worried about the impact on real model job opportunities, need to ensure value recognition
- Interested in novel methods, need to consider privacy issues

Personally, do you support digital fashion technology? What do you think are its pros and cons?

- Support, there are pros and cons, hoping to maintain a balance between convenience and real experience
- Support, see the potential, need to find the right balance to have a positive impact
- Cautious attitude, concerned about possible negative effects
- Neutral attitude, need to pay attention to negative effects, ensure recognition of the value of real models
- Worried about the future, neutral attitude, concerned about negative effects, ensure recognition of the value of real models
- Support, see the advantages, need to pay attention to negative effects and find the appropriate balance

Q & A 3, 3 fashion photographers from China with about 4 years of experience in the photography industry:

Are you familiar with digital fashion technology?

- Quite familiar
- Interesting field, pay close attention to the development of digital fashion technology
- Very familiar with digital fashion technology, have collaborated with designers to shoot digital clothing

What impact do you think digital fashion technology will have on traditional fashion photography?

- May lead to a decrease in demand for traditional photography
- Will not have too much impact on traditional fashion photography, which retains a sense of reality and atmosphere of life
- Mixed effects: creative space and the challenge of adapting to new skills

What do you think are the pros and cons of digital fashion photography compared to traditional fashion photography?

- Save costs
- Improve efficiency
- Reduce waste of resources
- Greater creative space
- Can be combined with emerging fields like the metaverse
- Reduced real-life interaction
- Cannot fully reflect the actual comfort and quality of clothing

What is your attitude towards digital fashion photography?

- Interested, think it has potential and innovation
- Can bring new possibilities and opportunities for fashion photography
- Need to find an appropriate balance, ensuring real-life interaction and the value of physical clothing are reflected

Conclusion

Summary of this thesis

Firstly, this thesis conducts an overall study on the application of digital technology in the clothing industry, analyzes the impact of digital technology on the clothing industry, and explains the reasons for writing this thesis.

In the introduction section, this thesis compares the similarities and differences between the traditional clothing design process and the digital clothing design process in stages. Then, according to the different sections of digital garment making, digital fabric making, digital accessory making, and digital clothing photography, it analyzes and compares the similarities and differences between the traditional design process and the digital design process. Furthermore, experiments are conducted at different steps based on the two software, CLO3D and Blender, to further verify, discover, and reflect on problems.

Finally, based on the above discussions and experiments, this thesis analyzes and predicts the possible impact of digital technology on the clothing design process and related industries, analyzing their opportunities and challenges. The thesis ends with a questionnaire and Q&A format, interviewing fashion designers, models, photographer regarding digital fashion technology-related questions.

Limitations and future research directions of this thesis

This thesis mainly focuses on the comparison between the digital clothing design process and the traditional clothing design process, how to use digital technology for clothing sample production and shooting, and the potential problems and solutions encountered in these processes. The emphasis is more on the introduction of the entire process, which leads to a lack of in-depth research on each step. For example, this thesis mainly discusses the use of relevant tools, possible problems and their solutions from the perspective of digital clothing modeling, but involves less design adjustment and modification. Therefore, it is possible to choose how to use digital technology to determine and modify the initial draft of clothing design as a theme for more in-depth research (in the field of **fashion design**).

During the experimental process, the author encountered computer overload situations multiple times, and in the questionnaire survey, the issue of excessive CPU usage by fashion design software was also frequently mentioned. Therefore, researching and optimizing the algorithm for fabric simulation to reduce model faces and CPU usage while maintaining fabric texture is a very necessary and worthwhile topic for study (in the field of **computer science**)

When discussing the digitization of clothing fabrics, this thesis mainly elaborates on how to scan fabrics, generate textures, and apply them to digital clothing. However, the overall introduction is relatively brief, without mentioning the comparison and use of professional fabric scanning equipment, or discussing how to use more professional digital fabric editing software (such as Substance Designer) to edit and create fabrics. In addition, the physical parameter settings of fabrics in different software vary, and researching how to make digital fabrics more realistic and better match the physical parameters of digital fabrics with traditional fabrics is a direction worth exploring (in the field of **computer science**).

As mentioned earlier in the thesis, there is currently a relative lack of digital models provided by clothing software, and research on digital models is relatively blank. Therefore, it is possible to study the production of digital models using 3D scanning and motion capture technology and explore their impact on the modeling industry, or discuss the potential social and ethical issues posed by digital humanoids (in the field of **film and animation**).

This thesis only discusses from a technical perspective how digital technology affects the clothing design process and briefly expands on the impact on related industries. However, overall, it does not touch on the possible negative effects of digital technology on clothing design and related industries, such as: the unemployment wave and social problems caused by industrial transformation; whether digitized clothing still has the value of real clothing; whether the market economy will lead to the development of digital clothing technology in an uncontrollable direction; the positive or negative attitudes of consumers towards digital clothing, etc. (in the fields of **sociology and economics**).

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Appendix

Appendix 1 Screenshots of parameter settings for exporting FBX and ABC formats in Clo3D

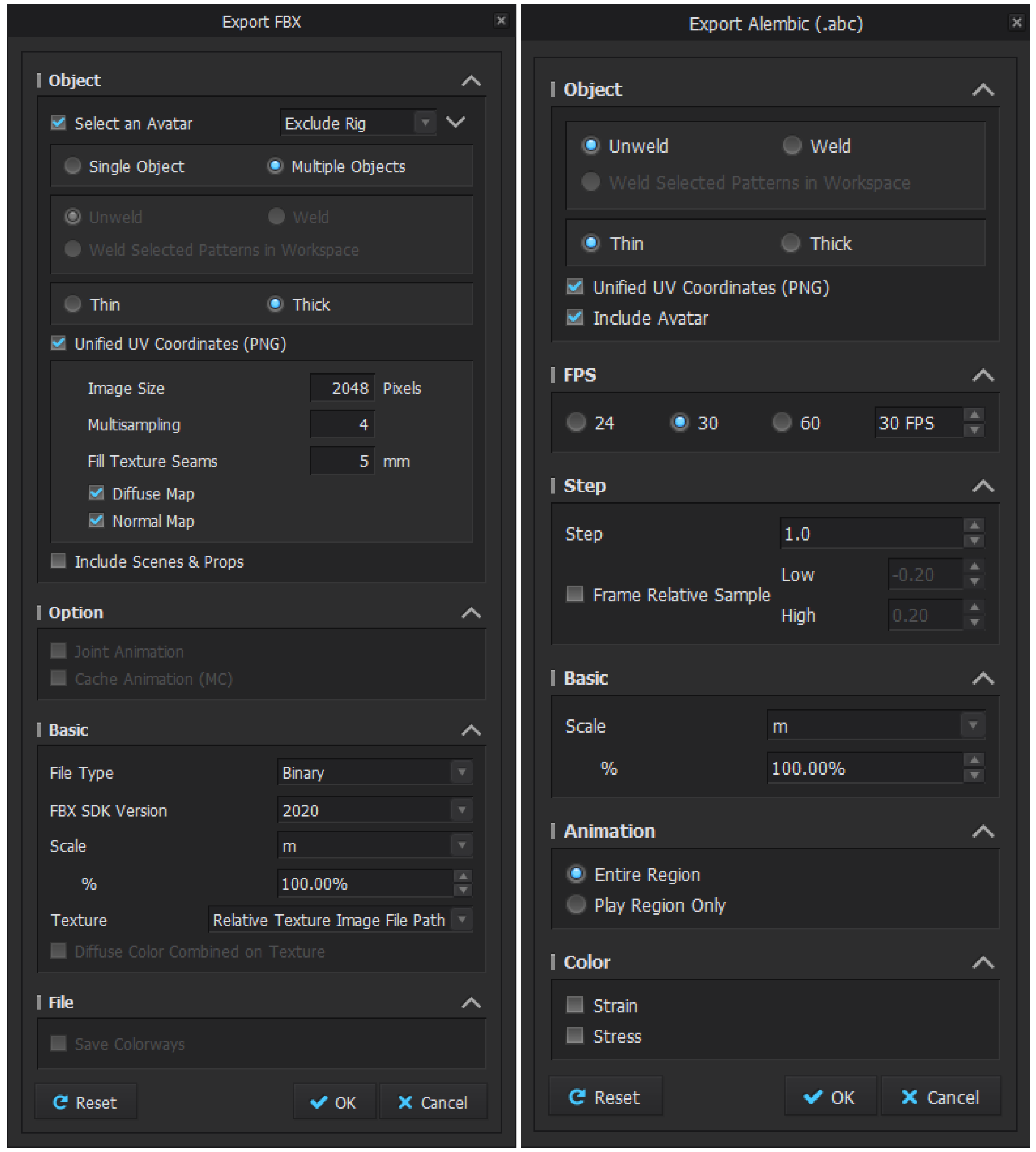

Fig 77. Screenshots from Clo3D's commonly used export settings, the left picture is FBX, and the right picture is Alembic

Appendix 2: Questions and Survey

Questionnaire 1

Q: Please describe the specific role of digital technology in the fashion design process as you understand it.

- Digital technology has long been widely used in the fashion industry, from early CAD pattern making to various 3D garment generating software today, digital technology has continuously participated in broader areas. If big data and AI are also considered as digital technology, then digital technology has even extended to the front end of the fashion industry chain, which is the generation of inspiration sources, as well as the back end of market sales strategies.
- I think that digital technology has the power to improve the technical aspects of fashion design and to provide creative ideas that are different from the usual. It means that it can help into non-creative activities such as pattern making or optomizing the sustainability chain, but also providing AI-generated concepts that could be interesting in the creative field.
- the role of digital technology in the fashion industry aims to bring a simplification and immediacy of the result to be obtained, capable of prototyping, digitally displaying, garments and pattern/texture applications that would require much more time and material if physically made. consequently the new digital technologies also aimed at a decrease in waste that damages the planet every day.

Q: Do you think digital technology helps reduce the cost of fashion design? Please share your views based on your experience.

- It depends on the operation mode of the fashion studio or company and the personnel using digital technology. At present, some costs are still unavoidable. In addition, the random variables generated in actual operation are irreproducible in the underlying logic of computer programs.
- Cost reduction is possible. By avoiding the actual production and labor costs of scene construction, shooting, and other aspects, a set of videos or MVs can be produced as brand promotion. This includes pattern making and trial-and-error, avoiding unnecessary cutting experiments, and also has a role in environmental protection to avoid waste. However, this may lead to the gradual decline of actual human ability and dependence on computer technology.
- Digital technology can effectively reduce material consumption, make iteration more efficient, and help strengthen the connection between enterprises and the market to improve efficiency. However, the costs of talent, technology, equipment, and adapting the technology to the original production mode also need to be considered in the cost accounting. In my previous research, the feedback of consumers brought by digital technology largely depends on the quality and authenticity of the visual effects. To achieve a digital twin image that is easily accepted by consumers will undoubtedly pose high technical challenges for users of digital technology, and at the current stage of development and popularization of digital technology, it may lead to higher costs than traditional methods. If it is to be used for communication with the market, the popularity of digital technology still needs to be improved. In a questionnaire survey I conducted earlier, a large proportion of traditional fashion consumer groups still prefer traditional physical methods. Consumer acceptance affects the efficiency conversion of digital technology, which naturally has an impact on this issue.
- I think that it helped reduce the cost of physical materials, since technological advances goes into a only digital direction, but it has other costs: teaching new technology to the working class, costs of programs, internet connection, specialized computers and the environmental impact that they have
- I don't really know the costs of the fashion industry at high levels, surely it will be able to reduce the costs of the production process, reducing the number of physical proto types necessary for the industrialization of a product

Q: What challenges do you think the widespread use and application of digital technology in fashion design still face?

- It is a high cost for practitioners to adapt to this working rhythm. In addition, the current digital technology is not yet mature.
- There is a shortage of professional talent, and the cost of hiring is high. Producing well-crafted digital MVs requires high-level professional skills, and there are few who can do it well. Although many people are now starting to learn various digital technology-related software, there is no denying that some are just following the trend, and very few can persist and become truly skilled. However, it can be considered as popularizing the technology, and it is a good thing that people are interested and starting to learn new skills. Once it becomes truly popular, like programmers, the cost of hiring will decrease slightly. However, it still requires the hard work of design aesthetics and technology, and the salary will not be low.
- In terms of application, it may be necessary for companies to introduce various software for various technical linkage, which requires a certain investment. It may be difficult for small businesses to truly get started, and big enterprises and famous brands are doing too well, which may create a big gap. It is both a low threshold (everyone can learn by themselves) and a high threshold thing.
- To be able to be used by more people, since some of them are so new that it's difficult to stay updated on them and to use them successfully at their full potential
- I think that the most important challenge that the digitization of fashion has yet to meet is the introduction of a new sensory level, touch&feel. only at that point can digitalization technologies in fashion really change the rules of the game.

Q: Do you support the increased application of digital fashion technology in fashion design?

- Of course, it supports. It can save a lot of time in some processes.
- Yes, it supports. Apart from the technological and cost barriers, digital technology can effectively solve the problems or improve the drawbacks of the traditional mode of production by providing visualization and sustainability. The diversity of information language can promote effective communication within the industry and help companies quickly capture market feedback. This can improve product quality, reduce "useless production," enhance market competitiveness, help mitigate risks, and promote sustainable development in the fashion industry.
- Yes, I support it, but it has to be used in a conscious way.

Q: Please share your expectations for the future trends of digital technology in fashion design, including possible directions and potential impacts.

- With the development and improvement of digital technology, the quality of its output can be improved, and the required cost can be reduced, making it more easily accepted by consumers and businesses. This will help promote the popularity of the technology, talent cultivation, and infrastructure construction.
- Based on the popularity of digital technology, the visual expression and information transmission of clothing products will become more diversified and convenient. In the future, I believe that digital technology may be used for communication and feedback (between internal and external parties), iteration, and digital consumer experiences (such as virtual fitting, virtual stores, and virtual films), among other things. On the basis of reducing material participation, digital technology can help the clothing industry transform into sustainability, help companies reduce costs and improve economic conversion rates, help consumers obtain higher consumer experiences, and help the clothing industry form new branches and opportunities.
- I expect digital technology to be closer to people in the sense that it will predict even more the needs of the clients, and also the realism of the digital renders that will become more realistic requiring less time of elaboration.
- Yes, I support it, but it has to be used in a conscious way.

Questionnaire 2

Q: Do you know about digital fashion technology?

- Well, I've heard a little bit about it. It seems to be about creating clothes using computers, and then we can try them on online to see how they look. Quite interesting, right? However, I still prefer the feeling of actually wearing clothes, being able to touch the fabric and feel their texture. But hey, this new technology sounds pretty cool!
- Yes, I keep an eye on the developments in the fashion industry. Digital fashion technology involves designing and creating virtual clothing through computer software, and then we can try them on and showcase them on digital platforms. This technology is gradually changing the way the fashion industry operates.
- I have some understanding of digital fashion technology. It is an emerging fashion technology that designs and creates virtual clothing through computers. Although I personally prefer traditional fashion methods, I am also curious about this new technology.
- I have a fair understanding of digital fashion technology. It is an emerging technology in the fashion industry that allows for designing and displaying virtual clothing through computers. I am very interested in it, but I am also a bit concerned about the potential impact it may have on the modeling industry.
- I don't know much about digital fashion technology. I know it has something to do with virtual clothing and fashion, but I am not familiar with the specific details.
- I am very knowledgeable about digital fashion technology. It involves designing, creating, and showcasing virtual clothing using computer technology. This technology has become increasingly popular in the fashion world, and I find it very interesting.

Q: What do you think the impact of digital fashion technology will be on the modeling industry?

- I think digital fashion technology might make our work a bit different. We might be trying on clothes on computers instead of actually wearing them. This sounds quite convenient, but I still like to actually wear clothes to feel their weight and comfort. As for other impacts, I'm not quite sure, but I guess we'll gradually see how this technology affects our industry.
- I believe digital fashion technology will bring some significant changes to the modeling industry. It can improve the efficiency of the fashion industry and reduce waste, as designs can be tested before production. Virtual models might pose competition for us, as brands may choose to use digital models to showcase their works. I am not very familiar with digital models, but for example, when I am shooting, I would pose based on how I feel about the clothes, which may be something digital models cannot do.
- Perhaps virtual fashion models will become more popular due to digital fashion technology. However, I believe that real-life models have a unique value in conveying emotions and connecting with the audience, so we still have a place in the industry.
- It might make some brands more inclined to use digital models to showcase their works, which could lead to increased competition for us, real-life models. This technology might change the way the fashion world works, forcing us to adapt to new challenges. Therefore, I am concerned about the future impact of this technology.
- Although I am not an expert in digital fashion technology, I think it might bring some changes to the modeling industry. For example, digital models can showcase digital fashion better and cheaper. However, I believe that real-life models have their unique aspects in showcasing emotions and connecting with the audience. Despite this, I think we need to pay attention to this trend and strive to improve our skills.

Q: Have you ever thought about scanning yourself and creating your own digital model?

- Wow, that sounds pretty interesting! I think it would be fun to scan myself into a digital model. That way, I could see my own 3D model on the computer and try out various clothing combinations. Although I don't quite understand how these technologies work, I would like to give it a try, as it seems cool! If I get the chance, I would definitely like to try it out.
- I've thought about it. Creating a digital model could allow me to use my image more flexibly in different projects. This way, I could participate in more job opportunities while reducing the actual shooting and fitting time. Of course, I am also concerned about privacy issues, so I would carefully consider the impact of this aspect before deciding to create a digital model.
- Although creating a digital model sounds interesting, I prefer to stick with traditional methods. I think the actual shooting and fitting process is an important part of modeling work, which also allows me to better understand and experience fashion. So, I'm not currently considering creating my own digital model.
- Although the idea sounds interesting, I approach it with caution. I am concerned that such technology could make our work more unstable. However, I also think we should pay attention to industry trends in order to adapt to potential changes.
- I don't know much about digital fashion technology, I think it might have potential. It could improve the efficiency of the fashion industry and reduce waste. However, I am concerned that it might affect the job opportunities for us real-life models and the interaction between models and the audience. So, in my opinion, we need to ensure that the value of real-life models is fully recognized while developing digital fashion technology.

- I am interested in this idea. Scanning myself into a digital model could allow me to participate more flexibly in different types of projects, especially in the fashion and advertising industries. Of course, privacy issues need to be considered, but if handled properly, I think it's an innovative approach worth trying.

Q: As for you personally, do you support digital fashion technology? What do you think are its pros and cons?

- I think digital fashion technology is quite interesting, and I am quite supportive of it. It allows us to try on clothes more conveniently and reduces waste, as we don't need to produce as many physical samples just for trying on. However, it might also have some downsides. For example, if everyone tries on clothes on computers, we might lose some of the fun of trying on clothes. Moreover, virtual fitting might not fully capture the comfort and quality of wearing physical clothes. Additionally, I am concerned that digital models might take jobs away from us real-life models, which wouldn't be good for us. Overall, I think digital fashion technology has its pros and cons. Although I'm not an expert, I hope it can bring us convenience while not making us lose the joy of actually wearing clothes and job opportunities.
- I support digital fashion technology because it brings many innovations and conveniences to the fashion industry. It can improve the efficiency of design and production, reduce waste, and allow us to try different styles and combinations. However, it also has some potential downsides, such as virtual fitting not being able to fully replace the actual fitting experience, and digital models possibly affecting our job opportunities. Overall, I believe digital fashion technology has potential, but we need to find the right balance during its development to ensure it has a positive impact on the entire industry.
- I have a cautious attitude towards digital fashion technology. The prevalence of digital fashion might disrupt the physical fashion industry and take away the interaction with real people, which is precisely what I value the most. Therefore, in my opinion, we need to pay attention to the potential negative impacts of digital fashion technology while utilizing it.
- I have a neutral attitude towards digital fashion technology. It does have some advantages, such as digital models being able to work without time or location constraints. As a result, I am concerned that this technology might affect the job opportunities for real-life models. However, if I were to be scanned and turned into a digital model, it might provide me with more job opportunities. Copyright issues might also become a problem, as digital content is harder to control in terms of copyright.
- In general, there are both pros and cons. Digital fashion technology can improve the efficiency of designers, making the fashion industry more efficient. Still, the fashion industry might become more stressful for designers due to the increased efficiency. Additionally, as I mentioned earlier, digital fashion models cannot interact with clothes in the same emotional way as real people, reducing the randomness and potentially making the clothing shooting process boring.
- I tend to support it. Digital fashion can reduce the number of clothes specifically made for fashion shoots, thus reducing environmental pollution. Also, it allows us to try different combinations and styles in a virtual environment, which is very beneficial for innovation and exploration. However, I also realize that this technology might affect the job opportunities for real-life models. So, I think we need to pay attention to the potential negative impacts of digital fashion technology while utilizing it, to find an appropriate balance.

Questionnaire 3

Q: Do you know about digital fashion technology?

- Of course! Digital fashion technology is a method of designing, displaying, and trying on virtual clothes using computer-generated imagery (CGI) and 3D modeling. I think this is a fascinating field.
- I know a bit about digital fashion technology. Although I mainly shoot for e-commerce, I still pay attention to developments in this area.
- I am very familiar with digital fashion technology. Not long ago, I collaborated with a designer on a photoshoot featuring their digital fashion.

Q: What impact do you think digital fashion technology will have on traditional fashion photography?

- Digital fashion technology will have a significant impact on traditional fashion photography. Firstly, it can greatly reduce shooting costs, as we no longer need to produce physical samples and organize actual photoshoots. Secondly, it provides photographers with more creative freedom, as we can try various unique designs and scenes in a virtual environment. However, this may also lead to a decrease in demand for traditional photography.
- I believe it won't have a significant impact on traditional fashion photography. Traditional photography has an irreplaceable sense of authenticity and liveliness, which digital fashion photography cannot fully achieve in some aspects.
- The impact of digital fashion technology on traditional fashion photography has both pros and cons. On the positive side, it provides new creative opportunities, allowing photographers to explore more ideas and designs in the virtual world. On the negative side, it may cause some photographers to feel uneasy, as we might need to learn new skills to adapt to the changes in the industry.

Q: In comparison to traditional fashion photography, what are the pros and cons of digital fashion photography?

- The advantages of digital fashion photography include cost savings, increased efficiency, reduced resource waste, and a greater creative space. At the same time, it can also be combined with emerging fields such as the metaverse, creating new opportunities for photographers. However, its disadvantages lie in the potential reduction of genuine interactions with models and clients, which may result in fewer spontaneously taken photos.
- I think the advantages of digital fashion photography lie in its cost-effectiveness, such as saving on expenses for cameras, studios, and models, and it offers a higher degree of creative freedom in some digital scenarios. The main drawback, in my opinion, is the lack of interaction with models, while other disadvantages are unclear to me since I haven't tried it.
- The pros of digital fashion photography include more creative freedom, higher efficiency, and lower environmental impact. The cons, on the other hand, are that it may lead to a decrease in interpersonal interactions and that virtual try-ons cannot fully reflect the texture of physical clothing.industry.

Q: What is your attitude towards digital fashion photography?

- I am very interested in digital fashion photography. I believe it is a promising technology that can bring new possibilities and opportunities to fashion photography. I am confident that digital fashion technology will bring unique creativity and unlimited potential to our industry.
- I maintain a neutral attitude. The advantages of digital fashion photography lie in reduced costs and increased creative possibilities for shooting scenes. However, as I mentioned earlier, it lacks the feeling of interaction between human models and real clothing, which may make it feel less personal. Moreover, I am also concerned that, due to the lower cost of digital fashion photography, it will increasingly squeeze the market space for traditional fashion photography under the drive of market economy, leading to unemployment for many people. Therefore, the true pros and cons of digital fashion photography need further consideration.
- Overall, I am very supportive and interested in digital fashion photography. I think it is an innovative field that can provide us with more artistic expression space. At the same time, I am glad to see that this technology can reduce resource waste and environmental damage. Of course, we need to find an appropriate balance in this field to ensure that genuine interactions between people and the value of physical clothing are fully reflected.

Survey:

The data comes from Google questionnaires and Wen Juan Xing (问卷星) survey results.
https://docs.google.com/spreadsheets/d/1mc4ccat3TR7kJqVl7_k40pTDcuwYm1xIqVZxdE-nOJxg/edit?usp=sharing
https://www.wjx.cn/report/215194012.aspx
A total of 20 people participated in the answer.

1, How many years of experience do you have in the fashion design industry?

Options	*Result*
Less than 1 year	3
1-3 years	11
4-6 years	3
7-10 years	3
Over 10 years	0

2, Have you ever used 3D fashion design software?

Options	*Result*
Yes	20
No	0

3, Which 3D fashion design software have you used? (Multiple choices allowed)

Options	*Result*
CLO3D	19
Marvelous Designer	1
Optitex	0
Browzwear	0
Other (please specify)	0

4, What are the main difficulties you encountered when using 3D fashion design software? (Multiple choices allowed)

Options	*Result*
Complex software operation	7
High system performance requirements	17
Compatibility issues with other design software	6
Limited or incomplete features	5
High learning costs	8
Other (please specify)	0

5, In what aspects do you think 3D fashion design software can help you improve design efficiency and quality? (Multiple choices allowed)

Options	*Result*
Quickly generate visualization effects	17
Reduce the number of sample productions	11
More accurately assess fabrics and cutting	9
Easier design modifications	11
Facilitate customer communication and feedback	8
Other (please specify)	0

6. (Optional) What improvements do you think are needed for the 3D fashion design software currently on the market? Please answer based on your actual experience.

- Complex user interface
- Insufficiently realistic effects
- Poor compatibility with other software

- High device requirements, leading to poor performance
- Make it more intuitive, I think the software is still too complicated to work with.

7, Have you tried to mix the use of fashion industry software like CLO3D with modeling industry software like Blender or UE4?

Options	*Result*
Yes	5
No	15

8. (Optional) What improvements do you think the mixed use of these software brings? Please provide examples.

- Helped to establish a more complete shooting scene

9, If you have never used 3D fashion design software, are you interested in learning and trying it?

Options	*Result*
Yes, very interested	2
Yes, somewhat interested	5
Unsure	0
No, not interested	0

10, What challenges do you think the popularization and application of digital technology in fashion design still face? (Multiple choices allowed)

Options	*Result*
High technology costs	8
Lack of professional talent	11
Rapid technology updates	8
Difficulty changing traditional concepts	14
Other (please specify)	1

11, Do you think digital technology will change the traditional fashion design process?

Options	*Result*
Yes, to a large extent	7
Yes, to some extent	11
No, it won't have much impact	2
Unable to judge	0

12, Do you think the impact of digital fashion technology on fashion design is positive or negative?

Options	*Result*
Positive impact	8
Negative impact	1
Both	11
Unable to judge	0

13, (Optional) Do you support the application of more digital technology in fashion design? Please explain your reasons.

- Yes, is sustainable and efficient. Sustainable is a material way, since it produces zero waste, and is also sustainable in terms of time.
- I think that technology could have a merely practical use. The physical dimension will always be fundamental in fashion.
- Yes, I think it can improve efficiency and save fabric
- Relatively supportive, can save sample and development costs
- Supported
- Supported. In addition to reducing the technical barriers and costs, digital technology can effectively solve the problems and improve the traditional mode in terms of visualization and sustainability. The diversification of information language can promote effective communication within the industry and help companies quickly capture market demand, thereby improving product quality, reducing "useless production", enhancing market competitiveness, helping to avoid risks, and promoting the sustainable development of the fashion industry.
- Supported, but still need to balance the relationship between virtual and actual.

14, (Optional) Please share your expectations for the future trends of digital technology in fashion design, including possible directions and potential impacts.

- I believe is important to use digital technology in a democratic way, making sure most of the fashion schools are giving the same tools to their students.
- I think that technology could help with the prototypical and visual part, therefore I hope that many improvements will be made in terms of usability. I hope one day they'll find ways to integrate it with real contents, not only developing futuristic/surreal concepts; otherwise, I think it will sooner or later go out of style/ become obsolete.
- With the development and improvement of digital technology, its output quality can be improved, and the required costs will be reduced, making it more acceptable to consumers and enterprises, which helps promote the popularization of this technology, talent cultivation and infrastructure construction. Based on the popularization of digital technology, the visual expression and information transmission of clothing products will become more diverse and convenient. In the future, I think digital technology may be used for communication and feedback (within the company and between the company and the outside world), iteration, and digital consumer experience (such as virtual try-on, virtual stores, and virtual films). On the basis of reducing material participation, digital technology can help the transformation of the clothing industry towards sustainability, reduce costs and improve economic conversion rates for companies, provide consumers

with higher consumption experiences, and create new branches and opportunities for the fashion ind ustry.

- It can greatly reduce waste, but at the same time, it will also cause qualitative changes in the product attributes of clothing.