Reproduction of Historic Costumes Using 3D Apparel CAD

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The candidate confirms that the work submitted is her own and that appropriate credit has been given where reference has been made to the work of others.

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Abstract

The progress of digital technology has brought about many changes. In the world of fashion, 3D apparel CAD is attracting attention as the most promising product which reduces time and cost in the design process through virtual simulation. This study highlights the potential of its technology and tries to extend the boundaries of its practical use through the simulation of historical dresses. The aim of this study is to identify the desirable factors for digital costume development, to produce accurate reproductions of digital clothing from historical sources and to investigate the implications of developing it for online exhibitory and educational materials.

In order to achieve this, this study went through following process. First, the theoretical background of the digital clothing technology, 3D apparel CAD and museum and new media was established through the review of various materials. Second, the desirable concepts for effective digital costume were drawn from the analysis of earlier digital costume projects considering the constraints of costume collections and limitations of the data on museum websites: faithful reproduction, virtual fabrication and Interactive and stereographic display. Third, design development was carried out for the embodiment of the concepts based on two costumes in the Museum of London: (1) preparation which provided foundation data with physical counterparts, (2) digital reproduction which generated digital costumes with simulations and (3) application development where simulations were embodied into a platform. Fourth, evaluation of the outcomes was carried with different groups of participants.

The evaluation results indicated that the outcomes functioned as an effective information delivery method and had suitability and applicability for exhibitory and educational use. However, further improvement particularly in the faithfulness of current digital costumes and more consideration for the concerns for virtual and intangible nature were pointed out to be required. Nevertheless digital costumes were reviewed to bring notable benefits in complete or partial replacement of the relics, presentation of invisible features, release of physical constraints on appreciation and provision of integrated and comprehensive information. This study expects that use of digital costumes may assist museums in terms of preservation, documentation and exhibition of costume collections giving new possibility especially to the endangered garments lying in the dark.

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Chapter 1: Introduction

1.1 Motivation for Study

Costumes are valuable historical and cultural heritage items which serve as resources for academic investigation, artistic inspiration and appreciation. When exploration of costumes is required, publications and internet materials may be the most frequently utilised to search for information. However they are often limited in their scope due to the 2D nature of their images and abstract nature of the texts. These fragments of the description may not be good enough to help the people visualise the 3D shape of the dress and imagine how it may feel when it is worn. If the person finds it very compelling, he or she may go to the exhibition where it is displayed to directly and meticulously appreciate it. However, sometimes that is impossible due to the constraints of time, distance or the presence of other limitations, such as the case when the clothing is not open to the public due to preservation purposes. In the worst cases, the dress no longer exists. Even if the person is able to see the dress displayed, the view is often restricted by the surrounding objects such as walls and other garments. In this situation, the intellectual curiosity of the public requires something that could more effectively satisfy their expectations. This study highlights the potential of digital clothing technology and new media as a means of satisfying such desires and explores their applications, their scope, and their implications.

1.2 Background of Study

The progress of technology and the digital revolution have brought about changes within many aspects of society. New forms of media have become widely prevalent across the spectrum. In the context of museums, new advances in visualisation have affected the way in which these institutions display their exhibits, how they conduct their operational processes and how they build the relationship with visitors (Henning, 2006). The development of new media has promoted the establishment of databases of information, such as the digitisation of collection information, the use of which has become commonplace. The distillation of media into computer data is characterised by its programmability, as a result of which the possibility of other features such as modularity, automation, variability and transcoding now become conceivable (Manovich, 2001).

These characteristics of new media reflect the potential for more attractive and efficient means of delivering the information that museum collections possess, and leaving behind traditional ways of displaying their materials.

Meanwhile, the advance of technology has assisted the world of fashion in developing a variety of computer-aided design systems. Most promisingly, 3D apparel CAD is attracting attention as a remarkable technology which could enable a reduction of time and cost in the design process through virtual simulation. Aside from this, the technology behind 3D apparel CAD is being applied in diverse ways. It has been combined with information technology to produce new collaborations and breakthroughs within the fields of cyber space, scientific fabrication and optical technique (Quinn, 2002). The prominence of fashion in virtual space has brought about many changes. One such change is the emergence of fashion designers who work exclusively on the internet and webcast. Many fashion brands are trying to provide personalised products using online avatars and virtual clothing. “Cybercouture” (Quinn, 2002) and “digital clothing ” (Fuhrmann et al., 2003) are words that are part of the new lexicon derived from this phenomenon. Additionally, digital clothing technology has been utilised in the film and game industries. It is expected that the range and the scope of the technology will increase over time.

The advanced technology in museums and fashion implies a range of possibilities of its applications. However, despite the possibilities, research on digital clothing has been parochial in nature, inclining primarily toward improving aspects of the engineering, such as simulation techniques and the development of tools on the technical side, and basic pattern development on the design side. Though these aspects form the fundamental base of its utilisation, this study claims that more attention is required to the ways of the applied use of the technology. As the technology became more prevalent in our daily lives, now we need to think about how to apply the technology more usefully for the improvement of human culture and heritage.

In this respect, this study explores the applications and prospects of digital clothing technology, and extends the existing boundaries of its practical use. It achieves this through the subject of reproduction of historical fashion, which optimises the benefits associated with new media to supplement the various constraints such as vulnerability and fragility of costumes, environmental and financial restrictions of exhibitions and constraints on public access supporting the value and role of the costumes for study and appreciation. It is expected that the application of digital clothing technology will not only enliven the display of lost and damaged costumes but also will contribute to the preservation and documentation of the relics and democratisation of knowledge. This study expects to produce meaningful results not only for museums and their audiences, but also for the field of digital clothing technology and new media.

1.3 Aims and Objectives

The focus of this study explores a way of recreating costume relics in a digital form and on the development of faithful and effective simulation using digital clothing technology to benefit museums and their audiences. This study aims to identify the desirable factors for digital costume development, to produce accurate reproductions of digital clothing from historical sources and to investigate the implications of developing it for online exhibitory and educational materials.

The main objectives of the study are as follows:

(1) To establish a theoretical understanding on digital clothing technology and 3D apparel CAD
(2) To understand the importance and constraints of costume collection
(3) To provide an overview of the influence of new media and clarify the status and problems of museums' current practice of applying websites
(4) To review methods, strengths and weaknesses of earlier digital costume projects and establish key concepts for the development of effective digital costumes and application
(5) To develop digital costumes and application
(6) To evaluate the effectiveness and faithfulness of the outcomes

To attain the aims and objectives, this study requires varied practices and investigations using the knowledge of different disciplines. By adopting a research strategy with the flexible use of several methods such as fieldwork, observation, fabric objective measurement, focus groups, and questionnaires, this study attempts to successfully fulfil different tasks.

It is expected that the performance of the research process will not only examine the advantages and limitations of current technology but also lead to the proposition of a desirable model of digital costumes, the development of digital costumes and the provision of reflective reviews of practices. It is considered that these outcomes will contribute with the rich design knowledge and insights into physical and digital methods of costume reproduction and improved and efficient digital garment design and application to human culture.

Chapter 2: Digital Clothing Technology

The industry of clothing today is a huge global business and the progress of science and technology has affected its expansion, acceleration and diversification. Digital technology especially has shown the tendency to be fused into clothing in various aspects of production, distribution and consumption. Among these phenomena, this study focuses its attention on the conversion of garment design into digital form, or so-called digital clothing. This chapter explores its concept, types of available systems and applications.

2.1 Concept of Digital Clothing

Clothing is one of the fundamental elements of human life, and has been worn on the body for protection, adornment, identification and other purposes. Advancements in science and technology have attempted to conflate digital technology with garments to reinforce the roles of clothing or confer new functions and aesthetics. Such influence has not only been applied to the physical context, but has also led to new trends through the virtual environment. The attachment or connection of digital devices to the garments and the development of textile substrates in which electronics were implanted are representative examples of this phenomenon.

In this study, the concept of the use of digital technology for clothing does not focus on these physical applications. While these cases indicate development of textiles or garments to network, control or embed electronic technology, this study gives attention to another fusion modality of clothing where the appearance of a garment is stereographically represented using technology. The clothing in this sense is generated in a virtual environment and appears in a 3D form through computer graphics and is stored as digital data, which consists of bits. A bit is “the smallest atomic element in the DNA of information” with “no color size, or weight” which can be delivered at the speed of light (Negroponte, 1995 p.14). Likewise, garments in virtual space do not have physically tangible characteristics, but the data visualise all features as a graphic presentation which has the advantage of fast transmission.

2.1.1 Terms

To refer to 3D garments which are constructed and presented in a virtual environment, there have been various terms used by the academic and industrial worlds and the public. The adjectives “digital”, “virtual” or “3D” were most commonly used together with clothing, garment, fashion, clothes or specific apparel terms such as dress and pants. Also, “3D” is sometimes used in combination with “digital” or “virtual.” In many articles (Loker and Ashdown, 2007; Jones, 2012; Gaimster, 2012; Watstein and Czarnecki, 2010) “virtual” was often used to describe the garments which are generated, displayed and played with in virtual spaces. The concept in this sense may integrate the presentation of garments in 2D as well as 2.5D effects[1]. As 3D graphics have become more available, however, the focus of this word has been changed to the 3D garments in a 3D environment related to games, social network services and the apparel industry. A more technical use of “virtual clothing” (Volino and Magnenat-Thalmann, 2000), “virtual garment” (Hardaker and Fozzard, 1998) and “virtual clothes” (Miaolong et al., 2013) were used in the research to name 3D outcomes resulting from the implementation of virtual drape simulation of a garment. Also, “digital clothing” and “digital garment” also appears in much the same sense in many works (Bridson et al., 2003; Kim, 2012).

In order to clarify the specific concept dedicated to more realistic garment creation, Ko (2009) rigidly compartmentalised virtual and digital clothing based on creation methods. In her study, virtual clothing was viewed as a wider concept of three-dimensionally created garments using any method through computer graphics, including modelling techniques and others. On the other hand, only the garments generated in a virtual space based on the conventional garment production process and garment pattern was defined as digital clothing. In other words, digital clothing specifically refers to the garments produced in a 3D environment adopting exactly the same principle of garment design and production in the real world. This concept was summarised in Ko’s book (2015) as “computer-aided design and production of clothing” (p.4). These definitions imply the significance of the fidelity of virtual clothing, considering its application in the apparel industry, where precise representation is essentially required.

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[1] 2D digital video representation style with the 3D appearance. similar to a 2D effect but with the appearance of three dimensions. If an object is “rotated 90 degrees about its x-axis it will be seen to be a single line, providing its 2D nature” (Jack and Tsatsulin, 2002, p.1).

By extension, the technologies which are involved in the creation of digital clothing is called digital clothing technology. Ko (2009) more specifically described it as a synthetic technology for garment reproduction which includes design, pattern making, dynamic 3D cloth simulation and rendering. Other researchers (Ko et al., 2012) defined digital clothing technology as the organic integrity of computer graphics modelling, animation and rendering technologies for the purpose of apparel production or animation of garments.

The point of view of Ko (2009) regarding virtual clothing accords with the current trends is that the different natures of 3D objects representing garments in virtual spaces are universally addressed as virtual clothing. Depending on the purpose of use, the form of production and the degree of delicacy of virtual clothing can be varied. While Volino and Magnenat-Thalmann (2000) and Wu et al. (2013a) put emphasis on more sophisticated garment creation, applying a cloth simulation technique for the apparel industry, there are general cases where garment presentation becomes more simplified: garments have less importance, technical constraints are imposed and priority is given to efficiency. In these cases, 3D shapes usually become morpho-structurally simplified or garment features are only superimposed on the surface of the objects through graphic images. These kinds of results can be achieved by merely using simple modelling and mapping techniques. However, this study considered that such types of virtual clothing abstracted lose genuine qualities of clothing and are more like 3D graphic methods to symbolise garments.

Although the basis of conventional garment making is dominantly inherent in Ko's meaning of digital clothing (2009), to draw an explicit boundary of more realistic virtual clothes, the term has been extensively applied to many fashion areas. It often refers to garments which are physically improved by use of high materials or digital devices. In Kwak's study (2009), digital clothing was regarded as a concept which applies the technology of a computing environment to the fashion area. Digital clothing in his study encompassed not only virtually simulated 3D clothing in avatar fashion, made-to-measure (MTM) clothing and 3D virtual fitting systems, but also wearable computers, intelligent garments and smart wear. Also, “digital” in fashion is often used as a digital catwalk and runway (Quinn, 2002), the virtual version of a platform where 3D garments are displayed on virtual models as well as fashion shows in the real world which use digital effects or digital media to display and broadcast. Digital fashion shows became more recognised as a fashion presentation using holographic technology as world famous fashion brands such as the autumn/winter Collection of Burberry in Beijing in 2011 and the Spring Collection of Ralph Lauren in New York City in 2015 have applied various imposing effects. Also, digital fashion week in Singapore and Bangkok is using the word “digital” simply because the streaming of the show is exposed both offline and online.

In addition, there are other terms which 3D garment simulation underlies as a key component. “i-Fashion” is a word combining IT and fashion that refers to a new concept in the fashion industry. It is a production and marketing system which allows customers to purchase garments based on their choice of colours and design through virtual fitting using an avatar (Telecommunications Technology Association, 2012). Park (2010) emphasised that the system can apply IT to all stages of fashion production. Software technology like 3D simulation, apparel CAD/CAM, virtual reality and web/mobile application technology and hardware technology such as 3D body scanner, DID (digital information display), RFID (radio frequency identification) and digital textile printing were suggested as applicable technology. Meanwhile, Choo et al. (2012) suggested an extensive concept of IT fashion which embraces 3D digital clothing and smart garments as its sub-areas, for example Kwak’s study (2009). In his study, IT fashion indicated any efforts and activities which optimise the value of fashion products and services through the use of partial or synthetic applications of IT into processes of production, distribution and consumption.

Quinn (2002) used “cybercouture” to introduce various designers’ fashion projects that applied cyberspace. He described “cybercouture” as a fashion ethos which is formed when “fashion, information technology, visual representations and interactivity” are aligned together in cyberspace. 3D digital collections in digital runways, fashion presented on the internet or through webcasts, and the application of digital installations were introduced through cybercouture. Besides, “cyber fashion” appeared to introduce virtual fashion runways in 2005 such as the students’ graduation showcase of Sungshin Women’s University (Fashion Insight, 2005). However, “cyber fashion” is also applied to imply technology-based bodywear.

Table 2.1 shows the cases where these words have been applied. The exploration of the terms denotes that the meaning of digital clothing may generate confusion. Firstly, the term “digital clothing” has shown its diverse inclusiveness, covering 3D garment simulation, the use of technology in clothes or the application of technology for displays of fashion, and it may even stand a chance to signify internal or external accommodations of technology to fashion cycles. Secondly, the terms which describe digital clothing vary and they are also applied to different applications of technology for garments. The reason why several words are interchangeably used may be that "digital", "IT" and "cyber" are intimately related to computer and electronic technology, and sometimes they were used as synonyms of those technologies. These words are also used to indicate the garment itself or the environmental involvement of technology(Tillotson, 2005).

Table 2.1 Use of digital clothing terms

Area / Term	Technology as clothing		Environmental involvement of technology for clothing
	3D garment simulation	**Technology-based bodywear**	
Virtual	✓		
Digital	✓	✓	✓
IT	✓	✓	✓
Cyber	✓	✓	✓

2.1.2 Definition and Qualities of Digital Clothing

In order to provide a more comprehensible understanding, this study clarifies the meaning and qualities that digital clothing is required to have based on its previously mentioned definitions, and the basic characteristic factors of clothes in the material world. "Clothes" is defined as "items worn to cover the body" (Oxford Dictionaries, 2016) and they are designed considering the shape of the body and aesthetic and functional aspects. According to Sorger and Udale (2012), the fundamental elements in garment design are silhouette, proportion, line, detail, fabric, colour and texture. The garment design is substantialised basically through measuring and mapping, pattern drafting, developing patterns, making toiles, markings and notches, draping on the stand, cutting the sample, sewing, fitting, and finishing (Jones, 2002).

This study cognises that the virtual sense of genuine garments needs to adapt these attributes to some degree. Firstly, as the definition of clothes, digital clothing can be understood as a virtual garment which is created to be worn or cover either the human or virtual body. Even though it is presented without underpinnings, its structure should be designed on the premise of accommodation of the body. Such facets accordingly demand reflection on garment production principles in the actual word. The section 2.3, which explores the application of digital clothing, shows that the tendency of its use not only covers the graphical presentation of constructed garments in virtual space, but also the assistance of garment production in the physical or augmented real world.

Secondly, digital clothing should be able to embraces to the essential factors of garment design. Silhouette, which refers to “overall shape and volume” (McKelvey and Munslow, 2012, p.51); line, which indicates garments cut and created by seams and darts (Sorger and Udale, 2012); and proportion, which subdivides shape, are required as the components which appear as morphological aspects of clothing in the virtual space. Such morphological features are generally created by the structure of garment patterns or with drape in the case of silhouette. Consequently, the adoptability of garment pattern and drapability can be considered indispensable for the rendering of digital clothing. Colour and texture are the major properties of fabric. These elements play an important role in expressing the visual and tactual characteristics of the material of digital clothing. Visualisation of such features is vital to the sense of reality of materials of digital clothing. Details which generally refer to the complicated and elaborate elements are particular or minor features of a garment (Picken, 1999). They are often omitted in virtual clothing, since the typical appearance of a garment can roughly be expressed without intricate features. However, it has an influence on the degree of completeness and provision of prominence of delicacy of digital clothing.

Thirdly, the formation of digital clothing should be on the basis of the application of garment patterns and construction methods. The garment production process stated above can be summarised into two major stages: pattern development, which embraces measurement, and pattern making, refinement, and construction, which ranges from cutting samples to finishing. The pattern and construction which may be seen as the core of garment generation were also emphasised by the concept of digital clothing in Ko’s study (2009). The essence of garment production operations is converting flat fabric pieces into 3D clothes. In most cases, fabric pieces are assembled by sewing (Chmielowiec, 1993). In the virtual sense, shells originating from each garment pattern become joined by welding the contour lines. Such adaption of garment patterns and construction methods enhances the generation of digital clothing with more reality and exquisiteness, and gives distinct advantages: the virtual presentation of clothes, and the capability of association with real garment production and augmented reality implementation.

In conclusion, this study considered the definition and quality of digital clothing as follows. Digital clothing is the computer aided 3D design of an item worn on a human or virtual body, which applies garment patterns and conventional construction principles for the purposes of its use in either the virtual, real or augmented real world. Like the clothes in the real world, it has the capability of accommodating of morphological factors of garments generated by structure and drape, graphical expression of visual and tactual factors of fabric and other additional elements, like details.

2.2 Virtual Clothing Generation Techniques

There are different types of techniques that can express the shape of a garment in a virtual environment. This section explores a few general techniques as well as the method dedicated to digital clothing.

Garments in a 3D space can be constructed in various ways when taking into consideration the role and efficiency. In the case of clothes whose form is simplified and abstracted or adhered to the body, garments are sometimes visualised onto the surface of a virtual body without construction of shape. Since such an expression of the garment is not considered as a formative aspect, this study excluded it from exploration.

2.2.1 Modelling

The most basic creation method that has been widely used from the earliest stage of 3D CAD to date is modelling. Autodesk Maya, 3DS Max and SketchUp are well-known 3D CAD systems for modelling. Modelling is the process of generating a mathematical illustration of the 3D structure of an object (Vaughan, 2011). In general, the 3D object is expressed as mesh that consists of points connected by line segments, and the shape of the object is formulated through moving, adding and merging the points. Modelling garments is normally carried out in two ways. One of the ways is to develop garments using the body’s geometry. Ebert (2014) and Patnode (2012) demonstrated garment generation by modifying the geometry of the body where clothing would cover it. The other method is shown in Koenigsmarck’s book (2013), and it involves creating separate surfaces to wrap the body. The virtual clothes being modelled do not involve garment patterns or construction methods. It only expresses the shape of the external appearance of the garment, and the garment drape is also artificially modelled. For this reason, realistic figuration of clothes can be difficult to achieve, and it is a time-consuming task. Many clothes models are built as an integrated form of the body. Additionally, the garments that are modelled separately from the body often neglect the structure of the parts not exposed. Sometimes these parts are not constructed or connected to one another.

2.2.2 Sculpting

Sculpting is considered another modelling technique and is often known as sculpt modelling or clay modelling. This method applies the physical component of sculpting methods, which involves carving, pulling and pushing into sketching in a 3D environment. Zbrush and Mudbox are representative tools for digital sculpting. Basically, modelling takes place by deforming the meshes of basic primitive forms, gradually making them into more complex shapes (Alcaide-Marzal et al., 2013). Tightly fitted clothes are generally produced from the mesh, which corresponds to the surface of the body base and then expresses thickness, drape and folds (Spencer, 2010). Creation of voluminous garments in Armstrong's study (2011) shows the process of using a large base shape with a certain silhouette; then form and drape became more elaborate through deformation.

According to Keller (2012), sculpting is a suitable tool for generating organic shapes and objects like clothing, and it is easily attained using sculpting brushes. Depending on skills of the user, realistic expression of natural garment drape, sophisticated details and texture of materials can be sculpted. However, the garment created through this method may not reflect the structure of the garment pattern; it may only show the shape of the draped clothes. Nevertheless, garment pattern generation to create sculpted clothes was demonstrated in Taylor et al.'s work (2013), and the process required the interlocking use of a pattern flattening and 3D apparel CAD systems.

2.2.3 3D Scanning

3D scanning refers to the process of taking a physical subject in the real world and generating a digital representation in the form of a 3D object using data acquired by a scanner. Scanners are categorised into two types: contact and noncontact. Contact scanners collect the data by physically touching the subject. Noncontact methods are subdivided into active scanners, which carry out mensuration using light or lasers that bounce or reflect back over the subject, and passive scanners. which use photogrammetry (Mongeon, 2000). To scan a garment, using the contact method would not be appropriate since physical touch may cause damage or changes of drape.

Use of a noncontact active scanner was shown in Kenkare's study (2005). His study captured a constructed skirt draped on a mannequin, and the study used a $[TC]^2$ 3D body scanner, which has two cameras in both the front and back. However, his study found that much of the drape was lost when the skirt was scanned. To resolve this problem, multiple scans were carried out at different angles by rotating the mannequin and then the data was combined. Accordingly, this entailed post-processing data such as “clean data, align data, merge data and refine polygonal mesh” (p.115) to achieve one complete 3D object.

An application of the photogrammetry method is shown in the study of Capacete-Caballero et al. (2013). Photogrammetry method creates a 3D form by applying algorithms that combine pictures (Mongeon, 2000) taken from various angles. Capacete-Caballero et al. (2013) used an iPhone and its application called Autodesk 123D Catch to capture and process the photographs of garments on mannequins. The study demonstrated that scanning garments mounted on a mannequin was difficult because of its large size. They added that smaller shapes have a better quality of result. In addition, limited space, uniformed colour and textures of the environment were mentioned as obstacles in achieving a successful result. The 3D object in this study also needed additional processing after it was captured to remove traces of markers that were used for distinction of unified materials for optimisation.

If there is an actual garment model, 3D scanning is theoretically the ideal method to create genuine shape and generate more faithful virtual clothes. The outcome will convincingly represent the external features of the garment as it is. However, the findings of previous studies revealed constraints that may hinder the achievement of an entirely complete form of garments. In general, depending on the dimension and shape of the clothes, the scanned object may appear lacking in some areas, or there may be irregularities of shape. The process may be one of trial and error, and it could require multiple scanning. Furthermore, to accomplish an optimised result, an additional treatment process is normally required. In addition, there are other limitations that vary based on the type of scanner being used. For instance, black garments, glossy paint and plastic are difficult to capture using a laser scanner (Kus et al., 2009). Additionally, it is not recommended to capture transparent, reflective or shiny materials (Autodesk, 2011) using passive methods.

2.2.4 Cloth Simulation

Virtual clothing generated by the techniques previously explained may be able to reproduce credible drape on a body. However, it is simply an expression of static shape and does not present responsive drape by movement of the body. Cloth simulation is the technology which facilitates dynamic expression of fabric taking into account the collision between fabrics, as well as cloth and other objects. In some modelling software, cloth simulation is built-in such nCloth for Maya and cloth modifier for 3DS Max. Also there are various plug-ins available on the market like Qualoth and Syflex for Maya and PhysX Clothing for 3DS Max. In a cloth simulation on modelling systems, generally garment-shaped objects or some objects which are designed to be parts of clothing is defined as cloth to simulate some degree of flexibility based on properties of the object. Draped on or attached to a body, these objects present reactive drapery to form and pose or movement of body. However, the material parameters in modelling systems generally facilitate users' operation and fast processing and not directly relate to properties which the apparel industry uses. Also the garment shape, which is unified with body as one object is not eligible for cloth simulation. Depending on systems, the shape of apparel patterns can be imported and assembled to reproduce a more realistic garment form. In the case of the construction of complex clothing, elaborate assembly can be time-consuming work because usability of most systems have been developed for the visual entertainment industry such as film, animation and game. Furthermore there has been concern about difficulty which fashion designers might be faced with when they try to use modelling systems (Wu, 2009).

2.2.4 3D Apparel CAD

Exploration of the above techniques suggested it is difficult to generate garments with a truthful concept of digital clothing. Although cloth simulation in modelling systems have the potential for virtualisation of the authentic form of clothes, the difficulty in complex construction and the concerns about complicated operations imply that using this approach is a serious undertaking.

On the other hand, 3D apparel CAD is a more specified system developed for the purpose of assisting real garment production. With regards to its use by garment designers, the process of pattern design and construction is carried out based on the garment production principle. Cloth simulation also functions as a core element in 3D apparel CAD to generate the garment shape according to the pattern structure, cloth properties, and the form of the body. The majority of commercial 3D apparel CAD software is developed to incorporate functions that fulfil the garment design elements such as morphological features and visual and physical characteristics of the fabric and details during production process to facilitate faithful virtualisation of clothing. Some positive findings from research on the similarity of real and digital garments (Ko, 2009; Ni et al., 2015; Guan et al., 2015) have indicated that digital clothing technology has a certain degree of reliability.

2.2.5 Technical Consideration for Exhibitory and Educational Digital Costume

The digitised form of clothes in this study primarily aims for realistic and actual source-based production and suitability for exhibitory and educational utilisation. Superficial configuration of the appearance of clothing will be obtainable using any method, though efficiency would be varied. This study considers that a more realistic form of a dress is achieved by the drape of a structured garment, which means clothes constructed by patterns. Modelling and sculpting are not adequate methods for this as they are not capable of draping garment objects and only express the external shape of draped clothes based on imagination or references.

On the other hand, scanning and cloth simulation are able to visualise the drape of structured garments. Scanning is useful technology for recording the 3D shape of an object as it actually is. However, previous studies (Kenkare, 2005; Kus et al., 2009; Capacete-Caballero et al., 2013) revealed some limitations such as constraints of installation, space, garment dimension, texture and colour and the likelihood of multiple scanning and additional processes for optimisation. In addition, this technique cannot be applied to the reproduction of costumes that are extensively damaged to be mounted and those that no longer exist. Another disadvantage is that scanned items cannot show the internal structure since mounted garments and underpinnings agglomerate together to form an object.

In the case of cloth simulation, garment drape can be virtualised based on the pattern structure, cloth parameters, and shape of the underpinning. The current technology may not be able to apply all variables that affect the garment drape. However, similarities between real and simulated garments to which earlier studies have testified indicate that a plausible garment drape can be achieved. Simulation can be implemented by both modelling and 3D apparel CAD systems. However, using 3D Apparel CAD systems is regarded as more appropriate for this study. Compared to most modelling systems that have been developed for visual entertainment industries such as film, animation, and game, 3D apparel CAD applications provide more efficient usability for complicated garment creation by integrating the fundamental garment design elements. These systems facilitate more accurate garment pattern creation and assembly based on actual measurements and the principles of the conventional method, which adds additional advantages like being able to maintain structural features in and out of the virtual world and the increased ease of using patterns. Such aspects are expected to enable various educational applications of digital costumes. In addition, the pattern flattening method that Taylor et al. (2013) demonstrated may also allow for the use of garment patterns from virtual dress generated by other techniques. However, uneven garment surfaces where the fabric is layered, gathered, pleated or shirred might not be sufficiently interpreted into two-dimensional patterns. Although garment reproduction using 3D apparel CAD is not a picture-perfect representation of clothing, its accommodation of principles of conventional garment construction is thought to have the potential to achieve a certain degree of exactness. The detailed concept, characteristics and design process of 3D apparel CAD is investigated in Chapter 3.

2.3 Applications of Virtual Clothing

Clothing is conventionally used for utility, modesty, sexual attraction, adornment, symbolic differentiation, social affiliation, psychological self-enhancement and expression of modernism (Jones, 2012). When the garments appear in a virtual sense, their roles can be classified in two ways

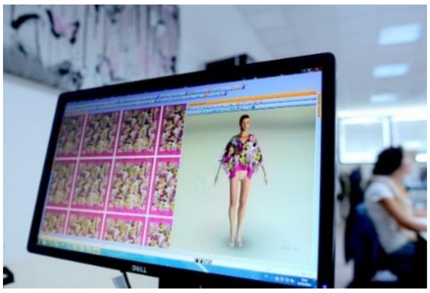
- A means to assist the design, production and consumption of physical and virtual clothes that have conventional functions.
- A virtual method to identify the individual self or an imaginary character in the cyber world.

In the first case, virtual clothing does not perform any peculiar roles except for the representation of design and providing indirect experience of wearing. However, such a supportive role is expected to bring about huge economic impacts, and technology for its applications are continually being developed and attempted. The garments in the second case inherit the meanings of physical clothing in most aspects. Clothing's utility to protect and comfort the body loses its significance, as no physical hazards exist in the virtual space. Garments in the virtual world carry more weight with expression of identity and physiological functions and are considered as a critical element for differentiation and symbolisation of figures. This section explores how these functions have been applied.

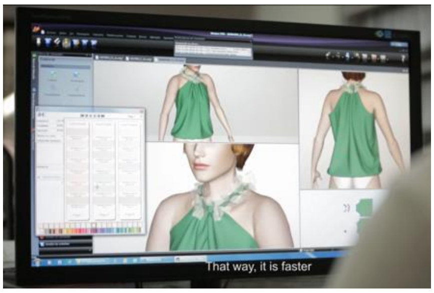
2.3.1 Clothing Sector

2.3.1.1 CAD/CAM Applications

The application of garment simulation to apparel CAD systems has brought huge changes in the design process and physical production. As 3D visualisations involving accurate shape of clothes become available, decision making and performance in design processes can promptly be executed without physical prototypes. Also virtual prototyping using a virtual model helps garment design for the infant or people who have physical deformity or lack of locomotion. As various 3D apparel CAD systems have been commercialised, virtual clothing has started to replace physical prototypes in the garment design process used by fashion brands (Figure 2.1), that are taking advantage of the opportunity to shorten the length of the design cycle through iterative design modification and rapid changes of materials and colours.



(a) Roberto Cavalli (source: Parisi, 2015)



(b) Cordeiro Campos (source: Lectra, 2013)

Figure 2.1 Digital prototyping

Affiliated with aspects of manufacturing, digital simulation is expected to play an important role in robotics, virtual sampling, virtual manufacturing and digital rapid prototyping being adopted by the clothing industry (Kenkare, 2005). The use of digital garments may not only result in an increase of productivity through the reduction of production and labour costs and time consumed by trial and error during design processes (Ko, 2009) but it might also facilitate improvement of communication between people who are involved in the production chain (Magnenat-Thalmann and Volino, 2005).

Besides the use of 3D CAD systems in the fashion industry, educational institutions are encouraged to adopt this new technology. In terms of the educational aspect, the application of virtual prototyping has many advantages to students such as the stimulation of design thinking, better recognition of mistakes, improving self-correcting actions and encouraging experimentations (Siersema, 2015).

2.3.1.2 Digital Runway

Presenting design collections at an authorised Fashion Week requires great expense including the cost of hiring models, acquiring staff and venue, and setting the stage and lights. Financial restrictions as well as regulative burdens inflicted by Fashion Week administration are thought to be part of the motive behind attracting designers' attention towards digital shows (Quinn, 2002). A virtual runway with digital clothing and models enables designers to be free from the physical and monetary constraints. Digital catwalks can be used as a discrete display method upon which such restrictions are not imposed. However, there have been attempts to use it in combination with actual fashion shows to maximise visual effectiveness. An example is Rick Lee's Collection in Figure 2.2.

Figure 2.2 Rick Lee 2015 S/S Collection in Milan (source: Korea Fashion Association, 2014)

Figure 2.3 Sungshin Women's University cyber fashion show in 2005

(a) Prada's s/s 2012 men's wear collection (source: Mau, 2012)

(b) Louis Vuitton s/s 2016 collection (Louise Vuitton, 2015)

Figure 2.4 Digital clothing for fashion advertisements

More active applications of digital fashion shows were observed through educational institutions and individual designers. Digital runways used for showcases of students' work appeared for Sungshin Women's University in 2005 (Figure 2.3), the University of Greenwich in 2011 and Nanyang Technological University in 2012. For individual designers, virtual catwalks became the platforms to introduce their collections through a personal blog or video-sharing website like YouTube. Today, presenting virtual runways even became a form of public entertainment as some applications such as My Virtual Fashion Show immediately create a show with virtual garments.

As a marketing strategy, there have been fashion pictorials exposed with digital forms of garments worn by virtual figures. The most well-known fashion brands that have attempted digitalisation of their collections were Prada and Louis Vuitton. Prada's spring/summer 2012 men's wear collection was converted into digital garments and mounted on game characters. The images of digital clothing were unveiled in the fashion magazine Arena Homme +. Louis Vuitton presented a virtual version of their garments as well as their accessories such as bags. Using a game character, the digitalised fashion items were displayed with various postures and dynamic actions in the forms of videos and posters on its website and in off-line shops around the globe. The virtualisation of fashionable clothing and adoption of popular fictional figures attracted media attention as a new and innovative method of enhancing the public's experience.

2.3.1.3 Virtual Fitting and Mass Customisation

One of the concerns that customers may have in purchasing clothes is being able to find a good fit, particularly if they are looking online. For this reason, clothing companies are trying to provide more accurate fitting systems. The online typical try-on methods involve overlapping an image of the product over the consumer's photograph (FittingBox[2]) providing images of a garment shape with certain ranges of a parametric body (My Virtual Model[3] and Metail[4]). i-Fashion Technology Center attempted to develop a more advanced form of a virtual fitting system that integrates 3D body scanning, digital garments and an avatar. Their system was designed to offer the customers their own body scan data to generate an individual avatar and visualise virtual garments draped on it.

The effort into the development of digital clothing and virtual fitting systems displayed a tendency to extend to a mass customisation service. Although there have been studies (Cordier et al., 2001; Satam et al., 2011; Baytar and Ashdown, 2015) suggesting its potential and advantages, commercialised cases are few for the present. The early

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[2] http://www.fittingbox.com/

[3] http://www.myvirtualmodel.com/

[4] http://metail.com/

virtual custom-made clothing service was introduced by Shinsegae department store in Korea in 2009 allowing customers to choose some garment elements such as sleeve style and material (Kim, 2009). As the technology has become more prevalent, the use of digital clothing for fitting and customisation is expected to be more readily available in the near future.

(a) Virtual custom-made system introduce by Shinsegae (source: Kim, 2009)

(b) FXMirror (source: Gwon, 2015)

Figure 2.5 Virtual and augmented real fitting systems

Meanwhile there have been attempts to build augmented reality-based try-on systems which visually imitate consumers' fitting experience. Generally try-on applications use a camera to capture a target person and show real-time images of that person getting dressed in the virtual clothing on a screen (Zhou et al., 2012). The early augmented reality fitting systems merely displayed a static image of garments however the advanced technologies today have evolved to show dynamic garment simulation tracking the motion of the wearer. In such systems, digital clothing performs a significant role in stimulating consumers' tactile sense through simulation and provides a more realistic experience. FXGear FXMirror, AR Door Kinetic Fitting Room and Cisco StyleMe are the examples of the augmented reality fitting systems introduced.
Digital clothing in garment fitting systems enable confirmation of the 3D shape of garments draped on a body similar or identical to the consumers'. Such a feature may supplement the situations both online and off-line when consumers are not able to physically try on the clothing. Especially in its application for online shopping malls, digital clothing is expected to have effects such as to decrease the volume of return of products, for sales promotion and for maximisation of purchasing satisfaction for consumers (Ko, 2009).

2.3.2 Film and Animation Industry

Virtual clothing has been applied to animation and gaming as a significant component of a figure to imply social, geographic and temporal context and to symbolise personality and characteristics of the wearer. In the movies, along with virtual actors, virtual garments have often replaced real costumes in order to portray scenes which may require high expense, incur danger or demand unattainable effects.

Although virtual garments in the early stage were generally attached to the skin layer of a character, thus restricting independent movement of the cloth, more realistic animation is now available, enabling independent simulation of the cloth. The computer animation and entertainment industry demands more true-to-life virtual garments as the appearance of virtual characters is considered important (Kenkare, 2005). To achieve more elaborate images of costumes, many companies have started applying the garment pattern and construction method (Figure 2.6), sometimes with 3D apparel CAD software (Figure 2.7). Their efforts have also secured more delicate expressions of details, textures and lustres of the fabrics. Realistic description of the virtual clothes not only contributes to the visual aesthetics, but also affects the degree of overall completion of the animation and movies.

(a) Character drawing (a) Flattened patterns

Figure 2.6 Animation “Brave” (source: The Pixar Podcast, 2012)

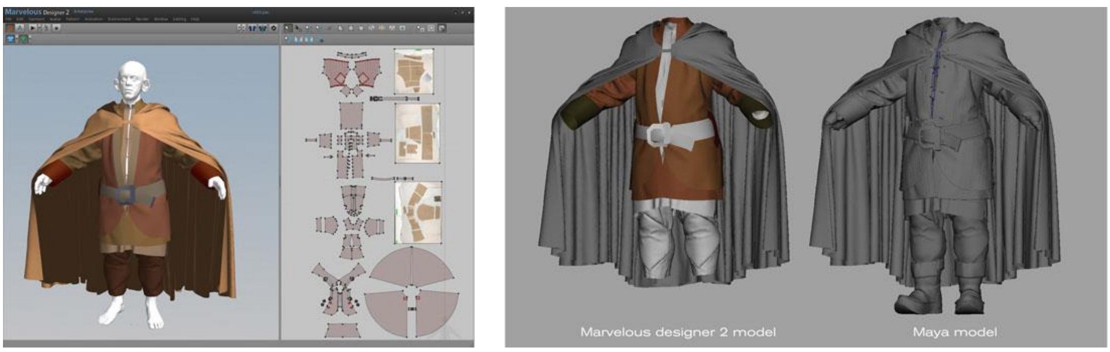

Figure 2.7 Movie “Hobbit” (source: Holmes, 2013)

2.3.3 Game and Social Network Service

The typical cases in which the general public gets directly involved in the use of virtual clothing are in game and social network services. Many of the games launched today support 3D presentation and user control, and several social network services have started to follow this tendency. Prevalence of PCs with high specification enables more users to take part in these entertainment types. The popularity of 3D games has stimulated the improvement of visualisation of clothing and some developers have started using 3D apparel CAD to offer more realistic garments.

Improvement in virtual clothing and users' commitment has been further encouraged by the introduction of customisation systems. Some game environments provide customised characters, costumes and other items, thus allowing users to manipulate certain levels of transformation and to choose from a variety of options. Similar customisation systems are also employed by social network service providers whose domain is based on 3D virtual spaces, such as Second Life[5] and My3Dchat[6]. This phenomenon implies that the role of virtual clothing, which used to focus on realistic and detailed visual effects, now encompasses an aspect which helps users to build their existence in the virtual world inducing involvement.

(a) The sims 2 H&M Fashion Stuff (source: EA, 2009)

(b) American Apparel store in Second Life (source: Holden, 2006)

Figure 2.8 Apparel products in games

The degree of personalisation of avatars has become expanded by participation of the users and fashion companies in designs and sales. For instance, a virtual version of H&M clothing collections was introduced into 3D game Sims 2 in 2007 as an expansion

[5] http://www.secondlife.com/

[6] http://my.3dchat.com/

pack (Ozler, 2007) and fashion brands such as American Apparel, Armani and L'Oreal launched their virtual products in Second Life (Jones, 2012). Also, users of these games and social networks have actively created their own designs and sometimes sold the virtual items through their own virtual store or eBay. Jones (2012) emphasised the potential market value of virtual garments, citing the case of the virtual American Apparel store in Second Life which achieved the sale of over 4,000 T-shirts in the first few months. The company also offered a percentage-off promotion for their virtual customers to purchase the same goods in their real shops. This presented potential for sales and consumption of fashion products in and outside of virtual worlds, creating synergy effects.

According to Jones (2012), users have a sense of real emotions and responsibility with their avatars' identity and are prepared to spend money on presents and items for them, just as they do in the real world. Since customising avatars is less expensive and more reversible, the displays of avatars have more weight than reality. In the virtual spaces, garments are highlighted as a critical matter for the users and are the most popular goods for trades. The fact that the virtual worlds enable individuals to consume and use the styles which they cannot achieve in the real life facilitates the virtual garments' abilities to satisfy the functions for the expression of identity and desire. With growth of the virtual worlds, users' demands on more realistic and diverse styles of virtual garments and virtualised contemporary fashion are expected to increase.

The virtual clothing in games and social networks appears to have the following aspects: (1) direct involvement of users in consumption and design, (2) virtualisation of fashion brand products, (3) psychological and social functions by personalisation, and (4) market formation at times. These aspects imply that virtual clothing is not merely a component of games or virtual societies but also extends and links to the physical clothes permeating the users and the real world.

2.3.4 Summary

This section explored the major areas and roles to which virtual clothing has been applied. Virtual clothing is frequently used for the following sectors: (1) clothing sector, (2) film and animation and (3) game and social network service. In the clothing sector, virtual clothing mainly performs a supportive role for design, production, marketing and consumption by taking advantage of stereographic representation of garment shapes without using materials. The scale of usages covers industry, academia and individuals throughout real, virtual and augmented real spaces. In the case of film, animation, game and social network industries, virtual clothing becomes regarded as a method to identify and express a figure and is a significant visual component of the fictional world. While film and animation industries provide a one-sided supply of virtual clothing presentation, games and social networks tend to provide an environment where the public becomes an agent to consume, create and trade virtual clothing. In this virtual environment, virtual clothing is empowered to have physiological and social functions, just as in the real world. Also, fashion brands' participation in virtualisation of their products enhances such functions of virtual clothing by contributing to the various choices of personalisation and development of the market in and outside of the virtual worlds.

The exploration of the application cases revealed some general tendencies. First, virtual clothing is being developed towards more realistic expression of garments and the use of 3D apparel CAD became more prevalent not only in clothing sectors, but also in visual entertainment areas. The pursuit for realism is the goal for virtual garments in order to comply with the concept of digital clothing and encourages the use of 3D apparel CAD as a tool for more delicate creation. Second, the realms where virtual clothing is designed, marketed and consumed include real, virtual and augmented real worlds, and sometimes multiple environments are applied, linking each other for maximisation of mutual benefits. Such phenomenon is expected to gradually bring closer affiliations between real and virtual worlds and ubiquitous application of virtual garments. Third, the influence of virtual clothing has been expanded. Virtual clothing in the early days was mostly used as a visual element in the images or as a method in the design process. However, it has permeated the human life and appears in its developmental aspects to be an object which is directly designed, worn, displayed and consumed by people. The active involvement of the public and fashion brands invigorated this propensity and virtual clothing is expected to exercise more socio-cultural, psychological and economic influences in the future.

The cases explored suggested the possibility that virtual clothing, particularly digital clothing, may effectively represent physical garments and be better used for various purposes. This study considered that technology can be applied to the virtualisation of costumes in museums and that the virtual form of a costume will be expected to perform the conventional roles of real costumes. The virtualisation of costumes is also regarded as having additional advantages, such as allowing for applications combining virtual, real and augmented real environments, and the reinforcement of association with the public.

Although the Chapter 5 in this study showed earlier projects of virtual costumes, its development focusing on curatorial aspects has scarcely been investigated. Most of them focused on image delivery in the appearance of the garments and paid less attention to the factors which reinforce and supplement the roles of costumes. For this reason, this study suggested an expanded viewpoint on virtual costumes as digital assets which can play exhibitory, educational and entertaining roles, and looked into its possibility and effectiveness. Since this study aims for more accurate reproduction based on the principles of garment production, taking the approach of digital clothing, virtualised costumes are called digital costumes hereafter.

2.4 Summary

This chapter discussed the fundamental concept of digital clothing and its qualities. Since various terms have been used to describe the application of technology into fashion for different purposes, it is considered crucial to separate the idea of digital clothing from other concepts as follows:

- Definition: computer aided 3D design of an item worn on a human or virtual body which applies garment patterns and conventional construction principles for the purposes of its use in either the virtual, real or augmented real world
- Qualities: (1) morphological factors created by structure and drape, (2) graphical expression of visual and tactual factors of fabric and (3) other additional elements like details

Although various techniques are available for digital garment generation, 3D apparel CAD was considered the most appropriate method for the purpose of this study through the discussion of its feasibility for the exhibitory and educational application. The main advantages were first, it is a method which enables accurate pattern drafting and assembly based on the physical garment construction method and actual measurements than any other techniques and secondly, it facilitates development of a range of simulation. Additionally, it does not require any physical installation of equipment.

The exploration of application cases of digital clothing supported the usability of 3D apparel CAD through the trend that 3D apparel CAD has become preferred as a more realistic garment creation tool in various areas and confirmed the lack of development cases of its use for curational purpose. The main application fields were clothing design and sales, film and animation and game and social network service. The design, marketing, and consumption of digital clothing has been realised at the industrial, educational and individual levels through real, augmented real and virtual real domains. The phenomenon that digital clothing has gradually become more and more ubiquitous implies not only positive possibility of introduction of digital costume but also various advantageous effects in its use through the application to real and virtual realms. This study expects that digital costumes may bring socio-cultural, psychological and economic influence on human lives in the future from a long-term perspective.

This chapter suggested prospect and necessity of the study through the exploration of concept, techniques and application cases of digital clothing technology. The concrete understanding of the tool applied in this study is provided in the following chapter.

Chapter 3: 3D Apparel CAD

3.1 Fashion and Technology

The advances within technology and the digital revolution have greatly influenced almost all areas of industry. The fashion sector is no exception, and it is working actively to optimise the use of digital or computer-based technology. According to Hu (2011), the major computer-based technologies commonly used in the fashion sector can be categorised into four groups: computer aided design (CAD), computer aided manufacturing (CAM), computer integrated manufacturing (CIM) and computer aided testing (CAT). The ramifications of each technology are as follows.

- CAD is an application to support creative design practices with regards to yarns, textiles and garments which allows users to develop and demonstrate virtual models on the screen and to simulate the appearance of the final product without wasting physical resources in the development in manufacturing techniques (Gray, 1998; Hu, 2011).
- CAM is a technology utilised in managing the machinery or systems used in the manufacturing process such as "grading, lay planning or pattern cutting" (Gray, 1998 p.2) in garment manufacturing and "spinning, weaving, knitting, printing or finishing" in textile manufacturing (Hu, 2011 p.xxiv).
- CIM can be defined as "the automation and integration of information, processes, and functions in a manufacturing environment, including customers and vendors, with the result being a closed-loop, functionally integrated manufacturing planning and control system (Weston, 1994 p.59)."
- CAT is a technology that offers "a digital and automatic solution for quality testing, evaluation and control of textile processing and products using computer-related testing techniques, such as computer vision and artificial intelligence (Hu, 2011 p.xxiv)."

Although there are further applications that can be classified into other branches, such as CAPP (computer-aided process planning) and CAQC (computer-aided quality control), CAD, CAM, CIM and CAT are often regarded as the primary technologies used for textiles and apparel in both academia and industry. Among these technologies, this study is going to focus on CAD technology, especially 3D apparel CAD which facilitates design development using the stereographic representation of virtual garments.

3.2 Fashion and CAD

Although the use of CAD has been the subject of study in various fields, a large part of the research has focused on its application as an engineering, industrial or architectural design method (Hardaker and Fozzard, 1995). While function is the predominant concern of the design in engineering, fashion industries place a further emphasis on the aesthetic aspects associated with the design process. In response to this, CAD systems tailored for the textile and apparel industries have been developed (Hardaker and Fozzard, 1995).

Within the textile and clothing industry, corporations can no longer avoid using technological advances (Chase, 1997) and they have gradually demonstrated an increasing preference for using computer-aided design techniques (Sayem et al., 2010) due to many advantages that this technology bestows. The main benefits of using CAD systems can be summarised as follows. Firstly, the visual presentation, which closely resembles the final products, reinforces the bonds between designers and buyers, buyers and retailers, and sales and marketing. Secondly, CAD applications facilitate the creations of more models in a shorter period by easily transforming or altering aspects of design and size. Thus designers can easily expand their creative capabilities in terms of the design development process. Also, in the same context, this technology enables designers to quickly respond to the needs of the market within rapidly changing design cycles. Thirdly, CAD systems can reduce labour by using fewer material and human resources to accomplish the same tasks. Finally, the high efficiency of CAD technology can diminish the product development costs and thus offer cost-effective design products (Ujiie, 2011).

There are many fashion CAD systems commercially available at this moment and these applications can be classified based on different criteria: the types of product that it is used to produce (yarn, fabric and clothing), the main design areas of clothing manufacture (textiles, shoes, garments and embroidery) and the dimensions used in production (2D and 3D).

3.3 Introduction of 3D Apparel CAD

The focus of early CAD systems associated with garment design was primarily in providing 2D illustrations (McCartney et al., 2000), technical flats (Sul, 2010) and 2D pattern drafting and alteration (Liu et al., 2010). Although a great degree of improvement in capabilities has been achieved, these 2D applications still have some critical defects in supporting the design and manufacture process. Though the enhanced 2D CAD systems facilitate the production of realistic drawings, and efficient pattern making and modification; the 2D form of designs often does not conform to a complete constructional specification (McCartney et al., 2000) and 2D flat patterns do little to contribute to predictions regarding the final appearance of garments. Eventually, such defects create a high dependency on the pattern maker's experience as well as the inefficient continuous generation of prototypes until the desired shape has been achieved.

Against this backdrop, 3D apparel CAD has been receiving attention as a system which is able to surmount the "poor intuition and low efficiency" (Liu et al., 2008 p.733) of previous 2D-based design tools. 3D apparel CAD is used by some fashion companies to assess the fit and shape of apparel products before mass production and their effectiveness has been proved definitively by the corporations who produce clothing for large-scale retail companies, where large volumes of designs have to be comprehensively examined by buyers (McCartney et al., 2000).

3.4 Concept of 3D Apparel CAD

The common conception of a 3D CAD application for garment design is considered to be a visualisation of the clothing and pattern making process (Hardaker and Fozzard, 1998). A better understanding of 3D Apparel CAD is as an application which integrates 3D computer graphic technology into the existing patterns of CAD systems so that users can visualise the appearance of clothing in a 3D form and estimate the feel of a garment when it is worn on a virtual body (Lee, 2007). This innovative application is sometimes referred to as 3D apparel CAD (Okabe et al., 1992; Sul and Kang, 2004), 3D garment CAD (Liu et al., 2008) or 3D clothing CAD (Meng et al., 2010).

Along with the visualisation of clothing design and pattern making methods, existing CAD systems have introduced diverse functions focusing on different aspects of the design process. Developers have enhanced certain parts of the program for specific uses, and the characteristics of each of these systems varies with these capabilities. The unique features of existing systems are described in the section 3.5.2.

Researchers have also explored the capabilities of 3D apparel from different points of view. This study listed the essential functions within a robust 3D apparel CAD system mentioned by other researchers (Hardaker and Fozzard, 1997; McCartney et al., 2000; Park and Kim, 2006; Luible and Magnenat-Thalmann, 2007; Liu et al., 2010) and classified them according to the fundamental and subsidiary capabilities regarding the objective use of 3D apparel CAD for virtual prototype production.

- 3D virtual model generation: A virtual model is the stand upon which the garments are draped. The precise visualisation of fit and the appearance of the intended design has a direct correlation with building the appropriate model. Therefore, the function for constructing customised or standardised body forms from two or three dimensionally measured markers of anthropometric data is essential for more precise design development.
- Automatic pattern development and description: CAD systems should be able to produce the desired clothing patterns through automation or minimal user input. Also, it is necessary that the developed patterns contain clear descriptions of interior points and lines, as well as the relationships between the them, for accurate garment construction in subsequent virtual and physical sewing processes.
- Virtual sewing and fitting: These functions convert 2D patterns into 3D dresses and display a clothed model. The functions need to be stable for the presentation of multi-layered or intricately decorated garments.
- Realistic drape simulation: Realistic simulation is the kernel of the 3D CAD systems. The systems need to take into account the various properties of different fabric materials, which affect the garment drape based on the objectively measured data.
- Textile mapping: Colours and materials are the major elements which have an effect on the impression of the clothing along with the garment drape. Usually, finding or matching the best colours for the garments requires many trials. Therefore, the ability to apply diverse colours and materials is crucial for design assessment and completion in the CAD systems.

- Stereoscopic visualisation: The 3D perspective which enables free rotation and zoom in and out view from all angles is an essential factor for efficient design and observation in CAD systems.

The functions which further strengthen the CAD applications are as follows.

- System integration for MTM products: Various systems are used in the clothing industry. Many CAD systems have expanded their capabilities to merge with existing applications, or worked to mimic their functions and processes in order to boost efficient production. There are commercial CAD packages which already offer several general functions such as grading, lay plan and cutting to support the mass-production processes. However, in a larger sense, a systemic integration of the design, manufacture and management processes have been attempted.
- Automatic 3D-to-2D pattern development and customised design: Although the 3D-to-2D flattening technique is not fully functional in current systems, this technique has drawn attention as a major function of future CAD applications. 3D-to-2D pattern generation allows acquisition of optimised personal patterns and it is expected that genuinely customised design and fit can be achieved by this technology.
- Dynamic visualisation and animation: This capability offers dynamic visual information of clothing which static simulation is not able to convey. It needs to be emphasized that the authentic appreciation of garment drape is realized primarily by the movement of dresses. This function involves not only aesthetic assessment but also a functional evaluation of the garments. Dynamic simulation enables users to observe garment appearance as affected by the motion of a virtual model. Moreover, some systems provide information regarding the comfort of clothing, and how it varies in movements by calculating air gaps and garment pressure.
- Constraining mechanism: Apart from composition of patterns and seams, there are many constraining factors which affect the appearance of garments. It is desirable that subsidiary materials can also be modelled and presented in the systems. Also, taking into account the physical influence of zips and other subsidiary materials, as well as finishing effects, will provide more realistic outcomes in the process.

3.5 Development of 3D Apparel CAD

3.5.1 Historical development

The current cloth simulation technology has been improved to show outstanding reality and many CAD systems which provide virtual prototypes for the fashion industry also became commercialised. Behind such progress, there has been trailblazing investigations and development over many years by scientific or commercial groups in different domains with different perspectives and goals (Choi and Ko, 2005; Fontana et al., 2005). The main fields which deal with cloth simulation and CAD systems are computer graphics and clothing and textile areas in general. While researchers in textile engineering focus more on microstructural aspect of delicate representations of garments (Kim, 2007) and precise modelling and calculation of non-linear performance of cloth (Choi and Ko, 2005), the computer graphic engineering community has a tendency to concentrate on efficient reproduction of appearance of cloth. In other words, they put more weight on "efficiency, stability, and visual realism (Choi and Ko, 2005 p.586)" rather than an accuracy. Besides, the focus of development of CAD systems for fashion industry is also different from that for the computer graphic realm. The CAD for clothing industry aims at assisting the whole design process of cloth and concentrates on definition and construction of detailed appearance of garment for manufacturing (Fontana et al., 2005). In computer graphics, clothing appears as an object that wraps a large part of a body and therefore elaborate outfits and drape are regarded as important factors in animation, films, cartoons, etc. (Fontana et al., 2005). Accordingly, the applications for computer graphics focus on the production of realistic images for computer animation systems (Kim, 2007; Fontana et al., 2005).

Theoretical research of cloth modelling began in the 1930s by the textile engineering field (Fontana et al., 2005) and representative studies includes Pierce's analysis of the geometric model of plain weave fabric (1937), Kemp's racetrack model (1958) and De Jong et al.'s energy method (1977a; 1977b). Since then studies in this area have been encouraged further by the intense interest of the computer graphics community in the late 1980s (Meng et al., 2010). In the computer graphics field, the first physical model work for cloth simulation in the computer graphics domain was introduced by Terzopoulos et al. (1987). Their work allowed a simple display of cloth simulation such as a flag or draping of a rectangular fabric using a technique based on Lagrange equations of motion and elastic surface energy.

According to Volino et al. (2005), however, the first system which actually simulated clothing began in the 1990s. The work by Lafleur et al. (1991), Carignan et al. (1992), and Yang and Thalmann (1993) made pioneering contributions considering different technologies supplementing cloth simulation, for instance, body modelling and animation and collision resolution. The techniques whose capability was limited to simple representation in the early stage have been gradually developed to simulate more complex features of garments (Kim, 2007). In addition, the progression of this technology has been further boosted with remarkable development of gaming, TV and movie segments since 1990s (Byron et al., 2006). Also, garment simulation has derived benefit from enhanced performance of computer hardware and software and the improvement of certain simulation technologies from which notable systems for computer graphics and the fashion industry has ensued. These investigations and developments of technology have influenced various applications not only for the fashion industry but also for many other areas.

3.5.2 A Review of 3D Apparel CAD Systems

In this section, the representative CAD systems which have been introduced in academic journals are reviewed focusing on the applications that assists the garment design process. By recapitulating the main features, this section provides an understanding of the overall development of 3D garment CAD and analyses the trends and capabilities that academia paid attention to.

The key features of these applications were analysed and shown in the Tables 3.1 and 3.2. The main features can be classified according to the following criteria in four major aspects; virtual body construction, design approach, pattern generation method, simulation trait, plus other features. Some criteria are adopted or modified from Sayem et al.'s review (2010). This study attempted to provide a clearer analysis of their work which did not offer the definitions of each criteria. The characteristics which were just suggested or not found were excluded from the analysis.

A virtual body, mannequin or dummy is used as the base for which the virtual garments are to be worn. It not only involves fitness evaluation and modification when garments were constructed but sometimes plays an essential role as a place where the design is directly conducted. There are several ways to prepare the virtual bodies and this part shows the methods from which the systems derived the virtual bodies.

- Parametric body: This is the case that different sizes of bodies could be generated by user input values in the parameters given by the system.
- 3D measurement data: Some systems established the models from the anthropometric data 3 dimensionally obtained. Diverse measuring apparatus could be applied including a 3D scanner, a sliding gauge, etc. The tables specified the methods applied if they were clearly stated.
- Photographs: The photographs which clearly depict an individual body can be used as the source to extract anthropometric data. In order to achieve as much accurate information, photographs need to be taken from different angles with a clear silhouette of the body shape and posture.
- Others: This section indicates the cases that the other methods were applied for the body preparation. This includes using the human figure generation software, etc.

There are three different approaches to clothing design which dominate the overall producer of the 3D apparel CAD systems.

- 2D-to-3D approach: The garment design in this formula starts from the 2D pattern development. Then the designed pattern pieces are assembled on a virtual model to achieve their drape through a simulation.
- 3D-to-2D approach: This is a method where clothing is designed as a 3D object first and adjusted into planar patterns through a flattening process
- Combined approach: A combined approach indicates the way in which the above two methods are applied together. In this study, combined approach will be divided as either of two cases. First case is the 3D-to-2D approach with a virtual sewing process performed after pattern flattening. It is employed to check and amend the arbitrary deformation of patterns which is attained using a flattening procedure for the accomplishment of the acceptable design. The other is the case in which the edited 2D patterns are achieved from the design modification of the patterns three dimensionally assembled on the model.

Conceptualised design is generally materialised from the development of basic pattern design or the modification of existing garment information. Along with those conventional approaches, there were various methods developed. This section classifies how the systems obtained such primary design bases and design developed to accomplish the garments.

- Drafting: Drafting is the most universal method to design planar patterns in industry. Usually, basal patterns are first generated based on the certain measurements and construction rules. Then the basic patterns are further developed to achieve more complicated and diverse designs.
- Draping: This method is often applied in couture production. In this means, patterns are directly obtained by pinning and cutting fabrics on a dummy.
- Sketch: Some applications called sketch based adopted the idea of drawing up a design on paper. These systems derived the patterns and the draping simulation from the user sketch on the systems.
- Design template library: Design template library is a set of databases of various clothing which allows immediate use and modification. It includes more than one of following data: patterns, 3D garments and assembling information.
- Others: This includes other methods or importing patterns from another CAD programme. The tables specified the methods applied if they were clearly stated.

This section presents the distinctive attributes of the simulation in the systems.

- Physical-based simulation: It means the capability of the systems that the simulation can be carried out taking into account the material properties of virtual garments
- Dynamic simulation: This refers to a function of the systems that simulates dynamic garment movement by the motion of a virtual model.
- Real-time simulation: Real-time simulation indicates the simultaneous reflection of design modification with 3D simulation.

Other features of the application were marked in this part.

- 3D block modification: This indicates the feasibility of design modification of the dress in a three dimensionally draped state.

- Grading: Grading is a technique which is normally used in mass-production to adjust a same design to achieve a range of different sizes. It automatically extracts the patterns of different sizes from the original patterns maintaining the same design.

The review of the various academic work showed the obvious objective of the development of the 3D apparel CAD systems. The ultimate aim from the overall tendency was to reduce the design cycle of prototype development through the automation of each stage such as automatic virtual model preparation, pattern generation and pattern pre-positioning. Also many researchers tried to devise more user-friendly tools pursuing minimum user intervention for non-experts to achieve the aim. Enhancing the quality of the simulated outcomes was another important objective to which the researchers intensified efforts. While many of the early studies were only able to demonstrate simple design garments. More detailed design or multiple layers were realised in later work with more realistic reorientation. This section will look through the capabilities of the applications classified in each category.

Firstly, various methods were applied to set up a virtual mannequin or a body. Much of the work had a tendency to use three dimensional measurement data for the body generation. This might be because three dimensionally measured data included not only the measurements but also the body shape therefore the generated virtual body would be more accurate and stereoscopic than other measuring apparatus. Various 3D measuring tools such as a sliding gauge, a 3D coordinate measurement system, a turn table and a pointer, a digitiser and a 3D scanner were used, and most work after 2000 was carried out with a 3D scanner. The review showed that the researchers used 3D measurement data to directly gain a virtual figure or to reconstruct the body model. Both practice often required a refinement process to make the virtual model useable.

The parametric body generation is a common feature in commercial software. Although this method has some limitations that the size adjustment is only feasible within given measurements, a variety of models is generated in a simple way. In this review, only two research studies had this function. It seemed that the interest of the academy was focusing on new technology rather than existing means which were already firmly established. Besides, the acquisition of an individual body form was easily attainable through a photo-based method in Wang et al.'s (2003) work. Since then there has being an intense study on the effective extraction of body silhouette from photography

(Pitas, 2000; Lee et al., 2000; Wang et al., 2003), it is expected that this method will be further improved and prevalent in future applications with high accuracy.

Secondly, this review considered patterns for apparel production as the ultimate outcome of the CAD systems and classified design approaches according to the stages that the patterns were generating. The tendency of the research was not inclined toward a certain method. It displayed that the academic interest was quite evenly dispersed as each approach has its own advantages. For example, 2D-to-3D approaches are effective to be applied to the clothing industry since the design process comes from the methods and the industry is very similar. Although 3D-to-2D approaches are not prevalently used and need more improvement at this stage, they have the merit of development of the optimised patterns for individuals. Moreover, the academy concentrated on those two approaches as well as the compromised method between those approaches which were able to edit and develop the patterns a step further.

Thirdly, the tables appeared that the academy attempted to employ various design methods for the systems. They showed that many applications provided a design template library as a primary base so that the intended garment design can be established by changing some elements. There were many systems which derived garment design and patterns from the sketches, this method is called sketch-based. The systems with this method, generally cognised the user drawing input and some gesture commands so that the users could develop the garment using a similar sense to sketching. The distinctiveness of those two methods is that the garment design can be accomplished without a pattern making process. In other words, these systems do not require users to have professional skills and knowledge therefore they facilitate more easy operation.

Drafting and draping in this review which indicates the conventional methods of the same titles were considered as the essential technique to be improved by some studies. The 3D CAD systems which applied drafting methods contained the functions of 2D pattern CAD software. The adaptation of draping into a CAD application was rarely attempted. This extraordinary case was introduced only in Sul and Kang's (2006) study. However, the demonstration of this method which was confined to the basic patterns inferred that further improvement will be required for more sophisticated manipulation of fabric. Bedsides, some research developed the design bases from the direct surfaces of virtual models. This method is beneficial to gain well-fitted patterns for individual bodies. Additionally, there was another method to achieve primary patterns through the input of actual paper pattern pieces. This would be useful to reuse or further develop the physical pattern data generated. Sometimes CAD systems applied more than one method for different purposes: the establishment of primary design and a further detailed design.

Fourthly, garment simulation was an essential sector which the academy made efforts to improve. More than half of the study in this review adopted physical-based simulation techniques. It is generally acknowledged that physics-based techniques produce more realistic simulations than geometric techniques because the approaches are capable of adjusting material values to the clothes. The analysis showed that the academy focused on the realistic representation considering mechanical characteristics of fabric as a crucial factor in CAD system development. Although there were not many cases which demonstrated dynamic simulation of garments in this review, these functions received attention due to its dynamic visual information delivery and fast interaction of design modification. These features were not found in a very nascent stage of the study mainly because of the low performance of devices and high consumption of computation time compared with these days. However, the technology of the day fully-advanced is expected to introduce a speedier and enhanced simulation technology which is even available online.

There are other notable features that this review points out. It is not an easy task to edit the flat patterns conjecturing the form three dimensionally draped. Depending on the design delicacy and users' experience, sometimes modification will be required several times. Without such effort, more intuitive design editing was possible in some applications. 3D block modification referred to this capability which allowed users to edit garments in a three dimensionally draped state. The intuitiveness of this function is further reinforced when real-time simulation is sufficiently available. Grading is one of the essential functions which is especially required by the industry. Since most systems were not developed as fully-completed commercial packages, a grading feature was used in the few applications. This review underlines that this feature needs to be settled to suit different design methods to become more inclusive in these models.

Table 3.1 Features of CAD systems developed by academia

Feature		Hinds & McCartney (1990)	Hinds et al. (1992)	Ito et al. (1992)	Okabe et al. (1992)	McCartney et al. (2000)	Kang & Kim (2000a; 2000b)	Kang and Kim (2000c); Kim & Kang (2003)	Wang et al. (2002)	Sul & Kang (2004)	Sul & Kang (2006)	Luo & Yuen (2005)
Virtual body generation	Parametric body								√			
	3D measurement data	√ Turn table & pointer	√ 3D scanner		√ Contact type digitizer		√ Sliding gauge	√ Sliding gauge/ scanner	√ 3D scanner	√ 3D scanner		
	Photographs								√			
	etc.											
Design approach	2D to 3D			√			√			√		√
	3D to 2D							√	√			
	Combined		√		√	√						
Design method	Drafting						√			√		
	Draping										√	
	Sketch	√	√						√			
	Design template library								√			
	etc.				√ Paper pattern input	√ Surface flattening		√ Surface flattening				
Simulation	Physical-based			√	√	√	√			√		√
	Dynamic									√		
	Real-time										√	
etc.	3D block modification								√		√	√
	Grading						√		√			

Table 3.2 Features of CAD systems developed by academia

Feature	Developer	Fuhrmann et al. (2003)	Fontana et al. (2005)	Volino et al. (2005)	Fang & Liao (2005a; 2005b)	Fang and Ding (2008a); Fang et al. (2008b)	Decaudin et al. (2006)	Kim & Park (2007)	Tuquin et al. (2007)	Meng et al. (2010)	Umetani et al. (2011)	Xu & Wu (2011)
Virtual body generation	**Parametric body**											√
	3D measurement data	√ 3D scanner			√ 3D scanner	√ 3D scanner		√ 3D coordinate measurement system		√ 3D scanner		
	Photographs											
	etc.											√ Body generation software
Design approach	**2D to 3D**	√										
	3D to 2D				√	√	√	√				
	Combined		√	√							√	
Design method	**Drafting**											
	Draping											
	Sketch						√		√			√
	Design template library		√		√	√		√			√	√
	etc.											√
Simulation	**Physical-based**	√	√	√				√		√	√	
	Dynamic			√								
	Real-time			√						√	√	
etc.	**3D block modification**			√	√							√
	Grading											

3.6 Commercial CAD Systems

Although the CAD systems in the previous section presented various and novel approaches to virtual body generation and design methods, the commercial apparel CAD software often adheres to conventional functions because the stabilisation of feasible technology is considered important. Merging the new functions will require the examination and improvement process to be settled. However, more innovative features are expected to be available soon, considering the fast evolution of the technology. This section gives an overview of some 3D apparel CAD programs currently available along with the system that is applied to this study. The overall features of each system are shown in Table 3.3 based on the information confirmed through the websites of the developers[1] and earlier reviews by Sayem et al. (2010) and Viļumsone and Dāboliņa (2012).

Table 3.3 Available commercial CAD systems

Feature		Developer	Optitex	Lectra	Gerber	CLO	Physan
Virtual body	Generation method	Parametric body	√	√	√	√	√
		Integration from 3D scan	√	√			
		Obj import	√			√	√
	Simulation	Posture	√	√	√	√	√
		Walking /movement	√		√	√	√
		External animated body				√	√
Design approach		2D to 3D	√	√	√	√	√
		3D to 2D	√				
Fabric	Drape	Fabric property	√	√	√	√	√
	Visual	Colour /pattern	√	√	√	√	√
		Texture	√	√		√	√

Optitex is a garment specialised CAD system provider based in Israel. Their 3D suite is a package of four different applications for the creation of 3D clothing: (1) 3D creator for garment drape simulation, (2) 3D digitizer for design alteration, (3) 3D flattener for

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[1] Optitex, http://optitex.com/
Lectra, http://www.lectra.com/
Gerber, http://www.gerbertechnology.com/
CLO, http://www.clo3d.com/
Physan, http://physan.co.kr/

tightly-fitted garment generation, and (4) photorealistic 3D for detailed higher resolution visual presentation. Each program possesses particular functions and is designed to be integrated. The remarkable characteristic of their system is the introduction of 3D-to-2D design approach, which allows more intuitive pattern construction, applying a similar sense to sketching. Additionally, Optitex offers a tool for the creation of 3D catalogues to enable the outcomes to be directly used for promotion and marketing.

Lectra is a company in France which provides integrated technology solutions for apparel, automotive, furniture, and other industries related to composites, textiles, and leather. The 3D application they developed for virtual garment prototyping is called Modaris 3D Fit. The main features of the system are its compatibility with garment patterns generated by various 2D pattern programs and a broad range of material in its library. Also, the system possesses the advantages of remote simulation and provides plus sized mannequins.

Gerber Technology is a hardware and software system provider in the USA that specialises in apparel, transportation, furniture, and packaging. They have developed a wide range of applications for the apparel industry to support the product design and manufacture process. Their virtual sampling product, AccuMark 3D, adopted the modelling, texturing, lighting, and simulation technology of a 3D simulation and animation application called Blender. Combined with the pattern design tool Accumark, the simulator helps with efficient pattern construction, facilitating manipulation techniques and drape simulation using various virtual models in gender and age.

CLO is a Korean company who developed the garment simulation software CLO 3D and Marvellous Designer, which target the apparel and computer graphic industries respectively. Comparing CLO to other systems, delicate garment pattern creation and the application of construction techniques, such as dart manipulation and suppression, currently require some manual controls. However, CLO’s interface has received attention due to its easy and intuitive operation in design. Additionally, their other product, Marvellous Designer, is also adopting the garment production method to enable users to create more realistic virtual clothing.

As is shown in Table 3.3, the above commercial applications basically retain the fundamental functions required for virtual clothing construction. These systems, which have steadily developed and improved, provide high fidelity of universal performance for garment design and drape simulation. The CAD system applied to this study is DC Suite, which is equipped with the essential features, as well as some additional advantages particularly designed for the reproduction of period costumes.

DC Suite is developed by Physan, which focuses on research and development of digital clothing technology based in the Seoul National University in Korea. DC Suite is an integrated software that enables users to complete the whole design process, from pattern construction to achievement of final design outcome, without using multiple applications. For the convenience of fashion designers and manufacturers, it provides various virtual pattern generation methods, including the conventional drafting method, importing patterns from 2D CAD, automatic block generation, and converting paper patterns using photographs. Various drafting tools, as well as automatic construction of technical elements, such as gathers and pleats, it also facilitates complicated garment pattern design. Furthermore, their newest software version, DC Suite 5.0, offers more enhanced visual effects for textures and details.

Sufficient capabilities of garment creation can be demonstrated using other commercial CAD applications. Nevertheless, using DC Suite has some benefits over other systems. Firstly, DC Suite provides easy operation within a consistent interface without required program transitioning during the process of pattern making, assembly, draping, adjustment of fabric properties, and visual features and rendering. The whole process can be accomplished in one intuitive environment, which presents flat and corresponding stereographic structures of garments together.

Secondly, the aim of this study, the reproduction of historic costumes and its exhibitory and educational applications, inevitably requires linkage between other applications. Therefore, compatibility with outside programs was a vital determinant. Although commercial CAD today provides parametric body for customisation, most only allow changes in measurement based on the standardised contemporary body shape. However, body silhouettes in the past, which noticeably varied depending on the times, may not be composed in that method to support the appropriate garment drape. Thus, the virtual bodies with static pose and motion were planned to be generated using external modelling programs. Another reason why compatibility was considered important was that the purpose of this study suggests the securement of practicability for the development of data through the editing and processing of digital costumes and display through new systems and media. Consequently, the CAD system for this study needs to have the capability to accommodate external objects, as well as a wide range of interconvertability of data with other programs. DC Suite possesses these advantages by encompassing existing apparel CAD systems and 2D and 3D design platforms.

Thirdly, various subjects of study have been conducted using DC Suite. The main research areas include garment design (Wu, 2009; Lee et al., 2014; Kang et al., 2014), fit evaluation (Vedder and Daanen, 2015), block pattern comparison (Cha and Kang, 2013a; Cha and kang, 2013b), material expression (Kim, 2010; Ryu, 2014), development of a virtual model (Kim and Ko, 2015) and an application for fashion shows (Wu et al., 2013b). Moreover plenty of comparative studies between real and digital clothing (Ko, 2009; Park and Choi, 2013; Lee et al., 2015; Guan et al., 2015) have been carried out with the system and the results of overall assessments were positive. The active research activities and positive level of similarity to real garments demonstrated the system’s usability, stability, and effectiveness to some extent. For these reasons, this study posited that DC Suite can properly implement digital costume production and interconvert data for further development with less strain.

3.7 Design Development Process with 3D Apparel CAD

According to Umetani et al. (2011), clothing can be understood as both 2D and 3D objects at the same time depending on the microscopic or macroscopic interpretation of its geometrical structure. While a garment is perceived as a 3D form of entity, it is regarded as the coordination of separate planar panels which are composed of holes and lines. Due to these distinct properties, apparel design and production requires capabilities of interpretation and composition of 2D and 3D objects. Generally, the satisfied design is achieved through several revisions which relies highly relies on the skills and experience of the specialists. This section will describe the technological innovation that 3D apparel CAD systems brought about in design development process comparing with the conventional method and will highlight its advantages.

The general product development process includes market research, product planning, product design and manufacture. The apparel design process typically embraces market forecasting, design, pattern generation, grading, lay plan, trim sourcing, and prototyping (Denno, 1997) and there are further detailed sub-phases involved. Figure 3.1 describes these stages in a larger development process. This study will mainly focus on the design stages which are comparatively less relevant to the manufacture aspect using the example of mass-production. In the case of 3D apparel CAD methods, the typical 2D-to-3D design approach which emulates conventional design practice will be applied.

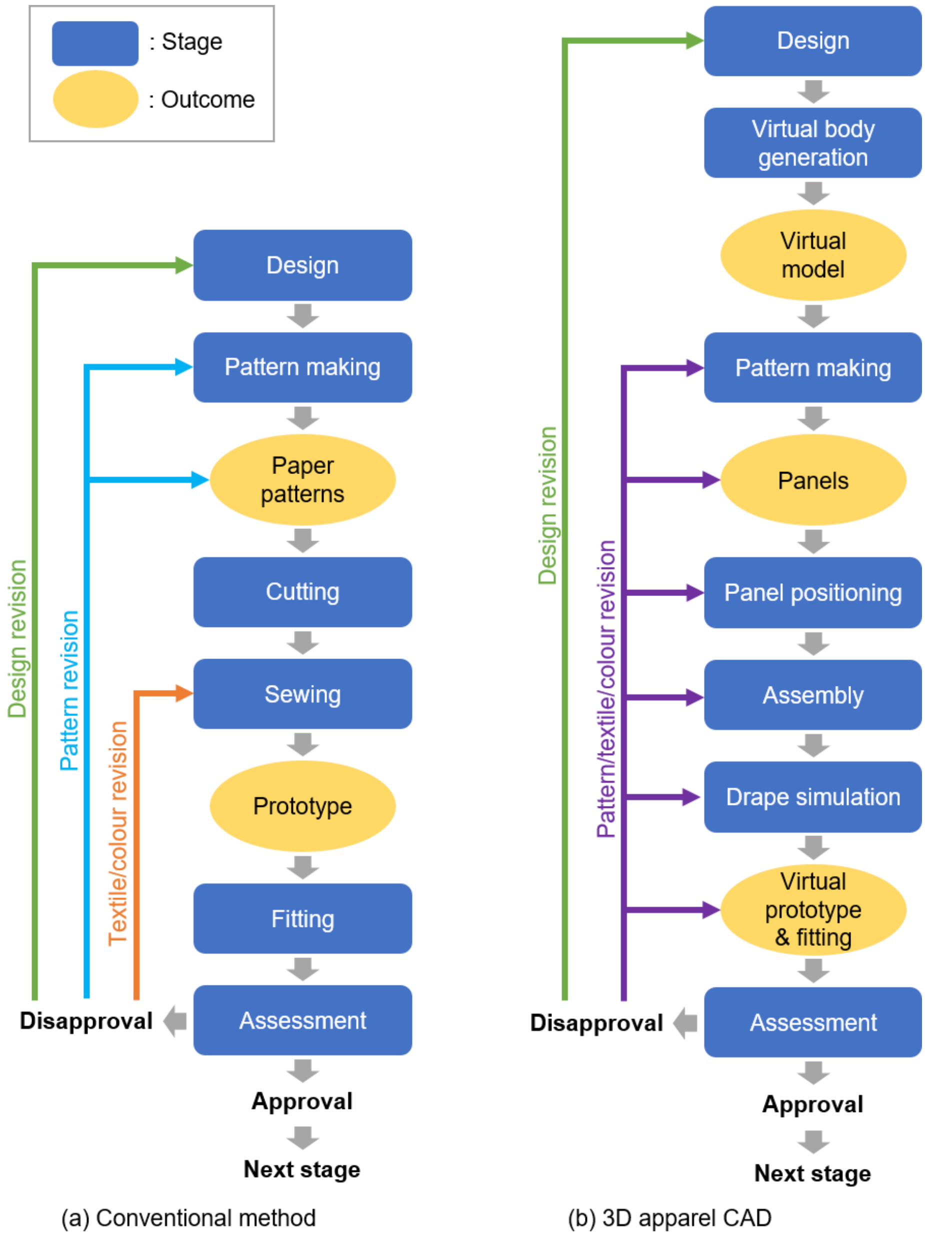

Figure 3.1 Garment design process

Traditionally, the process starts from designers' creative activities based on the trends, target segment (McCartney et al., 2000). Their design is conceptualized in the form of illustrations which are frequently exaggerated to emphasize its characteristics (Hinds and McCartney, 1990). Technical drawing which clearly depicts garment construction without exaggeration and small fabric samples are often accompanied for more concrete communication between and designers and pattern makers. However, McCartney et al. (2000) pointed out that a paper drawing method does not properly describe the specification of the entire garment construction nor the accurate 2D images of 3D clothing therefore it lays some possible risks: pattern makers' subjective interpretation of the design to 2D patterns and low approval rating at the evaluation phase. Based on the drawings and samples, pattern technologists convert the design into paper patterns considering proportions and balance, material characteristics (Hardaker and Fozzard, 1997) and target measurements. Generally, pattern development begins with basic pattern drafting which forms simple designs of garments according to "a set of drafting instructions and construction formulae" (Huang et al., 2012 p.681) based on certain parts of body measurements. The intended design is further developed by manipulating these patterns. Achieving a satisfactory level of fit and appearance of the design strongly relies on the pattern makers' knowledge and experience. Then using sample fabrics, the cloth panel pieces are prepared by a garment cutter based on the developed pattern. These pattern pieces are assembled to produce a test garment called a prototype and this sample is evaluated ahead of actual production of the final design (Hinds et al., 1992).

In 3D apparel CAD methods, generally garment design entails one or more of the five major phases: pattern development, pattern positioning, virtual assembly, drape simulation and design alteration in 2D or 3D (Meng et al., 2010). This study will include one more stage which is body preparation in the above process. As the conventional methods, development also starts from conceptualised design. While conventional methods require mannequins or a human model at the fitting stage, CAD applications need to set up a virtual model to which the intended measurements are properly applied in the beginning. Because the assembly of pattern pieces is carried out on the virtual body and consequently the fitting stage is omitted. Additionally, some 3D-to-2D systems directly develop patterns on the body (Hinds and McCartney, 1990; Decaudin et al., 2006) or from the flattening of a body surface (Kang and Kim, 2000c; Kim and Kang, 2003; Fang and Ding, 2008a), therefore preparation of a virtual body is essential in most cases. The patterns can be developed as the part of process of 2D pattern CAD systems, however each piece of pattern will be presented as a virtual panel. Then those panels are placed around the virtual model considering proper locations for each corresponding body section in the 3D environment. Some applications such as Meng et al.'s (2010) system provided a flexible pre-positioning method so that the rigid flat panels can be adjusted and more accurately placed. Assembly of the virtual patterns is conducted by definition of seam lines and then a complete form of clothing is accomplished by draping the simulation adjusting fabric physical characteristics. The assessment can be conducted using the pictures or animation of the prototype which enable an effective observation from any angle.

The achievement of satisfactory design occasionally requires repeating practices of these processes in part or whole. A number of prototyping repeatedly entails assessment, revision and re-fitting until the desired fit and appearance are accomplished (Huang et al., 2012). Except for the case when the fundamental design itself needs to be changed, revisions in the design process may be required in patterns and textiles. Generally, the modifications in patterns can be applied to new pattern drafting or directly to the developed patterns in both methods. In the case of 3D CAD, some applications with an interactive real-time simulation technique enable simultaneous modification of prototypes in both 2D and 3D therefore the revision cycle is extremely reduced. In terms of textiles, adjusting new colours or materials are involved at the cutting stage in conventional methods. On the other hand, in digital methods, colours are generally adapted at any stage once patterns or panels are created. If different drapes of materials are required for prototyping, the revision cycle will start from the simulation phase.

Although the revision process is unavoidable for optimal design, its benefit may not be valid if considerable time and cost is involved. The noticeable advantages of 3D apparel CAD are firstly, the whole process is carried out by simpler and faster operations than a manual process, secondly, no physical substance is consumed and thirdly, the revision cycle can be diminished. Thus, 3D apparel CAD not only prompts design completion but also lessens the expense of both materials and human labour.

3.8 Application of 3D Apparel CAD for Costume Reproduction

An example of a costume reproduction process can be found in Marendy's study (1993) which investigates the different drafting methods for authentic pattern blocks of a bustle dress. The whole process in his study can be summarised into an application of Pearce's artefact study model (1986) which is related to the in-depth investigation of costume information and development of toiles which involves pattern drafting, toile production, and evaluation. Although his study did not carry over into complete reproduction reflecting the characteristics of original materials, the stages to generate toiles are roughly similar to the garment design process in section 3.7. This study considered the advantages of using 3D apparel CAD that will be applied to costume reproduction.

The general costume pattern making methods adopts either of using some detailed measurements or tracing of the costume with tissue paper (Flecker, 2012). This may not produce an accurate foundation that requires repetitive revision using a toile. In the case of costumes, which do not exist, more revisions will inevitably be entailed because a researcher will mainly rely on textual, and relevant images and photographs. Conceptually, the digital pattern of drafting and sewing does not only enable a rapid and easy production of costume, but it also facilitates the constant revision without physical disassembly and reassembling. DC Suite, the application used in this study, enables the changes in virtual patterns to be simultaneously applied to the 3D garment shape, which accordingly leads to less demand for reconstruction with intuitive modification. Once costume patterns are generated, colours and textures can directly be applied to the virtual panels at any stage. This suggests that using 3D apparel CAD has the merit of eliminating the phase of toile generation because the digital costume itself functions as a toile, as well as a complete costume. In a physical reproduction of costumes, toile production is often regarded as lavish, which is difficult to afford because the accurate costume pattern preparation can be demanding and time-consuming (Flecker, 2012). The non-physical construction, alteration, and the omission of toile making processes are considered the major advantages of 3D apparel CAD, which may act as an aid for costumes that are not yet reproduced due to various constraints such as cost, time, human labour, and others.

3.9 Summary

This chapter begun by addressing the overall advantages in the fashion and textile industry such as enhancing commutation in sales and marketing through realistic visual presentation, facilitation of design rapidly reflecting changing trends and reduction of labour, material and cost which have been given by the product of advance of technology, CAD. Among CAD, 3D appeal CAD was highlighted as the tool which facilitates the prediction of 3D shape of finished product through the more intuitive and efficient creation of a prototype that contains more specified constructional details than

2D-based CAD. The concept and distinctive functions of 3D apparel CAD were explored as follows:

- Concept: an application which integrates 3D computer graphic technology into the existing patterns of CAD systems to enable users to visualise the appearance of clothing in a 3D form and estimate the feel of a garment when it is worn on a virtual body
- Fundamental functions: 3D virtual model generation, automatic pattern development and description, virtual sewing and fitting, realistic drape simulation, textile mapping and 3D presentation
- Specialised functions: system integration for MTM products, automatic 3D-to-2D pattern development and customised design, dynamic visualisation and animation and constraining mechanism

The literature review showed the development of 3D apparel CAD by the contribution of the textile engineering and the computer graphic engineering researchers. For more efficient digital clothing generation, new and diverse methods in virtual body generation, design methods, simulation and others have been introduced. The vigorous research implies that more innovative functions will be available in near future bringing more advantages.

A range of commercialised 3D apparel CAD systems are now available and among them, DC Suite which was developed by Physan was chosen as the main design tool as it was considered most appropriate to support the purpose of this study due to following advantages:

- Integrated design process
- Facilitation of operation through intuitive environments combined with 2D and 3D
- Compatibility with other programs which allow accommodation of external objects and export data into other software for further processes

Also various studies which applied DC suite were regarded to testify the usability, stability and effectiveness of the system to some degree.

The benefits of use of 3D apparel CAD for garment design were discussed as follows:

- Rapid and easy design process

- Reduction of material, labour, cost and time
- Less-constrained iterative revisions of design, pattern, textile and colour
- Alleviation of dependence on skills and experiences of an expert to achieve desired appearance and fit

This study considered the benefits of 3D apparel CAD can also be applied to the reproduction of costumes enabling omission of toile production process through fast and easy non-physical construction and intuitive and instant modification and refection and contributing recreation of costumes which were not reproduced due to constraints on cost, labour and time.

This chapter explored the concept, features and types of 3D apparel CAD to rationalise the use of the technology and reason for system selection addressing its expected advantages. In the following chapter, the importance of the museum and costume collection, limitations of management and use of costume resources were discussed to emphasise the need for digital costumes. Also, it explored the influence of new media in museums and investigated the current status of museum websites as the one of common practices of new media to identify the problems.

Chapter 4: Museum and New Media

4.1 Costume Museum

4.1.1 Museum

The Oxford Dictionary (2013) defined a museum as "a building in which objects of historical, scientific, artistic, or cultural interest are stored and exhibited". It is also explained as a non-profit organisation which functions as providers of information as well as interpreters of the collections for the audiences (Lin and Cassidy, 2008) and its role is expected to provide the well-balanced instructive and intellectual outlook. More synthetically, museums can be described as the "repositories of information and objects (Palmer, 2012 p.80)" which actively engage preservation, dissemination, education and promotion of culture and science.

To the casual public, a museum might be regarded as a collection of relics in the display stands which depicts certain sides of the past, however, rigorously museums are "repositories of evidence" which may be put together to verify a thesis or describe a theme and the exhibits that the audiences come across are simply single concepts among a variety of possibilities (McKeown, 2003 p.41). The evidence includes not only the exhibit itself and objective descriptions such as dimensions, colours, markings, etc., but also the various forms of materials which provide the intrinsic information about its purpose, meaning, history and overview and less directly pertinent but significant resources such as private note or correspondence (McKeown, 2003).

4.1.2 Costume Collection

The fashionable dresses in museums represent the "style, identity and culture (Melchior, 2011 p.1)" of the past and the present, and their exhibitions have the potency which creates presence within the background of interpreted connotation. Certain garments can become cultural relics whose significance is affected by sociocultural factors such as aesthetics, consumption, stratum, wealth and individuality (Martin and Mauriello, 2013). The exhibits with unique genuineness and aura enhances the specificity of a museum visit than other cultural organisations overwhelming the audiences (Melchior, 2011). Through the costume and textile exhibitions, heuristic experiences are generated causing a distinctive amalgamation of emotional, physiological and social elements.

From a more academic perspective, dress is the subject to collection, display and research in many museums (Melchior, 2011). Costume collections have been considered as essential resources where existing academic work in museums started from (Taylor, 2004) and are still important for scholars of fashion studies in the present time (Lin and Cassidy, 2008). The precise information of a dress provided by the collections became the objective of dress history or study (Taylor, 2004).

According to Melchior (2011), the emergence of fashion in museums is a phenomenon of the 20th century. She viewed the initiatives of fashion in museums as costume collections explaining its historic development. The early stage of the phenomenon dates back to the time before the Second World War. At that moment, dress collection was not unusual practice especially for the cultural history museums. By 1930 the well-established clothing collections were found in some museums of cultural history such as the main Scandinavian cultural historic museums and several local museums (Leilund, 2007; Liby 2010 cited in Melchior, 2011 p.4). Most of the collections consisted of dresses of people in different positions before the preindustrial era across areas. The time just prior to the Second World War show the steps forward on which clothing collections developed into a part of art museums building a connection with costume related organisations such as the Costume Institute and the Metropolitan Museum of Art or the Gallery of Costumes and the Manchester City Art Galleries. Melchior (2011) further stated that both organisations took note of the design and aesthetic of the dresses such as styles, cuts and materials, and the many cases of textile collections of the decorative art museums who shared the attention to materials became textile and costume collections or fashion collections. Since then the intensified phenomenon found the development of museums specialised in fashion and the diffusion of fashion exhibitions at the museums which did not possess clothing collections.

The development of costume collections and the research contributed to the formulation of the ICOM which internationally applied principles for treatment of costumes and the guidelines form the basis of the dress musicology (Melchior, 2011). The details of the guidelines by ICOM (1990) will be described in section 4.1.3.1. The dress musicology is a practical practice which is a method to carefully handle the dresses for their future conservation (Melchior, 2011) and involves the ways to collect, register, study, communicate and preserve the clothing (Taylor, 2004). Dress musicology offers precious information for the advancement of fashion history as well as the knowledge formation about the cut, structures and making of clothing (Melchior, 2011).

4.1.3 Practical Problems of Exposure of Costume

4.1.3.1 Constraints on Costumes from a Perspective of Museums

In museums, clothing has a relatively short life because it normally consists of organic matter, which is vulnerable to an environment and is continuously destroyed by light, dust, temperature, humidity, and physical stress (Ahn, 2007). Also, there is a potential danger as the textile and threads of a costume become weak and the seams may separate (Icon, 2006). For these reasons, costumes require special care and treatment. Many restrictions are imposed on their collection, accessioning, care, handling, storage, conservation and display.

To offer a reference and promote awareness, the committee of ICOM established the recommended guideline for costume collection (1990). The following summary is a guideline. According to them, the costumes collected are not instantly admitted to being archived with other collection objects. Inspection is required upon entry for infestation and treatment using mechanical methods, cautious brushing or vacuum cleaning with screening are immediately carried out, and recorded.

The condition of the storeroom must be designed based on each type of clothing. The lighting needs to be dark, and fluorescent or tungsten lights with UV screening should be turned on whenever working in that space. The recommended temperature and humidity of the environments are 18°C with RH 50-55% for textiles, and RH 45-50% for leather. The arrangement of storage units should consider the natural flow of air around them. All materials should be secured in the store units against damage and deformation, which may be inflicted by their weight and construction. Padding can be applied where shaping and trimming can incur rucking up.

When costumes are handled, stored and displayed, clean space without unnecessary objects is required. Costumes should be handled as little as possible using white cotton gloves, and carried in covered trays. They should be protected using calico dust covers, which is well-washed and not bleached, or acid-free tissue when they are not in an examination. If folding is unavoidable, it should be minimised by inserting pads of acid-free tissues to smoothen.

For the museums, display of costumes is the paramount issue. According to Palmer (2012), public exhibitions can trigger a rapid degradation of garments. Particularly, light causes irrevocable damage to the fibres and dyes, and the pull of gravity on the garments can distort their shape. In a display of costumes, ensuring prevention of damage or loss is the vital consideration, which requires constant co-operation of curators, conservators, scientists, and designers. From the preparation to the end of the exhibition, handling of costumes is observed by the same requirements above. Also, the exhibition area needs to apply the storage conditions, ventilation, and the use of 50 lux maximum of lighting is recommended during the viewing time. Any costume should not be displayed in a long-term exhibition (ICOM, 1990).

The careful treatment of objects in the guidelines suggest that costumes are delicate and sensitive subjects that must be protected by the museums. The best way to minimise potential damage and risk is by keeping them in a secured repository however the significance of the cultural heritages will be lost if the public study and appreciation are blocked. Museums make a considerable effort in offering benefits to the public by taking into account conservational factors in displaying delicate objects, which are immensely laborious. This effort requires expensive control mechanisms for an ephemeral feature exhibition. Furthermore, the production of customised mounts for each historical or ethnographical garment involves an enormous amount of expense, much more than commercial mannequins (Taylor, 2012). This process may hinder costume exhibitions from a managerial standpoint.

4.1.3.2 Difficulties of Exploration of Costumes from a Perspective of Students

Costumes play an important role in serving as representatives of the social configurations of the past and the present, as well as inspirations for future fashion and artwork trends. Also the information held within such artefacts is a valuable resource in fashion studies such as garment design and dress history, as well as in other areas such as sociology, anthropology, design and history (Martin and Ko, 2011).

However, exploration of the costumes is often under constraints in the exhibition. Firstly, physical location and opening hours for the exhibition may obstruct the visit for some people. Also the limited period of costume display sometimes does not allow the audience to thoroughly study or appreciate the exhibits. As displays typically deteriorate costume quality, costume exhibitions are often short-term or ephemeral. The globally admitted time-frame for such displays is four to six months (Palmer, 2012).

Secondly, viewing by observers is sometimes limited depending on the display methods, structure of the curational space and arrangement of objects. For instance, the back of the dress may not be observable when there is a wall or other objects behind. Additionally, the protective rope and display platforms which work to keep the distance between exhibits and observers constrain their experiences and prevent them from touching or viewing the objects up close, or even capturing a view of the inside of the garments (Martin and Ko, 2011).

Thirdly, costumes in the exhibitions may not be able to maximise the audiences' appreciation due to the constraints on display methods to emphasise their aesthetics. Depending on the condition of a costume, the pose of its dedicated underpinning can be limited. Furthermore, the authentic beauty of the costumes, which can only be realised through a moving body, is missed on static mannequins. While commercial showcases and fashion shows have actively used living models, artificial winds and various moving devices to emphasise the aesthetics of the clothing, costume displays are strictly static and constrained.

Besides, there are some objects to which access is not easily approved for in-depth academic investigation, photographing or for publication. Particularly fragile dresses are prevented from being exposed to the external environment, for fear that their condition may degrade further. Sauro (2009) emphasized that museums are increasingly limiting access to museum collections for designers as well as fashion students. Curators are apprehensive of excessive handling of costumes, which may cause damage and hinder conservation. Thus, primary research upon delicate antique clothing has been progressively regulated by curators and collection managers, who claim that this restricted access is necessary if these objects are to be preserved for the next generation.

In order to remedy this insufficient access, some schools have developed several methods to facilitate the study of these garments, such as (1) The development of discrete expendable educational collections for the classroom use, (2) The production of replicas using muslin, and (3) High-quality and detailed photography (Sauro, 2009). The first approach has the advantage that the original garments can be easily observed and handled. However, this method can ultimately sacrifice the clothes by exposing them to excessive handling. These classroom collections are also more likely to be composed of objects which are in good condition, and which hold relatively little value. The advantage of the second method is that handling these replicas is possible without triggering any damage to the original dresses. On the other hand, details such as textile and surface embellishment may not be completely expressed through the nature of muslin (Sauro, 2009). Moreover, this material may not function to illustrate the sophisticated feel and drape of the original fabric. Lastly, photography may fail to present detailed features of the garments, and it is generally held that this method can neither satisfy audiences' curiosity, nor provide in-depth information about the garments (Kim et al., 2010).

4.2 Museum and New Media

4.2.1 Development of New Media

The advanced technology and digital revolution have brought about many changes of various fields in society. In the museums aspect, there has been an improvement in the controls, security systems, conservation methods and documentation which are in the interests of their collections. For the audiences, improved computer technology facilitated the interactive exhibitions, quickened the interest offering the exciting approach to the information contained in the exhibits and allowed access to the whole documentation system of the collection (Mclean, 1996).

The most notable change in the museum was its extensive use of new media. New media is now well-established in the museums in the form of “hand-held information devices, information kiosks, installation art, display supports and archiving systems” and this introduced reform of exhibition, operational practice and the relationship between museums and visitors (Henning, 2006 p.302). Most are explained as computer-based or digital media which is the outcome of the concentration of the mass-media systems and technologies along with the data-processing technologies (Manovich, 2001).

New media engages with the transition of conventional practice and representation into digital format which implies not only the advent of new cultural technologies but also the conversion of existing things in the process of remediation (Bolter and Grusin, 2000). By means of the internet, networked portable devices such as cell phones and PDAs and affordable applications and hardware, the generation and dissemination of media contents progressed (Marty, 2008).

4.2.2 Shift in Museums

Museums could not overlook the impact of computer technology as our working method as well as a leisure tool of our everyday lives are more and more engaging in the use of new media (Mclean, 1996). Rather than staying within the confined physical boundaries, museums have transferred some portion of their endeavour to cyber space. Museums have been transformed aiming further extensive and ubiquitous information distribution and the increase of new visitors. The shift moved toward more access of information and transparent data about collections and study, and museums attempted to generate resources based on both visual and textual data developing databases and digital images (Jones, 2008). The capability to produce digital representations of such resources has affected the manner of users of the resources to explore the museum collections (Marty, 2008). Multimedia and PCs were combined by the information superhighway through the online facility (Mclean, 1996) and the huge levels of access has been caused by the extensive availability of digital exhibits and collections. Even the resources which were once unattainable to the public became accessible over the internet and more of the time of the museum specialists are being spent for the dissemination of the data outside of the museums (Marty, 2008).

Along with the growth of the World Wide Web (WWW), a great deal of museum websites have been created and played a successive role in offering access to museum data integrating knowledge practice, instructive subjects and the construction of appealing virtual exhibitions (Lin and Cassidy, 2008). This means that new media has not only stood for the objects in the existing museums but also introduced new forms of museums such as virtual museums (Henning, 2006). The significant aspect of this shift is the extension of curatorial space through virtual museums on the internet. This trend led to the curatorial consideration to be widened for the object to be accommodated with the energetic network system and curatorial practice consequently has been more broadly allocated between various mediators such as technological networks and applications (Krysa, 2006).

4.2.3 Advantages of New Media

The shift in museums, the digitalised collections and extension of curatorial space through new media does not simply mean the availability of the support in information delivery and physical exhibitions. This, firstly, indicates the capability of integration of the collections and the display. The new media enables objects which were conventionally given by curators' arbitration and particularly designed exhibitions to be exposed according to the audiences' choices (Henning, 2006). Secondly, new media provides a means to database the collections and their various relevant information to be available in digital form. This facilitates the organisation and sharing of the information of the objects including those that are not accessible (Marty, 2008) and to connect relevant collections in different displays or archives (McKeown, 2003). Thirdly, the relationship between museums and more visitors can be reinforced by the new media. The easy access free from constraints of time and physical environment and information search based on users' needs and choices break down the wall between museums and the public. In addition, it is noticeable that the digitised information resulted by this shift can be shared not only by the internet but also by diverse media such as kiosks and touch screens which may build a more enhanced engagement between them (Henning, 2006).

Meanwhile, according to Henning (2006), there has been different views on grafting new media on museums. The supporters of new media argue that it brings many advantages. They look on the bright side of new media which may help democratisation of knowledge, delivery of contextual details of objects, embodiment of complicated concepts and processes and offer various perspectives. Its use to increase the popularity and the attention of museums as well as stimulating exhibitions is emphasised as well. Also the advocates consider that new media helps with the improvement of the efficiency, flexibility and modernisation of museums and encourages social interactions. On the other hand, the people who view new media with scepticism regard it as a threat against the relics and prestige of historic sources of knowledge. Also they concern the lowbrowism of museums switching educational venues into commercialised spaces (Henning, 2006). These two contradictory outlooks signify the necessity of consideration of the appropriate use of new media as a large quantity of museum information as well as the data involving diverse subjects is increasingly available online and often provokes controversy about their validity and legitimacy. However, it is evident that the direction of application of new media needs to consider the maximisation of its effectiveness but not to detract from the fundamental purpose of the museums as well as the artefacts.

4.3 Costume Curation with New Media

4.3.1 Museum Website and Virtual Museum

The museum websites basically function to represent the individual organisation by offering information about the institution, its displays, collections, programmes, etc. to the audiences (Paul, 2006). Besides, these websites play an important role not only for providing helpful information but also for encouraging people to reuse this online space and stimulating their interest to physically visit the actual museums as a marketing method (Lin and Cassidy, 2008).

Virtual museums also perform the same role in most cases, however, Henning (2006) emphasised that they are not just the website of the physical museums. They are museums established in the form of new media (Henning, 2006) which are "intangible, without a space and place (Kaplan, 2006 p.164)." In virtual museums, the concept "halls" are reinforced by the use of metaphors rather than "page" and the audiences may access textual, visual and auditory materials which exist as digitally databased collections (Henning, 2006). Such museums on the internet can be categorised into two types: those which simply represent some parts of the contents of existing museums in the physical environment and those which only settle on the World Wide Web alone (Macdonald, 2002).

From the investigation of the meanings of museums, new media and virtual museums, this study considers the desirable concept of museum websites and virtual museums as the medium which virtually exist in cyber space for the purpose of sharing information and for connections of extensive knowledge for the public with respect for the authenticity and legality of museums and their collections by archiving, preserving, communicating and educating on the various forms of digital information of the collections in the databases. By conducting these functions, websites and virtual museums play an important role in constructing the cultural meanings of the history and to promote the culture.

4.3.2 Observation of Costume and Fashion Museum Websites

As an exploration phase, the websites of costume and fashion museums were observed in order to understand how museums are using their websites and how the collection information is provided. Two groups of subjects were selected as samples. For the investigation of the status of UK museums, the samples of the first group were chosen through search engines using keywords “fashion”, “costume”, “museum”, “gallery”, “archive” and “UK” as follows. Half of list was museums specialised in costume of fashion and the others are the museums who had dress collections.

- Fashion and Textile Museum (London)[2]
- Fashion Museum (Bath)[3]
- Hope House Costume Museum[4]
- London College of Fashion Archive[5]
- Manchester Art Gallery[6]
- Museum of London[7]
- National Museums Scotland[8]
- The Blandford Fashion Museum[9]
- The Bowes Museum Fashion and Textiles[10]
- Victoria Albert Museum[11]

[2] http://www.ftmlondon.org

[3] http://www.museumofcostume.co.uk

[4] http://www.hopehousemuseum.co.uk

[5] http://www.vads.ac.uk/learning/designingbritain/html/ffs.html

[6] http://www.manchestergalleries.org

[7] http://www.museumoflondon.org.uk

[8] http://www.nms.ac.uk

[9] http://www.theblandfordfashionmuseum.com

[10] http://www.thebowesmuseum.org.uk

[11] http://www.vam.ac.uk

In order to observe the status of the world famous museums, the samples of the second group were selected using the CNN news article "Fashion museums around the world (Jenkins 2012)" as follows:

- Fashion Museum (Bath)
- Kent State University Museum (Kent, Ohio)[12]
- Kobe Fashion Museum (Kobe, Japan)[13]
- Les Arts Décoratifs (Paris)[14]
- ModeMuseum Province of Antwerp (Antwerp, Belgium)[15]
- Museo de la Moda (Santiago, Chile)[16]
- Museo Salvatore Ferragamo (Florence, Italy)[17]
- Tassen Museum Hendrikje (Amsterdam, The Netherlands)[18]
- The Metropolitan Museum of Art (New York)[19]
- The Museum at FIT (New York)[20]

Among them, the Fashion Museum in Bath which was categorised into the first group and Tassen Museum Hendrikje in The Netherlands which focused on bag collections was excluded from the observation.

The observations were carried out between 1st and 7th January 2013 and main criteria of the observations were the types of information provided, the presence of digital collections, display method and form and quantity of the data. For the analysis of the form and quantity of the online collection data, this study monitored six objects

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12 http://www.kent.edu/museum/index.cfm

13 http://www.fashionmuseum.or.jp

14 http://www.lesartsdecoratifs.fr

15 http://www.momu.be

16 http://www.museodelamoda.cl

17 http://www.museoferragamo.it

18 http://www.tassenmuseum.nl

19 http://www.metmuseum.org

20 http://fitnyc.edu

randomly selected. However, the collection objects without any photographs were not considered. For the analysis of visual data, this study concentrated on the total quantity of the image and classified the focus of the image according to front, back, side, materials and others. The common features were marked in red and irregular ones were marked in black. In the case of the text data, this study enumerated the issues appeared. The auxiliary data which was not directly relevant to the dress itself such as images of other works by the same designer was not considered.

4.3.2.1 Findings

The dominant structure of the museum websites consisted of six major components: the museum information, introduction of exhibitions, news and events, workshops, useful links and online shop. The most important feature of the virtual museum, online collection function was provided by around half of the museums. These elements can be categorised into three attributes according to the main intention: marketing, education and information offering of clothing. The marketing property of the website includes the museum information which introduced the opening hours, location, admission charge and contact details, news and events which had a promotional purpose, and an online shop which directly sold various products. The workshops which provided practical or theoretical training can be understood in the context of education. The third attribute includes an introduction of exhibitions and online collections where actual information of dress was provided. However, the characteristics of those two functions are somewhat different. While the introduction of exhibitions provided the brief information of some featured objects and outline of the overall display in the past, current and future with some pictures, the online collection offered the intensified data of an individual set of clothing from the database. According to the presence of this capability, this study distinguished the websites functioning as online museums and the general museum websites as shown in Table 4.1 and five museums of each group had this capability.

Table 4.2 compares the findings from the observation of group 1. Except for the London College of Fashion Archive, all museums provided a keyword search function and most cases applied category search to narrow down the search result. Another method was categorisation. London College of Fashion Archive and Fashion Museum displayed the clothing through various categories. In the case of the Fashion Museum, the categories included some periods, some purposive dress (sportswear, wedding, underwear, uniform, etc.), several supplementary items (pockets, accessories and hats) and techniques applied to materials (Embroidery or bead work and printed textile). London College of Fashion Archive offered two options of categories: periods and other thematic categories which fell into a range of subcategories such as colour, artist, home dress and glamour. The categorisation methods of these organisations seemed somewhat unsystematic because the thematic categories were merely exhibited on the same level without particular structures. The Manchester Art Gallery was the only case which applied different methods: keyword search, categorisation and index all together. Their thematic categorisation consisted of designers, formal and casual, working clothes, sports and leisure, etc. Also their online collections were indexed by the maker or artist of the dress so that users may observe various work of a certain designer at a time.

Table 4.1 Two categories of museum websites

	General museum websites	**Websites functioned as online museums**
Group1: Costume/ fashion museum in UK	▪ Fashion and Textile Museum ▪ Hope House Costume Museum ▪ National Museums Scotland ▪ The Blandford Fashion Museum ▪ The Bowes Museum Fashion and Textiles	▪ Fashion Museum ▪ London College of Fashion Archive ▪ Manchester Art Gallery ▪ Museum of London ▪ Victoria Albert Museum
Group2: World top fashion museum	▪ Kobe Fashion Museum ▪ Les Arts Décoratifs ▪ Museo Salvatore Ferragamo	▪ Kent State University Museum ▪ Mode Museum Province of Antwerp ▪ Museo de la Moda ▪ The Metropolitan Museum of Art ▪ The Museum at FIT

The observation appeared that the type and quantity of the visual and text data provided was considerably varied between the museums. The least visual data was found on the Fashion Museum website. The organisation only provided frontal photographs and consequently, the users were not able to study the other sides and other details of the dress. On the other hand, the Museum of London offered a variety of images. Not only front and back views but also side and diagonal views and close views of textiles and details were found in many cases. However, there was a large difference in the quantity of visual data in this online collection. Sometimes objects had no image or just frontal pictures. The London College of Fashion Archive and Victoria and Albert Museum usually displayed front and back view of the dress. Compared with these two organisations, Manchester Art Gallery provided more rich data. Most observed collection objects presented front, back, sides and a close view of features.

Table 4.2 Comparison of features of online collection of group 1

Museum \ Variable	Display method	Visual data						Textual data
		F	B	S	M	Etc	No.	
MUSEUM OF LONDON	Keyword search	√	√	√	√	√	1~ 10	Production date, ID no, Location, Place of production, No of items, Measurements, Materials, Status, Credit, Copyright holder, Last updated, Record quality & Detailed description
Manchester Art Gallery	Keyword search, Categoris -ation, index	√		√	√	√	2~4	Object name, Place of creation, Accession number, Image Copyright, Medium/material, Technique, Description & Dimensions
Fashion Museum	Keyword search, Categoris -ation	√					1	Object name, Material(s), Technique(s), description, Creation date & Display status
vads	Categoris -ation	√			√		2	Description, maker, material, date of production, colour & detail
V&A	Keyword search	√	√	√			1~2	Place of origin, Date, Artist, materials & techniques, Credit line, Museum No, Gallery location, Physical description, Bibliographic references, Exhibition history, Categories & PDF download

(F: front, B: back, S: Side, M: material)

The universal text information of all websites in group 1 was the object name, ID number, materials and the overall description about the object. Also production date, place of production, techniques applied were commonly presented. Depending on the websites, measurements, artist or maker, status and other subsidiary information such as history, number of items, ID number, credit, etc. were sometimes introduced. The description often included is framed information again and illustrated further features: it normally focused on the composition and details of the garment or the story behind such as about the wearer or how the garment came to the museum collection depending on the objects. Museum of London, Manchester Art Gallery and Victoria Albert Museum were the good cases which offered relatively multifarious narrative description in many objects. However, the explanation about the garment parts which were not presented through the visual data was not observed from the samples. Meanwhile, the deficiency of the descriptions and the overall text information were found in other websites. The Fashion Museum often did not provide any description and the London College of Fashion Achieve just listed featured components of the dress without sentences.

Table 4.3 shows the findings of the observations of group 2. The keyword search function was the general means to provide collection information in all websites save for Museo de la Moda. Three museums in this group offered multiple methods for the exploration of the collections. The categorisation and index search was available by

Kent State University Museum respectively, and the Metropolitan Museum of Art and the Museum at FIT applied those means all together. In the case of the Metropolitan Museum of Art, the website initially displayed the five top level of categories: who, what, where, when and in the museums. Each category included various subcategories. For instance, the "what" category consisted of wool, cotton, metal, etc. groups. Also the website allowed to compositely use other subcategories of different high level class to narrow down the results. The Museum at FIT classified the categories into different periods, accessories, menswear and new addition and the hierarchy between categories was not found. The index of the Metropolitan Museum of Art was linked to the categorisation system so that all information was indexed by the themes of each subcategory. Kent State University Museum also provided specified indexing function in various contexts such as object name, creator, culture, material, description, date, etc. On the other hand, the Museum at FIT offered the one way of index based on the name of designers or brands. Museo de la Moda was a notable case which applied a virtual tour for the collection display. A 3D view of virtual space was introduced on their website where the users needed to explore to find the objects exhibited.

Table 4.3 Comparison of features of online collection of group 2

Variable / Museum	Display method	Visual data						Textual data
		F	B	S	M	Etc	No.	
MUSEO DE LA MODA	Virtual tour	√					1	Virtual tour: Object name, material, place of production & wearer Collection introduction page: Object name, dress specification, collected date, status
M	Keyword search, Categoris-ation index	√	√		√	√	2~13	Object name , Date, Culture, Medium, Dimensions, Credit line, Accession number & Description
The Museum at FIT	Keyword search, categoris-ation, index	√	√			√	1	Object name, Brand, Medium, Date, country, Credit & Object number
KENT STATE UNIVERSITY	Keyword search, index	√	√	√	√	√	2~10	Object number, Object name, Date, Culture, Description, Material, Lexicon category, Lexicon subject, Object code
MODEMUSEUM PROVINCIE ANTWERPEN	Keyword search,	√					1	ID, Title, Designer, Date, Place, Size/length, Description, Keyword, materials

(F: front, B: back, S: Side, M: material)

There were large differences in quantity of visual data of the online collections. Although the Metropolitan Museum of Art and Kent State University Museum presented many photographs in many cases, there were some objects with few pictures. The images of these museums basically included the front and back views and material close views or different angles irregularly appeared. Another three organisations provided only one image which was mainly the front or sometimes the back or another direction. In the case of Museo de la Moda which applied plenty of photographs to build the virtual place, the exhibits were displayed as a front image visualising only fragmentary information.

The text information of the collections of group 2 was not significantly different from the data of group 1. Every website presented the object's name and materials. The descriptive data, production date, culture or country frequently appeared and place of production, wearer, measurements, designer and other data such as credit, access number, etc. was occasionally found depending on the websites. It was found that the contents of the description often further elaborated other text information and illustrated the aesthetic features, about designer and historical background of the garments. Although there was some disparity of the detailedness between objects, the Metropolitan Museum of Art and Kent State University Museum generally offered rich descriptions. On the other hand, Museo de la Moda did not provide narrative descriptions.

4.3.2.2 Conclusion

This study observed the features of the information that the costume or fashion museums in the UK and the top fashion museums in the world mainly focusing on the online collection data. From the findings, it was found that the general information that the museum websites introduced was characterised by three aspects: marketing, education and collection information offering. According to the presence of the online collection, the websites can be classified into two groups: (1) websites functioned as online museums and (2) websites which introduced museums. The websites of both categories played a role as an information source on the collections by providing the brief information of the dress in display or of the collections. However, the in-depth data of discrete objects to study did not appear in (2). It seemed that these websites were mainly used for the promotional purposes.

The findings showed that the websites in (1) allowed access to the collection data through different methods. Keyword search appeared as the most common method followed by categorisation and index system. In the case of categorisation, the systems on most websites did not have a systematic hierarchical structure. They were rather thematic and themes of the categories varied from each other. The index systems also appeared varied between websites. The objects were indexed by designers in two websites and another two websites provided various criteria of the index. In addition, there was an outstanding method which was the virtual tour found in the website of Museo de la Moda. This system provided a virtual space using actual pictures of the physical museum and displayed some garments in the showcases.

Keyword search and index may be advantageous for the conative users with a sense of purpose to explore certain objects enabling fast selective access to a great deal of data. On the other hand, virtual tour has a certain theme and exhibits planned by the curators which means the audiences' choice of the object is not allowed within the given environment. In this respect, it may be a more interesting and effective method for those who do not have a specific objective to study and those who just seek expansion of knowledge or pleasure. However, it would not be an appropriate method to display a number of exhibits since the users would be required to wander to find them. Meanwhile the thematic categorisation has the merit of multiple exposition of the relevant or similar objects to the specific subject and this method seemed helpful for both of people who have exact ideas of the object and who do not. Besides, five museums appeared to apply more than one method to display the collections for users' convenience.

It was found that there were large differences in the type and quantity of the visual data of the collection objects on British museum websites as well as on the World's best museum websites. The disparities were found not only between museums but also between objects within each website. While the efforts to expose diverse images were observed in several museums, it was shown that many websites just provided one or two photographs. They tended to provide the front view as basic data and the rear and side views or a material image were optionally displayed depending on the aesthetic characteristics of the garment. The pictures from other directions or close-up photographs were found in several websites. Additionally, although this study excluded the objects without any image from the observations, it should be noticed that there were many such objects on the websites which strived to present more visual data. It may be natural that the absence or lack of visual data will obstruct the understanding of 3D aesthetics of the dress. Therefore, this study regards the rich image data as the basic premise of the well-established online collections which current museums need to improve.

The findings showed that the museums tried to provide text data using a certain coherent format and richer information through narrative description. Although each museum presented different standardised information formats as shown in Tables 4.2 and 4.3, there was no significant difference in the overall criteria of text data between the museums in the UK and the world top museums. There were large differences in contents and the amount of the descriptions. While some websites briefly enumerated the component features, some websites further elaborated its aesthetic properties, background story about wearers or designers depending on the objects. Also the description of the observed objects did not supplement the lack of visual data. There were some cases where websites which presented brief text data with one or two images. This study concerned that such cases may cause many questions about the dress and hardly satisfy the intellectual curiosity of the people.

Additionally, this study also points out that some websites tended to introduce different characteristics of information without a particular division. Such various text data can be categorised according to the features. Firstly, ID number or collection code, location, category and keyword can be characterised as the information for data access. Secondly, object name, production date, place of production or culture or country, number of items, dimensions, materials, techniques and colour and details can be understood as the fundamental garment information. Thirdly, wearer, status, bibliographic references and exhibition history may be classified as background information which may be needed for in-depth study. Fourthly, credit and copyright holders indicate the source of information, and other information such as last updated date, etc. can be classified as other data. It may be helpful to distinguish the fundamental data and other information so that the users optionally can take them.

In summary, many UK museum websites and the world top museum websites observed still did not robustly function as online museums as yet. The main problem being the absence or deficiency of the visual and textual data provided. It seemed they tried to release as much information as possible, however, it was assumed that it may need much time to digitise and manage huge numbers of objects through their websites. This study considers that the quantity of visual data determines the quality of the information when it comes to the understanding of the aesthetic features of garments. Also the variety of the type of text data may affect the information quality. In order to function as online or virtual museums in the true sense, this study argues that museums need to consider the effective display of the abundant visual and text data to provide the stereoscopic understanding of the objects.

4.4 Summary

This chapter had a main purpose to identify the current problems of museums' practical application of new media focusing on the case of their websites. Prior to this, the chapter explored the role and importance of museum and costume collection and influence of new media to provide general understanding and discussed the limitations of management of costumes to underline the need for remedies.

Museum was identified as a repository of information of which role is to store, preserve, disseminate, educate and promote culture and science. The emergence of garment into the museums started around the time before the Second World War and museums which are dedicated to fashion or holds fashion exhibition became a phenomenon together with development of costume collections. The introduction of costume handling guidelines and dress museology indicates that costumes are considered important as valuable cultural resources being a subject to conservation and inheritance for future generation.

Costumes were defined as the resources which represent the style, identity and culture of the past. They not only are used for fashion studies such as garment design and dress history, and in other areas such as sociology, anthropology, design and history but also provide inspirations for future fashion and artwork trends.

In an academic aspect, costumes are the subject to collection, exhibition and research in the museums. However, due to their vulnerability to physical stress, they are considered as the objects which require special care and treatment and the handling, public display and access are very restricted by museums. In the case of exhibition of costumes, degrading can be accelerated by diverse factors such as light and gravity. For this reason, preparation of exhibition requires laborious efforts of various specialists and substantial amount of cost and display period of a costume is restricted not to be long-term.

From the perspective of students, costumes are significant resources for learning and research. However, investigation of real costumes is often limited by the following reasons:

- Constraints on admission to exhibition: physical distance and opening hours
- Constraints on appreciation: ephemera nature, restricted display presentation (static and constrained pose) and limited view
- Restricted access to fragile costumes

To compensate for such constraints, following methods have been applied by some educational institutions though some limitations ensued:

- Development of expendable educational collections: confinement to relatively less-valued costumes in good condition and allowance of potential damage by handling
- Production of replicas using muslin: time and labour consuming for preparation and expression of less details
- Use of high-quality and detailed photography: less likelihood of providing detailed information and satisfying observers' curiosity.

The chapter provided review about the numerous constraints on costume collection in the museum and alternatives introduced by educational institutions which ease the restrictions in some degree but entails other limitations in applicable costumes and delivery of complete aesthetics and detailed information. It indicated the concern that the major functions of the museum such as dissemination, education and promotion of culture may not fully be performed with costume objects and need for the means to strengthen its roles. The following literature review on new media suggested positive possibility to remedy the problematic situation.

The development of technology has brought extensive application of new media into the museums in exhibition and operational practices, conservation and documentation methods and relationship between the museum and audiences. The notable changes are particularly the extensive availability of digital exhibits and collections based on digital database construction and network and expansion of curational areas into virtual space in the form websites or virtual museums. Such phenomenon is expected to have following advances:

- Integration of the collections and the display
- Selective exhibition considering the audiences' choice and need

- Facilitation of construction and sharing extensive information in digital form
- Reinforcement of the relationship between museums and audiences through less-constrained access and inducement of engagement

Also following general contributions of use of new media to museum were discussed:

- Democratisation of knowledge
- Delivery of contextual details of objects
- Stimulating exhibitions
- Improvement of the efficiency, flexibility and modernisation, popularity of museums
- Encouragement social interactions

However, there have been some concerning views on negative effects which use of new media may have as follows:

- Threat against the relics and prestige of historic sources of knowledge
- Concern for the tendency that museums became more commercialised
- Controversy issues with validity and legitimacy of spread of data online

The exploration of the meanings of museums, costumes and new media indicated the desirable concept of museum websites and virtual museums as the medium which virtually exist in cyber space for the purpose of sharing information and for the connections of extensive knowledge for the public with the respect of the authenticity and legality of museums and their collections by archiving, preserving, communicating and educating on the various forms of digital information of the collections in the databases. By conducting these functions, websites and virtual museums are expected to effectively supplement the constraints investigated above, constructing the cultural meanings of the history and promoting the culture.

The observation of costume and fashion museum websites appeared how museums are using their websites and how the collection information is provided. The elementary roles of the museum websites were identified into three major components: marketing, education and offering costume information. Based on the natures in offering costume information, the websites were categorised as follows:

- Ten websites with online collection offering the data of individual costumes
- Eight websites providing general information

The findings appeared that around half of museums did not perform as online museums due to the absence of the in-depth information of individual costumes. Also large disparity in type and quantity of visual and text data was observed between the websites of the first citatory but also between objects within each website. This implied that the online collections of many museums were not robust at present.

This chapter pointed out the absence or deficiency of the visual and textual data as the main problem. Especially, the visual data was considered as the critical factor which determines the quality of the information when it comes to the understanding of 3D aesthetics of the dresses. In order to function as online or virtual museums in the true sense, this study claimed the rich image data as the basic premise of the well-established online collections which current museums need to improve on.

To prepare the embodiment of digital costumes which may supplement the problems identified, the following chapter analysed the methods, strength and weakness of earlier digital costume projects and identified key concepts for development of effective digital costumes to remedy the general problems observed in this chapter.

Chapter 5: Earlier Digital Costume Projects

The section 4.1.3 briefly explained the circumstances behind the limited access to costume collections as well as methods for circumventing these restrictions, which have their own different advantages and disadvantages. Despite the important role played by costume resources, the inaccessibility of the originals coupled with the weaknesses of alternative approaches suggests that there is considerable scope for improvement. This study considers the virtual reproduction of the costume as an advantageous alternative method, which is able to effectively support the study of costumes while maintaining the value of the artefacts. This section analyses the previous work done on the reproduction and recreation of the garment using 3D computer graphic technology and compares the features used, techniques applied, and the strengths and weaknesses of each case, in order to seek desirable directions for the effective creation of virtual costumes.

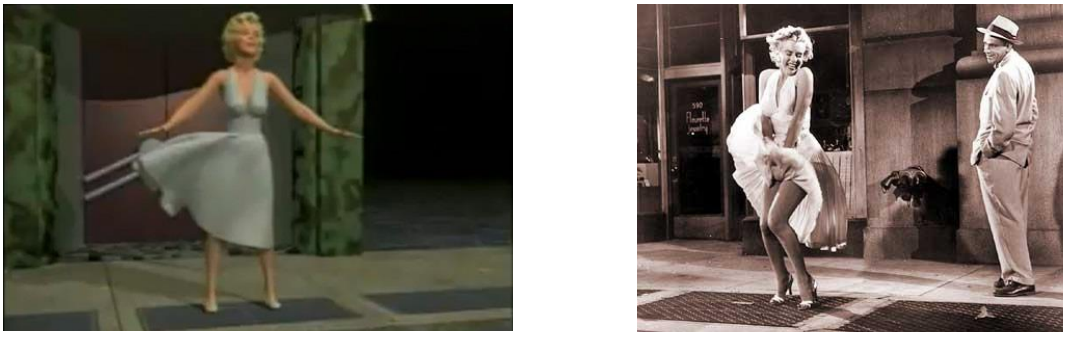
The subjects of investigation were confined to cases that replicated existing garment or costume design, as well as cases that produced the costume design based upon reliable historical references. Personal fashion design work based on individual creativity was excluded from this study. This study aims to focus on the outline of the project, virtual garment production approaches, and the configuration of virtual models and display methods through the simulated outcomes if accessible, and uses other references including the existing literature, developer websites, and relevant videos and images.

5.1 Projects by MIRALab

5.1.1 Flashback

The MIRALab at the University of Geneva works with cloth simulation techniques and applications, and is one of the leading research teams in the world in this field. Flashback was their early attempt to simulate a whole dress on a virtual figure, using a method that they had developed to efficiently deal with the collision problem for dynamic models in 1990 (Magnenat-Thalmann, 1992). Flashback is a short animation that re-enacted the famous blowing-skirt scene in the movie “The Seven Year Itch (1955)” by Billy Wilder. The animation presented a virtual Marilyn Monroe wearing a wide dress, accompanied by small pieces of paper flapping in the wind. It was distinctive in illustrating the dynamic draping effect of the skirt as well as depicting fluttering paper pieces in the air from the vent on the road. The sequence of this work followed several stages: (1) generation of the cloth by taking geometric and dynamic factors; (2) application of the cloth on the virtual figure; (3) body animation (Lafleur et al., 1991).

In this work, the geometric step was comprised of splitting the cloth into its constituent components that were semi-discretised on a separate mesh and nodes. Their system linked each point on the model, as well as the different cloth pieces, using virtual springs (Lafleur, 1991). For efficient computation, the researchers deconstructed the virtual body into sections and dressed each part independently. By specifying the curves of the body, fabric pieces were attached to certain parts such as the waist and shoulders. In the case of the skirt, the body of the virtual figure was divided at the waist level. Then the curve of the body was streamlined to acquire equidistant points, which constituted a closed curve and formed a simple conical surface with a certain length and angle attached to the waist (Thalmann et al., 1996).



(a) A frame from "Flashback" animation (source: MIRALab, 2007b)

(b) The original scene from "The Seven year Itch (1955)" movie

Figure 5.1 Flashback

For a dynamic and realistic simulation, the animation applied a physics-based approach which took two kinds of parameters into account: (1) Internal parameters such as mass, elongation, curvature elasticity and viscous damping; (2) External parameters such as gravity, air speed and viscosity (Volino and Magnenat-Thalmann, 2000).

Their work tried to concentrate on the realistic deformation and shape of cloth on an animated figure. However, the motion of the virtual actress appeared somewhat still. The only parts of the figure that were moving were her arms, and they did not play a role in the process of contact with the dress. In fact, their model was applied to a truncated body with pelvis and legs, and the skirt was modelled to simulate dynamic movement. Other sections of the garment were regarded as belonging to the surface of the body.

Additionally, the researchers did not implement a friction model because the skirt was floating in the air for most of the time, with very little interaction with the figure (Volino and Magnenat-Thalmann, 2000).

Since the purpose of Flashback was to demonstrate their simulation method, it did not try to create an accurate representation of the dress and the scene. There were visible differences from the movie in terms of the motion of the actress, the drape and behaviour of the dress, the effect of the wind and the background visuals. From the perspective of garment reproduction, some of these limitations gave rise to certain observations. Firstly, it seemed as though neither the measurements of the original dress, nor the application of general garment construction rules, were taken into account for the purposes of garment generation. Although the virtual dress looked similar to the original one on the surface, the approach taken with the cloth creation, and the attachments relying on the division of the body, might not have resulted in a structure similar to the real garment. Secondly, a partial simulation of the garment naturally contained unrealistic elements. Mahal (2010) further pointed out the weaknesses within their cloth simulation by mentioning that Flashback was essentially designed to generate an aesthetically plausible cloth rather than a precise representation of the complex interactions between the fabric and the dynamic forces of the wind. In addition, the methods used for the expression of the pleats, textiles and colours were not specified in the literature.

Volino and Magnenat-Thalmann (2000) considered the project to be a success with regards to the goal of dressing and animating a skirt on a virtual figure. The research team has further improved the technical aspects of their system and worked upon various projects pertaining to virtual garment production.

5.1.2 Virtual Heritage

The MIRALab has created the virtual heritage project, whose fundamental aim is to realise a complete framework for revitalising objects that possess cultural heritage, and are not readily accessible due to an absence from the physical record, distance, or other restrictions. The research team introduced the concept of virtual heritage as the application of interactive computer-based technologies to record, protect or recreate relics, sites and performers which are historically, artistically, religiously and culturally meaningful, and to make the outcomes public in order to offer formative learning experiences via the means of visuospatial electronic operation (MIRALab, no date). In their study (Foni et al., 2002; Papagiannakis et al., 2003; Magnenat-Thalmann et al., 2004a; Magnenat-Thalmann et al., 2004b; Foni et al., 2007; Magnenat-Thalmann et al., 2007), selected ancient monuments were virtually reconstructed through 3D modelling, texturing, lighting and real-time simulation technologies.

The distinctiveness of these simulations was that the research team gave considerable thought to the social aspects of their research, which was articulated in the form of a recreation of historical life. Such attention to detail was noticeable in their work on the reconstitution of the Hagia Sophia, Aspendos and Pompeii. The significance of these historical sites was expressed through the societal interactions of virtual characters, who re-enacted certain circumstances and activities that would have been normally carried out in those places during that period (Magnenat-Thalmann et al., 2007). For the fabrication of the characters' clothing, they based their work on thorough historical evidence. In this section, only the virtual costumes of the characters in these three projects are discussed, since the focus of the study is upon the virtual reproduction of garments.

The subject of each project is as follows:

Firstly, Hagia Sophia is a monument with a deep architectural heritage, located in Istanbul, Turkey, which expresses the highest manifestation of Byzantine style and prosperity. The site has been continuously used for more than 1400 years for a variety of different purposes, such as an orthodox church, a catholic cathedral, a mosque and a public museum. The project recreated the monument as it functioned as a cathedral and a mosque, in the 11th and 16th centuries respectively, and depicted virtual humans performing the Morning Namaz Prayer during the 16th century.

Secondly, the theatre of Aspendos is well-conserved Roman playhouse located in Asia Minor, Turkey, that was built approximately between the years 161 and 180 A.D. during the reign of the emperor Marcus Aurelius (Magnenat-Thalmann et al., 2004b). Along with the virtual recreation of two replicas of current status and the form in the third century, the simulation of ancient Hellenistic drama was produced using virtual actors as a part of the ERATO INCO-MED EU Project (2003-2006) (Papagiannakis et al., 2006).

Lastly Pompeii, located in the western part of Italy, and one of the most well-known ancient Roman cities, was another subject for MIRALab's study. The researchers tried to apply the on-site augmented reality simulation to the Lucius Placidus Thermopolium, which is a well-documented and well-preserved tavern located at the site, and involved in the LIFEPLUS project (2002-2004) (Magnenat-Thalmann et al., 2007). In the simulation, Pompeian daily life was recreated by re-enacting authentic scenes in a real tavern.

In these works, life in the ancient era was embodied through virtual humans and their performances. The garments that framed the appearances of these characters were also regarded as an integral element in recreating that particular environment and evoking an atmosphere of historical realism. Therefore, deliberate investigation into the garments worn at the time was conducted to accurately form the representations of the costumes for each project.

For the recreation of the costumes in Hagia Sophia, the researchers stated that they collected the patterns of different types of clothing and images of textiles from the Ottoman Empire and used them to generate various costumes for the simulation (Foni et al., 2002) as shown in Figure 5.2. The garment generation process, as well as the fabric properties that the simulation took into account for modelling cloth deformation, were not specifically mentioned in their study. As they unified the bodies and cloth into one single mesh and attached it to the skeleton of the characters, the garment did not appear to move by itself.

The demonstration movie (real-time simulation of ceremonies in 3D), and the images showed some drawbacks with regards to the accuracy and exquisiteness. In general, the costumes in the simulation appeared simple and lacked details, with the exception of textiles. The seams and other decorative elements were not included. The drape of the garments was also not formulated with regards to the movement. This is probably due to the limits of real-time simulation and to the greater consideration paid to the primary focus of the project, which was not merely the accurate reproduction of costumes. Although the costumes lacked finesse, the team tried to equip the characters in turbans and hats, subsidiary items that evoked historical reality and corresponded with the dress.

In the case of the Aspendos and Pompeii projects, the methods used for the production of ancient outfits were described in detail in Magnenat-Thalmann et al.'s study (2007). The researchers used historical frescos, mosaics and sculptures, along with literature and other data relating to clothing, fabrics, colours and accessories, as the foundation for dressing their virtual characters. Different forms of clothes were then created based on collected information about garment patterns, historical image references and reports. Additionally, in the explanation given for the creation of Roman costumes, the researchers mentioned that they produced the physical prototypes for these costumes by entrusting them to a dressmaker. It is very interesting that physical garments assisted the process of virtual dress development, by offering substantial references for the simulation.

(a) Samples of clothes and patterns

(b) Historical source Images

(c) 3D characters

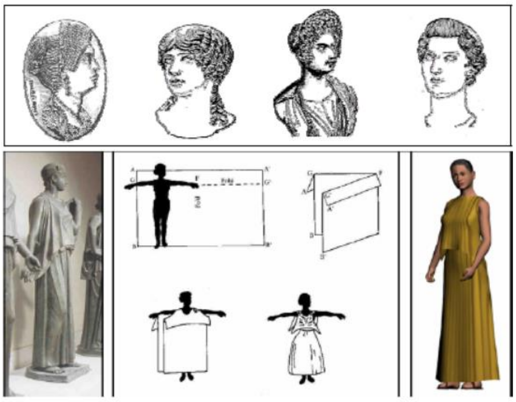
(d) A 3D character re-enacting Namaz Pray

Figure 5.2 Historic references and 3D characters in Hagia Sophia project (source: Magnenat-Thalmann et al., 2004b)

(a) Examples of Roman theatre masks (top) and actor's outfits (bottom)

(b) 3D characters

Figure 5.3 Historic references and 3D characters in Aspendos project (source: Magnenat-Thalmann et al., 2007)



(a) Virtual figure based on ancient hair and garment style

(b) 3D characters in an AR scenario

Figure 5.4 Historic references and 3D characters in Pompeii project (source: Magnenat-Thalmann et al., 2004b)

The applied system was an in-house integrated system which took into account general mechanical and collision detection plots to achieve fast 3D virtual garment prototyping. The functions of the system included a flat pattern design, physical-based cloth simulation on the animated 3D models, comfort assessment, and real time animation and visualization of the simulation outcomes. The costume generation process followed several stages: (1) pattern creation in a 2D environment, (2) pattern positioning and seaming around target body, (3) texturing and assigning physical properties, (4) interactive fitting. Finally, clothing was deformed according to the underlying virtual body shape, by employing mechanical simulation and seam lines.

Supplementary objects such as masks and instruments for Aspendos actors, amphorae for the tavern scene, and some parts of the garments were also produced as accessories for the virtual actors. In order to enforce the completion of the accessories, as well as reinforce the credibility of the 3D modelling historical information, engravings, frescoes, iconographic, and photographic records were employed. Additionally, actual references were used for the recreation of ancient instruments. The 3D objects were then attached to the skeleton of the virtual actors and their position and orientation were controlled based upon the performance of the actors.

The costumes used in the simulation of performance (MIRALab, 2007a) provided more detailed visualisation with regards to the expression of drape than in the case of Hagia Sophia. However, their movement was rigid and conveyed the impression that the costumes were fixed on the virtual bodies. Although the researchers claimed that they used a platform that enabled the physical simulation of garments during the production process, the simulated scenes in their project outcome did not recreate the animated rhythm of clothes.

Compared to prior simulations, the movies (MIRALab, 2007e; MIRALab, 2007c; Laboratory, 2011; MIRALab, 2007d) which showed the results of the LIFEPLUS project presented the dynamic movement of garments. The drape of costumes was taken into account, reflecting the shapes of the virtual bodies as well as their motion. It is remarkable that the simulation recreated various human activities such as walking, running, hairdressing, etc. Accordingly, the characters' outfits reflected a more realistic visualisation.

In these virtual heritage projects, MIRALab emphasized the human aspect by depicting recreations of the social interactions that plausibly existed at these sites. It played an important role in working towards obtaining a better comprehension of the purpose and significance of particular monuments and the role they played in the cultural aspects of ancient life, as well as in generating more lifelike simulations with the inclusion of certain moods and impression (Magnenat-Thalmann et al., 2004b).

In the Hagia Sophia project, the virtual characters were developed as one unified model that took into account the total amount of polygons applied, to generate meshes that maintained a balance between the constraints of 3D real time simulation, and the surface deformation accuracy of the figures (Foni et al., 2002). They presented individuality, emotion, body, costume and dialog simulations, and displayed the capability to implement choreographed storytelling scenarios (Foni et al., 2007). The methods and references used were not described. In the cases of Aspendos, virtual bodies were developed through automatic creation techniques based on a template body of their in-house application. They also applied real-world measurement data together with manual revision and refinement (Magnenat-Thalmann et al., 2007). Available historical information was employed as a reference. The same methods of model generation were also used to create the Thermopolium simulation. In this work, it can be seen that the researchers made more efforts to model and simulate ancient hairstyles. All these three cases used facial modelling which worked to synchronise the lips of the characters with what they were saying.

The performance of the virtual characters was carefully planned based upon the situations and activities that generally took place at the sites in the era. For the simulation of the Hagia Sophia as a mosque, the Morning Namaz Prayer was chosen. The movement was organised with the cooperation of historians, architects, and scientists, who supervised the authenticity of the project. Motion capture was used with a person performing the Namaz Prayer using a VICON optical motion-capture system (Foni et al., 2007). For the simulation of Roman sites, three Greek performances were chosen- the Agamemnon of Aeschylus, the Antigone of Sophocles and a choral song. Furthermore, two situations depicting daily life in Pompeii, taking place in the Thermopolium of Vetutius Placidus and in a garden of a neighbouring villa respectively, were prepared. With regards to the choreography of the ancient Pompeian life, the researchers tried to reproduce particular scenes illustrated on the frescos located at the site, as well as the dialogues engraved there. Moreover, a group of expert screenwriters worked on the main scenario, with the support of Archaeologists and experts in ancient Pompeian life, to guarantee the historic validity of the scenarios being re-enacted. In both projects, a VICON Optical Motion Capture system based on markers was applied to animate the virtual models. Some videos of actual actors performing the scenarios, organised with the support of historical consultants, were used to assist the procedure (Magnenat-Thalmann et al., 2007).

The simulated outcome of Hagia Sophia was exhibited through a virtual reality application implemented in a PC system (Foni et al., 2007). In the case of Aspendos, the interactive real time simulation was controlled by a keyboard and a mouse, and displayed through a polarized screen that allowed a 3D perception of the virtual environment (Magnenat-Thalmann et al., 2007). The advantages of these virtual reality systems were that they allowed open control by users, who could use it to observe the virtual building and humans from any angle at different distances. While the simulations of Hagia Sophia and Aspendos exhibited large architectural structures with complex geometry, the augmented reality system of Pompeii displayed a scaled-down scene which simulated human life through a HMD (head mounted device) that connected the actual site with the simulation (Magnenat-Thalmann et al., 2007). Moving the direction of the HMD, virtual characters could be seen in various angles.

The general features of the representation of virtual costumes in these works can be summarised as follows:

Firstly, the projects tried to produce credible costumes based on historical information from literature, images and relics, including frescoes and mosaics. However, the appearances presented were slightly simplified. Although the shapes of the garments from these periods were generally not complicated, decorative elements and details did not appear except on textiles and some supplementary objects. It seemed as though the researchers were more focused on the representation of the overall silhouette of the dresses and the structure of the clothing to reflect the historical and cultural aspects of the time, and tried to avoid delicate and complex outfits in consideration of the constraints of real time simulation.

Secondly, the garment simulations in the movies appeared to possess some limitations. Except for the costumes used in the simulations of Pompeii, the movement and drape of the costumes in response to the characters' motions were not distinctively observed. They looked unnatural, as though they were stuck on the body. Accordingly, the aesthetic elements and the realism of the costumes were not completely expressed. The researchers admitted that the garment preparation was limited due to some constraints underlying the real time simulation (Foni et al., 2007; Magnenat-Thalmann et al., 2007). In the Hagia Sophia simulation, the garment and body was produced as one single mesh. The dresses in the virtual Aspendos were separately created, however dynamic movement was not shown in the simulation of the scenes. Furthermore Magnenat-Thalmann et al. (2007) stated that even the real-time animation of the costumes used within the Pompeii simulation was not physically right.

Thirdly, digital costumes of these projects had the advantage of facilitation of observation. Through the virtual or augmented reality systems, the costumes can be monitored from various angles. In the case of Hagia Sophia and Aspendos, not only the garments but also the architects could be displayed at different distances. Moreover, the integration of virtual historical life with historical costumes, and the inclusion of sound and speech, may enhance the realism and contribute to audience immersion. At the same time, it provides interesting experiences, along with an understanding of the historical and sociocultural characteristics of the time.

Though this study pointed out some weaknesses with regards to the virtual garments, it cannot be denied that the primary purpose of these works was not to further better observations of the aesthetics of the costumes. It is observed that these projects achieved their genuine purpose, which was not only to attempt the virtual restoration of heritage sites and their accompanying social life but also to give viewers a feeling of interactive engagement. The virtual garments in their work played a role as basic elements in composing the shape of virtual life.

5.1.3 High Fashion Equation

“High Fashion Equations” was the 3D animation project in which MIRALab more intensively focused on the visualisation of garments. This project was undertaken for the *Robert Piguet* exhibition in Yverdon les Bains, Switzerland, and took place in 2005. It was arranged by the Swiss Fashion Museum in collaboration with MIRALab. The research team generated virtual dresses from the illustrations of 18 haute couture designs by Marc Bohan, Serge Gu´erin, and Hubert de Givenchy (Volino et al., 2005).

Haute Couture dresses are one the most sophisticated forms of clothing, made of exquisite materials and delicately created patterns. These distinctively tailored pieces that only a small segment of customers can afford are not merely coverings for the body but masterpieces reflecting current cultural features, inclinations, and trends. In this project, the overall process of the creation of such unique garments depended on information gleaned from the designers’ sketches. Volino et al. (2005) underlined the uniqueness of the artistic Haute Couture illustrations as an informative medium, as well as artworks describing the cultural aspects of a dress corresponding to a specific time. However, the information presented within the drawings required individual interpretation to visualise the stereoscopic garment shape, since the drawings only presented the object in two dimensions.

Considering the nature of sketch, experienced specialists who could interpret what the 3D forms of the dresses would look like created the dress patterns. The patterns were designed based on certain construction rules as well as information derived from the investigation of past fashion trends (Luible and Magnenat-Thalmann, 2008). For garment generation, MIRALab’s Fashionizer, a virtual garment prototyping system, was used and the process followed several phases.

In order to derive the fabric properties and colours of the garments, the researchers referred to the tiny cloth samples attached to the illustrations. However Volino et al. (2005) mentioned the difficulty in applying the swatches accompanying the Robert Piguetdesigns. The swatches provided on the drawing were too small to conduct the

KES-F or a similar test. Hence alternative fabrics that were similar were used to obtain the physical parameters. The input parameters of the system were physical parameters such as gravity and collision distance. Furthermore, detection modes and fabric mechanical properties such as elasticity, surface density, bending rigidity, friction values, Poisson coefficient, viscosity and nonlinear elasticity values were also taken into account (Volino et al., 2005). In order to select similar cloth, the researchers depended on the descriptions provided about the structure and fibre components (Luible and Magnenat-Thalmann, 2008).

Figure 5.5 Original illustrations and virtual dresses of High Fashion Equations (source: Swisshouse, 2010; Magnenat-Thalmann and Volino, 2005)

For the visualisation of textile colours, the handwriting information on the drawings which sometimes did not accord with the fabric samples though played a role as prior references. Since the original colours of fabric samples were degraded as time went on, the team put more weight on the importance of handwritten information. Then the similar colours were chosen through a fabric library and photographed. Then the images were processed to be repeated for texture mapping. Additionally, the representative style of buttons and buckles in 1940’s were also photographed to be expressed as details through mapping (Volino et al., 2005).

The generation of virtual models were carried out regarding the general female curved body shape of that time as well as the ideal beauty of specific period which was represented by the appearance of body silhouette in the drawings. Reflecting the exaggerated temporal trends, the typical wasp waist in the post-war time was modelled as excessively slim form combined with a regular female body in the 1940s. The team tried to produce a model which has both traits of abstract body and realistic body. In order to allow a direct affiliation between illustrations and virtual dresses, postures illustrated on the drawings and natural walking were recorded as the motions of the virtual model using the Vicon Motion Tracking System (Volino et al., 2005).

5.2 3D Costumes of Turandot in Puccini Exhibition

There has been a case that 3D virtual costume display was actively applied for a physical exhibition, titled “La Scenadi Puccini” (“Puccini Set Designer”) in 2003 at the Ragghianti Foundation in Lucca, Italy. Displaying a variety of objects such as the original illustrations of costumes, scenery and settings ideated by Puccini and miniature stage sets, it tried to highlight Puccini as an inventor in opera set design describing not only as a great composer but also as a specialist in costume design as well as special effects (Sparacino, 2004b). For the plan of the exhibition, a team consisted of a main curator, scenography specialists, a multimedia and interactive experience curator was organised.

The exhibition featured its effort for manipulations of a variety of high technologies based on the purpose of introducing Puccini’s work to all people of different ages from different backgrounds through an innovative exhibit method involving interaction methods and an experienced designer. Applying modern technologies such as synchronised projections, wearable computers and 3D animation, the exhibition constituted “body-driven multimedia narrative spaces (Sparacino, 2004b p.5).”

The noticeable aspects of the exhibition were the applications of 3D stage set reconstructions and 3D costume animation. The 3D theatrical sets, one scene of each Puccini’s well-known operas, Schicchi, Manon Lescaut, Fanciulla del West, Tosca, Madame Butterfly and La Bohème and five sets of Turandot were reproduced from Puccini’s drawings and displayed in the form of holograms and architectural animations. Especially, for his last opera Turandot, the team made special effort not only for the 3D sets but also for recreating 3D virtual costume. Taking seven arias and five stage sets that Puccini designed, 3D simulations of characters singing with costumes were created (Sparacino, 2004a).

For the representation of the characters, the team attempted to duplicate the original drawings as much the same as possible and particularly paid huge attention to the costumes to portray the aesthetics of them (Sparacino, 2004b). The systems employed were Alias Wavefront Maya 4.5 for virtual actor modelling and animation, and the Syflex plug-in for cloth simulation. However, the process of virtual costume generation was not elaborated in the available literature. Sparacino (2004a) stated that the team devoted laborious works to generate realistic drape simulations of costumes which ideally accorded with the virtual figures' movement.

(a) Original illustrations (b) Virtual characters

Figure 5.6 Original illustration and virtual characters (source: Sparacino, 2004b)

As the viewers were expected to mainly concentrate on the costumes than other features of the virtual characters, the team granted some degree of vagueness of to the countenance and hands of the 3D figures by applying transparent and luminescent effects. However, in the case of lips of the characters, the team strived to synchronise its movement with the aria in order to provide the audiences an impression as if the virtual singers sung. Since the original costumes of the first opera of Turandot in New York were an important part of the display, the scenes for the animation were chosen from the same performance. As a result, a total 12 minutes of animations generated by a group of four character and cloth animators and the completion of the work took around six months (Sparacino, 2004a).

The animations were planned to display through the immersive cinema and wearable devices. The immersive cinema is the space which enables users' involvement. It consisted of an animated interactive mat of light, a camera and two computers and a huge projection. When a user input command on the light mat by motion, the camera captured the user. Then his or her location, shape and movement are identified by the computer and the projection appeared the output3D virtual actors singing according to the user's command. The room for the immersive cinema was installed next to the space where the actual costumes were displayed to help the audience to easily compare the actual and virtual ones (Sparacino, 2004a).

Another display method, a wearable device named Museum Wearable which was an interactive augmented reality tool. It provided the audio-visual information about the artworks according to the users' interests through the analysis of their path and time which spent to appreciate display. This device comprised of a heads-up display which produces a video clip and virtually embeds in the user's sight when they observe the actual environment connected to a lightweight small-size computer, and headphones. Using this device, the team intended to make an impression as if the 3D characters come out of the illustrations when the audiences approach them (Sparacino, 2004b).

At present, the completed animations and the photographs of the original costumes are not available. However some features of the work could be found based on the several original illustrations and 3D results shown in Sparacino's (2004b) study.

First, the silhouettes and the shapes of the 3D costumes were roughly similar to the drawings. However, the forms of the costumes did not appear delicate details on the illustration in general. For example, garment layers and folds were sometimes not separately configured as the original illustrations and details such as necklines were omitted. Also it is questionable whether the virtual costumes were constructed based on the garment patterns due to their somewhat vague structure to some degree.

Although Sparacino (2004a; 2004b) stated that the team made a great effort for realistic drape, the virtual costumes did not appear sophisticated in their shape. Especially, compared to the illustrations and the images of original costumes, the overall shapes of virtual drape looked quite different. Besides, the material parameters to realise drape were not specified.

In terms of the visualisation of textiles, the team seemed to take the patterns as they appeared in the original images. However, the proportion and arrangement of the motifs were not exactly the same as the references and sometimes distorted. In addition, omission of the colour and simplification of accessories such as shoes and headdresses were other factors which lowered the degree of completeness.

There were some differences in appearance between the virtual actors and drawings. It seemed that the shape of the virtual bodies was prepared compromising with the silhouettes depicted in drawings, body forms in real-world and some degree of animational aspects.

In display methods, the exhibition attempted innovative approaches. While conventional showcases provide one-sided text or image-based information in general, this exhibition focused more on visual storytelling methods adopting interactive devices which reflected audiences' preferences and interests. It is anticipated that such methods might more encourage visitors' participation and absorption offering enjoyable exploration.

As a whole, the virtual costumes in this project appeared less detailed but the harmony of garments and accessories delivers the distinctiveness of characters and atmosphere of the background. In some respect, the defects in the garment representation can be seen as the results that the team depended more on the 2D illustrations rather than actual costumes as basal resources for the garment modelling. It is regarded that some extent of imagination and arbitrary modification or exclusion might be applied during the virtual costume production process according to the producers' cognition in illustration. If the virtual garments were generated for fashion show or display, the accuracy and quality of the work was not good enough for such purposes. However, the goal of the exhibition was actually to illuminate the Puccini's talents for stage design and the character animations were a part of the exhibit. In this respect, this study considered that the animations were created at an adequate level considering technology available in that time and underlines the effort to use technologies for amusing presentation.

5.3 Empress's New Clothes

The virtual costume project led by Jane Harris named "Empress's New Clothes" is one of the simulation works presented at a relatively early stage that started to give more priority to curational aspect and to highlight the potential of the academic reproduction of dynamic expression of costume. Through this project, Harris attempted to apply 3D computer graphics and motion capture technology into the research and visual art practice collaborating with an organisation and specialists in various areas: Museum of London, a fashion designer, a 3D computer graphic operator, a choreographer and Vicon motion analysis. The team attempted to create a highly sophisticated digital product where computer graphic intrinsically performed as a method to present costume on the screen (Harris, 2004b).

(a) Original costume (source: Harris, 2004a)

(b) 3D costume (source: Ual, 2015)

Figure 5.7 Original and digital costumes

Robe à la française which consists of a robe, stomacher and under skirt in the Museum of London was selected as a subject of the project which typifies the ideal female style in the 18th century. The process of digital reproduction of the costume included following stages: (1) mounting and presentation, (2) photographing, (3) technical drawing, (4) construction of the 3D costume, (5) choreographing movement and motion capture (Harris, 2004a). According to Quinn (2010), Alias Wave front Maya was used for garment creation however the exact method and application of fabric properties were not mentioned.

To enhance the plausibility, the motion of the virtual figure was designed based on 'The elegant art of the eighteenth-century movement' by Annas (1983) and performed by a person wearing a corset, crinoline and heels to mimic the custom of Georgian women (Quinn, 2010). The movement was captured and imported into the virtual body for dynamic simulation of the dress. The final outcome of the project was produced as a 40-second animation and displayed with the original costume at the Museum of London in 2004.

Harris viewed that her project achieved successful collision detection of multi-layered clothes, convincing expression of silk fabric and advanced digital fabric, weight and kinetic movement. However, there were some difficulties mentioned such as cling film-like behaviour of virtual fabric and individual rendering of garment layers. Although her project made good use of the high technology of the time, this study points out some weaknesses which could be further strengthened with the use of technology available today (Quinn, 2010). First, the garment form and volume presented some differences from the original dress. This study presumed that the reflection of more accurate garment patterns, structure and fabric properties which may be able to improve its shape. Second, expression of details and small decorations such as oblong frills were not distinctively represented and sometimes not rendered. Third, the texture of the fabrics appeared less realistic merely overemphasising creases. It is considered that more investigation into shaders is required.

5.4 Fashion Curation '13

The MA fashion curation graduates of London College of Fashion introduced a different approach of 3D costume generation in the "MA'13 the London College of Fashion Graduate School Exhibition" in 2013 with the collaboration of LCF Fashion Digital Studio and a videographer. Their project featured its challenge to integrate the online site, inexpensive and user-friendly systems and content in order to enrich the experience of costumes in the exhibition space through the use of different technologies which provided a website which was designed to encourage online participation, a fashion film projected by immersive environment and 3D scanning to generate the virtual costume object of this project.

According to the overview of the project (Capacete-Caballero et al., 2013), there were little cases of 3D scanning in fashion and curation realm due to the deficiency of institutional proficiency in digital technology and finances demanded to attain high cost equipment. In this project which proposed the use of 3D scanners as an advanced documentation and archiving method, a cost-effective scanning system was employed. By scanning costumes, the project explored the potential of the 3D virtual object which may provide truthful reality having advantages of conservation.

The applied software for garment modelling was a mobile phone application called Autodesk 123D Catch launched in 2012. The system creates 3D objects from photographs which are taken from varying angles. The developer recommends the user to prepare at least a loop of about 20 sequential digital pictures placing some marks around the subject. The construction of 3D model is automatically carried out through the matching feature process by cloud computing when the users upload the files. The application is currently free and the project team took note of its advantages of accessibilities and cost effectiveness for the use of capturing a costume.

(a) WW2 coat

(b) Layered skirt

(c) Digital costumes

Figure 5.8 Original and digital costumes (source: Fashion curation '13, 2013)

The virtualized garments for the exhibition were chosen from the Arckiv collection of private collector Fraser Laing. Archive known as a menswear fashion label today has been developed by the collection of male working clothes and military uniforms ranging from the early stage of 19th century to the 1940s. The selected objects were a coat in the Second World War, a layered underskirt which was produced for dress rehearsals in the English National Opera and a male undershirt which has an early 20th century aesthetic with buttons in the 1940s (Fashion curation '13, 2013).

The digital representation of costumes followed several procedures. In order to prepare the capturing process, three garments were first mounted on a mannequin: the skirt was worn on the shirt and the coat was slipped covering other two objects. Then markers were positioned on the costumes to enable the application to identify the surface and shape of the subject. Then 40 photographs of the mounted garment were taken at different levels by the application of an iphone and an ipad controlling exposure and focus. The captured images were submitted to the cloud sever where the pictures were converted into a 3D model and saved as an OBJ file. Subsequent stage was refining process which eliminated the traces of markings using Adobe Photoshop. Rendering was carried out in Autodesk 3Ds Max and the refinement and rendering process repeated to accomplish the improved images. The images for the projection in the exhibition were prepared as an animated sequence which showed a slow transition of the rotating 3D object from a mesh structure to the final outcome images applying Adobe

After Effects. For the interactive display of the 3D model, the images were imported to the Unity program, the freeware which allow the viewers to rotate with zoomed view of the rendered model.

The display of the transition animation of digital costumes was implemented in both physical and online sites. In the actual exhibition site, the continuous animation was projected on a transparent screen so that the audiences could appreciate the 360-degree rotation of the costumes from the front as well as from the back. The screen was installed in front of the original garments displayed in a flat state on the stand. Along with the transition animation, the interactive presentation of the digital images was available on the website. An installation of a web player was required to access the content which allows the users to manipulate the digital object using the mouse on their personal computer.

Besides, the immersive environment and the website applied played an important role as enhanced display and communication mediums associating with the original and digital costume display. The immersive environment which consisted of three screens was designed to surround the audiences through its triptych construction. The projected film showed garment response to the human act such as wearing, grabbing and sweeping to illustrate the relationship between the apparel and a living body. Combined with the sound and the film, the immersive environment was intended to offer the audiences a better impression of sensing costumes on display. The website tried to integrate the useful information offered online and the exhibition promoting the use of mobile equipment such as iPads available on the site or individual personal devices. The information shown on iPad replaced the physical signage of the exhibition as a digital information panel introducing more about the installation methods and the theme and helping the people to understand the context of the collection through communicating the viewpoint of the collector on the objects. The website also performed as a showcase providing the fashion film, interaction and 3D costume model which were the core constituents of physical installation.

The imagery of the 3D costumes in this project has the following advantages. First, the appearance of the virtual garments provided more accurate and realistic representation since their shapes were extracted from the photographs of the original objects. By means of scanning, the actual drape and volume of the mounted clothes were modelled as they actually were. Scanning will be the optimum approach for capturing and visualising static objects in terms of accuracy without causing manual errors. Second, the 3D model of the mounted costumes allowed observations from various viewpoints. Both animation and interactive content visualised the overall shape of garments: while the animation merely introduced the rotating images of costumes, the digital garments presented by the Unity player enabled the viewers to control the perspective. However, zoomed view and the perspective from lower angles were not available in this content.

There were also some weaknesses of the work that this study points out. Firstly, this attempt of digital costume display embedded some fundamental errors. For the exhibition, the different garments pieces were coordinated disregarding their genuine uses and gender of the wearers. It could be interpreted as new expression for some purposes, however, if an exhibition focuses more on each object and its meaning, such presentation of layered garments may confuse the audiences. Moreover, it is assumed that the mannequin used was not specified for the benefit of optimised display. The selection of the mount requires the gender and body shape of the wearer. In the case of this project, the plausible wearers of the Second World War coat and the layered underskirt may be a soldier or officer and an actress respectively. Although these figures were considered to have different body shapes, the garments were exhibited on a same mannequin in this project. It is assumed that the project put more emphasis on using technologies rather than the clothing itself. Secondly, the image quality was not good enough to clearly visualise the details. Although the system illustrated the overall shape of the costume in 3D, the subtle features such as buttons and seam lines were not clearly visible. Also, some pixels of the imagery were unnaturally stood out with regard to the quality. Thirdly, the scanning method applied could not display the appearance of discrete items and movement of the fabrics as the shape of garments mounted was modelled as one mass.

The project made up for some weaknesses of the virtual costumes through the integration approach. For example, the movement of garments which gives the impression of wearing sensation and thickness, drape and texture of the fabrics was alternatively expressed by a model wearing them in the fashion film. Also some garment details were introduced by the photographs which tagged with descriptions and links to other websites.

Additionally, this study points out some disadvantages of the scanning method using 123D Catch: constraints of identification of objects and limited quality of input data and outcome. There are some limitations in capturing objects. The modelling cannot be achieved if the garments are made of reflective, glossy or transparent materials. Also less identifiable features such as white plain fabric cannot be recognised by the system. Besides, there are other restrictions on environmental conditions such as the magnitude of the space and light. In order to satisfy the requirements of its curational use, the digital collection needs well-elaborated presentation. However, the high resolution of image input is not valid because the maximum resolution allowed is 3 mega pixels and the quality of the resultant outcome could not be desirable. According to Capacete-Caballero et al. (2013), the better quality can be achieved when the object is small. Furthermore, the application still needs improvement for smooth operation.

Capacete-Caballero et al. (2013) evaluated that their demonstration of integrating technologies was successful and showed advantages of 3d scanning method for fashion curation area. Although the digital costumes remained some drawbacks, the integrated methods mutually supplemented and reinforced each medium and their attempt implied the affirmative potential of the use of technology.

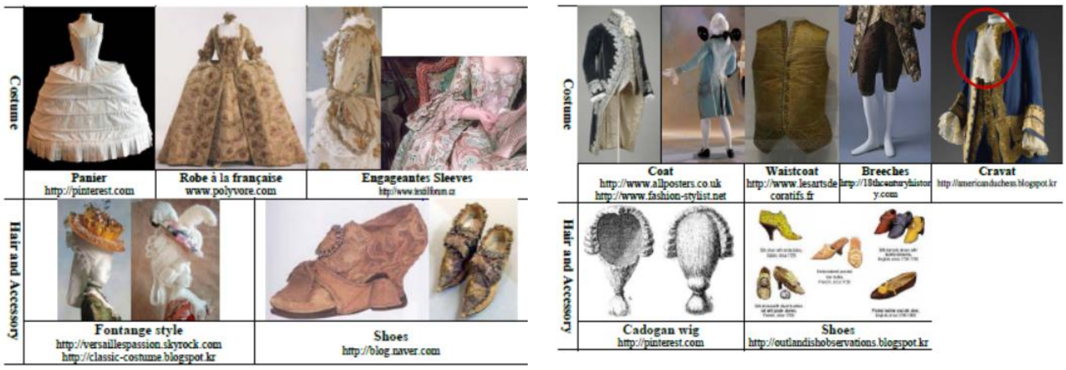
5.5 Digital Production of Rococo Costumes

The Digital Clothing Center which is the developer of virtual garment production software in the Seoul National University has actively worked on projects for cloth simulation and its various applications. They have demonstrated the capabilities of their system through a number of 3D animations based on different themes. For instance, a fashion collection using a variety of denims[21] and Transform dress animation (Wu et al., 2013a) stressed the possibility of their system which may replace the runway in real world and enhance the designers' creativity in a way of virtual fashion shows.

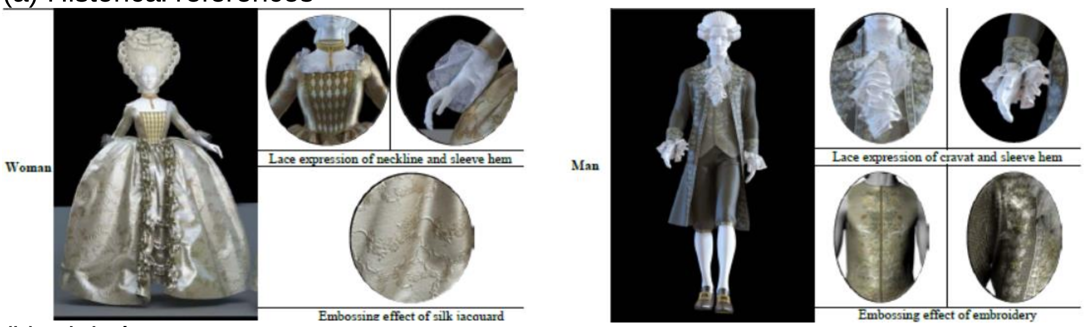
Exploring more effective use, the research centre suggested the potential of digital clothing technology for a better application of social tagging service for online costume museums. In Kang et al.'s (2013) work, the team produced two costumes using their system and Maya with a plug-in called Qualoth as experimentation for enhanced social tagging services of museum websites. The project planned to design the costumes in Rococo style in the 18th century highlighting its extravagance in fashion history. In order

[21] http://www.youtube.com/watch?v=uI8751R6dGY

to assure the plausibility of the results, the team searched and used the images of Rococo costumes on the internet as references conducting the study on fashion history. Based on the investigation, two garment designs which represented the classic style of the high class outfits were determined. Figure 5.9 (a) shows the resources applied.



(a) Historical references



(b) Digital costumes

Figure 5.9 Historic references and digital costumes (source: Kang et al., 2013)

The process of the project is as follows: (1) virtual body production in Maya (2) pattern making in DC Suite (3) panel generation, (4) body import into DC Suite, (5) panel placement, (6) 3D fitting simulation, (7) garment transfer into Maya, (8) textile generation, (9) textile and texture mapping and (10) simulation and rendering. This procedure required several times of switching applications part-way in terms of achieving optimised results in each stage.

According to the data collected, the composition of garments for each model was defined: a suit with a coat, waistcoat, shirts and cravat for a male figure and a *robe à la française* with *engageantes* sleeves and a stomacher for a female character. The garment patterns were produced in DC Suite. Through this process, some detail elements of the references were substituted to another form. For example, the tuck decoration of the skirt was replaced by gathering due to the limits of the technology.

The virtual models which would support these costumes were modelled using Maya trying to refer to the body shape of the people in the 18th century. They especially emphasised the slim waist and a full bosom of the female body to actualise the typical X-shaped silhouette of the gown in the past. The hair of the male and female model was modelled in the forms of *Cadogan* wig and *Fontange* style with a large frame respectively. Besides, the colours of the skin were excluded. Such representation of body enabled the costumes to stand out more. Also the motion of walking of the female figure was naturally designed but the position of the arms was widened to avoid excessive collision with the dress.

The accessories were also modelled in Maya. A pair of low-heeled shoes with buckles was produced for the male character and a necklace, jewelled shoes and a panier with bell-shaped frame were prepared for the female model. In the case of the panier, it can be regarded as a part of the garment. However, in this work, it was generated as an object which just had the same silhouette of the actual panier and fixed onto the waist of female body to follow the body movement sustaining the voluminous skirt shape.

The generated garment panels and the bodies were integrated in both systems. In DCS, the panels were assembled and draped on the designed bodies to examine their qualities in terms of the accuracy and fit. For the final outcomes, the garments and bodies were simulated in Maya with a Qualoth plug-in.

For the visualisation of fabrics, the team selected jacquard, lace, brocade and silk which were frequently used in the 18th century as main materials and tried to reproduce them. The mapping sources which described the fabric features such as colours, texture and other details like lace and embroidery were produced using Photoshop. In order to enhance the realism, they even expressed the embossment of the fabric surface applying bump mapping and shading effect. The rendering was carried out in Maya with V-ray plug-in.

Kang et al. (2013) estimated that the major strengths of the outcomes were their feasibility as exhibits which could allow dynamic display from various perspectives and virtual demonstration of the wearing of costumes, and their realistic visualisation of different textiles. Besides, the researchers admitted some limitations of the projects which were incurred during the process. Firstly, some decorative elements of the original dress were not reproduced. In fact, the dress in the references was adorned with tucks and *Watteau* pleats on the waistline and neckline at the back respectively. However, their system was not capable of implementing such sewing techniques. For this reason, the team excluded those components and in the case of tucks, gathering was applied to substitute for them. Secondly, the researchers stated that the stiffness of the fabric of the gown was more rigidly expressed than the reference material. Thirdly, shrinkage and puckering were observed in the production of the skirt and flounce detail of the gown.

Although Kang et al. (2013) underlined the outcomes' potential for digital exhibit and their application of social tagging for museums, this project was completed at the level of demonstration of garment production. The final animation the Rococo gown and some images of the costumes are shown on their website[22] to promote their system. Based on the outcomes presented in their report (Kang et al., 2013) as well as on the website, this study discusses the quality of the work. In general, the animation and images showed higher quality pictures than other projects stated in previous sections. However, there were some weaknesses with regard to garment shape, detail and movement of the dress.

Firstly, apart from the omission of tucks and *Watteau* pleats stated above, some components of garments present differences from the reference data. In terms of garment shape, the trapezoidal silhouette of reference skirt was expressed as a bell-shape. Also the overskirt of the virtual gown did not form the A-shape opening in the centre as the original and accordingly, the details of the underskirt were not displayed. When it comes to details, some elements were eliminated or simplified. While the lace was decorated around the squared neckline of the dress in the reference and the simulated image, the decoration did not appear in the dynamic simulation. Also bows which were attached to the stomacher were omitted on the virtual dress. The flounce of the sleeves which consisted of several layers of a fabric and lace was simplified to two layers of lace. Additionally, the decorations on the overskirt, the shape and arrangement were modified in different form. In the case of the man's coat, it is regarded that the centre contour line of the front pattern was supposed to be designed more on the slant so that more distinct difference in length between front and back would be made as the reference image. However, it is thought that the amount of available data to precisely reproduce entire parts from references would not be enough since the project was not

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[22] http://www.physan.co.kr/

based on the data directly taken from the real costumes. Therefore, it may not be achievable to perfectly replicate the structure of the garment. This study considers that this project recreated the plausible costumes in Rococo style successfully reflecting some typical features of that time from relevant images.

Secondly, the simulated movie appeared somewhat to have unnatural movement of the gown which arouse from the one-sided collision of the dress with the panier. Since the panier in this work was not shown over the costume, an object with panier-like shape was produced to perform its function considering the efficiency of the work. However, a panier is actually an undergarment which consists of fabrics and other materials. Although some stiff materials such as animal bones were used to maintain the shape of the garment silhouette, its body is not solid. In other words, it has movement affected by not only the motion of the wearer but also the weight and movement of the dress which is worn on it. Therefore, the movement of the robe needs to be simulated taking into account the interactive collision between the gown and the panier.

Thirdly, material parameters of fabrics which determine the simulation result were defined by the fashion experts relying on their intuition based on the experiences. Thus the outcomes were the products of simulation of plausible fabrics and as a result, its dynamic simulation was visualised against the expectations of the team as mentioned before.

Nevertheless, the outcomes showed the good quality and completion of the work. Particularly, the overall presentation of textiles and details were sophisticated. For instance, the lustre on the jacquard, embossment of embroidery and patterns of the laces were very detailed and realistic. In addition, the hair styles of the time and inclusion of accessories enriched the completeness of the work.

This work can be seen to be more like rearranged costume designs rather than the restoration of relics. However, the team produced meaningful outcomes making better use of the techniques of their technology. Also the work implies the possibility of exhibition of digital replicas of artefacts with high quality.

5.6 3D Simulation for Historic Fashion from DHCC

The Drexel Historic Costume Collection (DHCC) is one of the well-established educational collections in the United States. The DHCC has been grown by the donations from Drexcel family and their extended relatives, retailers, designers and supporters and now it possesses more than 12,000 items including dresses designed by famous designers such as Charles Worth, Charles James, Vionnet, Fortuny, Adrian, Chanel, Dior, St. Laurent, Givenchy and other modern designers (Martin and Mauriello, 2013).

This organisation is noticeable in making an effort for digitisation of the collections. They have paid attention to the digital clothing technology expecting that it will help digital archiving of historic garments. Currently, they are working on a 3D simulation for a historic fashion project collaborating with the Seoul National University for the exhibition in the Winterthur Museum in Delaware in 2016 (Martin and Mauriello, 2013). In this project, 30 dresses of the HDCC were chosen to be virtually duplicated considering the aesthetic and status of the garments as well as their cultural relevance and historical meaning increasing the educational possibility of the items (Martin and Ko, 2011).

In terms of establishment of credible garment reproductions, the team focused on the external appearance of silhouette, structure, textile and details of the dress and physical features of virtual body such as height, circumference and proportion as essential aspects for historical accuracy (Martin and Mauriello, 2013). For the production of virtual replicas, they chose to apply a virtual garment generation system, DC Suite. The application features physical-based simulation, virtual body customization adjusting 82 body landmarks and instantly adaptable various body motions (Martin and Ko, 2011).

Applying DC Suite, the garment reproduction was carried out in the process of (1) measurement specification of the dress, (2) pattern development using measurement data, (3) panel generation, (4) input of material parameters and textile data (5) draping on the 3D body, (6) simulation and (7) rendering (Martin and Ko, 2011; Martin, 2013). In addition to this, the researchers mentioned that the material parameters were determined by the specialists in fashion design applying a qualitative study based on their experience treating similar cloths since the fabric test could not be applied due to the fragileness of historic cloth.

(a) Helena Rubinstein, Evening gown (b) Prototype 3D simulation

(c) Virtual Carole Lombard

Figure 5.10 Original and virtual dresses and virtual figure design (source: Martin, 2013)

Citing an example of an evening dress by Helena Rubenstein in 1931, Martin and Mauriello (2013) stated that the modification of the basic body in DC Suite was needed because the project required more precise representation of body specification identified by the original dress and this could not be achieved by the customisation function of the software. The appearance of the virtual model was constructed inspired by the iconic actress Carole Lombard in the 1930’s. The motion of the model was designed based on the movements and gestures of Carole Lombard and Irene Dunne in the movies of that time. The recording of motion was carried out with a human model who had similar height to the virtual one utilising a Vicon Blade system. Besides, a period corset bra and vintage shoes were worn under the motion capture outfit for more perfect historical description.

Since this project is still in progress, its final outcomes were not yet presented. Therefore, this study only discusses some features shown in the prototype virtual dress of Helena Rubenstein. The overall silhouette and the structure of the garment appeared fairly approximate to the original dress mounted on the mannequin. However, the aesthetics of the texture and patterns were not properly illustrated because the rendering quality of the images was not good enough. The design of the original gown was generally simple and had chrysanthemum-shaped motifs on the fabric and a large bow decoration on back as details. The arrangement and size of the motifs in both real and virtual dresses looked similar. However, the large bow embellishment did not appear on the virtual garment. In addition, the prototype garment was displayed on the body provided by DC Suite and any additional accessories which enhance the total image of the dress were not prepared yet. At this point, it is regarded that the virtual dress may require more procedures to enhance the quality and accuracy.

The team announced that the outcomes of the project will be displayed along with the original dress in the Winterthur Museum in Delaware. Also it is anticipated that they may also be used for the DHCC's another digitisation project named *digimuse*[23] which is a searchable database of good quality of photographs consisting of selected dresses in DHCC and the gowns lent to the project (Westphal, no date).

5.7 Discussion

In this study, comparisons were made of the projects based on the role of the digital costumes; virtual garment creation methods and characteristics; attributes of the virtual figure; and display methods through simulated outcomes if accessible; while using other references including existing literature, developer websites, and relevant videos and images. Through the analysis and comparison, this study discussed the general tendency towards the use of digital costumes and its advantages and disadvantages to suggest desirable directions for the effective creation of virtual costumes and its application.

5.7.1 Analysis of the Projects

The results of the analysis are presented in Tables 5.1 and 5.2.

Most costume simulations were produced for exhibitory purposes. The majority of the costumes appeared as the main object to be displayed, and showed a good quality of presentation in general. In some projects, however, costumes were not the major object, but rather played a role as a supportive element for other subjects, such as historic monuments. The costumes in these projects tended to be less detailed and less realistic, probably for cost reasons. It is more desirable than the exhibition of

[23] http://digimuse.westphal.drexel.edu

costumes should be designed considering its clear aim for the better presentation of the dresses in generation and display excluding other factors.

As shown in the tables, the generation of the costumes was achieved using different methods: 3D apparel CAD, 3D modelling application and 3D scanning technique. Half of the projects applied 3D apparel CAD systems for costume modelling, and the outcomes presented more sophisticated structures as they were based on garment patterns. Moreover, most of the outcomes took advantage of dynamic simulation through the virtual garments. The Turandot costume project, which utilised 3D modelling CAD, also visualised garment movement using a cloth simulator plug-in. However, costumes in this work did not express accurate structural features and details. Some layered structures and decorations were visualised through mapping data or removed. The most realistic costume case was shown in Fashion curation '13, which applied a 3D scanning technique. However, 3D scanning outcomes do not have the capacity of simulation of dynamic drape. With the 3D scanning outcomes, the exposed surfaces of a garment are converted as a single object, disregarding its genuine structure.

The dynamic simulation of garment drape is considered as an interesting factor because it is not realised in the real costume exhibitions. However, accurate simulation is an ever-challenging issue constantly studied, as diverse variables have influences on it. Nonetheless, four projects attempted to apply particular fabric properties to the simulation. On all four projects, measurement and determination of property values were not specified. Although dynamic simulation is highly effective for visualisation of aesthetics of garment drape, static simulation is considered to have a merit of facilitation of audiences' observation without distracting their attention by switching momentary images.

The expression method of the textiles was not specified in many cases. In some projects, the images of the original textiles were applied to the digital garments. The others used alternative textiles suitable to the original design. The textiles of which visualisation method was not mentioned probably applied either of these methods or blending of fabric textures with other images to create plausible textiles depending on the availability of the original garment. However, the application of a textural feature was not certain in some cases whereas the colours of the textiles were more obviously presented.

Table 5.1 Comparison of earlier projects

		Flashback	Hagia Sophia	ERATO	Pompeii	High fashion equations
Purpose		Demonstration of technique	Enhancement of socio-cultural aspects of ancient life in VR/AR environment			Virtual catwalk
Costume	**Reference**	Movie “The Seven Year Itch (1955)"	Historical information (patterns, & textile images)	Historical information (fresco, mosaics, sculptures, literature, etc.)	Historical information (fresco, mosaics, sculptures, literature, etc.) & prototype	Original illustrations, fabric swatches & description
	Tool / technique	Physics-based technique	Not specified	In-house platform	Fashionizer	Fashionizer
	Material property	Mass, elongation, curvature elasticity, viscous damping, gravity, air speed & viscosity	Not specified	Not specified (general mechanical and collision detection plots was applied)	Not specified (general mechanical and collision detection plots was applied)	Gravity, collision distance, elasticity, surface density, bending rigidity, friction, Poisson coefficient, viscosity and nonlinear elasticity
	Texture & colour	Not specified	Not specified	Not specified	Not specified	Fabric library & photographs
	Subsidiary item	Not specified	3D modelled	3D modelled	3D modelled	Mapped
	Features	Not based on garment structure	Single mesh structure of character with costume	Garment pattern-based	Garment pattern-based	Garment pattern-based
Figure	**Modelling reference / features**	Actress "Marilyn Monroe"	Not specified	Real-world measurement & historical information	Real-world measurement & historical information	General female body shape & body silhouettes in drawings
	Posture	-	-	-	-	Poses in illustration
	Motion	Lowering arms Dynamic drape by wind	Morning Namaz prayer Movement No dynamic drape	3 Greek performances (Agamemnon of Aeschylus, the Antigone of Sophocles & a choral song) No dynamic drape	Performance based on frescos & scenario by archaeologists & other experts Dynamic drape	Natural walking & spinning Dynamic drape
Display	**Venue**	-	-	-	On heritage site	Robert Piguet exhibition
	Medium	-	PC system	Mouse, keyboard & polarized screen	Head mounted device with camera, laptop & wireless trackball	Not specified
	Style	Animation	Real-time simulation	Real-time simulation	Real-time simulation	Animation
	Features	-	Open control	Open control	Augmented reality	-

Table 5.2 Comparison of earlier projects

		Turandot	Empress's new clothes	Fashion curation '13	Rococo costumes	DHCC
Purpose		User-interactive exhibition contents	Visualisation of garment movement	User-friendly exhibition contents	Demonstration of technique	Digital exhibition contents
Costume	Reference	Original costume drawing	Original costumes, photographs & technical drawings	Original costumes	Historic information (photographs & illustration)	Original costume
	Tool / technique	Alias Wavefront Maya 4.5 & Syflex plug-in	Not specified	Autodesk 123D Catch	DC Suite, Maya & Qualoth plug-in	DC Suite
	Material property	Not specified	Not specified	-	Parameters determined by fashion experts' intuition based on experiences	Parameters determined by a qualitative study with fashion experts based on experiences
	Texture & colour	Not specified	Original textiles	Original textiles	Similar fabric samples	Original textiles
	Subsidiary item	3D modelled	-	-	3D modelled	Not specified
	Features	Not based on garment patterns	Not specified	Single mesh structure of torso with costumes	Garment pattern-based	Garment pattern-based
Figure	Modelling reference / features	Vague faces & hands	Semi-transparent figure with no features	Torso mannequin	Body shape in the 19th Century	Actress "Carole Lombard"
	Posture	-	-	-	-	-
	Motion	Performances in premiere in New York	Choreography by Ruth Gibson	-	Walking	Movements & gestures of "Carole Lombard" & "Irene Dunne" in the movies of that time.
Display	Venue	La Scenadi Puccini exhibition	Museum of London	MA'13 the London College of Fashion Graduate School Exhibition	-	Winterthur Museum
	Medium	Immersive cinema & wearable device.	Not specified	Transparent screen & Unity web player	-	Not specified
	Style	Animation	Animation	Animation & interactive contents	Animation	Not specified
	Features	Story telling through Interactive augmented reality tool	Display with original dress	Association of different media on-site & online	-	-

The virtual figures in most cases were produced based on specific references: (1) historical research or illustrations and (2) appearance of the public figures. Reflecting the appearance of people or an iconic figure of a certain time may enhance the plausibility and harmony between costumes and the overall atmosphere giving an impression that the dresses worn on more humane bodies.

On the other hand, three of the projects took rather vague expression in forms excluding some features or applying the effects such as translucency and luminosity. The ambiguity of the virtual models may help the audiences' attention to the garments and mitigation of any concern regarding the identity of the wearer.

The presentation of costumes took either a form of animation or interactive display. Animation was a little more often applied, and tended to be more dynamic. The reason may be that more delicate and vibrant expression could be visualised in animation since animation merely played the rendered scenes premade. Whereas the performance of costumes in interactive contents especially real-time simulation which allowed various perspectives controlled by a user could be constrained by the data processing of the device. However, more enquiring exploration may be better supported by the interactive and user-controlled environment than the one-side presentation of the animation.

Display methods in some cases were explained in detail. Most projects had an intention of the exhibition onsite or online and used different types of equipment. Although it was not clearly mentioned, the costume animation probably required relatively straightforward installation, such as a screen. In the case of interactive contents, costumes were projected through the wearable devices, computers and portable personal devices. Although the interactive contents may enable more stimulating display, installation of appropriate display systems or having personal devices can be regarded as an important consideration for the effective utilisation.

5.7.2 Desirable Directions for Digital Costume Development

From the findings of the comparison exercise, this study could draw several considerations which are addressable and feasible for more effective digital costume generation. Suggesting the factors which may produce improved outcomes, this study provides rationale for the purposive approach to development of digital costumes as exhibitory and educational materials which may supplement the limitation of costume collection in section 4.1.3 and general disadvantages of online museums, which appeared in section 4.3.2.

First of all, more faithful reproduction can be attempted through improvement of delicacy of design elements and retainment of authenticity reflecting the original costume. In the earlier projects, lack of reality was observed mainly due to the absence or negligence of structural foundation, which led to the unnatural shape with incorrect visualisation of silhouette, line and proportion. Other design elements such as fabric colour and texture and details were not clearly expressed in some cases. This study contends that these garment elements should not be overlooked or omitted in reproduction and should be established based on the measurement and analysis of the original artefact for reliable presentation in a genuine sense. However, discreet reproduction, which involves in-depth historical research and manipulation of existing resources, may be considered when conservation issues are concerned or the costumes no longer exist.

Second, various virtual fabrication of scenes can be realised through static and dynamic simulation of costumes. The simulation methods can allow a range of experimental effects on the costume; poses and motions which were inhibited in physical displays can be visualised. In most projects, movement of garments was virtualised to demonstrate dynamic drape in place of fragile or inexistent costumes. Such a dynamic effect is expected to arouse audiences' interest and to reveal the aesthetics of garments. The utilisable aspect of virtualisation suggests boundless potentialities for digital costumes. This study highlights the utilisable aspect of virtualisation which suggests boundless potentialities for digital costumes to be developed not only for audiences’ interest, but also for a more effective appreciation and satisfying academic curiosity.

Third, interactive and stereoscopic appreciation of costumes can be realised applying various display methods. There were some cases where open control was applied to enable the users' exploration from different perspectives in VR or AR environments. As a media, various types of devices such as a PC system, Unity web player or wearable device could be applied onsite, online or both. Since each method has different strengths and weaknesses, the selection of the method will need some consideration depending on the purpose and main functions of digital costumes.

These main considerations indicate three desirable attributes for effective digital costume development: (1) faithful reproduction based on the design elements of the original garment to give authenticity, (2) virtual fabrication to satisfy audiences' appreciation, interest and intellectual exploration; and (3) interactive and stereographic appreciation. Adopting some desirable aspects of earlier projects, this section clarifies the applicable methods related to the concepts suggested. Figure 5.11 illustrates the factors applied to the earlier projects and the factors adopted to this study.

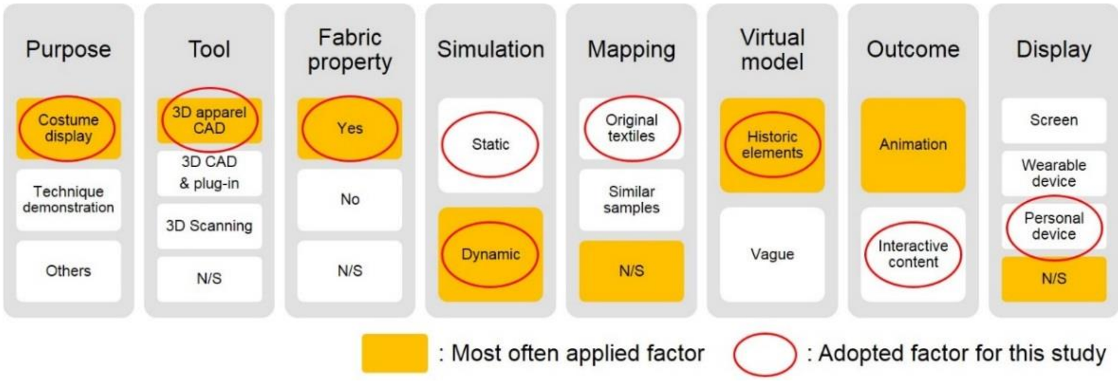


Figure 5.11 Factors applied to digital costumes

The focus of this study distinctly aims for the exhibition of the digital costumes which the faithfulness in shape holds a core part. Based on the review of the virtual garment generation techniques in section 2.2 and comparison of the earlier projects, 3D scanning and 3D apparel CAD were regarded as the most appropriate methods. However, 3D scanning was excluded from the consideration because the technique does not entirely satisfy the second concept of the effective digital costume in terms of dynamic fabrication and has limits to scan some materials and a large garment.

Although 3D scanning is a strong technique for accurate surficial presentation, the structural factors of garments are not incorporated to the outcomes, and the outcome merely unifies superficial features into a single shape. Accordingly, the underpinning and all coordinated garment items are not able to be separated from each other. Such limitation brings restriction on dynamic effects of garment simulation. Also the other constraints on dimension, shape and material of the object addressed in section 2.2.3 signified that 3D scanning may not be applied to certain garments.

3D apparel CAD was regarded as a more effective method which generated the digital clothing with similar characteristics to the physical garments than the other digital techniques because its construction is based on the garment patterns which reinforces the structural aspect of the garments and morphological elements of the design. The review of the earlier projects also confirmed the advantages of 3D apparel CAD in use of the accurate garment patterns, such as elaborate structure and drape simulation, derive from the shape of the body and fabric properties.

This study expects that sufficient reproduction of costumes will be possible using 3D apparel CAD if historic references are thoroughly interpreted into 3D objects. To enhance the fidelity, the digital costumes need to be generated based on the data collection through the measurements and analysis of the original dresses.

This study established the morphological aspects applying the actual costume patterns and measurements and visualisation of texture and colour utilising the images of the surface of the original materials. The digital costumes combined with the original components is anticipated to bring the significant improvement in realism than the earlier works.

Additionally, historic references can be reflected to other elements to further strengthen the historic atmosphere of a certain period. This study attempts fulfil the historic sense of coherence and completeness in preparation of the auxiliary elements within the possible range of application. Many of the earlier projects appeared to use some accessorial components which may enhance the completion of costumes and historical atmosphere: coordination of subsidiary items and reflection of historic and cultural aspects to the virtual figures through appearance, pose and motion.

The second concept of effective digital costumes, which is the fabrication of simulation, takes into account three aspects: aesthetic appreciation, inducement of interest and educational information. While earlier projects were inclined to the dynamic simulation, this study applies both static and dynamic expression taking different advantages. It is considered that static simulation has a merit of facilitating observation minimising dispersion of the audiences' attention and dynamic simulation may stimulate the audiences' synesthetic imagination to feel weight, texture and sound of the dress through the visual excitation. Although virtual simulation enables diverse manifestation, this study specifies three types of simulation to be targeted considering time constraints. First, aesthetically expressed static simulation which helps appreciation. Second, rhythmic expression of garment movement which arouses audiences' interest. Third, deconstruction process which delivers scholarly information on garment structure.

To achieve drape simulation, which shows different characteristics of fabrics, adjustment of system parameters is required. However, the earlier projects tended not to clarify how fabric properties were determined and applied. Although it is not sure whether the parameters were reasonably set or not, this study assumes that there were three reasons which obscured the application of fabric properties. First, physical testing of the costume materials should be avoided to prevent any potential damages. Second, utilisation of the similar fabrics can be suggested as an alternative -- however objective selection may be constrained if investigation of original textiles is restricted or not available. Third, there may be technical difficulties in measurement and translation of the material properties into CAD systems.

The simulation using built-in or plug-in of 3D CAD and some 3D apparel CAD such as CLO 3D does not cooperate with quantifiable properties except for weight. Hence the application of fabric parameters is dependent on the user’s intuition. There are 3D apparel CAD which supports the use of objective fabric measurement methods: Optitex 3D Runway which accommodates KES-F and FAST, Fashionizer and Lectra 3D Fit which allow KES-F, Physan DC Suite which provides the translation method of KES-F properties and Browzwear VStitcher which recommends the use of its own fabric testing kit. Although the capability of these 3D apparel CAD software implies the possibility of more realistic simulations, the feasibility of reflection of fabric characteristics can be hindered by the availability of the required testing apparatus and psychological burden of the users especially designers on unaccustomed scientific experimentation.

This study makes the most of the possible methods to demonstrate the measures worth considering for drape simulation. From the perspective which advocates the conservational concerns, selection of the alternative fabrics is suggested based on subjective comparisons with minor touch of the original textiles under the supervision of a curator. In the case of fabric measurement and translation of the properties, this study follows the guideline of DC suite as this system was regarded as the appropriate tool for the purpose of this study in section 3.6. A successful result is not assured because of the constraints. However, this study provides some foundation for future research.

A range of state-of-the-art technology can be applied to realisation of interactive and stereographic costume display. However, choice of the method has restrictions on the following aspects. First, development of digital costumes in this study places emphasis on facilitation of individual access and use of the costume. This means that the application of the media is confined to the ubiquitous devices. Second, the aim of this study is based on the premise of utilisation of digital costumes for online exhibition.

Therefore, suitability of the media and outcome format for online operation is considered essential. Additionally, the technology which requires costly installation is excluded from the consideration.

Based on these conditions, a user-controlled VR system, which can be accessed through the common web browsers using a personal computer, is regarded as applicable to interactivity and stereographic display. Although the sense of realism and immediacy may relatively be outdated than the personal VR devices that are currently prevalent, this approach has less constraints on expense and facility for both the developer and users. Unity 3D is proposed as the system development tool because the software has the capability to produce outcomes compatible with various platforms. This allows the publication of the contents for a range of new media including internet, websites, computer multimedia, CD-ROMs and DVDs, accessible on various digital devices.

Figure 5.12 illustrates the summary of the concepts of the effective digital costumes. The methods considered in this section were applied to the design development process in Chapter 7 to embody effective digital costumes and the functions and implication are discussed in Chapter 8.

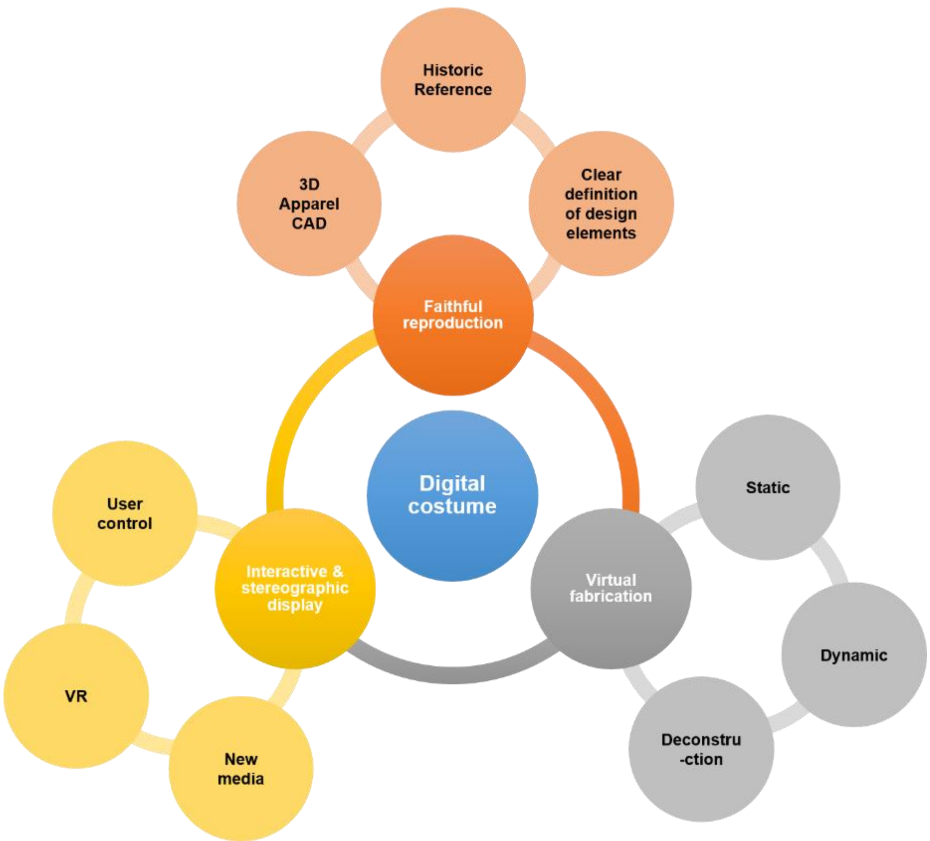


Figure 5.12 Concepts of effective digital costume

5.8 Summary

This study considers the virtual reproduction of the costume as an advantageous method which enables facilitated construction and allows unlimited public access maintaining the value of the artefacts. In order to specify the concrete direction and methods for the development, this chapter explored the methods and features of digital costumes of ten earlier projects and clarified the advantages and disadvantages by comparison. The general tendency and identified characteristics are as follows:

- Role: display of costumes, demonstration of techniques and supporting other 3D objects
- Garment construction tool: 3D apparel CAD, 3D CAD with a plug-in and 3D scanning
- Simulation type: static and dynamic
- Textile mapping: original fabrics and alternative fabrics
- Expression of virtual model: historical references, iconic figures and vagueness in features
- Presentation: animation and interactive display
- Display method: screens, wearable devices, computers and portable personal devices

Based on the analysis, three addressable factors were drawn for effective digital costume development which may generate improved outcomes more suitable for the exhibitory and educational purposes and supplement the various constraints mentioned in Chapter 4. The feasible methods to satisfy the suggested factors and their advantages are as follows:

(1) Faithful reproduction

- Reflection of historic references: enhancement of fidelity through measurement and analysis of original costumes and historic research
- Use of 3D apparel CAD: reinforcement of the structural aspect and morphological elements by accurate patterns, expression of design elements and drape simulation
- Clear definition of design elements: improvement of reality through a detailed illustration

(2) Virtual fabrication

- Static simulation: aesthetic appreciation with facilitation of observation
- Dynamic simulation: inducement of interest
- Deconstruction simulation: provision of educational information

(3) Interactive and stereographic display

- User control: operation by the user's intention
- Virtual reality: elimination of physical constraints
- New media: facilitation of individual access

This chapter provided the desirable concepts as the guidelines for digital costume development. These specified concepts were embodied through the process of design development practice described in Chapter 7.

Chapter 6: Research Methodology

This chapter outlines the research strategy and explains the selection and reasoning of the methods applied for the study.

6.1 Introduction

This study takes a form of pragmatic inquiry to convert a problematic condition into a desirable one through the design of artefacts. Pragmatism, which attaches significance to the knowledge as “a constructive way to contribute to change and improvement” (Goldkuhl, 2011, p.87) is in accordance with the future-oriented nature of this study. Its approach, which allows eclecticism in determination of methods, is considered most appropriate for this study which involves various tasks in different domains.

Pragmatism is “a school of thought that considers practical consequences or real effects to be vital components of both meaning and truth” (Hevner, 2007, p.91). To the pragmatists, the authority of science is “to facilitate human problem-solving” (Powell, 2001, p.884). From the pragmatic view, truth is “what works” (Robson, 2011, p.28) and “what is useful” (p.53) as well as reality is considered as “the practical effects of ideas” (Anderson, 2013, p.40). The epistemic attitude of pragmatism is not only to describe the existing world but also to intervene into the future with a view to construct a better world (Goldkuhl, 2012). Current truth, meaning and knowledge, is regarded tentative and mutable. Pragmatic approach is aware of practical matters being led by practical experience than theory. Theory is considered to become truth depending on how it works. It supports strong realistic pragmatism as a way to determine what is effective (Robson, 2011).

According to Goldkuhl (2011), pragmatism has been suggested as a suitable approach in many information system (IS) design research. He emphasised that following epistemological bases of pragmatism can justify fundamental qualities of design research:

- The focus on utility, usefulness and contribution to practice
- Knowledge development through building and intervention

- Problematic situations as a starting and driving point for inquiry and design
- The search for what is possible and desirable
- Going beyond description; aiming for prospective, normative and prescriptive knowledge

These foundations are considered to appropriately pertain to this study since it essentially shares some general purposes and characteristics with IS design research. Furthermore, an IS is included as a part of the artefacts of the study although small scale. The research strategy in the following section is designed considering the establishment of these epistemological foundations.

The purpose of this study is not merely to design (Chapter 7) and evaluate artefacts (Chapter 8) but also to identify the current status of the problem (Sections 4.1.3 and 4.3.2) and assess the existing artefacts to develop a desired model (Section 5.7.2) and to explore the phenomenon which happens during the development process seeking new insights. By doing this, this study accomplishes the aim and objectives providing knowledge contributes to the design practice and new ideas for future research.

6.2 Research Strategy

6.2.1 Bricolage

The main subject of this study deals with is costume reproduction and the application of 3D apparel CAD. Although it fundamentally rests on the field of clothing-related study from a global view point, the research is multidisciplinary covering computer graphic technology, curation, and further IT. To accomplish the objectives, this study uses a procedure which requires different types of techniques and data with different natures. For this reason, this study demands highly flexible research design and therefore a bricolage approach is used to facilitate the most appropriate selection of methods for this study.

The term “bricolage” is derived from French which is similarly understood as English expression of “making-do” (Yee and Bremner, 2011), “DIY (do-it-yourself)” (Gordon, 2013) or “tinkering” (Louridas, 1999). However, there is not a precise equivalent word in English for this term (Louridas, 1999). The term was introduced by the book of the

Claude LéviStrauss titled “The Savage Mind” (1966) and defined in an anthropological sense as an improvisatory creative action which utilises any resource available for accomplishment of desired results (Yee, 2012). The use of the term and its concept initially rooted in qualitative research in social sciences (Kincheloe, no date) and other fields of knowledge such as entrepreneurship, IS, pedagogy, economics, biology, politics and art have employed them.

In design research, bricolage has been introduced as a useful and essential notion as it approbates combining available and formulated strategies, methods, and creation of new means and techniques to express questions beyond the domain of the established knowledge. (Yee and Bremner, 2011). Table 6.1 shows the concepts of bricolage suggested in design research. Based on the concepts in Table 6.1, this study understands bricolage as follows: It is a technique of design for the future which uses multiple and various methods to generate new and creative outcomes. The design process led by the activities which re-appropriate, combine and connect the tools and resources culturally and materially available conglutinating knowledge and actions. The activities have creative and contextual improvising nature which is not restricted to the conventional principles.

Table 6.1 Concepts of bricolage

Longo (2009)	▪ A form of design and construction alternative to the classical principles of engineering and architecture: given the unbreakable bond between knowledge and action. ▪ A technique for planning the future. ▪ A form of creative and contextual improvisation of paramount importance.
Wängelin (2007)	▪ Use of multiple, diverse research methods. ▪ A way to understand the design process as a more complex activity
Yee and Bremner (2011)	▪ Activity of re-appropriating and combining elements into new and original outcomes ▪ Combining methods from social sciences, humanities and hard sciences.
Viļumsone and Dāboliņa (2012)	▪ A way of making which draws on what is already there both culturally and materially. ▪ A practice that favours making connections between the tools and materials at hand.

The distinctiveness of bricolage is interdisciplinary and constrained but flexible application which may be seen as improvisation. The term normally indicates a process that traverses the borders of disciplinary and applies analytical frames of many fields of knowledge (Kincheloe, 2001). Such interdisciplinary nature is reflected through the “act of sourcing, comparing and combining different elements from different origins" (Yee, 2012, p.464) of bricolage. In bricolage, use of tools and materials is constrained to the elements at hand. However, these elements can be recombined and their use may be designed in a nonconventional way for different purposes (Longo, 2009), by the requirements of the task and the bricoleurs' intentions.

In bricolage, a bricoleur uses and reinterprets the functions of the elements for the current task. Bricoleurs are fiddlers or tinkers who resourcefully and creatively use materials at hand to construct new outcomes out of the existing things (Yee, 2012). They do not require equipment and knowledge of all businesses and professions (LéviStrauss, 1966). However, they operate on the basis of interpretations of connection between the elements they encounter (Vallgårda and Fernaeus, 2015). Bricoleurs are guided by the purpose or goal (Longo, 2009) while drawing on their experience in their acts (Vallgårda and Fernaeus 2015).

Yee and Bremner (2011) claimed that methodological bricolage is necessary and a valid approach in design research because of the indeterminate characteristic of design. Yee (2012) also emphasised that multi-perspective and interdisciplinarity of bricolage is appropriate for attributes of the design questions viewing the activity of bricolage to re-appropriate and combine components into creative artefacts as close reflection of designers' activities. Additionally, the study of Lauridas (1999) and Wängelin et al. (2007) which highlighted design as bricolage comparing their similarities further supports the suitability of its use of design research.

Bricolage which connotes interdisciplinarity and flexibility can be useful for investigation of a particular problem or a specific matter. It has merits for facilitation of new idea generation, providing potentials to analyse design activity and identification of inner design process which connects research to design practice (Wängelin et al. 2007).

6.2.2 Research Design

The process of the research was designed based on the objectives of this study forming four main phases which embrace various activities. The process of the activities, tasks and resources in relation to the objectives of this study are illustrated in Figure 6.1. Following the designed process, this study attempted to answer the following research questions:

- What kind of technique is available and the most effective for digital construction of clothing?
- What are the constraints which lie in management and use of costume resources?
- What is the status of the displayed information of garment collections on costume and fashion museum websites?
- What are the methods and outcomes of earlier digital costume projects and what are the factors to be reflected in digital artefact design?
- How is the applicability of the digital costumes of the current technology for exhibitory and educational purposes and what effects would be expected?

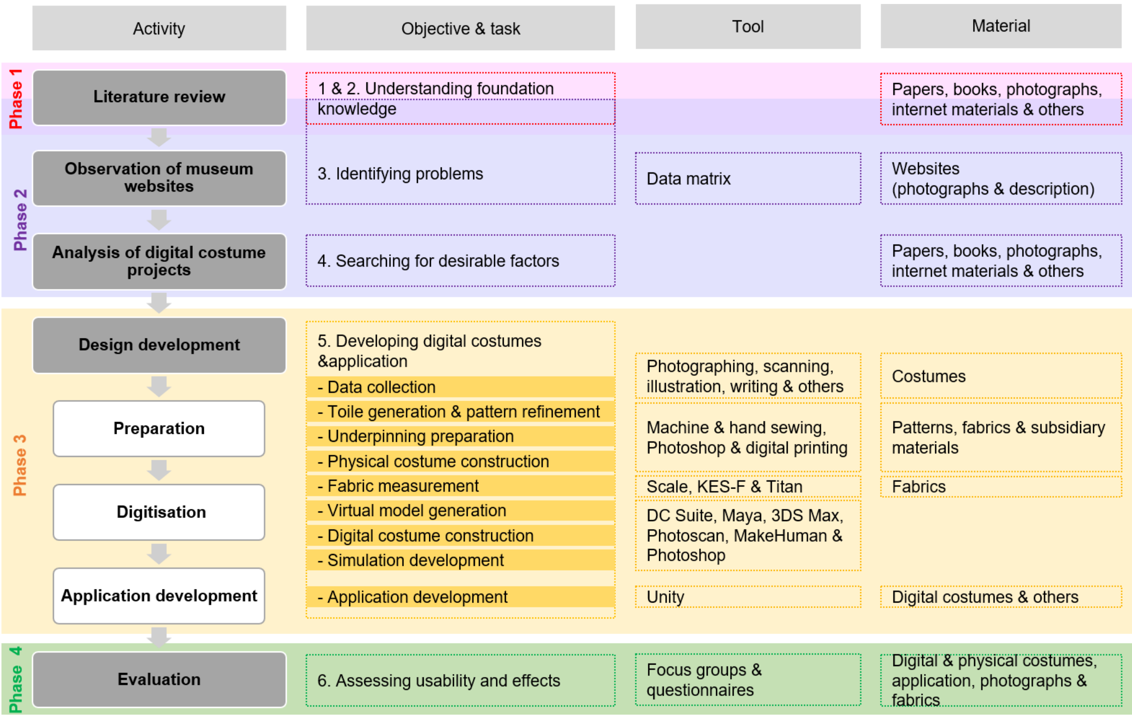


Figure 6.1 Research design

The first phase is the literature review to establish background knowledge to identify the research gap and its potential. This requires extensive exploration of knowledge about digital clothing technology, 3D apparel CAD, costume museum and new media.

The research gap is intended to be further developed through the following phase by investigating the limitations of data on the museum websites as a problematic situation. The features of earlier digital costume projects are analysed to elicit desirable factors.

The findings of these activities are planned to be reflected in the design development phase as elements which could be re-appropriated for generation of new artefacts. These phases can be seen as the first step of bricolage where a bricoleur “has to turn back to an already existent set made up of tools and materials, to consider or reconsider what it contains and, finally and above all, to engage in a sort of dialogue with it and, before choosing between them, to index the possible answers which the entire set can offer to his problem” (LéviStrauss, 1966, p.18).

The materialisation of a set is then carried out in the third phase tinkering with the elements interrogated in the previous phases and physical and digital resources available. This design development phase consists of three stages: preparation, digital reproduction and application development; each stage entails different tasks. Firstly, the preparation stage is designed to provide the foundational base for reproduction of digital costumes. This includes costume data collection, generation of toiles, physical dress and underpinnings and fabric property measurements. This stage does not directly engage with the production of the eventual outcomes however, offers physical samples and data that replace the original objects in the museum for a conservational reason. The realisation of the actual artefacts is planned to be carried out on two levels at the second stage: digital reproduction of the costumes and underpinnings and generation of simulation data. Then the third stage plays a role in the development of a digital application and integration of the 3D data.

The final phase is prepared to evaluate the artefacts by focus groups in different levels: (1) digital application, (2) digital costumes, (3) digital costumes and application. Then research is concluded with the summary, discussion and recommendation for future work.

To summarise the process in a sense of bricolage, the first and second phases are prepared to specify a pragmatic situation and to explore the concepts of existing tools and materials. Their result would be the understanding gained and interpreted into the abstract objects from which the researcher was intended to elicit new meanings (effects). The third phase is designed to realise the abstract into concrete ones applying and adjusting the resources available. This activity could be considered the bricoleur’s response to the problems. Then the meaning of the materialised artefacts is examined through the assessment in the fourth phase. The evaluation is not only for examination of bricolage but also for future reflection of further re-appropriation for constant process of tinkering.

6.2.3 Research Model

To proceed the design development, two costumes were chosen as samples considering accessibility, efficient data analysis and variety of morphometric features: a day dress in the1860s and an evening dress in the 1920s. These costumes which presented a large number of contradicting features with a variety of details and techniques regarded ideal to examine the feasibility of the technology.

The aim of this study ideally requires the use of the original costumes in the museum for the completion of the artefact. In order to eliminate any potential damage to them, however, this study additionally required substitutes for the costumes which could be unconstrainedly handled and tested. For this reason, a physical replica of each sample was reproduced based on its data to represent the costume. Figure 6.2 illustrates the relationship between the sample, representative and model.

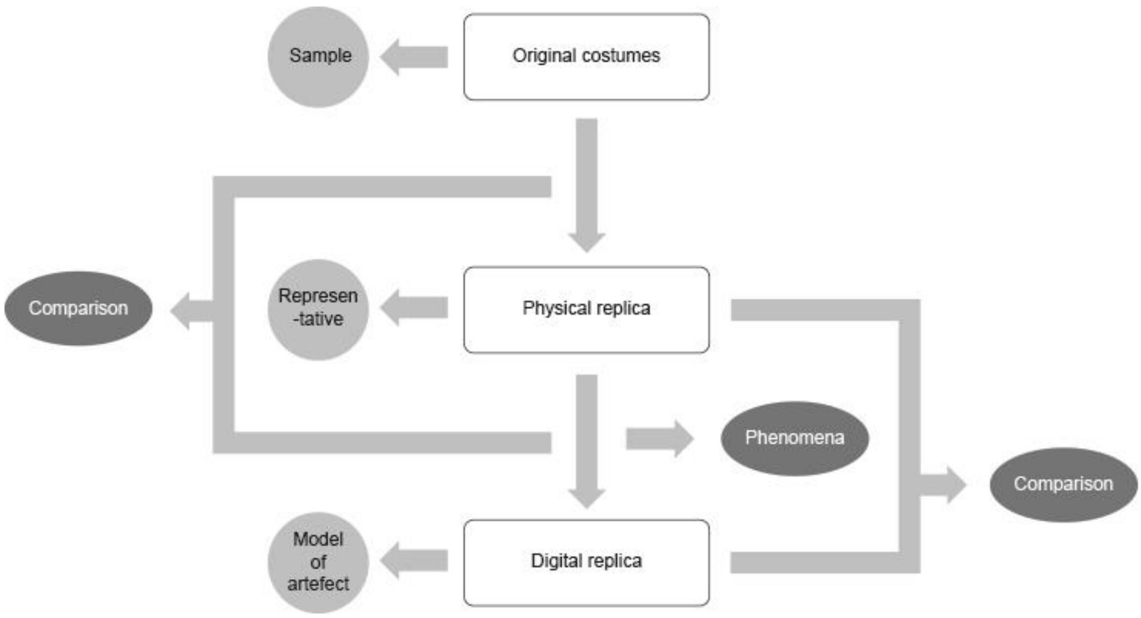


Figure 6.2 Relationship between sample, representative and model

The digitally reproduced costume that came from the representative plays a role of a model of the artefact. Through the models, this study intended to explore the design process, attributes, and effects of the eventual artefacts. It is meant to draw a theory from the phenomena observed during the digitisation of the representatives into models that can be applied to the digitisation of samples to models. It is also considered the theory may be applied to predict or explain the case that applies other samples. Moreover, the process in Figure 6.2 has additional merit to offer systematic design knowledge about conventional as well as digital reproduction methods through understanding, interpretation, and comparison of the experiences occurred during the practice of samples to representatives and representatives to models.

6.3 Secondary Research

A review of an extensive range of literature was conducted using diverse material including papers, books, magazines and internet resources for two separate purposes: (1) exploration of document to broaden understanding of the study area and to identify research gap for objective 1 and 2 and (2) comparative analysis of earlier projects to search for desirable methods and elements for design development for objective 4.

6.4 Primary Research

The primary data in this study was collected applying different methods depending on the objectives and tasks involved.

6.4.1 Observation

Objective 3 sought to understand the current situation and clarify the problems. For this, observations of museum websites were carried out to identify how museums use new media, focusing on costume information provision methods and types and quantity of the data. Two groups of museums were selected as subjects: ten museums in the UK and eight world museums. The data was collected through six objects randomly selected on each website and analysed using the contents analysis method. Content analysis is “a quantitative method that involves counting and summing phenomena in images or texts” (Muratovski, 2015) and it has advantage of generating persuasive results based on reliable and replicable evidence, and facilitation of presentation and reading (Stokes, 2003). This method was selected because the numeric feature of the results may objectively explain the current status of the situation and facilitate the understanding of overall tendency as well as comparison between subjects.

6.4.2 Fieldwork

Fieldwork was planned as a part of the process of the design development to fulfil objective 5. This step was necessary because the physical reproduction of dresses required meticulous information about original costumes. Thanks to the support of the Museum of London, fieldwork was carried out between 27th and 29th February 2013 in its archive under the supervision and help of curator Timothy Long. Information about each costume was investigated through the original costumes, underpinnings, publications and advice provided by museum. Table 6.2 shows the types of data collected and methods applied. The fieldwork offered abundant first-hand data that secondary research hardly provides.

Table 6.2 Costume data collection methods

Data	Methods
Dimension	Tape measure
Structure	Photographing & illustrating
Material	Photographing & scanning
Colour	Panton color cue & Panton color guide
Pattern	Tape measure, photographing, scanning & illustrating
Detail & technique	Tape measure, photographing & illustrating
Underpinning & others	Note-taking

6.4.3 Fabric Objective Measurement

Fabric property measurement was carried out to provide the input values of the parameters for virtual drape simulation as a converting stage of physical dresses into digital ones during the design development process. Measured properties were weight, bending, friction, stretch resistance and shear resistance which were selected based on the pilot exercises (p.191) and software manual. Six silk and one cotton fabric which were applied to physical reproduction were conditioned and tested using scale, KES-F and Titan at the textile lab in the School of Design, the University of Leeds. Scale and KES-F were selected because the manual provides guidelines for the data converting method for system input. KES-F is a system which comprise FES-FB-1 to 4 to assess 16 mechanical properties of fabrics by calculation of the low deformation forces. However, KES-FB-1, which was supposed to be used for estimation of stretch and shear resistance, was not available in the institution. Instead, this study adopted universal strength tester Titan and adapted its extension data to replace the data (EM and WT) of KES-F.

Table 6.3 Fabric properties and methods required

Parameter	Instrument	Measured property
Density	Scale	Weight (g/1cm^2)
Bending	FES-FB-2	B
Friction	KES-FB-4	MIU
Stretch resistance	Titan	Extension
Shear resistance	Titan	Extension

6.4.4 Focus Groups and Questionnaires

Focus groups and questionnaires were applied together for the evaluation of the research outcomes to fulfil the objective 6. A focus group is “an organised discussion among a selected group of individuals with the aim of eliciting information about their views” (Gray, 2014, p. 468). This method was selected because this study required an in-depth understanding of collective perspectives on the outcomes, and the interactions and discussions between respondents were considered to provide synergetic enrichment allowing observation of participants’ feelings, attitudes and reactions (Gray, 2014). In the evaluations, questionnaires were embedded in the focus groups. Questionnaires are the tools which ask respondents to answer to the same list of questions in a predesigned order (Gray, 2014). They were adopted in order to offer standards which enable the expression of the assessment with objective degrees using the five-point Likert scale. It is regarded that the use of descriptive data together with numeric narratives could offer more specific explanations with objectivity to some degree.

The evaluations proceeded on two levels: discrete appraisals of digital costumes and application and overall assessment of final outcomes. The first two evaluations were prepared to take note of detailed findings of each artefact. By separating assessments, this study intended to moderate more focused discussion. Moreover, the results of these activities were considered to further support the findings of the overall evaluation or provide additional insights.

Sampling was differently planned depending on the subject of appraisal and the number of samples were adjusted to be between five and eight to ensure sufficient range of perspectives and manageable operation (Moore, 2000). Firstly, convenient sampling was applied to the evaluation of digital application. Since its purpose was testing the usability of the application which put emphasis on universality, the assessment did not require particular types of respondents. A total of 11 M.A. students studying Fashion Management in the University of Huddersfield were recruited and divided into two groups. Secondly, purposive sampling was adopted for the evaluation of the digital costumes which compared their appearance. With the support of the Museum of London, seven curators and fashion and costume specialists in the museum took part. The sample was one of the stakeholders of this study with a great store of technical knowledge considered appropriate for rigorous assessment. Finally, purposive and convenient sampling was respectively planned for the overall evaluation. The representative samples were recruited considering the premise of this study which is the use of the artefacts by students and the public. While the target samples of one group were decided to be fashion majored students who have a good knowledge of garment structure and construction, the sample of the other group was conveniently selected based on the accessibility and availability of individuals. As a result, six second- and third-year students studying fashion design at the University of Leeds and six other general people were recruited.

Table 6.4 Evaluation plans

	Evaluation 1			**Evaluation 2**	
Subject	Application		Digital costumes	Digital costumes & application	
Sampling	Convenient		Purposive	Purposive	Convenient
Target	General public		Fashion/costume specialists	Fashion design students	General public
No. of samples	5	6	7	6	6
Focus group	Face-to-face				
Questionnaire	Paper-and-pencil				

The data of the focus groups was recorded through note-taking and audio-recording, and thematic coding analysis was applied to identify and classify the information of interests. This method has the advantages of the summarisation of the main elements of a large quantity of qualitative data and a relatively flexible level of interpretation (Robson, 2011). The quantitative data of the questionnaires were statistically analysed and translated into narrative and graphs.

Chapter 7: Design Development

This chapter addresses the development of the artefact models which may improve the problematic situation reflecting desirable factors identified in section 5.7.2 and provides design knowledge through a comparison of physical and digital reproduction processes and an exploration of the phenomena in digitisation of costumes. The development process consists of three stages as follows: (1) preparation, which builds physical foundation for digital reproduction, (2) digitisation, which converts physical objects into digital ones and (3) application development, which is a digital platform for displaying the outcomes in (2). This chapter explains in details how the procedures flow and how the artefact is constructed.

7.1 Samples

The design development required costume samples as the subjects for digital reproduction. The subjects were selected with the support and advice of the curators Beatrice Behien and Timothy Long in the Museum of London and following criteria was applied to consideration: (1) costumes which can be accessed for data collection; (2) costumes which had patterns that had already been analysed to minimise time consumption and handling during the investigation of garment structure; (3) costumes which appear as various features as possible.

Among the costumes collection of the museum, two costumes with patterns diagrammed by “The patterns of Fashion” (Arnold, 1977) were selected: a c1861-3 day dress, a c1911-2 day dress and a c1928-9 evening dress produced in the UK. They are the oldest and the newest objects based on the criteria above. These costumes were considered as presenting the most contradicting features in structure, silhouette, details, techniques and others. Since it may be difficult to generalise the characteristics of the existing costumes because their distinctiveness may vary widely, exemplifying a small number of dresses with large differences regarded feasible to study within the period of the study and worthy for future research. The characteristic features of the costumes are as follows:

The day dress in the 1860s is characterised by the tightly fitted silhouette of the bodice and the voluminous skirts made of double box folds round the waist. The silver-grey silk fabric with the prints of leaves and flowers covered a large portion of the shell and the charcoal grey silk which forms pleats around the neck-line and hem, and A-shaped insets play an important role as decorations. Also this costume displays delicate details such as fawn-coloured braid trims on both bodice and skirt and little picot-edged ruches inside the open sleeves.

The evening dress is a typical example of a trend in the mid-1920s, where short skirts gradually became longer. The dress was designed by Pilgrim and Claridge and consists of two items: a slip made of black silk and a dress made of black crepe silk chiffon. The slip has a relatively simple structure; however, the hem is picot-edged and zigzagged. The chiffon dress is decorated with a number of cloth sections around the bodice cut into triangular, petal-like shapes (Arnolds, 1977).

(a) Day dress in the 1860s (a) Evening dress in the 1920s

Figure 7.1 Original costumes (Source: Museum of London, 2014; 2015a; 2015b)

7.2 Preparation

The process of the preparation stage is categorised into three activities: data collection, physical production and fabric property measurement. The physical production is again classified into five tasks: pattern preparation, toile generation, pattern refinement, preparation of underpinnings and physical costume reproduction.

Theoretically, the concept of digital reproduction does not require this complex series of tasks. However, the last two sub-tasks were needed to build alternatives to original objects to allow handling and its use for experiment for their protection, these were required to the first to third sub-activities which identify and modify the errors.

7.2.1 Data Collection

Fieldwork was mapped out for a close investigation and data collection of the original costumes between the 27th and the 29th February 2013 in the Museum of London. Information about structure, dimension, material, colour, pattern, detail, technique and others were gathered using various methods under the supervision of the curator.

Figure 7.2 Data collection

First, garment structures, dimensions, detail and techniques were investigated. This study especially focused on attaining detailed data that Arnold’s book (1977) did not address and looking into specific garment parts which demonstrated complex structures, irregular shapes or sophisticated techniques by measuring, illustrating and taking photographs. This was regarded important because it is sometimes difficult to understand corresponding 2D images and text information to the complicated 3D structure of a garment.

Second, information about materials, textures, colours and patterns was identified. The material information was provided by both Arnold's book (1977) and the curator. The colours of the fabric were identified using a tool called PANTONE Color Cue which automatically analyses the colour from the target material. Each colour was measured three times for accurate analysis and categorised according to a PANTONE colour name. However, occasionally the colour of a small section was not precisely identified due to the lack of correspondence between the focus of the tool and the target area. Furthermore, the unevenness of the fabric sometimes yielded different outcomes. As an assistive secondary tool, a PANTONE Formula Guide and Color Libraries in Photoshop were additionally applied. Using this tool, the investigation identified the name of the colour that corresponded most closely to the sample. The textures and patterns of the fabrics were recorded by a digital camera and a scanner, and the size and space of each pattern motif was measured using a tape measure.

Third, information regarding the ideal body shape at the time, particulars about the mannequins and underwear such as a crinoline and corsets was provided by the curator Timothy Long. He demonstrated the process of preparing the mannequin for certain costumes and presented some crinolines and corsets from the same era as examples. However, measurements of the mannequins and the underwear matching each costume could not be carried out since these items did not correlate to the dresses. Nevertheless, the information was very useful in display of the costumes and this was taken into account during the preparation of the virtual bodies in digitisation process.

7.2.2 Physical Production

The aim of this stage is to generate costumes and underpinnings which would play roles as substitutes for original costumes, as objects of digital reproduction and as subjects for evaluation late on. This stage also demonstrates the conventional reproduction method which individual researchers or students might attempt.

7.2.2.1 Pattern Preparation

The patterns of each costume were drafted based on Arnold’s book (1977) and the data collected in the museum. Arnold’s book (1977) provides pattern diagrams illustrated in the proportion of one to eight. Patterns were constructed according to the shape of the eight time enlarged diagrams and the dimensions of each pattern were corrected based on the measurements of the data collection. Also there were some factors which needed further adjustments to achieve balanced shape. This study made alterations of patterns in the following cases and some critical modifications were determined based on the discussion with staff in fashion design in the University of Leeds.

First, patterns or seam lines of which corresponding parts presented large differences in shape or size. If such sections are joined together, the appearance of a garment may look distorted and abnormal unless it was intended. Also forcing assembling can cause critical damages of the fabric. Therefore, this study generally adjusted one part to fit the principal parts. However, the differences in size of arm holes, elbows and darts around the bust were excluded from the adjustment and those disparities were used for easing.

Second, asymmetric patterns which were supposed to be symmetric with respect to a certain axis were altered. In most cases, garment patterns have bilateral symmetric structure on the y-axis at the centre. When such patterns appeared asymmetrical errors, the patterns were revised mirroring one side’s based on the axis.

Third, patterns which displayed notable differences to the original costume in measurement or shape were altered. In these instances, this study altered the length or shape of some contour lines of the patterns trying to keep the original form of the other parts.

Fourth, descriptions which did not specify the definite shape of the costume parts were subjects to alterations. In Arnold's book (1977), there were some equivocal marks which indicated the approximate positions or size of the fabric pieces; Those were generally related to the decorative elements of garments which have a repetitive structure. In these cases, this study determined some standard positions or measurements and then equalise the propositions of positional or dimensional changes.

The modification patterns of most cases were carried out within the limit of 12.7mm (1/2 inch) which was the error limits allowed by Arnold (1977); however, some adjustments required the exceed of this limit. This study only allowed excessive alterations when it was unavoidable.

This study used DC Suite for pattern construction and modification because both physical and digital reproduction need to apply identical patterns. Then the patterns were cut using a laser cutter due to the unavailability of a plotter.

C1861-3 Day Dress

The Bodice

- Asymmetry of bodice patterns

The front bodice patterns appeared different in the shoulder, armhole, darts and hem lines. In order to maintain the symmetry, this study mirrored the right side of the bodice pattern and eliminated the part which was extended for the buttons.

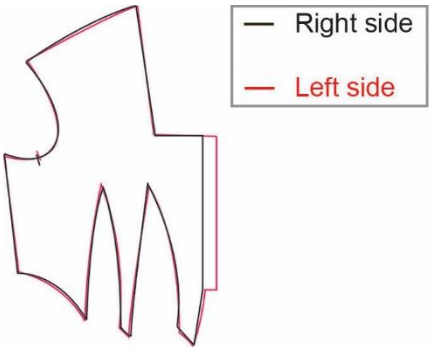


Figure 7.3 Asymmetry of patterns

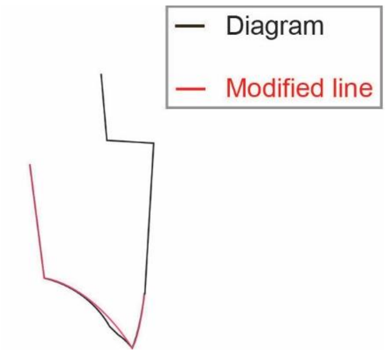


Figure 7.4 Uneven hemline

- Uneven hemline

The hemline of the bodice was not even in assembled state: the bottom lines next to the darts form a slight rugged shape. This study slightly refined the bottom lines to produce a smooth shape referring to the illustration and photographs.

- Incorrect position of decorative strip

The decorative strip in Figure 7.5 is designed to be mounted on each side of the bodice. However, the shape of the marked position on the bodice was in discord with the actual decorative strip. Firstly, the widths of the parts where the shape of marked position is divided by the dart were different from each other. Secondly, the angle and size of the shape of the mark were larger than the strip pattern. Therefore, this study re-established the position. Putting the edges of the dart together, and the contour line of the decorative strip was traced on the bodice.

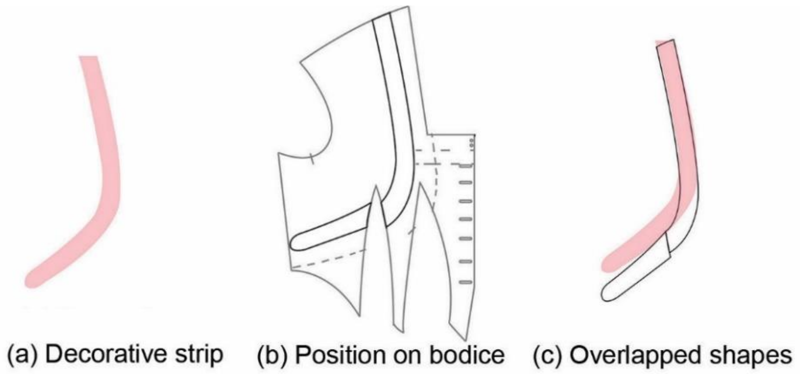


Figure 7.5 Incorrect position of decorative strip

- Uneven position of buttons and button holes

The bodice has seven buttons and holes at the centre to fasten. Since the position of each button and hole was not equally placed, this study adjusted their intervals regularly based on the top and bottom buttons.

- Pointed lines around back neck

The back bodice was presented as a folded pattern in half. The back bodice has symmetry with respect to the centre-back line. The neckline and the shape of the position of the decorative strip became rather pointed when the fabric was unfolded. As the lines of those parts of the original costume were rounded, the centre of the lines was flattened to form smooth curves. Also the shape of the back neck trimming was altered according to the modified neck-lines on the back bodice.

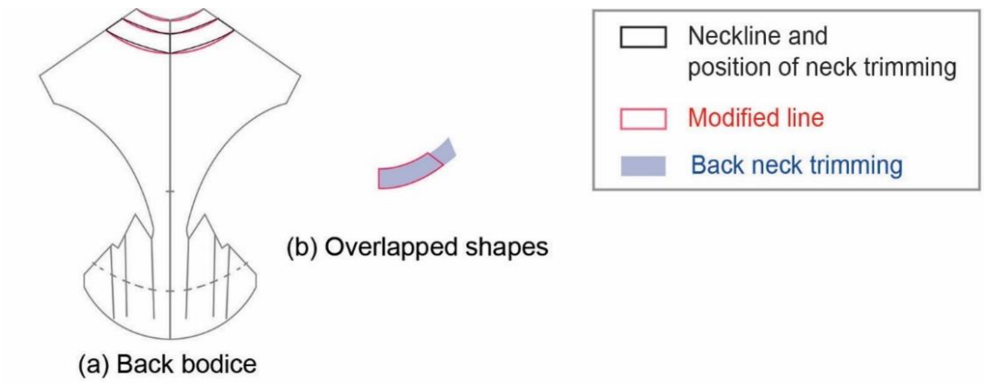


Figure 7.6 Pointed lines around back neck

- Side line of back bodice

Two tips on the bottom part of the side line of the back bodice are formed by the folds of the tail. This study neatened the line by folding the pleats based on the marks and cutting the side line.

- Unnecessary edge of side back pattern

As it is shown in Figure 7.7, the side back pattern has a very short line at the bottom. If the patterns are assembled as they were, the back hemline would have a small protrusive section due to this line. In this study this small edge was removed and sharp point was formed by welding the bottom points of the side and hem lines.

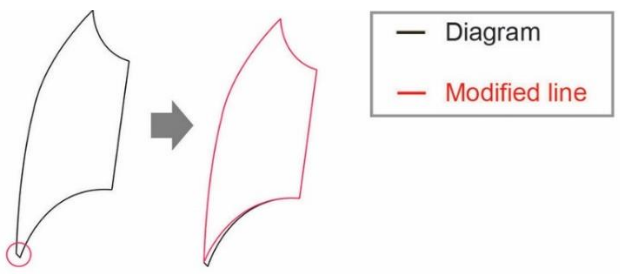


Figure 7.7 Unnecessary edge of side back pattern

- Incongruence of length of armhole lines

The front and back armhole lines of the bodice were measured 248mm and 158mm in length and Figure 7.8 displays the position of their joint edges on the sleeve. Since the length of front and back joint edges were 304mm and 138mm respectively, the incongruence of length differences between bodice and sleeve was emerged. If the patterns are assembled as the diagram, stretching and gathers are expected to be occurred by 20mm of shortage at the back sleeve and the surplus of 56mm at the front sleeve. In order to prevent such deformation, this study modified the bodice side seam position on the sleeve pattern so that the length of the back armhole line on the sleeve would be extended to match the bodice armhole lines.

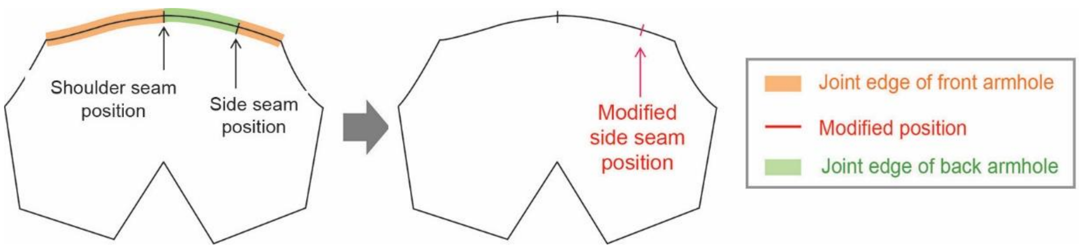


Figure 7.8 Incongruence of length of armhole lines

The Skirt

- Centre back skirt

Janet Arnold's book (1977) does not clearly illustrate the centre-back skirt pattern. While one side is drawn, the other side was not completely illustrated. This study considered that both right and left sides of the pattern are identical in appearance and modified the back centre skirt pattern to be symmetrical with respect to the vertical line drawn on the point where it meets the centre back waistline.

- Uneven interval of pleated panels

The interval of pleated panels on the hemline is slightly uneven. The gaps between panels were evenly adjusted based on the positions of the front and back panels.

- Pleated panel

The folds of the panel overlaps at the top according to the original costume. However, if the pleats are folded according the diagram, they do not overlap. Also the width of the folds is different from the real costume. Therefore, a new pattern is drafted as shown in the Figure 7.10, adopting the actual measurement and leaning the fold lines.

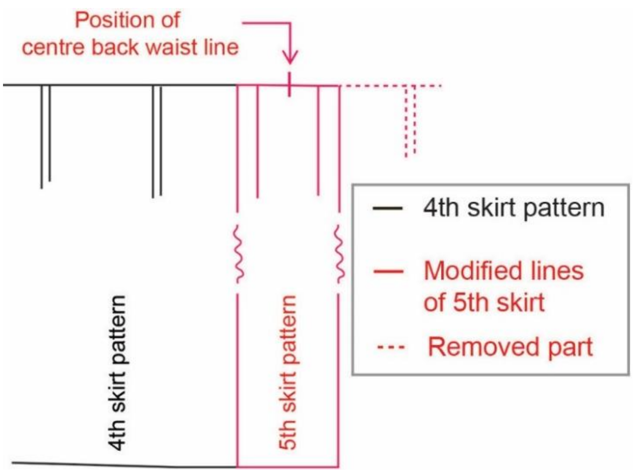


Figure 7.9 Centre back skirt

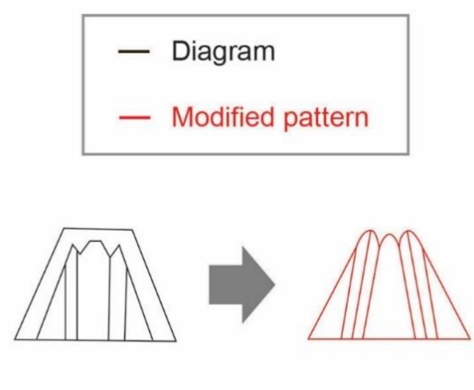


Figure 7.10 Pleated panel

C1928-9 Evening Dress

The Dress

The major changes of the dress patterns were as follows.

- Asymmetry of bodice patterns

The front and back bodice patterns had slightly asymmetrical shape. The right side of the patterns were altered reflecting the left side on the centre to take symmetry structure.

- Unequal lengths of Side seam lines

The side lines of these patterns showed slight differences: 81.1cm at the front, 81.5cm at the back. This study reduced the length of back side lines to match the front pattern.

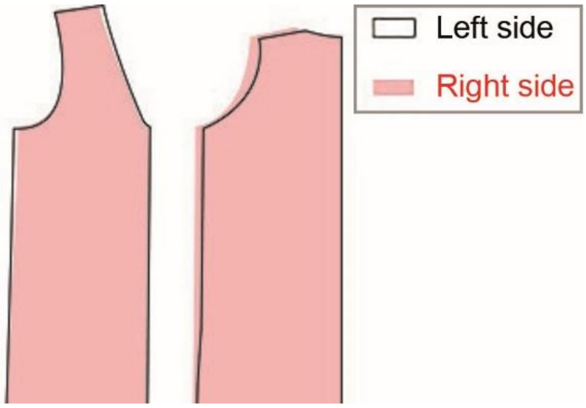


Figure 7.11 Asymmetry of bodice patterns

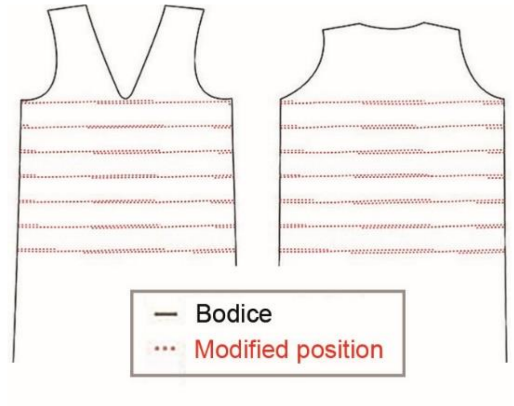


Figure 7.12 Modified position of petal shapes

- Irregular position of petal shapes

One of the distinctive features of the dress is the 28 pieces of cloths which reminds of petals around the bodice. On the surface, they look evenly arranged as if four petal shapes in seven layers are placed on the equally distributed levels. However, their actual positions are quite irregular. In Janet Arnold's book (1977), the author illustrated seven dotted lines on both the front and the back bodice patterns to guide their locations and the exact position of each petal shape was not marked. Her supplementary explanations are as in the following.

"The dotted lines mark the approximate positions of the tops of the petals shapes for stitching. ... They lap over and under each other alternatively. Each petal is mounted individually so that no two petals are stitched on the same line. ... The petal shapes were probably pinned into position when the dress was on the stand, so that they hang correctly. They are all mounted by hand. (p.77)"

According to the observation, however, the side tips of petal shapes did not overlap alternately and some petal shapes were sewn on the same positions or on the place far out of the dotted lines. Also they were stitched on the bodice or on the other petal shapes irregularly. Since the researcher was allowed to try only a delicate touch, more accurate methods such as contact tracing could not be conducted. For this reason, this study attempted to rearrange the positions surmising the design intention. It is assumed that the triangular cloths are intended to be sewn together forming a consistent geometrical shape but the irregularity appeared probably due to manual work based on the intuition when they are stitched. For the realignment, this study first adjusted the interval of dotted lines to be equal based on the top and lowest lines of the front and the amended the back patterns according to the front. In order to avoid the overlaps in the stitching of petal shapes on the same level, the position of each shape was determined to leave 2mm of space between them. Then the right side tip of each triangular shapes were placed to be covered by the left side tips of adjacent shapes.

- Rounded neck-line

The neckline of the dress was revised based on the test simulation in the study of Kang et al. (2014) by comparing the neck-line of the diagram and the simulation result. This study made an arbitrary decision that the neck-line of the front bodice pattern needs to be revised. In order to be faithful to the original form, the neck-line was redrawn to be more sharp. Based on the side neck points, two straight lines was drawn toward the centre point and then the edge where these lines meet were a bit rounded off as it is shown as red line in Figure 7.13(c).

(a) Original costume (b) Test simulation (c) Modification

Figure 7.13 Rounded neck-line

- Joint edges of petal shapes and floating panel

The dress has two layers of four floating panels which are attached to the bottom row of petal-shaped fabrics on the 7th dotted lines. However, the length of each joint edge of petal shapes and the panels appeared different. In the case of the front right petal shape, the differences of each side were 29mm and 17mm. The differences appeared 35mm at the maximum and 10mm at the minimum. In order to prevent the stretch of fabric, the length of joint edges of petal shapes were adjusted to the handkerchief points of the floating panels.

- Discordance of Armhole lines

While the length of front and back armhole lines of bodice were 235mm and 188mm respectively, the length of their counterparts on the sleeve pattern were 192mm and 200mm. If the dress is assembled according to these measurements, the fabric of the front sleeve will be stretched due to 45mm of size difference of armhole lines. For this reason, the modification of patterns was inevitable. Keeping the original shape of the sleeve, the width of the front section was extended to 15mm. The length of the front and back armhole lines of modified sleeve became 200mm and 232mm. In the case of bodice, this study tried to minimise the alteration. The armhole line of the front pattern was slightly reduced from 235mm to 229mm. The remnant which was generated by the differences in length of armhole lines of modified patterns was used for ease.

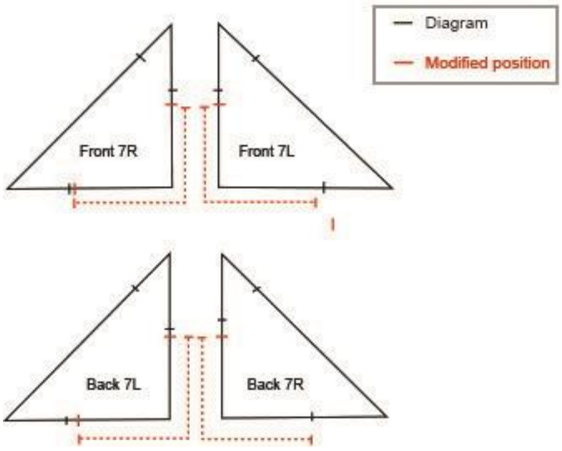


Figure 7.14 Modified handkerchief points

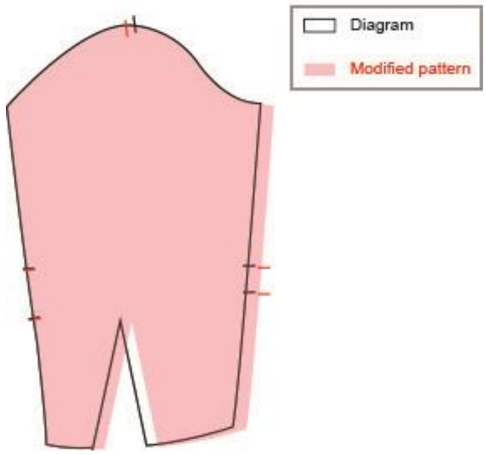


Figure 7.15 Adjustment of armhole line

- Discordance of length of seam lines of sleeve

The length of side seam lines below the position of the ease for elbow appeared as 165 at the front and 159mm at the back. The seam lines were modified to 162mm which is the median value of those two lengths. Accordingly, the volume of the ease of both sides was adjusted. Also lengths of the joint edges of the sleeve and cuff showed 5mm of differences. This study revised the length of the edges of the sleeve to fit the cuff.

The Slip

The slip consists of one large bodice and two straps and few minor alterations were carried out for the refinement.

- Asymmetry of bodice patterns

The front and back bodice was slightly asymmetries. To refine the sections where they were supposed to be symmetrical were revised by mirroring the left side of both front and back on the centre.

- Discordance of side seam lines

Since the front of the slip has two darts on each side, the length of the front had to be longer than the back. The length difference is normally predicted by the size of the dart. In this case, the size of two darts was 30mm. Therefore, the length of the front bodice was extended to 30mm so that the side seam lines of the front and back would be exactly matched with each other when the darts are sewn.

- Unevenness of zigzag hem line

The hem line of the slip was cut in a series of zigzags. However, the interval and shape of zigzag line was not even. This study simply unified the zigzag shapes and interval by equally dividing the width of the slip at the level of the first and last zig and zag.

7.2.2.2 Toile Generation and Pattern Refinement

A toile refers to a rough copy of a design which is faithful to an original garment, but is made from inexpensive cotton or old fabrics. Toiles are useful when important modifications of a pattern have to be made to check the fit and appearance of the alterations. To achieve perfect form, the alteration of a toile may be needed more than once. The fabric pieces of the toile are disassembled to be used as patterns, or the changes are copied onto paper patterns (Thompson, 1985).

In this study, toiles of each costume were produced to ensure alterations of the patterns in the previous section. This study examined the 3D form of the assembled pattern pieces in order to discover specific errors to be changed. This process not only enabled further improvement of patterns without wasting costly materials, but also helped to identify and solve problems which could be encountered during the process of actual work. Optimizing this process is valuable considering the importance of high fidelity to original costumes. In addition, toiles facilitate the anticipation of the shape and fit of the final outcome. This advantage is associated with another major consideration of the study with respect to costume mounts, which have varied in shape throughout history.

While the general goal of making toiles is to achieve perfect patterns for a finished garment, the toiles in this study aimed to create patterns close to the original costume both real and virtually. The toiles in this study could thus also be used as a foundation for costume stands, which require several mountings to build proper shape. Additionally, they can be used to prevent the damage to fragile costumes which may result from repetitive mounting. Prior to the preparation of costume stands, this section explains the process of toile generation, the problems which arose, and the final alteration of the patterns.

C1861-3 Day Dress

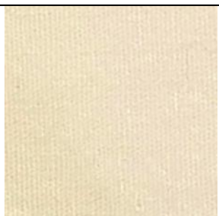
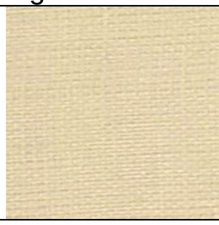
Thompson (1985) recommended that toiles be produced as exact copies of a finished dress, not counting facings, and that the seams be finished using inexpensive cotton or old fabric. The toiles produced in this study focused more on the overall outer shape of the costume rather than elements related to the inner structure or decorations. Therefore, some minor elements of the costumes were omitted in this process. Table 7.1 shows the main components and the materials used for the toiles. As shown, most inner components were excluded, except for the hem lining, to which only a few pieces of fabric were applied to cover the inside. Additionally, the pocket was omitted, since this study mainly concerned with the external appearance. As for the decorative elements, bows and braids were omitted, but piping, buttons and pleated frills were expressed by applying alternate materials.

Table 7.1 Main components

	Part	**Costume**	**Toile**
External	Bodice	Silk taffeta	Plain cotton
	Skirt	Silk taffeta	Medium calico
	A-shaped insets	Silk taffeta	Plain cotton
Internal	Bodice lining	Fine silk	(omitted)
	Skirt lining	Coarse stiff muslin	(omitted)
	Hem lining	Fine silk	Medium calico
	Pocket	Fine silk	(omitted)
	Boning	Featherbone	(omitted)
Decorative	Buttons	Twisted silk	Resin
	Piping	Cord	Cord
	Bow	Silk ribbon	(omitted)
	Braid trims	N/A	(omitted)
	Pleated frills	Silk taffeta	Light calico

The materials used for the toile production are shown in Table 7.2. The main fabrics were plain cotton, medium calico and light calico; they were applied to the bodice, skirt and pleated frills, respectively. Since the skirt used a large amount of fabric and was heavier than the smaller volume bodice, lighter fabric was chosen for the bodice toile construction, and relatively heavier materials were selected for the skirt toile. For the frill, cream-coloured light calico was used to differentiate it from the plain white of the bodice fabric. As such, white plain cotton was applied to the A-shaped pleated panels around the skirt hemline. In addition, to replace the corded buttons, imitation buttons were produced by a 3D printer.

Table 7.2 Materials

Fabric	Plain cotton	Light calico	Medium calico	Button
Image				
Weight	10.30g	7.32g	14.11g	N/A

(a) Front (b) Side (c) Back

Figure 7.16 Bodice

(a) Front (b) Side (c) Back

Figure 7.17 Skirt

Using the modified patterns, the fabrics were cut with 1cm of seam allowance. The fabric pieces were then sewn using a household sewing machine with a cotton thread. The sewing technique used was a straight stitch 0.5~2.5mm in length. Sometimes, the fabrics and toiles were flattened or steamed using a household iron to remove crinkles or to retain their shape. The patterns were assembled in the following order. For the bodice, the darts were sewn first, then the pleated frills and piping were attached to each fabric piece where needed. The connection of the bodice, sleeve and decorative strips was carried out last for the sake of convenience. Meanwhile, the skirt toile was constructed from the main parts to small parts. First, eight pieces of the skirt were connected by sewing the side seams of each section. Next, the pleated panels were stitched and attached to the hem of the connected skirt parts. Then, the waistband of the skirt was assembled after the folds on the top of the skirt were formed.

Further Refinement

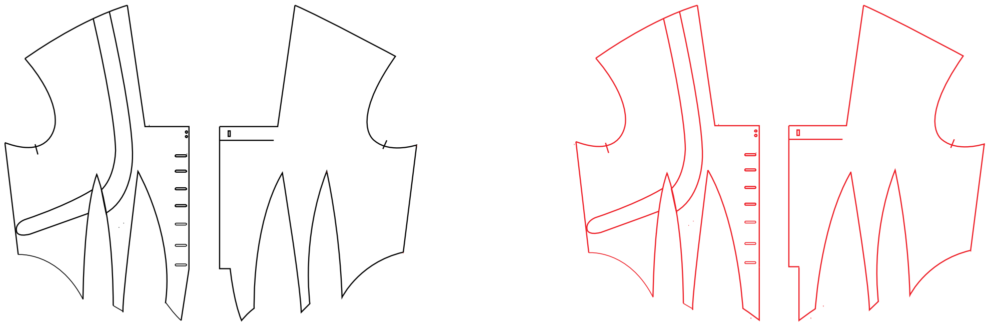
The 3D shape of the completed toiles facilitated the inspection of the structure of the assembled patterns. As such, differences in appearance between patterns and original costumes were observed. First, while the original costume had straight lines in the front centre of the bodice where the buttons are fastened (Figure 7.18(a)), the centre of the toile had oblique lines at the bottom (Figure 7.18(b)). As shown in Figure 7.18(a), the patterns adopted the front centre lines of the diagrams, where the bottom part was slanted outwards. In order to achieve a shape which was more faithful to the original costume, this study straightened the front centre line of both the left and right bodice pattern. This was accomplished by extending the vertical centre lines and hemlines.

(a) Original costume

(b) Toile

Figure 7.18 Comparison between costume and toile

Secondly, a winding curve was observed at the centre-front hemline of the skirt (Figure 7.20(b)). Due to the delicate condition of the skirt, this study could not obtain a mounted image of it. According to the illustration in Arnold’s book (1977), however, the back of the skirt was purposely longer than the front with the train. Even if a skirt has a train, normally the hemline is not designed to be rugged. In order to smoothen this undulation, the hemline of the first and second patterns' lines was modified, as shown in Figure 7.21.



(a) Diagrams (b) Modified patterns

Figure 7.19 2nd refinement of bodice patterns

(a) Illustration
(source: Arnold, 1977, p.20)

(b) Toile

Figure 7.20 Error in hemline

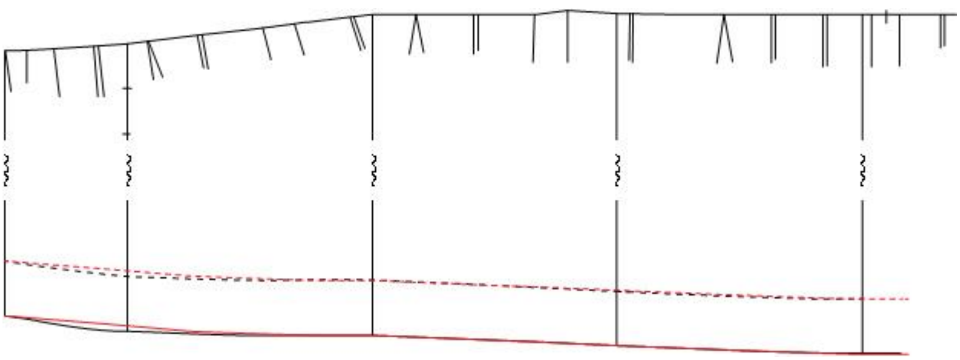


Figure 7.21 2nd refinement of skirt patterns

C1928-9 An Evening Dress

The toile of the evening dress was produced by focusing on the overall appearance and decorative elements. This study especially pays attention to the triangular petal shapes, a major feature of the dress. Although the dress appeared to have a relatively simple structure and silhouette, seven layers of petal-shaped pieces of cloth were hung on the bodice to enhance its decorative aesthetic. The main components of the dress are shown in Table 7.3. Apart from the reinforcement bands sewn on the inside of the dress, press studs on the sleeves and the lingerie straps, other components were generated as indicated in Arnold (1977). In most cases, toiles may not require finishing off the raw edges, as their influence on the overall garment shape is generally low. However, this study applied picot edges and neckline facing in an attempt to explore different sewing techniques and to prevent distortion around the cut edges of the fabric.

Table 7.3 Main components

	Part	**Costume**	**Toile**
External	Slip	Silk crepe-de-chine	Medium calico
	Dress	Silk chiffon	Light calico (washed)
Internal	Bands	Silk chiffon	(Omitted)
	Press studs	N/A	(Omitted)
	Lingerie strap	Silk chiffon	(Omitted)
Decorative	Petal shapes	Silk chiffon	Light calico (washed)

As shown in Table 7.3, light and medium calico were used as the materials. Since silk chiffon fabric is shear and presents a sophisticated drape, light calico was selected for the toile. In order to get rid of the sizing from the fabric surface, the calico was washed for limpness. As the original fabric of the slip was thicker and less flaccid than the material of the dress, medium calico was selected.

Table 7.4 Materials

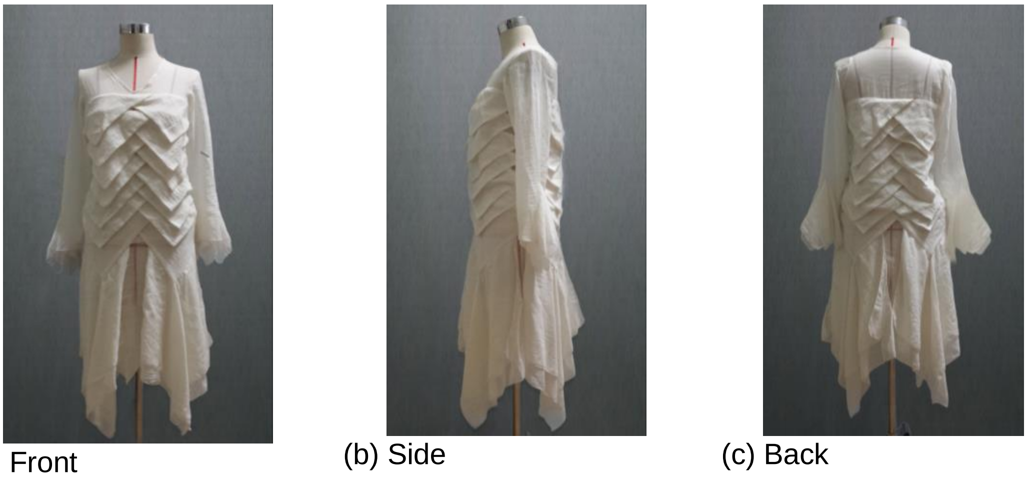
Fabric	Light calico	Medium calico
Image		
Weight	7.32g	14.11g

For the toile, each piece of fabric was cut with 1cm of seam allowance and sewn using a household sewing machine. 0.5~2.5mm of straight stitch was employed in assembling the fabric, and decorative joining stitch was applied to the hemline for the picot edges. Sometimes tissue paper was sewn together with the light calico to increase the stiffness of the fabric surface. The paper was taken off after the sewing process.

Assembly was carried out by starting with the decorative elements. For the production of the slip, picot edges were firstly applied to the zigzagged hemline of the bodice. Then the side seams and the back slit were stitched. After this, the straps of the slip were sewn and attached to the bodice. The picot edges of the dress around the bodice, cuffs, and floating panels were created before assembly. Then, construction of the dress was carried out part by part: the petal shapes and floating panels; the sleeves and their cuffs; the front and back bodice. After that, the neckline facing and the sleeves were attached to the bodice to build the basic shape of the dress. The petal shapes were then placed and stitched around the bodice.

(a) Front (b) Back

Figure 7.22 Slip



(a) Front (b) Side (c) Back

Figure 7.23 Dress

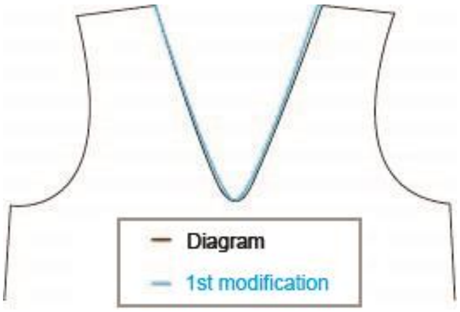
Further Refinement

The toile which was generated properly reflected the features of the original costume to a certain degree. However, a noticeable difference between the toile and the costume was observed on the neckline. Although the pattern on the front neckline was altered, the centre of the line was still markedly more curved than the original garment. There is thus a need for further amendment and acumination of the centre of the neckline.

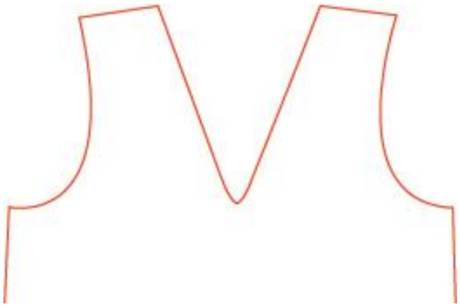
(a) Original costume

(b) Toile

Figure 7.24 Difference in neck-line



(a) Diagram and 1st modification



(b) 2nd modification

Figure 7.25 2nd refinement of neck-line

7.2.2.3 Underpinning Preparation

Measurements and shape of female body have been dramatically changed over history. Such changes are not only because of dietary reasons but also related to socio-cultural conditions and aesthetics that people of the time pursued. The distinctive features of the silhouettes have importance as one of the most important criteria to classify history of fashion. Therefore, reflection of the correct silhouette on underpinnings functions as a major element for realistic presentation and aesthetic appreciation of costumes. Also proper shape of the underpinnings provides structural stability for costume mounting. In historic costume display, especially, stable and safe support is a fundamental issue dealing with preservation of physical state of garments. In this regard, individualised requirements were often applied to costume stands based on measurements and other features of each costume. Additionally, suitability of types and materials of underpinnings are also important factors to be considered.

Since the reproduced garments were designed to represent the costumes in the museum, the original dresses are not handled in this study. Although the conservative aspect is not regarded as prime concern in this case, review of the basic requirements of costume mounting was considered to some degree. The aims of this section is to understand the basic and morphometric considerations in preparation of underpinnings focusing on the base stand so called a mannequin and to generate appropriate costume stands. This section explores the fundamental concept, types and characteristics of mannequins and features of body silhouettes in the 1860s and 1920s. Also the process how this study tried to provide aesthetic and stable underpinnings is described. These underpinnings were applied not only to support physical dresses but also to become a foundation for virtual body generation in digitisation phase.

Mannequins for Costume Display

A mannequin or manikin refers to a human figure form to exhibit items of clothing and accessories (Picken, 1999). Preparing mannequins is significant especially in costume exhibitions since the dress mounting has effects on the condition of the garments in conservational respect and the representation of the desirable stylisation of the certain period in aesthetic aspect. The selection of costume stands generally involves a range of factors including the design, length and budget of the exhibition, specific requirements of individual dresses, composition of figures, addition of accessories and necessity of limbs and heads (Flecker, 2012). The aim of this section is to construct the dress stands which fulfil the requirements of costume mannequins for both physical and digital exhibitions. This section investigates the physical and aesthetic considerations of the mannequins prior to the production.

Types of Costume Stands

In general, there are four different types of mannequins which have been utilised for the costume display: (1) artists' lay figures which are different from fashion mannequins and take the creative design based on the purpose of artists; (2) commercial display mannequins; (3) dedicated mannequins for the exhibition of the period clothing; (4) wax mannequins which are often used for the representation of historic or famous character in realistic forms (Taylor, 2012). In this study, the artists' lay figures and the wax mannequins are excluded from the consideration. Because the artists' lay figures generally more focus on the artistic purpose than the proper garment presentation and the wax figures have risk of melting to damage dresses.

Costumes require different shapes and measurements of stands depending on the period of the time and their wearers' body sizes. Therefore, it will be ideal to have customised stands which exactly fit to each garment. According to Flecker (2012), the customisation of a figure needs the measurements from the dress, historical data and the costume or preferably its toile. The general process of customisation of a figure needs two or three dress mounting to accomplish a good fit and it is normally a collaborative work between the sculptor and curator but also with the conservator and designer to generate the best shape, fit and support for the dress. Although customising mannequins is the most desirable method to achieve the ideal costume display, these are often not possible due to the financial constraints. Compared to the ready-made mannequins, these figures are exceedingly costly. Also it requires enough time to be produced.

On the other hand, the ready-made figures in various shapes sizes, materials and finishes are easily available with less expense. Although a wide range of choice is available, selection of the mannequins should meet the design and conservational requirements considering the other practical aspects such as the individual demands of the dress, the overall exhibition style and time required to be manufactured and shipped. In addition, applying ready-made mannequins to the period clothing may be less desirable since the commercial figures are mostly produced based on the standard sizes and contemporary silhouettes. To adapt mannequins according to the requirements and suitability of the individual dress and display, the alteration of their shape and size is required. The fabric-covered figures which enable stitching of padding and the papier maˆché bodies of which hard shell can be cut off using hand or tools are universally used as foundations. These figures have advantages of repetitive recycling for other costume mounting (Flecker, 2012).

- Recommended Materials

The paramount consecration in preparation of costume stands is the conservational matters (Taylor, 2002). To minimise the damages to the garments, Flecker (2012) suggested avoiding the high-density urethane and polyurethane foams. Because these materials can be quickly broken down and produce reactive chemicals which are harmful to garments. She mentioned that the fibreglass, Plastazote®/Ethafoam®, buckram and wax, are regarded as safer materials and the water-based emulsion or cellulose paints is more recommendable than solvent-based paints in terms of surface finishes. Also surface finished figures were advised to off-gas at the room temperature at least for three weeks in the space with good ventilation. However, she emphasised that the test will be needed for any materials and finishes to ensure the safety.

Consideration on Shape

As it is mentioned above, the shapes of the stands required for each costume vary. This is because not only of the differences in body measurements of individuals but also of the changes of the body silhouettes that the people of the time pursued. There are various factors that have affected human figure such as “diet, health and exercise” (Flecker, 2012, p75) however this section will only discuss the effect by the garments which can be seen as the artificial effort to change the appearance. The desire to minimise, exaggerate or transform the body shape using garments may be associated with the origin of clothing to adorn the body. Saint-Laurent (1968) underlined that the beginning of the clothing should be considered between religion and art and everything that could ornament the body is regarded as clothing in this manner. In this context, the hats and the farthingales and crinolines can be considered as ornaments to provide height to head and to transform the hips to wings respectively. He claimed that the human desire to alter their natural form can be understood as their refusal to nature and their control over it and by doing so the individuals reconstruct oneself based on one's own vagary and image. Meanwhile, Carter (1992) explained that such artificial changes of human body shape probably came from the complicated multiple reasons such as discontent with human figure, drawing sexual attention, “conspicuous consumption through the extravagant use of materials and sophisticated technology,” (p.11), conformation with the trend and other aspects of height and supports together with the stimulus for capricious fashion.

The clothing item which has made a great impact on the changes of the female body is the underwear and corsets are a good example which moulded the shape according to the trend of the time (Flecker, 2012). The use of the underwear is closely connected to the body silhouette which has been dramatically changed throughout history. This section will discuss the changes of fashion silhouette and the underwear worn in 1860s and 1920s to provide guidance for the proper construction of the mannequins of the study.

Silhouette in the 1860s

From 1890 to 1940, a range of newly labelled clothing and shifts in silhouette emerged in consequence of technical advances (Carter, 1992). Although the undergarments between 1919 and 1939 appeared with diminished bulk, they acquired a new significance and complexity. In this period, composite garments consisted of two or more parts ebbed and flowed and the clothing which had been dressed by the male in the past came into feminine guise (Cunnington et al., 1981).

- Chemise

Chemise generally indicates a combination loose-fitting under garment which was worn above the skin. It drapes straight from the shoulders and covers the female torso (Picken 1999). The chemise in 1860s took a form of a simple double rectangle with gussets on the underarms and sides. The form was altered being less voluminous and less plain and the length became shorter giving shape to the bust (Carter 1992).

- Petticoat

Originally, petticoats were shirt-like clothing for women dressed with a jacket or a gown between the sixteenth and eighteen centuries. From the nineteenth century, however, petticoats have been used as a female undergarment to support the skirts or to maintain warmth (Baclawski, 1995). According to Carter (1992), there were two predominant types of petticoat worn in 1800s: the full-length petticoats with a back-fastening bodice, deep waistband to shape the bosom with a full skirt and the waist petticoats folded to a wide waist band. The petticoats in 1840s were worn with one or more layers and the flounces became more prominent to enrich the skirt volume (Carter 1992). Beside, petticoats were also worn under the crinoline and these were made of fine plain materials (Cunnington et al., 1981).

- Bust improver

Bust improvers were the method hidden inside a female undergarments or bodice to reinforce the voluptuousness of the bust (Picken, 1999). They are kind of pretend bosoms made of cotton wool like the contemporary padded bras (Carter, 1992).

- Drawer

Drawers were the undergarments of which shape looked like trousers (Picken 1999). The drawers in 1850 did not have gussets and consisted of two tube-shaped leg parts which were set on the waistband. They had front ties or fastened with the waist drawstring overlapping at the front. The closed drawers which was sewn inside to join the crotch sections were called knickerbockers in the beginning and as the knickerbockers drawers by 1879 (Carter, 1992).

- Frame

Frames consisted of steels horizontally and vertically arranged and fabric that covered them. The frames worn during the day time were short and slender and had a cone-like shape, the evening frames were larger and had a support for the train in the back (Carter, 1992). By 1860, the day and evening crinolines generally had nine and up to 18 watchspring hoops respectively (Cunnington et al., 1981) and the dimension of the hoops extended to 18 feet in 1860s. (Carter, 1992). Between 1857 and 1859, the shapes had gradually changed from dome to pyramidal. Then the front of the crinolines became flattened in 1862 and the bulk of the dress extruded at the back with a flat front with no springs by 1866. (Cunnington et al., 1981)

- Corsetry contraptions

Corsets were undergarments made of robust cotton twill or cotton sateen strengthened with whalebone. Using the breast and hip gussets with a busk, corsets slenderised the waist and support or accentuate the breast. The abdominal corsets with belts, straps and buckles were worn to cover the plumpness of the belly (Carter, 1992). As the whalebone became rare and costly, steel and cane were used as alternative (Baclawski, 1995). The time between early and mid-Victorian the period when the corsetry became well-developed. As the skirts became more voluminous towards 1855, the length of the corsets became shorter and less tight. It was inferred that this tendency stopped in the late 1850s and early 1860s (Carter, 1992).

Figure 7.26 Day dress in 1862 (source: Cassin-Scott, 1997, p.138)

Figure 7.27 Day dress in 1862-64 (source: Metropolitan Museum of Art, 2013)

The 1800s is the time which appeared frequent changes in female silhouette. In general, the body shape in the 1860s had a tendency to focus on slimming waist size and this increased enlargement of bust and hip. The waistlines appeared slightly above its natural level and more structured corsets accentuate the slim waists. Use of hip and bust gussets supported the body to be swollen creating a curvaceous shape. The level of bust was raised and breasts were separately positioned supported by gussets and central busk. (Flecker 2012). The volume of the skirts became enormous by the 1850s (Flicker 2012) and sophisticated ladies further emphasised on contrast between large skirts and slight waists in the early 1860s (Cater 1992). The frame had a flattened shape at the front and widened at the back (Nunn, 1984). The Illustration of Cassin-Scott (1997) of the day dress in 1862 presents the typical silhouette of the ladies' dress with a tightly-fitted bodice and a wide pyramid-shaped skirt.

Silhouette in the 1920s

From 1890 to 1940, a range of newly labelled clothing and shifts in silhouette emerged in consequence of technical advances (Carter, 1992). Although the undergarments between 1919 and 1939 appeared diminished bulk, they acquired a new significance and complexity. In this period, composite garments consisted of two or more parts ebbed and flowed and the clothing which had been dressed by the male in the past came into feminine guise (Cunnington et al., 1981).

- Petticoat

The petticoats in 1920s appeared straight and loose fit and ribbon shoulder and straps were commonly used. Although the no-waist style of the 1920s preserved, the petticoats with full-length known as 'Princess petticoats' were popular and lasted for the following decade. Later, Princess petticoats became known as Princess slip and finally as slip (Carter, 1992).

- Slip

Slips were the undergarments which were produced to fit the bodies smoothly under dresses or skirts (Baclawski, 1995). The shape of the slips in the early 1920s was straight and the front and back looked similar. They often had a stove pipe shape to give appearance of waist petticoats which had been pulled up and joined at the shoulders with thin straps. The general slips in the 1930s are regarded to be formed at the bust and cut on the slant with inlet side flares from around 1933-4 (Carter, 1992).

- Chemise

Although chemises were worn until the 1930s, chemises gradually gave their place to new undergarments like combinations (Baclawski, 1995). The boundary between the chemises and slips became indistinct around 1920. However, while the slips of silk helped in shaping to the torso to some degree and had a trimmed hem, the chemises had a tendency to be simpler though more decorative chemises appeared in a later period. By 1914, the chemises fell to above the knee and showed the drawers (Carter, 1992).

- Vest

According to Cunnington et al. (1981), the chemises were noted as vests by 1924. Although Carter (1992) admitted the similarity between vests and chemises, she distinguished the vests as slimmer and shorter undergarments. They were made of knitted wool, cotton or blends (Baclawski, 1995) and either of an open French or opera neck or covered-in shoulders was applied. Some vests in the 1920s were decorated with elaborate tops with ribbon around the neck and at the armholes and some in the 1930s had a round neck, short- or no sleeves, built-up shoulders or with straps (Carter, 1992).

- Camisole

The camisoles had performed as covers for corset or cache-corsets and became worn without corsets later. Generally, buttons were used to fasten and the neck was most likely high with embroidery, lace and frills or plain with satin ribbons at the shoulder or rarely without straps hitched by straps under the arms (Carter, 1992).

- Corset

The corsets which had a straight-fronted and formidable configuration by 1900 had been changed as the natural slim look became trend by 1909-10. Around 1914, corsets had a long, low-fronted and backed-laced tube shape being shortened. Under the influence of the First World War, less boned (Carter, 1992) and lighter corsets were more prevalently worn. During the post-war period, loose clothing was still fashionable and the corsets met this ease (Baclawski, 1995). Some corsets were nothing other than belts made from narrows pieces of ribboning. In the 1920s, light, unrestrained undergarments sometimes combining with elastic woven materials were prevailed and stretchy roll-on were widespread by 1930s. It is considered that corsets became displaced to corselettes from 1921 and brassiere and belt from 1928 (Carter, 1992).

- Combination

Combinations referred to the undergarments which combined chemise or camisole and drawers. They derived in 1877 and were designed in various forms and materials by the 20th century. They were popular items with females engaging sporting activities because of their advantages to reduce bulk under the new slenderer trend and to maintain the warmth and decency (Carter, 1992). They were originally made of cotton or linen and had a centre front opening and a split crotch (Baclawski, 1995).

- Camiknickers

Cami-knickers were undergarments performing the function of a camisole or chemise and wide-legged knickers. They had shoulder straps and closed under the crotch. The cami-knickers were introduced during the First World War and became popular in 1920s and 1930s (Baclawski, 1995). The length is considered varied from hip to mid-thigh and became shorter from 1927. The cami-knickers were available in a range of materials and colours (Carter, 1992).

- Corselette

Corselettes were newly developed undergarments in 1920s and combined the functions of brassière and corset or girdle (Baclawski, 1995). The underbelt corselette which had a belt to support the abdomen was called the 'foundation garment'. Also subsequent variations were designed: Corslo-silhouette combining bust bodice, hip belt, jupon and pantalon; Corslo-pantalon-chemise incorporating knickers, corset and camisole with suspenders stick on the inside; and combined bodice with hip belt (Cunnington et al., 1981).

- Belt

Belts were the alternative to corsets and including the abdominal support and the light suspender belt, a variety of belts were available. The belts which were solely made of elastic were called 'roll-ons' and those which had a zip fastener were labelled as 'step-ins' (Cunnington et al., 1981).

- Drawers, Knickers and Panties

According to Baclawski (1995), knickers were the abbreviation of the knickerbrockers and referred to a pair of ladies' closed drawers. This term was also used to refer to open-legged drawers and 'drawers' and 'knickers' were used together by the time that the open-legged drawers started to be out of mode in the early 20th century. Carter (1992) regarded that the drawers were transformed into the knickers and the between-the-leg opening started to be closed before the First World War period. The knickers with buttons and knee-length legs were popular in the early phase of 20th century (Baclawski, 1995). The knickers developed into directoire knickers around 1909, French knickers in the 1920s and camiknickers in the 1930s. In the 1920s, the length of the knickers progressively became shorter and brought about the 'pants' or 'panties' of the 1930s (Carter, 1992).

Fashion in this period appeared mineralised tendency than other times. The distinguishing feature of the female silhouette of the 1920s is diminution of excessive undergarments. In the middle of the 1920s, young and immature figure as the ideal shape and curvaceousness became eliminated (Nunn 1984). Undergarments played an important role in achieving flattened and slim look. More importance became attached to the bust confiners or flattener. Brassidères and elastic gussets were worn to compress the breasts and hips. Furthermore, purchase of two sizes smaller corsets were even advised by magazines for desired shapes. (Carter 1992).

Figure 7.28 Day dress in 1928
(Source: Cassin-Scott, 1997, p.173)

Figure 7.29 Evening dress in 1927
(Source: V & A, no date-a)

The slips in the 1920s had minimal shaping and decoration to maintain slender shape. The trend of skirts became straight, slim and shorter by 1914 and the level of hems around the calf rose to the knee between 1918 and 1926 (Carter, 1992) and descent of waistlines to the hips appeared. The silhouette of bodices became straight and loose-fitting as well. Such tendency also appeared through the shape of evening dresses which are typified by slim straight cylinder silhouettes of various length (Nunn 1984). Good examples of the silhouettes were shown in the illustrations of a lady with a straight and knee-length dress (Figure 7.28) and Figure 7.29 with a tube shaped evening dress.

Considerations

The undergarments have been developed and worn to attain various purposes. The basic functions of the underwear are generally classified as follows: (1) protection of the body from the weather; (2) supporting the garment shape; (3) hygienic purpose; (4) erotic use; (5) class differentiation (Cunnington et al., 1981). Although undergarments were usually not visible, their roles were considered significant. The undergarments which have constantly evolved and emerged brought the diverseness of their type. The completion of proper silhouette may be accomplished by wearing the full undergarments. However, this study focused more on the undergarments which played the fundamental role in supporting the garment shape following the view of Carter (1992) on a bigger scale. It is because the impact of the undergarments with other functions on the silhouette is regarded as small.

In her book “Underwear: The fashion history”, Carter (1992) made a distinction of underwear between ‘linen’ and ‘structural’. She described the initial linen as a second skin to cover decently the naked body, to moderate the temperature and to give the skin comfort. They also offer a sanitary layer between the skin and the visible clothing to protect the garments which were difficult to wash and to shield the skin from discomfort. Chemises, camisoles and vests, drawers and knickers, combinations and sometimes petticoats have belonged to the ‘linen’ underwear category.

On the other hand, the ‘structural’ underwear played a role in restriction or enlargement of the natural silhouettes of the human shape forming frames. This provides the essential foundation for the stylish clothing of the time. For example, corsets constructed and replaced the flesh and the frames expanded the shape using whalebone or steel and they developed the natural shape of the bust, waist and hip. The ‘structural’ underwear includes crinolines, bustles, bottom and bosom pads, brassieres, corselettes and girdles. Additionally, petticoats sometimes can also be considered as a ‘structural’ undergarment due to their function as supporter to broaden skirts (Cater 1992).

In this sense, this study separated the undergarments in 1860s and 1920s into linen and structural underwear. Amongst the undergarments in 1860s, the chemise, drawer and petticoat could be classified into linen as they did not directly develop the garment form. The petticoat also had been worn to develop the skirt volume in 1800s, however this study regarded the petticoat as linen which was worn with the crinoline. According to the curator in the Museum of London, it is presumed that the wearer of the C1861-3 day dress might use a crinoline as a supporter for the skirt and the petticoats were worn under and above the crinoline. Meanwhile the bust improver, frame and corset which were used to exaggerate or shape the human body were considered as structural undergarments. Compared to 1860s, the structural undergarments in 1920s were less bonded and less strained. However, they did play a role in supporting the body and creating the desirable look. This study included the brassière, corset, corselette and belt in the structural undergarments and the petticoat, slip, chemise, camisole, combination, camiknickers, drawers, knickers and panties in linen.

Due to the constraints of the time, this study did not cope with the production of the whole undergarments which might be worn under the costumes. Instead, this study tried to reflect the silhouettes which were achieved by the application of the structural undergarments in the mannequins. In the case of the C1861-3 day dress, an upper body was generated by filling the empty space inside the toile. By doing this, the mannequin would be able to fit to the costume properly and accordingly, the mannequin could have effects of having a body with the undergarments. However, the crinoline which supports the large skirt was separately produced as it facilitated the mounting costume. On the other hand, a ready-made mannequin was prepared for the C1928-9 evening dress considering the body shape that the structural undergarments had affected. The reason for using the ready-made stand was because unlike the underwear of the past, the undergarments in 1920s did not drastically transform the body and pursued the straight and loose silhouette which can be shown even today. Therefore, this study considered that applying the ready-made stand was tolerable. The detailed process of preparation of the mannequins will be explained in the next section.

Preparation of Underpinnings

Mannequins

The preparation of both costume stands was carried out based on the ready-made mannequins considering feasibility to manage time and cost. However, this study decided to take different approaches to each costume: developing a dedicated mannequin for period costume and using commercial display mannequin. Using commercial mannequins has merits of a less exorbitant expense and a wide range of availability in shapes, measurements, materials and finishes. On the other hand, their standardised modern sizes and shapes can be less pleasing for costume display (Flecker 2012). For this reason, it was considered that the C1861-3 day dress of which silhouette appeared distinctive from modern bodies required a customised underpinning through modification of a ready-made mannequin. In the case of C1928-9 evening dress, a commercial stand was used without alteration as its silhouette does not remarkably differ from the look today.

According to Flecker (2012), there are two means to prepare the costume mounts: (1) converting measurements of the costume into the mannequin size; (2) accurate toile method. Once the measurement of the costume is carried out, the information on the dimensions can be translated into a figure. However, having a figure with same bust and waist measurements as the costume does not assure the perfect fit since the nape to waist length have varied depending on the costumes. For this reason, converting costume measurements requires careful consideration. Meanwhile, the accurate toile method has advantage of the enablement of sculpting a complete set of foundation for costumes protecting their condition from damage by handling when they are mounted. Since the toile of each costume was generated in the previous stage, this study applied the accurate toile method for mannequin preparation.

The main considerations of the selection of base stands were firstly to perform a basic role in costume mounting and display. Due to time constraint, this study could not prepare the entire body of the figures. As a rudimentary part of a body, this study only focused on the torso excluding the other parts such as a head, arms and legs. Secondly, the stands need to minimise the harmful impact on the condition of the dress. In terms of the materials of ready-made mannequins, the mannequins which were made of high-density urethane and polyurethane foams and solvent-based surface finish were excluded from selection as Flecker (2012) recommended. Another important factor of the selection was the materials of the stands which facilitate medication and appropriate measurements and silhouette which would minimise adjustment of the shape. For the easiness of alteration, the choice of options was confined to the fabric covered stand. Also the measurements of the most fitted or influential body sections in formulating garment drape performed as a decisive element in preparation. Then the stands which have the most similar form to the period silhouette were prepared among the mannequins.

The commercial mannequin prepared for each costume is shown in Figure 7.30. For the day dress in the 1860s, a second-hand torso mannequin which was made of a fibre-board, sponge and calico was purchased. The form covered with sponge and calico fabric was considered to help application of padding and stitching upon the surface. Since the expected measurements of the figure were noticeably bigger than the standardised commercial mannequins in general, the size of the stand was not significantly considered in selection. However, the waist circumference and the distance from the nape of the neck and the centre back waist were regarded important as the costume is most fitted at the waistline and the length centre back is difficult to adjust. In the case of the stand for the evening dress of the 1920s, bust circumferences and shoulder length were primarily considered in selection. Because the tubular shape of the dress creates straight silhouette being draped on the upper chest section. To ensure the suitability, toile was repeatedly mounted on different mannequins. In addition, Arnold (1977) described the silhouette of the figure mentioning that the bust and hips would have been flattened with a bandeau and elastic girdle. On this basis, a torso with a flat bust hip was considered more desirable. A stand made of a polystyrene form and fabric cover fulfilling most conditions was chosen as a torso for the study. The original measurements of the mannequins were shown in Table 7.5.

(a) Base stand for the day dress in the 1860s

(b) Base stand for the evening dress in the 1920s

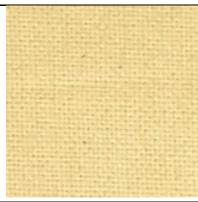
Figure 7.30 Base stand

The most process and method of adaptation of the modern stand to develop a historical silhouette followed the guideline by Flecker (2012). The underpinning for the day dress in the 1860s was developed through reshaping shoulders, creating body shape, making new neck and finishing stages. The materials consumed were shown in Table 7.6. The main materials to develop the shape of the stand were polyester wadding and cardboard calico and jersey fabric were applied to cover the surface.

Table 7.5 Measurements of base stands

Measurement	C1861-3	C1928-9	Measurement	C1861-3	C1928-9
Around waist	62 cm	63 cm	Across front	28.5 cm	29 cm
Around bust	84.3 cm	82 cm	Across back	32.5 cm	31.5 cm
Around ribcage	76 cm	74 cm	Length of shoulder	36.2 cm	38.5 cm
Bust point to point	16 cm	15.5 cm	Front neckline to waist	33 cm	27.8 cm
Shoulder point to side waist	31 cm	27 cm	Around hip	83.5 cm	80 cm
Nape to back waist	37.5 cm	33.5 cm	Around bottom	89 cm	N/A

Table 7.6 Materials

Product	Wadding	Cardboard	Medium calico	Jersey
Image				
Material	Polyester		Cotton	Viscose & elastane
Colour	White	White	Cream	Black
Width /dimension	44”	A3	54”	62”
Yardage /quantity	2yds	1	1.5yds	1yd

The shape development process focused on the fitness and silhouette of the 1860s. The costume stands were required to reflect the body shape and silhouette of undergarments of the certain period. In this regard, the ideal way to achieve this will be reproducing undergarments and mounting with the dress. However, producing whole undergarments dedicated to a certain costume is complicated and time-consuming without specified data. Besides, the undergarments which have excessively bonded structure like corsets may provide a rigid and undesirable foundation for costume display (Flicker 2012). For this reason, rather than applying undergarments, this study aimed at creating the shape of a corseted underpinning referring to the silhouette of the costumes of that time and forms of the costume stands used by museums. In addition, in the case of the undergarment which a torso mannequin cannot accommodate its form and functions and had a decisive effect on garment drape was individually produced. Also, in order to prevent damage or distortion of the garment during display, development of the costume stand aimed at the establishment of well-fitted support to the toile with softness as well as firmness. This prerequisite demanded repetitive toile mounting and careful modification using layered wadding.

Since the prepared stand for the dress in the 1860s was considerably smaller than the toile, shape adaptation process proceeded without cutting down the base form. The shoulder parts which appeared noticeably different in length and angle were firstly modified. In order to shape the sloping shoulder of the nineteenth century, tightly rolled wadding pieces were piled up and stitched on each shoulder of the stand to change the angle. One layer of wadding was then applied over the rolls to finish.

(a) Rolled wadding (b) Piling roles (c) Covering

Figure 7.31 Sloping shoulder

Further modification was carried out on the shoulder to extend its length. Based on the distance between a shoulder point to a side neck point of the toile, and the width of the armpit, new shoulder and armpit parts were generated using cardboard stitched with calico. These parts were stitched on the sloped shoulder in Figure 7.31 (c). Flicker (2012) emphasised reshaped shoulders to be solid since it is the part which endures a great deal of weight of a costume. In order to reinforce the rigidity of the extensions, the void which was caused between the extended shoulder points and the original armpits was filled up with small pieces of wadding.

(a) Materials (b) New shoulder and armpit

Figure 7.32 Shoulder extension

After reshaping the shoulder, the toile was mounted on the base stand to estimate the approximate amount, positions and shape of padding for construction of proper volume. The corsets of the nineteenth century in general had a tendency to reduce waist and consequentially increased the bust and hips (Flecker 2012). In order to express the voluptuous shape, the application of padding was carried out putting more emphasis on the front and back upper chest leaving the waist and bottom. This study disregarded the bottom section since it was intended to be covered by a crinoline.

Figure 7.33 Volume construction

The key positions such as the level of the bust and bust points were marked and the shape of the stand was gradually built up using multiple layers of wadding pieces based on the reference marks. The edges of the wadding were slashed or feathered to smoothen the boundaries of wadding and connection. As the first step, inflation of the bust section was conducted attaching graded oval wadding. The expansion of the bust also developed an inverted triangular silhouette of the upper chest. Although Flecker's guideline (2012) underlined the separation of breast taking into account the function of a busk and gussets of the corsets, this study decided to adopt an approach to fill up the space between the breasts. This was because that the surface with less curvedness was considered more firm to secure centre front of the bodice with frills. Then side and back of the torso was padded to attain the natural shape and toile was repeatedly mounted to correct the form.

(a) Materials (b) Front (c) Side (d) Back

Figure 7.34 Making new neck

As the pile of wadding was cumulated on the shoulder to give slopes, the neck of the initial mannequin was relatively retracted. Since the neck is an essential part of a body which enhances the aesthetic figuration of a torso and supports garment collars or necklines (Flecker 2012), a new neck was shaped covering the previous neck. Flecker (2012) suggested the height and circumference of a female neck as between 4~7cm and 30-35 cm. The dimension of the neck recommended and also its angle was adjusted using a paper pattern and the toile mounted. Based on this, a new neck and a disk which would cover the top of the neck were prepared using calico stitched together with cardboard. The new neck was joined to the shoulders and filled with wadding pieces inside. Then the disk was sewn on the top of neck and a layer of wadding was applied around the new neck.

After padding, the overall surface and borders of wadding were trimmed to make the shape more even. To finish, a shell made of calico was applied to the whole torso for isolation of the fibrous wadding, concealment of unprepossessing surface and consolidation of the shape. Additionally, black jersey fabric was used to cover the torso again at the later stage considering actuation of the colours of the costume. The measurements of the principal sections of the padded torso are shown as in Table 7.7.

(a) Front (b) Side (c) Back

Figure 7.35 Finished stand

Table 7.7 Measurements of padded torso

Measurement	**(cm)**	**Measurement**	**(cm)**
Around waist	62	Across front	46
Around bust	104	Across back	37
Around ribcage	85	Length of shoulder	47
Bust point to point	32	Front neckline to waist	39
Shoulder point to side waist	29	Around hip	83.5
Nape to back waist	39.5	Around bottom	89

Crinoline

A cage crinoline was made as an underpinning for the skirt following the process in Figure 7.36. Firstly, dimension of the crinoline was estimated through mounting the skirt with a temporary padding using multiple layers of calico. As reference, an illustration of a large crinoline in Hunniett's book (1991) was consulted to shape an appropriate volume. Measurement of circumferences of eight different points under the waist line was taken over the surface of the temporary padding.

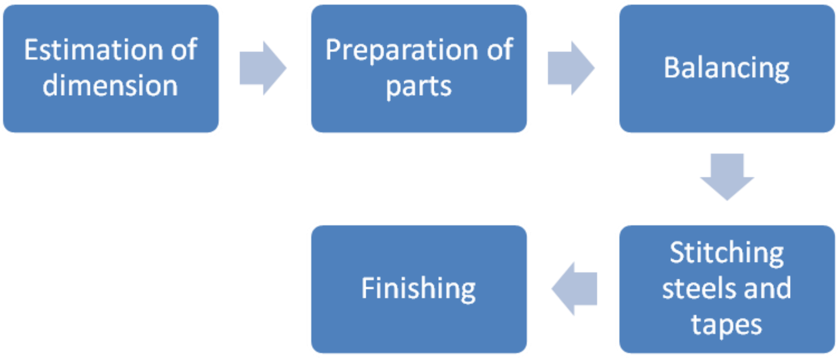
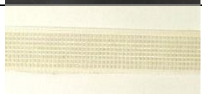


Figure 7.36 Crinoline production process

Using the measurement, the lengths of the steel cuts were determined. The lengths of the first to the third steels from the top were shortened than actual measurement to open at the front to be put on. In the case of the other steel cuts, the lengths were increased to give an overlap of 5cm on two ends when they form a hoop shape.

After the estimation, individual components including steel cuts, a waistband and half-moon shape were prepared for the provisional construction of structure. Steel boning was cut based on the estimation and encased in cotton calico fabric to facilitate impalement by pins. The waist band was produced using a half folded long calico strip which gave extra length to the waist measurement. Half-moon shape was stitched to the centre back of the waistband. According to Hunniett (1991), half-moon allows more sloping at the back of crinoline. In order to increase the strength, four layers of calico were cut in half-moon shape and stitched together. Cotton taps which function to support the steel boning were attached around the waistband and the half moon.

Table 7.8 Materials

Product	Image	Material	Colour	Width/dimension	Yardage/quantity
Medium calico		Cotton	Cream	54”	1yd
Herringbone tape		Cotton	White	25mm	10yds
Boning		Steel	White	9mm / 7mm	10m / 6m
Boning		Plastic	White	12mm	2m
Ribbon		Polyester	White	7mm	5yds
Eyelet		Metal	Gold	4mm	16
Buckle		Metal	Silver	22 x 26mm	1

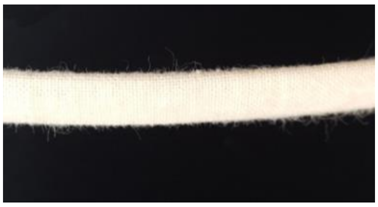


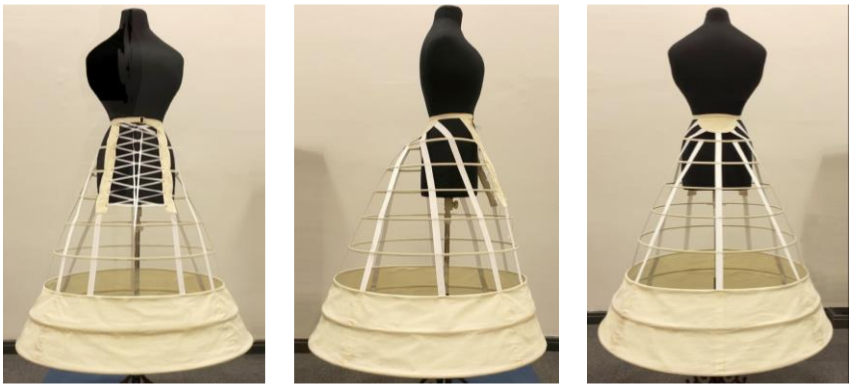
Figure 7.37 Boning encased

Figure 7.38 Waistband and half moon

The steel cuts were arranged in order of length. The position of each steel cut was decided as Figure 7.39 and its anchoring to be straight and not to be tilted using its own weight and tapes. Balancing and shaping required iterative adjustments of the positioning of the boning. The lengths of tapes were controlled to be 21cm away from the bottom as Hunniett (1991) recommended not more than 23cm. After the settlement of steel cuts, their positions were stitched to be permanently fixed.

(a) Front (b) Side (c) Back

Figure 7.39 Balancing steels



(a) Front (b) Side (c) Back

Figure 7.40 Completed crinoline

To make the crinoline more stable, a bag was made stitching ends of four pieces of calico. The bag was sewn onto the crinoline to cover three bottom hoops. For the fastening, a buckle was attached to the right side end and the eyelets were applied to two tapes at the front. Then using a ribbon penetrating, the crinoline was fastened.

7.2.2.4 Costume Reproduction

Material Selection

This section explains the selection methods of the fabrics and other subsidiary materials. The main considerations of selection took into account Arnold's descriptions (1977), the measured data of the costumes and subjective evaluation by the researcher.

Fabrics

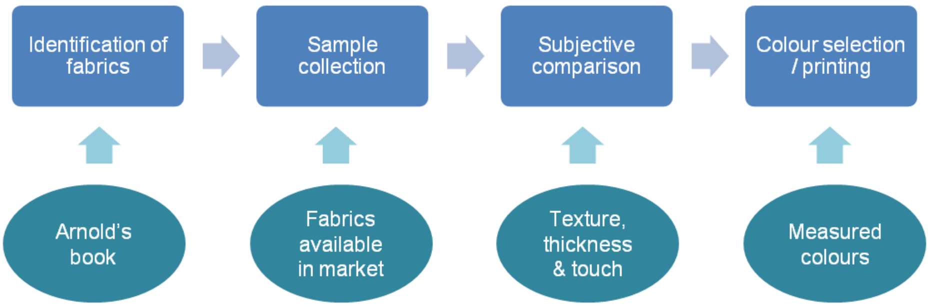


Figure 7.41 Fabric selection method

Figure 7.41 illustrates the process of fabric selection. The selection gave priority to the materials first and then colours. In order to prepare the similar materials as possible, this study collected various swatches based on the information about the fabric types provided by Arnold's book (1977). Then the most similar fabric samples were selected as the alternative materials through the subjective comparison by the researcher. After the decision of alternative materials, colours were chosen among the obtainable fabrics in the retailer shops which provided the fabric samples.

Tables 7.9 and 7.10 show the types of fabrics and colours indicated by Arnold's book and the colours measured using Pantone Color Que and Pantone Color Guide and colour library provided by Adobe Photoshop application. According to Arnold (1977), the C1861-3 day dress was made of silk taffeta, fine silk and muslin. The fine silk used for lining and decoration appeared as taffeta through the observation of the costume. Meanwhile, the C1928-9 evening dress consists of two fabrics which are silk chiffon and crepe de chine. According to the textiles identified, the fabric samples in various weights and touches were collected through different suppliers in the UK and Korea. Collection of the swatches was confined to the textiles of the same category as the original fabrics which were affordable. Then the swatches were compared with the original fabrics through subjective evaluation. Since the original fabrics could not be taken out for objective measurement, the comparison had to rely on the researcher's senses with the minor touch of the costumes. This study tried to choose the fabrics with similar texture and thickness. Besides, Arnold's book (1977) suggested detachable engageante as a coordinating item for C1861-3 day dress. As the real item does not exist, white cotton lawn was arbitrary prepared based on her description.

Although Arnold (1977) described the colours of each fabric, colours were more specifically analysed applying Pantone Color Que and colour chips. Although the Colour Que electronically captured and analysed colours, this method sometimes could not sufficiently measure the colours on the fabrics with lower density like the muslin and chiffon and narrow parts such as the twig motif. Additionally, the analysed colours sometimes looked different from the colours perceived by the naked eyes. For the visual identification of colours, Pantone Colour Guide and library were used. Through comparison, the colour chips that closely represent the fabric colours were employed as standards. Based on the results of both methods, the fabric with similar colours was determined among the products available of the suppliers. However, this study could not find the colour chip which corresponds to the white taffeta fabric. The taffeta fabric was slightly discoloured from the passage of time and neither electronic or visual methods could accurately distinctly stand for its colour. Thus a white fabric was prepared as the Arnold's (1977) information. In the case of the taffeta of C1861-3 day dress which has prints, the pattern was printed on the white material. The procedure of the printing is explained in the following section.

Table 7.9 Fabrics of C1861-3 day dress

	Arnold's book				Measured colour	
	Fabric type		**Colour**		**Pantone Color Que**	**Pantone Color Guide**
Main material	Taffeta		Main	Pale silver grey	7536C	415C
			Motif	Light mauve (varying shade)	7538C	5215C
				Deep lilac	408C	8062C
				Fawn overprinted in grey	8321C, 4503C	7497C, 7531C
Lining	Fine silk		Bodice	White	7521C	N/A
			Skirt	Light greenish-grey	454C	454C
	Muslin			White	N/A	7500C
Decoration	Fine silk			Charcoal grey	5487C	3425C
Sleeve	Lawn	N/A		White	N/A	N/A

Table 7.10 Fabrics of C1928-9 evening dress

	Arnold's book			Measured colour	
	Fabric type		**Colour**	**Pantone Color Que**	**Pantone Color Guide**
Dress	Chiffon		Black	N/A	Black 7C
Slip	Crepe-de-chine		Black	Black 7C	Black 7C

Tables 7.11 and 7.12 show the list of selected fabrics, yardages, costing and names of the suppliers. The yardages in the tables included some extra fabric for unexpected errors and for the measurement of fabric properties in later stage.

Table 7.11 List of alternative fabrics for C1861-3 day dress

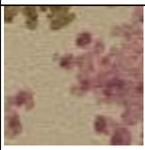
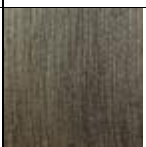
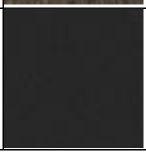
	Image	Material	Fabric type	Colour	Width / Yardage		Cost (£)	Supplier
Shell		Silk	Taffeta	White	44”	19	210.62	Silk Road (ROK)
				Digital printing	44”	19	144.11	Samwoo Print (ROK)
Lining		Silk	Taffeta	White	44”	4	44.34	Silk Road (ROK)
		Silk	Taffeta	Light green	44”	1	11.09	Silk Road (ROK)
		Cotton	Light calico	Ivory	38“	9	11.16	WBL FABRICS (UK)
Decoration		Silk	Taffeta	Dark green	44”	4	44.34	Silk Road (ROK)
Sleeve		Cotton	Lawn	White	60”	2	8.46	WBL FABRICS (UK)

Table 7.12 List of alternative fabrics for C1928-9 evening dress

	Image	Material	Fabric type	Colour	Width / Yardage		Cost (£)	Supplier
Dress		Silk	Chiffon	Black	44”	10	93.35	Sangmi Fabrics (ROK)
Slip		Silk	Crepe-de-chine	Black	44”	3	16.24	WBL FABRICS (UK)

Digital Printing

While most fabrics of the costumes were plain, the pale silver grey taffeta fabric of C1861-3 day dress has prints. As the printed fabric covers the large parts of the dress, this study considered the patterns as a significant aesthetic element. For this reason, the pattern repeat was designed according to the scanned textile data. Due to the limited dimension of the scanner, scanning was carried out nine times using the skirt which consisted of large fabric pieces. Each area was scanned to be slightly overlapped for smooth connection of images and the scanned data were then linked to each other to identify the motif design and repeat type using Adobe Photoshop application. In connecting patterns, this study considered the errors which were produced by hindrance of the folds and creases of the skirt.

1st	2nd	3rd
4th	5th	6th
7th	8th	9th

(a) Scanned areas

(b) Scanned textile

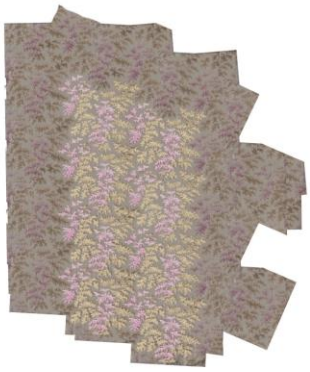
Figure 7.42 Pattern scanning

From the connected images, one motif with flowers and leaves were extracted and the pattern repeat layout was identified as half drop style. Since the surface images of the original presented many creases and fabric structure, the data could not be directly used for printing. Therefore, the motif was reproduced using Photoshop based on the colours measured (Figure 7.43 (b)) and its layout was determined with the similar spacing to the original pattern (Figure 7.43 (a)). After the design of the pattern, this study gave a digital printing agency a commission to print on the white taffeta fabric. However, the printed colours appeared with some differences from the Pantone colour chips to the unaided eye. The colours were slightly adjusted through the test printing twice. However, the final outcome still presented subtle differences. This problem possibly occurred due to the differences between the colours displayed on the screen and the colours printed. Also types of fabric may have an influence on the presentation of colours. This study considered that further investigation of the colour adjustment and calibration will be required for a more accurate reproduction of the pattern.

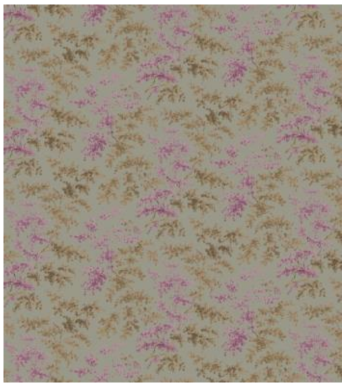
(a) Connected images

(b) Reproduced motif

Figure 7.43 Identification of pattern



(a) Scanned images overlapped with reproduced motif



(b) Re-designed pattern

Figure 7.44 Layout design and reproduced pattern

Besides, the texture of the taffeta was changed after the printing process. Touch of the printed fabric on the hand gave an impression that the stiffness was decreased. According to the printing agency, the preconditioning for the preparation of printing might have affected the texture of the fabric.

Subsidiary Materials

The types and colours of subsidiary materials of the costumes which were described or illustrated in Arnold's book (1977) are as shown in Tables 7.13 and 7.14. While the evening dress from the 1920s only applied pressed studs, the day dress in 1860s was made of various materials including buttons, braids, boning and others and some of them had distinctive characteristics in terms of material or appearance. According to the curator of the Museum of London, feather bones were used as boning for the bodice. However, such material is not readily available in the market today. Also the decorative features of the buttons and braids of the day dress which shows antique and elegant details are not easily found among the modern products. Therefore, preparation of the subsidiary materials had to rely on the alternative products with different materials and design.

Table 7.13 Subsidiary materials for C1861-3 day dress

Arnold's book / observation					**Measured colour**	
Item	**Colour**	**Material**	**Width/ dimension**	**Feature**	**Pantone color cue**	**Pantone color guide**
Button	Grey	Silk	½"	Acorn shape, twisted silk	419C	
Braid	Fawn		7mm	Looped	7497C	
Hook & eye	N/A	N/A	N/A	N/A	N/A	N/A
Cord	N/A	N/A	1/16"	Piped	N/A	N/A
Boning	N/A	N/A	3/8"	Set into casing	N/A	N/A
Embroide -red panel	White	Cotton	-	Cutwork embroidery	N/A	N/A
Ribbon	White	Silk	1 1/8"	Pleated ruche, Picot edge	7521C	
	Ivory	Silk	½"	-	7521C	
	Pale greeny-grey	Silk	1 3/8"	Bow	415C	

Table 7.14 Subsidiary materials for C1928-9 evening dress

Arnold's book / observation					**Measured colour**	
Item	**Colour**	**Material**	**Width/ dimension**	**Feature**	**Pantone color cue**	**Pantone color guide**
Pressed stud	Black	N/A	N/A	Left open	Black 7C	Black 7C

The standards of selection were prioritised as shown Figure 7.45. First of all, the role of the materials took precedence over other considerations which can be categorised into functional and decorative purposes. This study considered that the boning, buttons, hooks and eyes and studs put more emphasis on functions for figuration or fastening. With regards to the selection of these materials, types and styles of the materials were somewhat neglected and the performance of function of the material was dominantly considered. Then the decision depended on the order of material, dimension, design and then colour of the items. For example, while markets offer a wide choice of other materials, feather boning is no longer used for modern clothing manufacture. Accordingly, synthetic boning was applied for this study as an alternative. Since the size of the polyester boning was limited, a 12mm width-product was prepared as the closest material and the design and colour of the product were disregarded as the bones would be covered by fabric cases.

Figure 7.45 Priority in selection of alternative materials

On the other hand, selection of the decorative elements regarded the types of materials as priority. The secondary consideration was the dimension of the item. This study tried to obtain the same or similar size of products as the original materials because the proposition of the decorative elements was considered to have a significant influence on the impression of the garment. The design of the items was given third priority. Through the comparisons between the photographs of the materials and the products in various suppliers and vintage textile fairs, the item which presented the similar aesthetics as the major features of the original materials were carefully selected. Colour was given the lowest priority since the range of the choice was too much diminished if it was considered as a prerequisite. Based on the measured data, similar colours were prepared or dyed if commission was available. In the case that this study could not satisfy a prior requirement, the subordinate priority was more focused.

The day dress from the 1860s was the subject which required more consideration of materials as it has various decorative elements including pleated frills, braids, piping and a bow. For instance, the fawn braid which took the largest part of decoration in length was regarded as an important component. Since the material of the braid was not identified, the selection of the item focused on its dimension. The width of the original braid measured approximately 8mm and its repetitive looped shapes were the most distinguished feature. The closest-sized product was 10mm and the one which has similar looped details was chosen. Although the colour of the item was white, a similar colour could be achieved through a dying agent using the colour data.

However, some items like silk ribbons could not be purchased due to the limited product range available based on the standardised size or prevalence of synthetic materials. Also the distinctive features such as lustre and picot edge of the silk ribbons were regarded as important elements that stood out. For this reason, ribbons of the day dress were produced to apply more appropriate aesthetic effects. The details of preparation are described in the following section.

Also there were some materials which were more arbitrarily prepared by the researcher. It was considered that these items did not play a decisive role in appearance because they were not visibly outstanding or did not belong to the genuine costume. These materials included hooks and eyes, embroidered panels and buttons or studs of sleeves and the size or shape of the hooks and eyes, embroidered panels and buttons or studs of sleeves. Although their approximate shape and position were illustrated on the diagrams of Arnold's book (1977), the precise size and other features were not specified. For the selection of these materials, this study focused more on their functions or plausibility for coordination.

In addition, other materials such as threads and dye were also required for sewing or preparation of a more appropriate colour. These materials were prepared based on the colours perceived by naked eye. Figure 7.46 presents the whole materials used and the list of the materials are the specified in Tables 7.15 and 7.16.

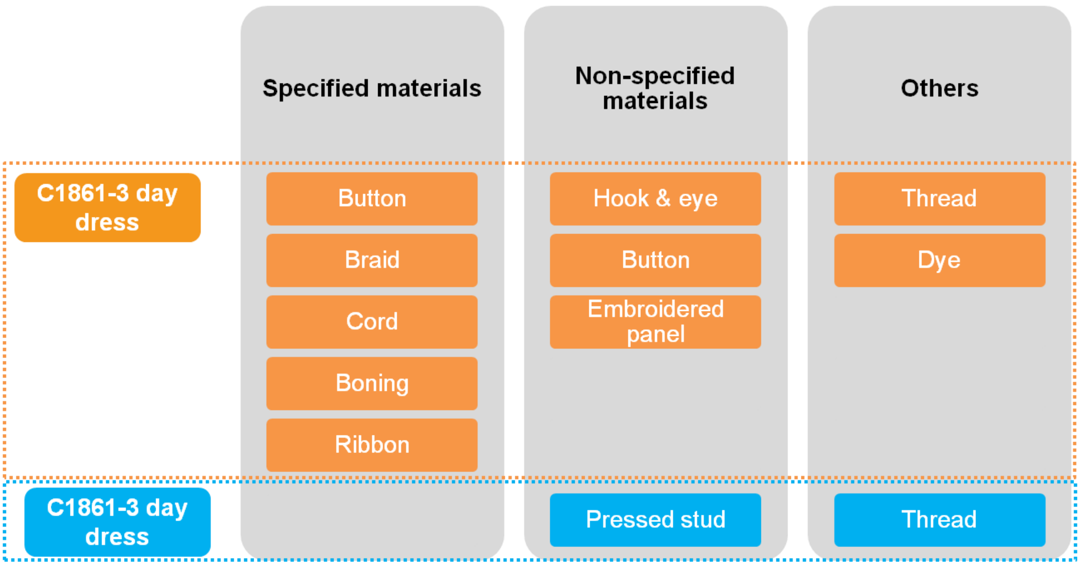


Figure 7.46 Subsidiary materials consumed

Table 7.15 Subsidiary materials for C1861-3 day dress

Image	Item	Material	Colour	Dimension /quantity		Cost (£)	Supplier
	Braid	Rayon	White	10 mm	15 yd	12.18	Sangmi Lace (ROK)
	Dyeing	-	Fawn	-		7.97	
	Hook & eye	Metal	Silver	15x8 mm	2 pairs	0.70	RIBBONMOON (UK)

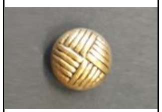
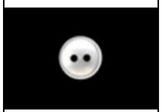
	Cord	Cotton	White	2mm	2 yd	1.98	Personalbridgecharity (Ebay)
	Boning	Polyester	White	12 mm	1yd	0.50	RIBBONMOON (UK)
	Ribbon	Silk	Dark green	35 mm	1yd	2.64	Ebay
	Ribbon	Silk	White	29 mm	5yd	-	-
	Ribbon	Silk	White	13 mm	2yd	-	-
	Button	-	Gold	-	7	2	Vintage fair
	Button	-	White	-	2	0.14	RIBBONMOON (UK)
	Thread	Silk	Grey	-	2	3	FASHIONMADE (ROK)
			White	-	1	1.50	
			Fawn	-	1	1.50	
			Dark grey	-	1	1.50	
	Thread	Cotton	White	-	1	1	FASHIONMADE (ROK)
	Buttonhole thread	Silk	Fawn	-	1	2.10	The Lining Company (UK)
	Corded motif	Polyester	Ivory	30x 11cm	1 pair	12.90	MACCULLOCH & WALLIS (UK)

Table 7.16 Subsidiary materials for C1928-9 evening dress

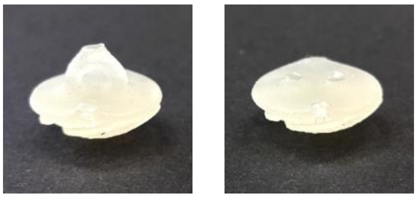
Image	Item	Material	Colour	Dimension /quantity		Cost (£)	Supplier
	Snap fastener	Brass	Black		1 pair	0.74	RIBBONMOON (UK)
	Thread	Cotton	Black		1	1	FASHIONMADE (ROK)

3D Printing

As stated above, buttons were considered as functional materials to fasten the garment. However, the buttons which were attached to the centre of the bodice of C1861-3 day dress were externally outstanding and displayed unique shape. According to Arnold (1977), the buttons were characterised by the half inch-sized acorn shape and the twisted silk material with grey colour. On the surface of the buttons, the twisted silk took a spiral form. In order to imitate their decorative aspect, this study generated the buttons with spiral patterns using a 3D printer (Figure 7.47 (b)).

(a) Original button (b) Reproduced buttons

Figure 7.47 Original and reproduced buttons



(a) Button holes in original and damaged states

(b) Antique bottons

Figure 7.48 Replacement of buttons

In the later stage of the study, however, some of generated buttons on the reproduced costumes were broken during the fastening process. The damaged part was the hole of the buttons where the thread penetrated for attachment to the garment (Figure 7.48 (a)). It seems that the relatively thin part around the hole was too fragile to withstand the tension and force in mounting. Consequently, antiques buttons were used to replace the 3D printed buttons. The substituted buttons consisted of metal and had engraving which mimicked the shape of cord aligned with two different directions (Figure 7.48 (b)). Since similar material and style of products could not be found, this study tried to reflect the shape of the twisted silk strings in the selection of design.

Preparation of Ribbons

There were three types of silk ribbons which were applied to C1861-3 day dress: (1) ½ inch-wide ivory ribbon, (2) 1 1/8 inch-wide white ribbon and (3) 1 3/8 wide pale greeny-grey ribbon. The production of the ribbons was carried out with the white taffeta fabric mentioned in Table 7.15 and silk threads.

Although the description given in Arnold's book (1977) differentiated white and ivory ribbons, the measurement of each colour appeared to be the same data therefore the same fabric was used for both ribbons. The ribbons were basically produced by cutting fabric in the warp direction and stitching straight along the folded edges. The picot edges of the 1 1/8 inch-wide ribbon were generated applying shell tuck stitches over the tissue papers. However, silk thread applied showed a tendency to get tangled or snap while loops were sewn. Through several experimentations using different types of threads, cotton thread was chosen as a replacement as it appeared to give the most satisfactory result. Figure 7.49

(a) ½ inch-wide ribbon around neckline

(b) Generated ribbon with ½ inch-width

(c) 1 1/8 inch-wide ribbon inside sleeve

(d) Generated picot edged-ribbon

Figure 7.49 Original and reproduced ribbons

Pattern Cutting and Sewing

After the preparation of the fabrics required, production of costumes was conducted through several stages: paper pattern preparation, fabric cutting and sewing. In order to produce physical costumes which were identical to the digital replicas, the patterns refined were plotted on large papers in full proportion using a digital printer.

Pattern layout and cutting was carried out considering minimisation of consumption of fabrics, the warp direction and the arrangement of prints if necessary. In order to remove creases and folded marks, the fabrics were flattened using the iron before the layout of patterns. Then, paper patterns were arranged and pinned on each fabric according to the warp direction. The important sections such as contour lines, seam lines, cross sections of seams, parts where gathers were applied and others were marked using chokes. The seam allowances applied to each fabric piece were 10mm in general and 50mm on the centre front of the bodice for fastening.

(a) Paper patterns (b) Fabric pieces

Figure 7.50 Paper patterns and fabric pieces cut

Sewing Process of C1861-3 Day Dress

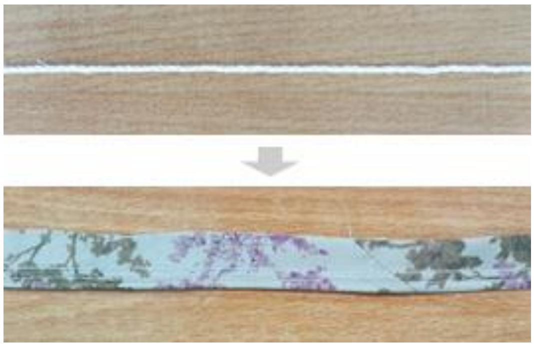
For efficient production, the costume was divided into different parts: (1) decorative elements such as pleats, strips, A-shaped panels and piping, (2) functional or supportive parts such as boning, pocket and waist bands, (3) outer shells, (4) lining and (5) closure. These parts were first individually produced and then assembled together.

Figure 7.51 Sewing process

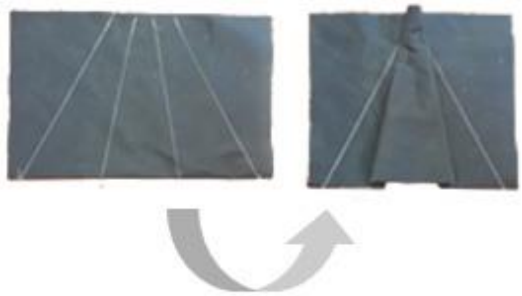
Decorative and other

The garment parts which were priory produced were decorative or other functional elements. In fact, they were not the major components of the costume but they were prepared beforehand for that they were required in the sewing process of other parts.

(a) Pleated frills and ruche



(b) Piping



(c) A-shaped panels

(d) Decorative strips

Figure 7.52 Decorative parts

- Pleated frills and ruche

The pleated frills in white and charcoal grey were simply prepared by folding and pinning the fabrics to form the box pleated-shape. The charcoal grey frills were applied on the bodice, decorative strips, sleeves and hemline and its function was mainly decorative. Meanwhile, the white ruche was used inside the sleeve and played a role to cover the raw edges of the charcoal grey frills.

- Decorative strips

The decorative strips are the most conspicuous element of the bodice. They consisted of three sections: one piece of fabric on each right and left centre of the bodice and three pieces for the trimming of neck and bodice. The edge of the strips was decorated using braid and then frills were attached.

- Piping

Piping was the elements which functioned as embellishment as well as reinforcement for the edges around the armholes and the hemlines. In order to produce single and double piping, one or two strings of cord were covered with the fabric cut on the bias.

- A-shaped panels

The A-shaped panels were the decoration which were inserted into slits around the hemline of the skirt. The original costume had a total of 28 panels and their folds were inconsistently pleated. While some of them were folded right side over the left, some were folded on the other way. For the garment of this study, right sides of all panels were firstly folded and the left were folded over the right side.

(a) Boning (b) Waistband (c) Pocket

Figure 7.53 Functional parts

- Boning

The bodice of the costume contained a total of five pieces of boning at the centre back and front darts. Each strip was converged by white taffeta to be attached to the lining fabric.

- Pocket

The pocket was designed to be attached to the right side of skirt and the waistband. To produce the pocket, a rectangular fabric piece was half folded and then pleated on the top. The pleated section was fastened by a piece of fabric to connect to the waistband.

- Waistbands

The waistbands for the bodice and the skirt were prepared by folding long strips of fabric and sewing side seams.

Outer Garment Shells and Linings

The outer garment shells and linings which were divided into the bodice and skirt parts were first individually produced. The order of the assembly put priority on the pattern parts which were more close to the centre of the body and the other sections were then attached.

- Bodice

(a) Main parts assembled

(b) Main bodice parts with piping

(c) Sleeve

(d) Completed outer bodice shell

Figure 7.54 Outer bodice shell

(a) Bodice lining with boning

(b) Sleeve with ruche

(c) Completed bodice lining

Figure 7.55 Bodice lining

The main parts of the bodice consisted of two and three front and back bodice pieces respectively and two sleeves. The sewing was carried out as follows. Firstly, the princess seams of the back bodice were sewn and the back and front bodice parts were sewn together through side and shoulder seams. Topstitches were applied where enhancement or securing seams were required. At the hemline of the outer bodice shell, doubled piping was added and braid was sewn on the top of it. Secondly, sleeves were attached to the armholes of the bodice. In the case of outer bodice shell, corded piping, braid and pleated frills were added to the sleeves in order beforehand. Then the raw edges of the seams were finished with overcasting stitches and boning inserted at the centre back and the darts of the lining.

- Skirt

The outer skirt shell was made of eight large printed silk fabric pieces and it could be prepared by sewing side seam lines. Meanwhile the lining consisted of eight large cotton parts and eight more separate hem sections made of silk. Also a facing which was made of the same fabric as the outer skirt shell was sewn on the top of skirt. The outer skirt shell was simply prepared by sewing seam lines.

(a) Outer skirt shell (b) Skirt lining

Figure 7.56 Outer shell and lining of skirt

These hem linings were first attached to each main skirt lining part and the whole outer shell and lining pieces were respectively connected through side seams. In order to insert the pleated panels, the centres of their position at equal distances on hemlines of both outer shell and lining were slashed and folded back to form small slits with triangular shape. The pleated panels were sewn under the slits of the outer shell showing A-shaped appearance and braid was trimmed on top of them.

Combining Outer Shells and Linings

The individually prepared outer shells and linings were combined and the shape bodice and skirt was almost completed in this stage.

(a) Facing of bodice (b) Bodice inside (c) Sleeve

(d) Waistband of skirt (e) Pocket (f) Skirt hem

Figure 7.57 Inserted linings into shells

- Bodice

The lining part was inserted inside the outer bodice shell and pleated frills were applied to the piped hemline. For prevention of tangling of the yarns, overcasting stitches were applied around the frills. Then, the decorative strips were sewn on the bodice. In order to neaten the frills, the frills round the neckline and the bodice were fixed on the surface of bodice or on a ribbon. Also a little white ruche was attached inside each sleeve to over the edge of the frills. Finally, a waistband was added inside the bodice.

- Skirt

The lining and the outer skirt shell were joined together through sewing of seams of the hemlines. Based on the positions of the slits of the outer shell, the slits of the lining were fixated applying hemming around triangular edges. Then, the opening of the pocket bag was set into the right side seams of the skirt.

In order to pleat the skirt, the outer shell and the lining was temporarily tacked. The top of the skirt was then folded down to match the waist band: the folds were generally double-pleated but the folds around the centre front and the fold at the centre back were folded once and three times respectively. Although Arnold's diagrams (1977) did not illustrate the construction of the waist part, it was observed that the original costume had a facing sewn inside. The facing was made of the same fabric as the outer skirt shell and it covered the top of the skirt lining to join the waistband with over-stitches. However, the shape of the facing was somewhat uneven and its dimension could not be measured: the lengths of sections where each fold was joined differed from each other and some parts were folded together with the pleats while some parts were not. For this reason, this study made the decision to leave the facing out of consideration. The folds of the skirt and the waistband in this study were directly joined up showing layered details. Also the supportive strip of the pocket bag was also attached to the waistband to stabilise the position of the pocket.

Finishing

Small components such as buttons and hook and eye were attached to the costume.

(a) Buttonholes and buttons

(b) Hook and eye of skirt

(c) Bow on the front bodice

(d) Hook and eye of bodice

Figure 7.58 Finishing

- Bodice

The bodice was designed to be fastened up by buttons at the centre front and hook and eye at the front waistband. A total of seven buttons at equal spaces were attached on the left side of the front bodice and their corresponding buttonholes were generated on the right front bodice based on the buttonhole technique on Authentic Victorian Dressmaking

Techniques (Harris, 2013). Two pairs of hook and eye were stitched at the tips of the waistband.

- Skirt

Two pairs of hook and eye were sewn on the waistband of the skirt: one pair to fasten the surplus inside and the other pair to secure the position of folds where the skirt is open.

Coordination Item

For construction of the detachable engageante, cotton lawn was cut based on the diagrams of Arnold (1977) and a pair of corded motifs was sewn on the centre of each sleeve. The bottom of the sleeves was gathered to fit the wrist bands. Then the cuffs were trimmed with scallop stitches and attached to the wrist bands. These plausible sleeves were worn before the bodice mounting to enhance completeness of the costume display.

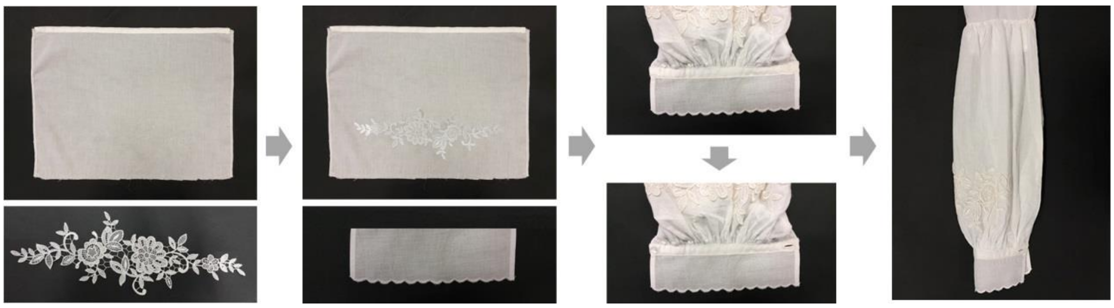


Figure 7.59 Production process of engageante

(a) Front (b) Side (c) Back

Figure 7.60 Completed reproduction of C1861-3 day dress

Sewing Process of C1928-9 Evening Dress

The reproduction of evening dress in the 1920s was accomplished following the process in Figure 7.61. The dress consists of two garment items which are slip and dress. In general, small parts which were considered as components of major garment parts such as straps, cuff and decorative panels were prepared ahead. The main parts which were essential and larger pieces to form a garment such as bodice and sleeves were separately assembled. Then small components were combined with the major parts.

Figure 7.61 Sewing process

Slip

The slip of the evening dress was simply made up of one large piece of bodice and two fabric pieces for shoulder straps. The straps and bodice were first individually prepared and then joined.

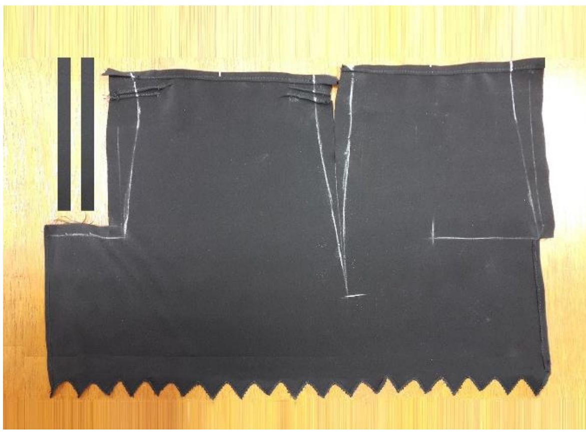


Figure 7.62 Slip pieces

- Shoulder straps

The straps were prepared by vertically folding fabric strips in half with the right sides together and stitching one of the end and long side of the strap. Then the straps were turned right sides through one side of the ends which was not stitched. The straps were pressed to be flattened and the open end was stitched.

Figure 7.63 Sewing of slip

- Bodice

Hemming was first applied to prevent unravelling. The hem at the top and side and flap were rolled and top-stitched and hem at the zigzagged hem at the bottom was finished applying a picot-edge. Then four single-pointed darts around the bust were sewn and pressed. The side seams were stitched to form a tubular shape of slip and overlocking was applied to the seams. The flap section was stitched under the back of the slip. The straps were attached on the top of the completed slip.

Dress

While the structure of the slip was very simple, the dress was characterised by the complicated geometric configuration. The parts of the dress were categorised into three elements: (1) bodice and sleeves as main parts, (2) layered petal shapes, floating panels and cuff as decorative parts and (3) lingerie straps and bands as functional parts. The construction was proceeded according to these categories. Firstly, decorative and functional parts were sewn individually. The elements were attached after main parts were assembled.

- Petal shapes

The evening dress was designed to be decorated with a total of 28 triangular fabric parts in different sizes. The petal shapes were produced using doubled layered chiffon stitched together. The fabrics were turned after the seams at corners of each shape were trimmed. Ironing was applied to tweak the overall shape. Except for four largest petal shapes, the contour lines of the doubled layers were enclosed. The 90 degree angled-corners of largest shapes were left open to attach floating panels.

- Floating panels

Floating panels are other main decorative elements of the dress flowing at the bottom of the petal shapes. Each part was made up of one small and one large fabric piece layered together. Two pairs of fabric pieces for each front and back were prepared and picot-edged. The small pattern pieces were positioned upon their corresponding large panels and basted to be joined. Then each pair was joined to the petal shape.

- Cuffs

The cuffs have a plain square shape and a picot-edge was applied all round to neaten the contour lines. The centre of the cuffs was vertically slashed to join to the sleeves.

- Lingerie straps

One pair of lingerie straps was prepared using two straight fabric strips. These parts were produced in the same way as the shoulder straps of the slip.

- Bands

The bands are the parts for reinforcement inside the bodice. The edges of the band were folded to be stitched in the next stage.

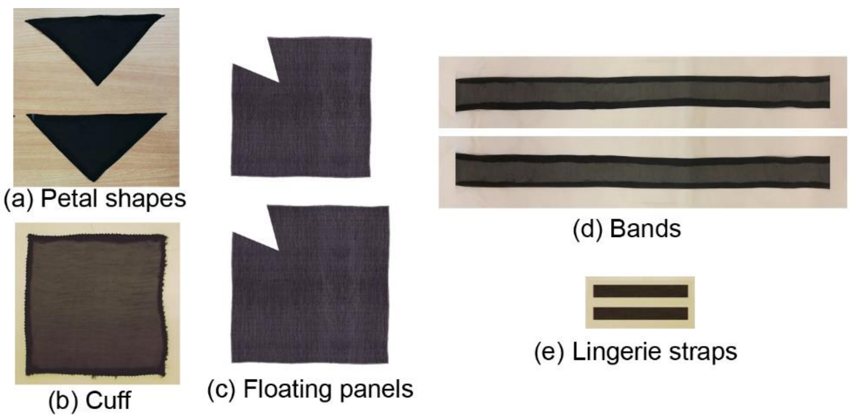


Figure 7.64 Decorative and functional parts

- Sleeves

The cuffs prepared were combined to the sleeves through the openings. In order to join the side seams, the ease for elbow and sleeve head was double stitched within the seam allowance from the wrong side. The ease was distributed by pulling the threads stitched. The side seams were sewn and overlocked and then the sleeve hem was rolled to neaten the edges. press studs were attached to the sleeve at the wrists to be left open.


(a) Attatcing cuff


(b) Sewing side seam

Figure 7.65 Sleeve and cuff

- Dress

Before sewing the dress, each hem line of the front and back bodice were picot-edged to avoid unravelling. The assembly of bodice was basically accomplished through stitching the shoulder and side seams and overlocking was applied to the edges. In order to strengthen the shape of the neckline and encase raw edges, seams around the neckline were trimmed and wrapped in binding. Then the sleeves were attached to the bodice and seams around the armholes were finished with overlock stitches. The bodice bands for reinforcement were hand stitched on the wrong side of the dress and each of the four petal shapes were arranged and sewn on the right side of bodice in seven layers in the form of an inverted triangular shape. The petals at each level overlapped left corners over and right corners under. Stitches were applied on the longest sides of the shape which were cut on the bias and the ends of the shapes were suspended free. Lastly, lingerie straps were stitched on the wrong sides of shoulder sections.


(a) Binding on neckline


(b) Petal shape with floating panel


(c) Attaching petal shapes

Figure 7.66 Bodice

(a) Front (b) Side (c) Back

Figure 7.67 Completed reproduction of C1928-9 evening dress

Applied Sewing Techniques

Although the day dress was produced after the introduction of the sewing machine, hand sewing was frequently applied alongside the machine stitches. Figure 7.68 shows the types of stitches utilised.

- Machine stitches

In general, a sewing machine was used for the assembling of most fabric pieces applying straight stitches. The applied lengths of stitches varied between 1.5 and 2.5 mm: while 2.5mm of stitches were used in most cases, 1.5 mm of stitches were applied where more strength was required. Also some decorative stitches that the domestic machine provided were used for some cases. For example, shell tuck stitches were attempted for the imitation of picot edge of the ruche. Although the reproduction was accomplished on a superficial level, it was considered as being the most feasible method due to the unavailability of picot stitch machine. In the case of cuffs of the detachable sleeves, satin scallop stitches were applied on the hem to express the decorative shape of the diagrams of Arnold's book (1977).

- Basting

Basting refers to the temporary stitches which are generally applied to mark the fabrics, prepare garments for fittings and secure the position of different fabric layers during the construction process (Shaeffer, 1993). In this section, even, uneven and diagonal basting stitches were mainly used for holding fabrics in appropriate position as fitting was assured in the previous section using the toile. Even basting or doubled even basting was applied to the fabric sections where easing or gather were required. Uneven basting was used for basting hems and seams in general and diagonal basting was applied to prevent shifting folded or layered fabrics. These stitches were removed after the application of appropriate sewing techniques.

- Overcasting stitch

Overcasting stitches are diagonal stitches which were used to finish raw edges of fabric (Fischer, 2015). They were applied over the edges of seams to keep the threads of the fabric from unravelling.

- Hemming stitch

Hemming stitches were applied to the seams where unravelling of yarns and neatening were needed. Hemming stitches are slanting stitches

- Back stitch and prick stitch

Back stitches are the strongest and most elastic techniques among the permanent hand stitches (Shaeffer 1993) and they were mainly applied to join the seams where a sewing machine could not delicately work. Prick stitches are the same type of back stitches which generate points of thread on the surface and long stitches on the other side (Fischer 2015). These stitches were used to attach the pleated frills and ruche to the dress.

- Fell stitch

Fell stitches are applied to join a raw or folded edge of fabric flat against another layer of fabric under it (Shaeffer 1993). This stitch was used to attach the lining to the outer skirt shell and to secure the position of the slits for the A-shaped panels

- Hemming stitch (blind stitch)

Hemming stitches are slanted stitches in the same direction and have even size (Harris 2013). They were applied over the single folded hem of the dress to prevent fraying.

- Buttonhole stitch

In order to fasten the buttons, the corresponding buttonholes required some degree of strength. Buttonhole stitches were applied not only to reinforce the strength but also to prevent cut fabric from unravelling. Besides, the buttonhole thread was waxed to build up resistance to twisting during sewing as Shaeffer (1993) emphasised.

- Slip stitch

Slip stitches are a fine edge finish technique which are invisible from both in and out sides of fabric (Fischer 2015). This technique sews two layers by picking one or two threads of the fabric. In this study, slip stitches were applied along the neckline of the bodice to finish edges using ribbon.

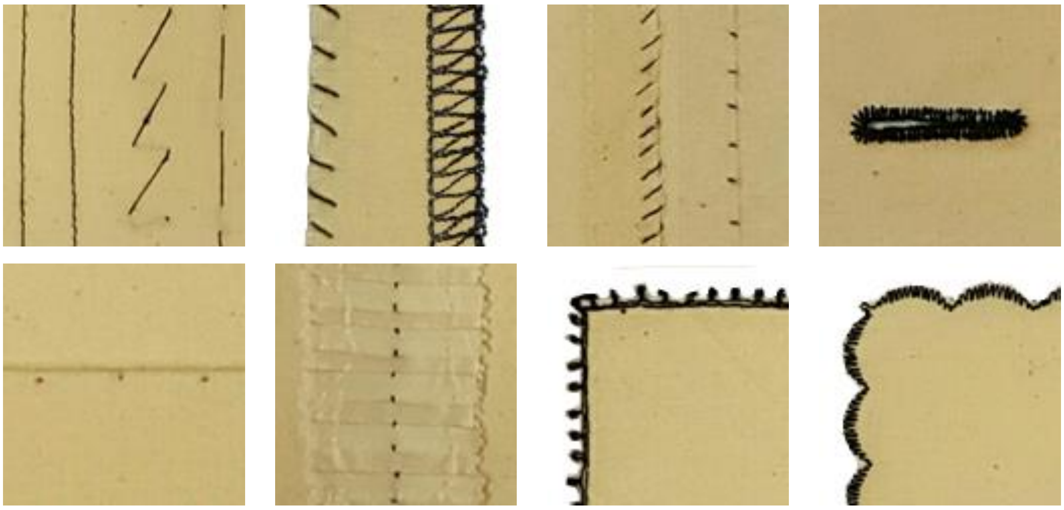


Figure 7.68 Applied stitches

7.2.3 Preparation of Fabric Property Data

Drape refers to “the manner in which the fabric falls, shapes or flows with gravity on a model form or on a human body” (Jedda et al., 2007, p.219) and it is one of the important factors which determines the external appearance of the fabric (Jeong, 1998). It not only affects the volume and elegance of garments defining the shape of the fabric (Kenkare et al., 2008) but also has influence on garment fitness, mobility and comfort. In this sense, drape plays a significant role in both an aesthetic and a practical aspect.

In this study, drape of the digital clothing is important to the formation of the garment shape in relation to real garment form. Since each reproduced dress has distinctive drape behaviour, this study tried to achieve similar features using the material parameters of the 3D apparel CAD system. For this reason, it is necessary to understand the capability of the system, effectiveness of system parameters and to take measurement of fabrics properties for parameter input. Therefore, this stage consisted of two main sub-stages: pilot exercises for exploration of material parameters of the system and application of fabric measurement. During the process, the 3D apparel CAD system, DC Suite was upgraded from version 3.0 to 5.0. The newest version was applied to the later stage.

Table 7.17 shows the definitions of the material parameters of the system which were investigated in this study. Some parameters were excluded from the consideration: (1) those which the guidebook recommended to set as default: air drag and (2) those which are not relevant in this study: rubber weft and rubber warp. According to the manual, air drag and rubber parameters can be adjusted to create the effect of wind and to express elastic materials respectively. In this study, effect of wind is not required for simulation and none of physical materials has elasticity. Therefore, application of these parameters are considered irrelevant.

Table 7.17 Material parameters in DC Suite

Material properties	**Unit**	**Definition**
Density (weight)	g/cm^2	Grams per $1cm^2$ of the fabric.
Stretch stiffness (weft and warp)	$kg/s^2 \fallingdotseq$ 1.02gf/cm	Has a larger value when it is tougher to stretch a fabric along the weft and warp direction.
Shear stiffness	-	Has a larger value when it is tougher to stretch a fabric along the bias direction.
Bend stiffness	$kg{*}cm^2/s^2$ = 1.02gf·cm	Has a larger value when it is tougher to bend a fabric.
Friction	-	The friction coefficient.

7.2.3.1 Pilot Exercises

Many 3D apparel CAD developers boast realistic physical-based simulation in their applications and often offer comparison images which the real garments and virtual garments appeared almost identical to, to prove the effectiveness of their tools. However, it was not clear whether the objective application of drape visualization was accomplished because the investigation of the validity of the material parameters of existing software was scarcely carried out. In the case of DC Suite 3.0, adjustment of fabric parameters may be problematic particularly for the inexperienced users because it uses less universalised parameters and devolves the decision of the values upon the user’s intuition. Therefore, the pilot exercises were planned to establish standard to derive realistic representations of various drapes. However, this study adapted measured data of fabrics in the later stage as the guidelines which helps the use of objective measurement for drape simulation input were proposed with new version of DC Suite. Nevertheless, the pilot exercises provide good understanding of system capability and characteristics of some material parameters. The pilot exercises consisted of two experimentations: testing reproducibility of garment drape and testing effectiveness of individual parameters. This section gives brief explanation of test processes and results.

Simulation test 1

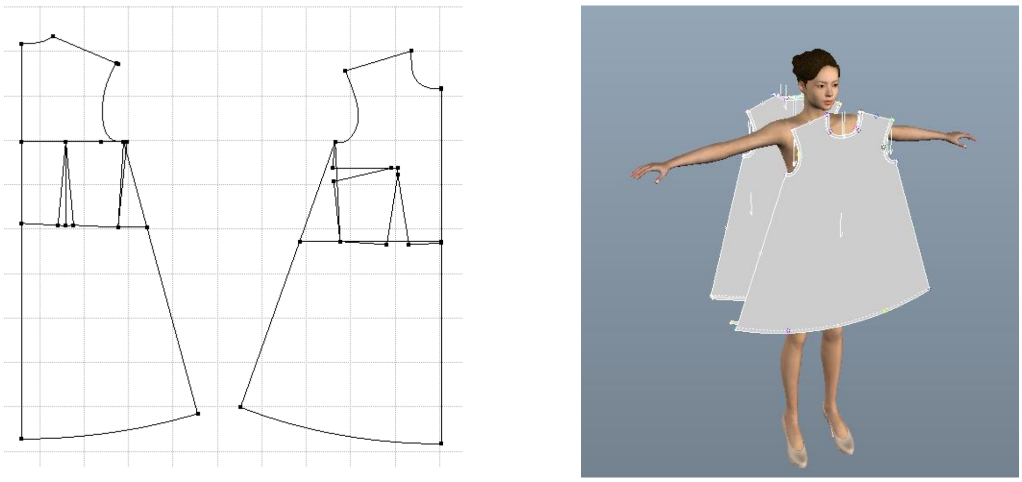
The aim of this experiment was to reproduce two actual garments which have different drape characteristics. Through this experiment, this study attempted to verify the capability of the software and acquire the reasonable data of various drape shapes.

Two garments which were made of cotton fabric with a different stiffness quality in Sanad et al.'s study (2013) were applied as samples. They are A-line dresses developed from the basic blocks in Shoben and Ward's book (1987) applying size 12 measurements. To observe the images of the actual shape of the garment drape, the samples were worn on a 12-sized human model and two photographs from the front and side were captured (Figure 7.69). The more drapeable garment was labelled Sample A and the less drapeable garment as Sample B. This study selected front and side views because the distinct drape was mainly developed from the chest part which follows the convexity of the body in this design. Thus, the differences of the drape were more obviously observed from the front and side perspectives.

(a) Sample A (b) Sample B

Figure 7.69 Samples

Preparation of Garment Simulation



(a) Generated patterns (b) A virtual figure and panels

Figure 7.70 Garment patterns and virtual figure

The essential requisites of garment simulation are a virtual figure and the garments themselves. Virtual model generation is the first task in most 3D apparel CAD systems. This study set a virtual body which applied the shoulder width and chest, waist and hip circumferences of the actual human model using the parametric body generation function. Other measurements were not considered since there was no significant effect on drape with those features. Then 2D garment patterns were reproduced based on the information achieved at the sample structure identification stage. In order to maintain the equivalent structure, seam allowance and bindings were also applied. Figure 7.70 presents the patterns developed and a virtual model with pattern pieces.

Determination of Reference Values

This study attempted to find out input values which visualise different drape features from the sample material properties provided as the initial point of the test. Table 7.18 shows the values of some parameters of seven sample fabrics. Figure 7.71 presents the images of simulations applying each fabric values to compare the drapability.

Table 7.18 Material properties of sample fabrics

	Thick cow leather	**Cotton span**	**Cotton velvet**	**Cotton twill**	**Wool**	**Silk chiffon**	**Silk satin**
Weight	0.01	0.018	0.015	0.01	0.01	0.01	0.01
Stretch stiffness	110	85	88	90	100	90	90
Shear stiffness	0.15	0.05	0.05	0.1	0.2	0.05	0.1
Bend stiffness	0.15	0.0001	0.001	0.01	0.2	0.0001	0.01
Friction	0	0	0	0	0	0	0

In order to establish the values which expresses the most and least drapability, this study attempted to distinguish the garment drapability of each simulation result. As the criteria of the drapability, this study applies the cross-sectional diagrams and air gap ratio of the garment bottom line and waist line from the y-axis. The cross-sectional diagram of this software illustrates the contour lines of body and garment from a certain point and the air gap ratio is automatically calculated based on the areas of the contour lines as follows.

$$Air\ gap\ ratio = \frac{(\text{total cross sectional area} - \text{cross sectional area of body})}{\text{cross sectional area of body}}$$

This study regards the air gap ratio can be used as an alternative to drape coefficient to characterise the degree of drapabilty since drape coefficient is dependent on the proportion of an area and will accord with the air gap ratio. While air gap ratio can objectively explain the drapabilty, the overall shape and the cross-sectional diagrams were visually evaluated relying on the researcher's observation.

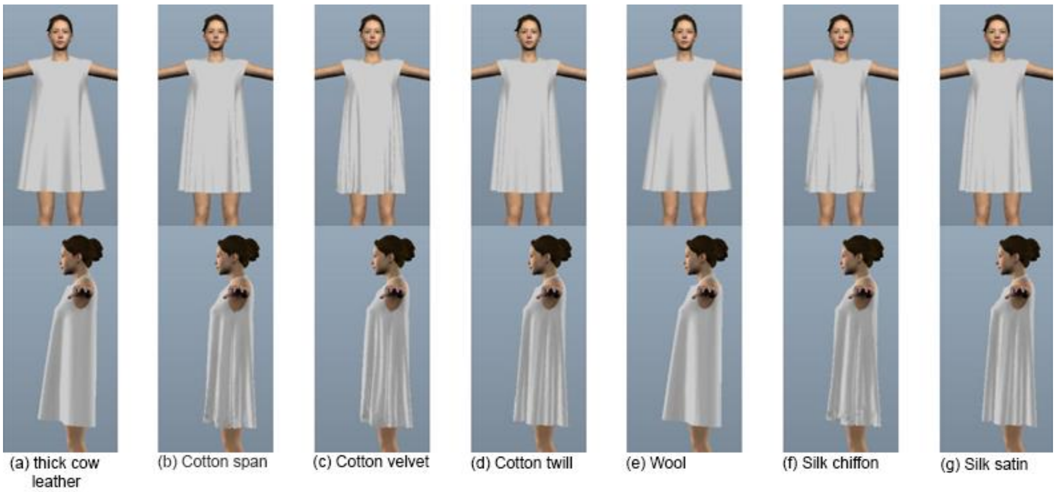


Figure 7.71 Simulation results of seven sample properties

Table 7.19 Cross-sectional diagrams and air gap ratio of simulated garments

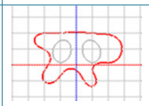
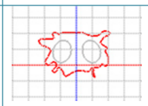
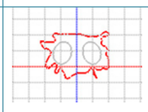
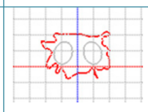
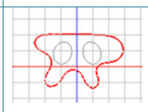
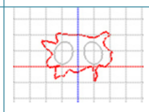
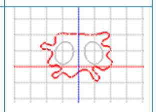
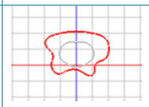
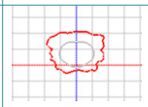
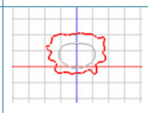
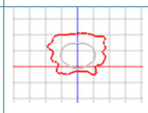
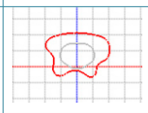
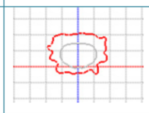
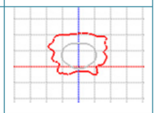
		Thick cow leather	Cotton span	Cotton velvet	Cotton twill	Wool	Silk chiffon	Silk satin
Bottom line	Diagram							
	AGR	0.90	0.85	0.86	0.86	0.89	0.85	0.86
Waist line	Diagram							
	AGR	0.66	0.68	0.63	0.62	0.66	0.62	0.62
Average AGR		0.78	0.765	0.745	0.74	0.775	0.735	0.74

Table 7.19 presents the extracted cross-sectional diagrams and the air gap ratio of each simulation result. The simulation of silk chiffon produced the lowest average air gap ratio and simulations of thick cow leather showed the highest values. This study considered that the material properties of silk chiffon and thick cow leather presented the most salient contradictory drapabilty.

Although it was not stated what kind of silk chiffon and cow leather was selected in terms of sample choice, it is assumed that the system intended to apply the representative fabrics and their general drape features which reflect the common users' general concepts rather than fabrics with extraordinary traits for establishment of sample data. Hence, as Figure 7.71 and Table 7.19 depicted, this study considers that the provided sample data represented the material properties of chiffon fabric with very loose drapabilty and leather with rigid drapabilty. Since the subjects of this study were not made of materials which were more drapeable than chiffon or less drapeable than thick leather by observation, this study set these two sample data as the minimum and the maximum input values.

Drape Simulation

For the generation of various drape simulations, this study equally divided the intermediate values of each parameter of above two sample data as shown in Table 7.20. The first and fifth levels in Table 7.20 indicate the minimum and maximum values respectively, and the material values of each level between those two increases in ratio. The values were calculated to six decimal places. Figure 7.72 presents a variety of drape produced by the simulations based on these values. This study tried further visualisations to achieve a stiffer drape than the fifth level (Figure 7.73(b), Table 7.21) and the median drapabilty in between levels 1 and 2 which presented a huge difference (Figure 7.73(a), Table 7.21).

Table 7.20 Interval values

	1	2	3	4	5
Weight	0.01	0.01	0.01	0.01	0.01
Stretch stiffness	90	95	100	105	90
Shear stiffness	0.05	0.075	0.1	0.125	0.15
Bend stiffness	0.001	0.037358	0.07505	0.112525	0.15
Friction	0	0	0	0	0s

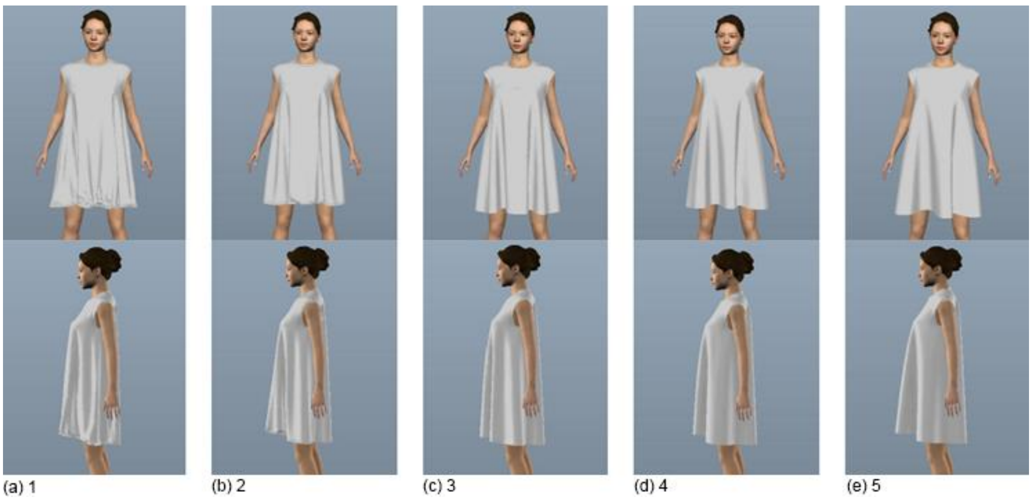


Figure 7.72 Simulation results of data in Table 7.19

Table 7.21 Values further generated

	6	7	8	9
Weight	0.01	0.01	0.01	0.01
Stretch stiffness	92.5	115	96.6	98.3
Shear stiffness	0.0625	0.175	0.0833333	0.0916666
Bend stiffness	0.019679	0.187475	0.049921	0.062486
Friction	0	0	0	0

(a) 6 (b) 7 (c) 8 (d) 9

Figure 7.73 Simulation results of data in Table 7.21

Table 7.22 Cross-sectional diagram and air gap ratio of the garments

		1	2	3	4	5	6	7	8	9
Bottom line	Diagram									
	AGR	0.82	0.84	0.87	0.88	0.87	0.82	0.88	0.85	0.87
Waist line	Diagram									
	AGR	0.59	0.62	0.63	0.64	0.65	0.61	0.66	0.62	0.62
Average AGR		0.705	0.73	0.75	0.76	0.76	0.715	0.77	0.735	0.745

Approximate Drape Results

The approximate drape simulations of the sample garments were determined according to the researcher's observation focusing on the overall silhouette, the shape of the folds from the front and side view. The simulation outcome of the fifth input level appeared similar in drapabilty to sample B in terms of a stiff silhouette and the wide shape of the folds. In the case of sample A, the simulation of the second input looked alike however it seemed possible to achieve a more corresponding result. Therefore this study suggested two proportional intermediate values between the second and the third input data. Figures 7.73(c) and (d) are the outcomes of these two middle stages and Table 7.22 presents their cross-sectional diagrams. Although their overall silhouettes looked similar, the peak point of the fold of (d) which was induced by the chest appeared more prominent like the fold of sample A. Figure 7.74 presents a comparison of the images of the samples and the virtual garment.


(a) Sample A (B) Sample B

Figure 7.74 Physical and digital garments

Conclusion

The pilot test attempted to take an approach to visualise a certain silhouette and drape of dress through the control of the material values. The results of this test showed that a variety of drape could be generated with this approach. The increase or decrease of material parameter values in equal difference produced the equal degree of different drapability. In order to generate simulation results which were more closely related to the sample, this study subdivided the interval values in between two similar data. Although the similarities between samples and virtual garments were not objectively assessed, the outcomes appeared similar to the actual dresses.

This experiment has following the limitations. Firstly, the objective image data of the sample garment drape was not achievable. The precise analysis may require a number of trials with the same posture to investigate the average drape features. In this study, sample garments were worn on the human model therefore the different garment behaviours under a same condition could not be considered. Also the cross-sectional images were not collected in view of human rights.

Secondly, the drapabilty of virtual garments was evaluated through the air gap ratio and visual assessment. Since the software was not developed for the purpose of drape analysis, it did not provide other objective drape parameters. Although the air gap ratio which explains the garment area can characterise the degree of drapability, it does not describe drape profile. Therefore this study was dependent on visual assessment to distinguish shapes of drape.

Thirdly, as this study set reference material parameters based on two sample fabric data, the effects of individual parameters were not explored since this study only focused on the drapabilty led by the overall values of the equal differences.

From these limitations, this study concludes the major considerations of future experiment for more convincing evaluations and comparisons as follows. Firstly, the objective data and methods need to be applied. Secondly, more delicate drape visualisation will be accomplished if the impact of various values of each parameter were investigated. Therefore the effects of individual parameters were explored in following pilot test and application of objectively measured data was attempted in the later stage.

Simulation test 2

The second simulation experiment was conducted by focusing on individual material parameters. The objectives of the test were to identify the minimum and maximum values of each material property and to observe their effects on garment drape, which was induced by adjusting the numerical value of each material parameter. The subject of the experiment was the same an A-line female dress which was used for the first test. The material parameters tested in this experiment were confined to stretch stiffness, shear stiffness and bend stiffness, which appeared as different values between two reference sample data in the previous test.

Control Parameters

It is optimal to compare drape under the same conditions in order to properly evaluate the effect of each parameter value. Initially, this study intended to set every value to zero to get rid of any influence. However, it was found that the garment form was not sustainable when either the value of density (weight) or stretch stiffness was zero. A density (weight) value of zero left the connected panels hanging in the virtual space with no change (Figure 7.75(a)). In the case of a stretch stiffness with a value of zero, the dress kept extending downwards (Figure 7.75(b)). It seemed that those parameters were sensitive to the force of gravity. This means that weightless objects do not appear to change under gravity and the designed conditions within the system. Also, the stretch stiffness value of zero, which indicated a fabric with no vertical resistance, made the material constantly respond to the gravitational pull. For this reason, the decision was made to apply the default values as control variables and to substitute different values of each parameter in turn.

(a) Density (weight): 0 (b) Stretch stiffness: 0

Figure 7.75 Invalid simulation outcomes

Weight	0.01
Stretch stiffness	100
Shear stiffness	0.1
Bending Stiffness	0.1
Friction	0

(a) Front (b) Side (c) Bottom (d) Default values

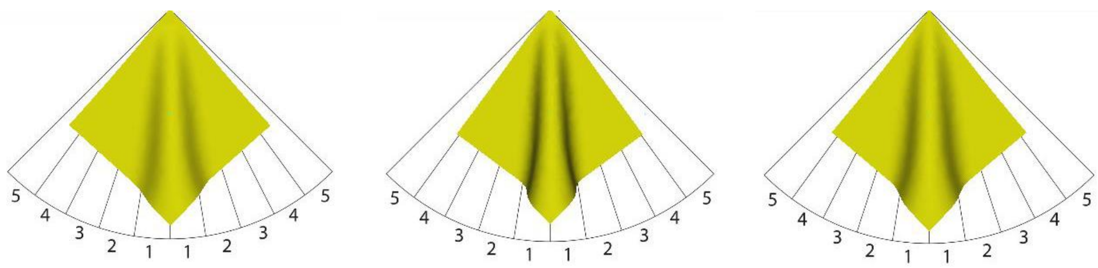
Figure 7.76 Simulation result of default values

Establishment of Parameter Value Range

The first step of the experiment was to define the minimum and maximum values of each parameter. It was necessary to control the values based on the certain measures within a limited scope. While a value of "zero" was considered as the minimum, the system did not confine the maximum boundary of property values. In other words, users are able to input extreme numerical values whose outcomes may give the expression of non-fabric or unreal materials.

In order to identify the appropriate maximum values to be used as the properties of the least drapeable fabrics for garment production, this study applied the simple drape measurement method proposed by Aldrich (1996) . This method was designed to use 20 cm^2 samples and a 90-degree sectorial scale which consists of five equal parts of graduations from the centre to both sides. The fabric samples were hung on the centre point above the tool and vertically draped within a one to five area scale. The drapabilty of the fabric is evaluated as high, high-medium, medium, medium low and low drape according to the area into which the sample falls.

For the preparation of this method in a virtual environment, a 2D object with an image of the sectorial scale was generated and a $20cm^2$ square of virtual cloth was pinned on the centre point of the virtual scales. The individual material values were gradually increased until the sample reached an area of 5, at which point it regarded those values as a maximum to express the stiffest fabrics for garments. Based on arbitrary values, this study increased 5 and 0.001 for every simulation for stretch stiffness and the other parameters respectively. These quantities were determined according to the number size of their initial values given by DC Suite. As a result, the maximum value of each parameter for this test was determined, as shown in Figure 7.77.



(a) Stretch resistance: 145 (b) Shear resistance: 0.227 (c) Bend resistance: 0.12

Figure 7.77 Virtual drape measurement

The values were divided (from zero to the determined values in Figure 7.77) into four and five simulations for each parameter were conducted. Table 7.23 displays the different values tested in order. In the case of stretch resistance, value one was applied as the minimum.

Table 7.23 Applied parameter values

	1	2	3	4	5
Stretch stiffness	1	36.25	72.5	108.75	145
Shear stiffness	0	0.057	0.114	0.170	0.227
Bend stiffness	0	0.03	0.06	0.09	0.12

Simulation Results

Figure 7.78 shows the simulation results of different stretch resistance values. Except for Figure 7.78(a), the simulations presented a stable shape of the garments. Although the system allowed for small numbers to be input, this caused too much stretch to be regarded as fabric. The garment folds of this simulation were mainly induced by the hip section of the figure as the length of the dress aberrantly extended. Therefore, this study considers Figure 7.78(a) as an irrelevant case.

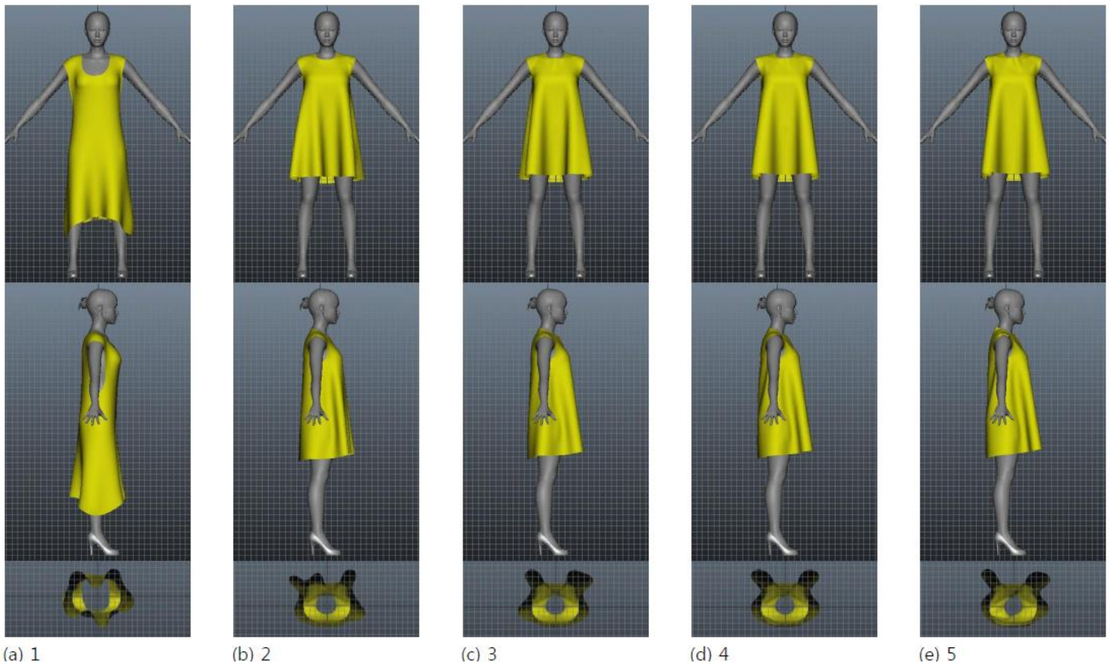


Figure 7.78 Stretch stiffness

As stretch stiffness is associated with gravitation, the outcome showed that the length of garments was influenced by this parameter's value. The differences in length is most visible between Figures 7.78(b) and (c). Although the difference was not large, the length was reduced when a larger value was applied. It was also found that the width of the garments decreased in accordance with an elevation of the value. It was assumed that the stretch stiffness engages with the stability of the garment shape towards gravity in both vertical and horizontal directions. Besides, the lines of the garments from the bust point to the peaks of the folds from the side were observed to be straighter as the values increased. The number of folds tended to decrease as the stretch stiffness increased.

Figure 7.78 (b), which applied a relatively small value, yielded more folds in front; however, the depth of the folds was not large. On the other hand, Figures 7.78(d) and (e), whose values were a large, showed large depth in two embossed folds. While Figures 7.78(b) and (c) presented obvious differences in the number of folds and their shape, Figures 7.78(d) and (e) showed a small dissimilarity.

The simulation outcome of shear stiffness (Figure 7.79) also presented different drapabilty. It was shown that the parameter values of this property have an influence on the width of the garments as well as on the stiffness of the cloth. The width of dresses in Figures 7.79(a) to (d) visibly decreased as the values increased. However, contrary to this, Figure 7.79(e), which adopted the highest values, showed an increased width. It is assumed that relatively low values, which imply less stiffness in a biased direction toward the outside force, allowed for some deformity of the garment width. The increased stiffness up to some degree seemed to reduce the deformation through gravitation, and the large shear stiffness values appeared to contribute to the stiffness of the cloth, which led to the dress being stretched out. The increase in stiffness was noticeable from the side view of the garments. The boundary of the garment which connected the bust point to the peaks of the folds became straight as the values increased. Also, the outcome showed that the elevation of the values induced a larger depth between the front and back hem. Besides, shear stiffness did not affect the length of the garments.

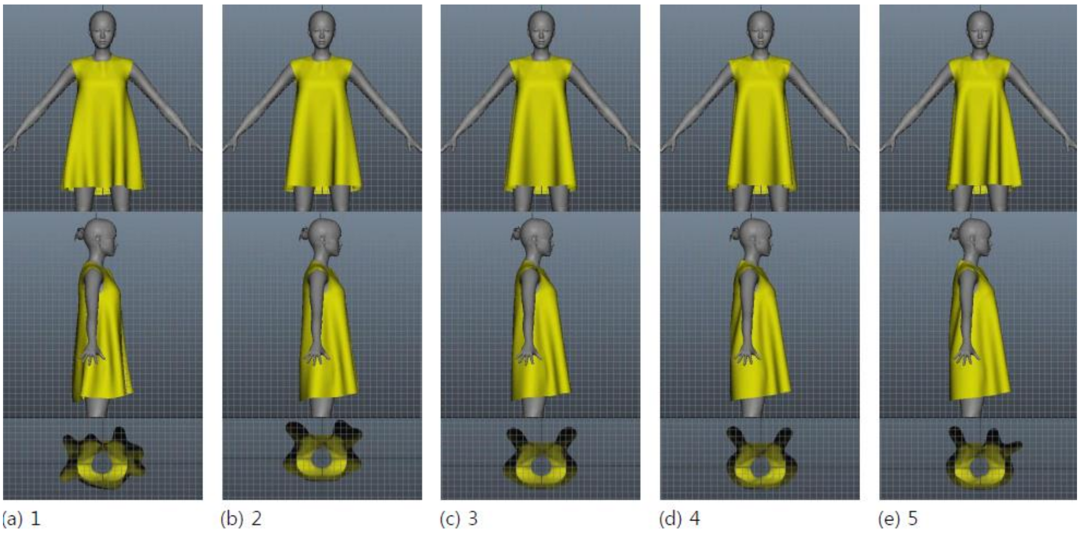


Figure 7.79 Shear stiffness

The number of the folds was large when the value was small. Figures 7.79(a) and (d) showed that the number and shape of the folds became small and simple as the values increased. However, Figure 7.79(e) showed an unlikely increase in the folds. It is assumed that a node was generated due to the relatively stronger resistance to the force in a biased direction, compared with the fixed force acting on the warp and weft direction. In addition, while the position of the folds appeared quite evenly dispersed in Figure 7.79(a), the folds converged toward the front below the bust as the values were elevated.

The simulation results of bend stiffness are shown in Figure 7.80. The outcome showed no significant differences in length and width among the dresses. However, the bend stiffness had an influence on the depth of the garments. As the values increased, a larger space between the front and back hems was found. It was also observed that the number of folds was greatly influenced by the bend stiffness. A large number of folds was yielded in Figure 7.80(a), which had a value of zero, whereas Figure 7.80(e), with the largest value, showed two simple folds below the bust. The results indicated that the small values had less stiffness and were more vulnerable to bend. Meanwhile, as the number of folds increased, the garments showed more complex contours with a lower amplitude. In this manner, the larger value had a tendency to induce a small number of simple folds but with larger amplitude due to the higher stiffness. This interrelationship between stiffness and the form of folds more clearly explains the reason why the depth of garments was increased in accordance with the elevation of bend stiffness. Overall, Figure 7.80 shows sequential, but the most dynamic changes in the level of drape.

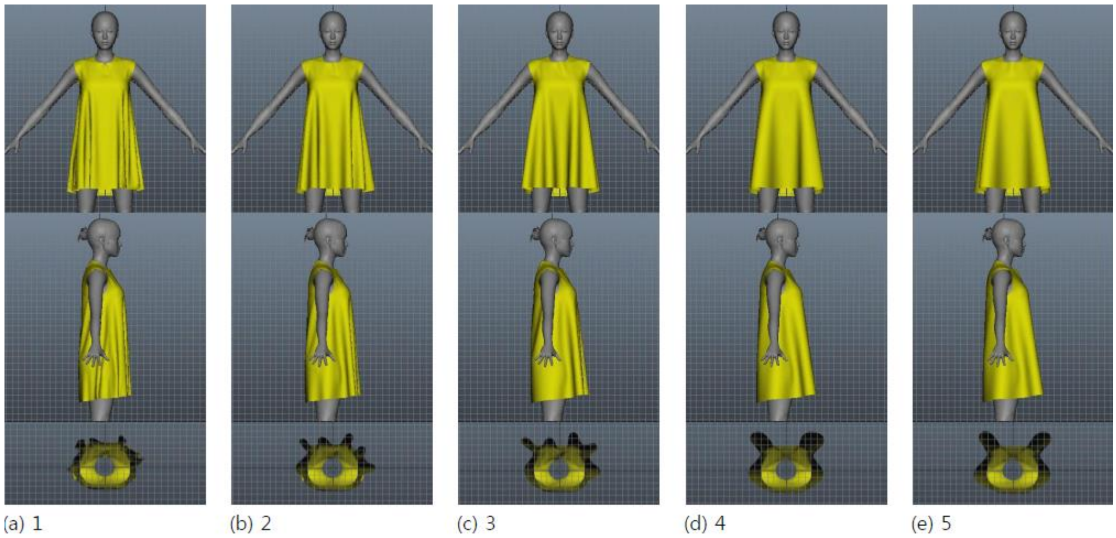


Figure 7.80 Bend stiffness

Conclusion

In the experiment, stretch, shear and bend stiffness had an impact on the garment drape. Among them, bend stiffness had the most striking effect and generated the most radical changes in terms of the number and complexity of the folds. The number and complexity of the folds became simpler depending on the level of increase of the value. Stretch and shear stiffness were also observed to affect the number and complexity of the folds, and in most cases, these features tended to become simpler with an elevation of the values. However, at least some large shear stiffness seemed to engender the folds in a biased direction. In addition, the diffused folds had a tendency to concentrate at the front below the bust along with an increase in their size and depth as the values of these three properties increased.

All three factors appeared to relate to the drape of the virtual fabric. As the values of these parameters increased, the stiffness of the garments became intense. Especially, the stiffness which was enhanced by stretch, shear and bend values involved some directivity: warp and weft direction and biased direction, respectively. The effects of those properties were observed in the length, width and depth of the dresses. In the case of stretch stiffness, changes in length and width were presented. The influences of shear stiffness appeared in the garment width and depth. Additionally, bend stiffness affected the depth of the garments.

This simulation experiment attempted to investigate the effect of each of the parameters and found some different influences on garment drape, as discussed above. The limitations of this test are as follows. Firstly, this experiment did not define the minimum range of each parameter which would provide an acceptable expression of the garment fabrics. The minimum values of the properties applied were zero or one, and consequently, excessive deformation of a garment was produced in a stretch stiffness simulation. Secondly, the boundary of the maximum value of each parameter was determined by a non-standardised method, which is not generally used in academic studies. Although Aldrich's (1996) drape measurement enables designers to quickly and conveniently check fabric drape, it does not provide accurate quantitative indications of drapabilty. Thirdly, the results of drape simulations were not objectively analysed. The system used did not provide any function to measure the garment drape. In order to reduce the risk of subjective observation, this study applied grid lines to the garment images. Fourthly, the experiment was carried out without considering the multiplicative effects of the different parameters; fabric drape is configured by the association of various physical properties which may not be explained by the influence of one factor.

Approach for Further Step

From the simulation tests, this study can confirm that the 3D CAD system is capable of visualising different drape features and to specify the changes in the stiffness of fabrics, and the number and size of folds to some extent, through the adjustment of the individual parameters. At these stages, however, the specified standards for representation of fabric drape were not established at the practical level. Meanwhile new version of DC Suite became available with the guidelines to apply objective fabric measurement for adjustment of material parameters and this study decided to adapt this method. It was considered that the application of values derived from quantitative measurement of specified properties is more efficient rather than the estimation of each value based on the characteristics of drape. By taking this method, this study considered to be free from some limitations of the previous tests such as use of the non-standardised method and need for establishment of valid parameter ranges. The following section describes how this study applied the fabric measurement into system parameters.

7.2.3.2 Fabric Objective Measurement

The fabrics used for physical reproduction have distinctive characteristics. This study considered the expression of the drape behaviour that each fabric displays as an important factor to visually differentiate the uniqueness of the materials. The adjustment of material parameters based on measurement of fabric properties is expected to create distinct drape as previous tests testified the derivation of various drape from the effect of the independent parameters. For this reason, this stage was planned to identify some characteristics of the fabrics which are related to the parameters of the software and grant virtual fabric-specific attributes based on it. In this way, this study expected to achieve more authentic shapes of different fabric drapes.

The subjects of the measurement were the fabrics used in the physical reproduction in Tables 7.11 and 7.12 (p.166). Among them, lawn, which was used for detachable sleeves of C1861-3 day dress was excluded from the test because the sleeves were not a part of the original costume. All fabrics were conditioned for 48 hours in standard atmosphere: 65 ± 2% relative humidity and 20 ± 2ºC according to the British Standard (BS EN 20139:1992 ISO 139:1973) before the tests. Tests and estimation of parameter values were achieved using scale and KES-F as the main apparatusis based on the software guidebook however KES-F was replaced with Titan in the middle of the stage due to being out of commission. Titian is a straightforward strength tester which can measure the extension of a fabric with the force up to 5000N and speed up to

4000mm/min. The following sections briefly explain measurement process, results and estimation of values.

Weight

The fabrics' weights were measured using three samples of each fabric which were cut in 100 square centimetres using a fabric weight sampler. Table 7.25 shows the average gram per 1 square centimetres of the fabrics.

Bend Stiffness and Friction

According to Ko (2015), the bend stiffness and friction parameters of the DC Suite are the same as the bending stiffness and friction coefficient of KES-F respectively. KES-F is the system developed by Kawabata in 1972 to identify and assess mechanical properties of fabrics by calculation of the low deformation forces generated when a fabric is in use. This system consists of four instruments which measure tensile and shearing, bending, compression, surface friction and roughness specifying 16 features. Among them, relevant properties to the parameters of DC Suite is shown in Table 7.24. The KES-F system provides a stress-strain plot which is generated by the applied force. The force and deformation are measured and recorded in the form of continual curves which present the hysteresis behaviour of samples. To achieve bending stiffness B and coefficient of friction MIU, three samples cut in 20 x 20 cm were tested using KES-FB-2 and 4 as follows.

Table 7.24 Relevant fabric properties of KES-F

Test	Property	Description	Units
Tensile (KES-FB-1)	WT	Tensile energy	gf.cm/cm^2
Bending (KES-FB-2)	B	Bending stiffness	gf.cm/cm^2
Surface (KES-FB-4)	MIU	Coefficient of friction	None

KES-FB-2

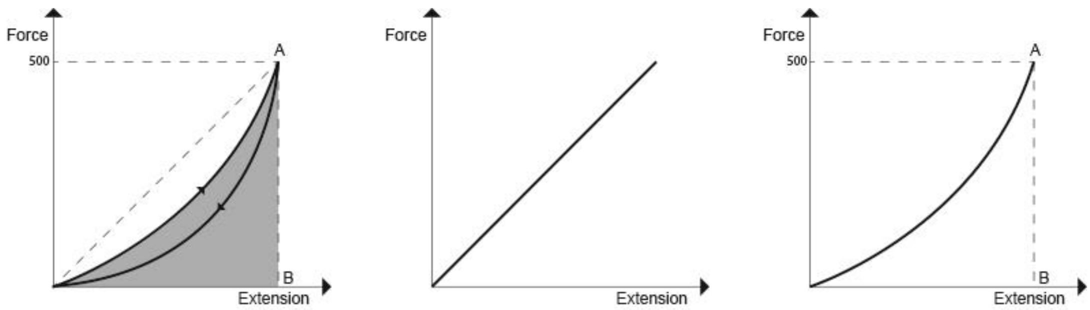
This test measures the force which is required to bend a sample in both the inside and outside direction. Force is applied to the sample, of which one side is fixed and the other side is movable, and bent through a curvature at a constant rate of 5mm/sec. The moment-bending curvature relationship is recorded. The average bending stiffness of the fabric is shown in Table 7.25.

KES-FB-4

This test measures frictional forces using a moving sample fixed at a winding drum which rotates at a constant speed of 1mm/sec and a tension devise, and contact sensors which simulate a fingernail or the points of the fingertips. In the surface friction test, a series of U-shaped piano wired sensor with a contact force of 50gf measure the force required to pull the sample past the sensor. Force(friction)-a distance curve is generated based on the average values of coefficient of friction (MIU) and mean deviation of coefficient of friction yielded.

Stretch and Shear Stiffness

The software guidebook (Ko, 2015) explains that DC Suite applies linear elastic model to stretch (Figure 7.81(b)) and this can be approximated to 2xWTm/εm2 measured in both warp and weft directions. In the case of shear, the guidebook recommends using the same method and formula as stretch stiffness but measured in bias directions. The reason for this is that the shear parameters in DC Suite means the bias-directional deformation is unlike its general concept in material science.



(a) KES-F (b) DC Suite (c) Titan

Figure 7.81 Force-extension tensile curves

KES-FB-1 tensile test was required to obtain tensile energy WT which is acquired by measuring the area under the initial curve and extension εm (Figure 7.81(a)) for the estimation of both stretch and shear stiffness based on this recommendation. KES-F measures the tensile response of a specimen and a pair of tensile force-strain curves which involve deformation and recovery of the sample is plotted. In this test, the 5 x 20 cm dimension of a sample is subjected to a constant tensile force which lasts up to the maximum force of 500 gf/cm (4.9 N/cm). Then, the specimen is released to return its original position.

Due to the unavailability of the tester, however, the tensile test was conducted using a universal tester Titan to achieve the data up to 500gf/cm. Since WT and extension are not associated with recovery, the data gained by releasing sample was not considered in this study as shown in Figure 7.81(c). The settings of the tester were adjusted to follow the procedure of KES-FB-1: 12.00mm/min of speed with 5 cm of gauge length. However, it was not able to use the same size of samples as KES-F, because the maximum width of the sample loaded on Titan was 10 cm. Under this constraint, this study decided to infer the data of KES-F by testing the different sizes of samples with Titan. For this reason, tensile properties were measured using two different dimensions of each fabric which were cut in warp, weft and both bias directions: (a) 5 x 5 cm and (b) 5 x 10 cm. This study regarded that the data from 5 x 20 cm of dimension of a sample can be assumed by the ratio of the data from (b) to the data from (a) in the same proportion. Table 7.25 shows the estimated warp and weft stretch stiffness and shear stiffness in this way.

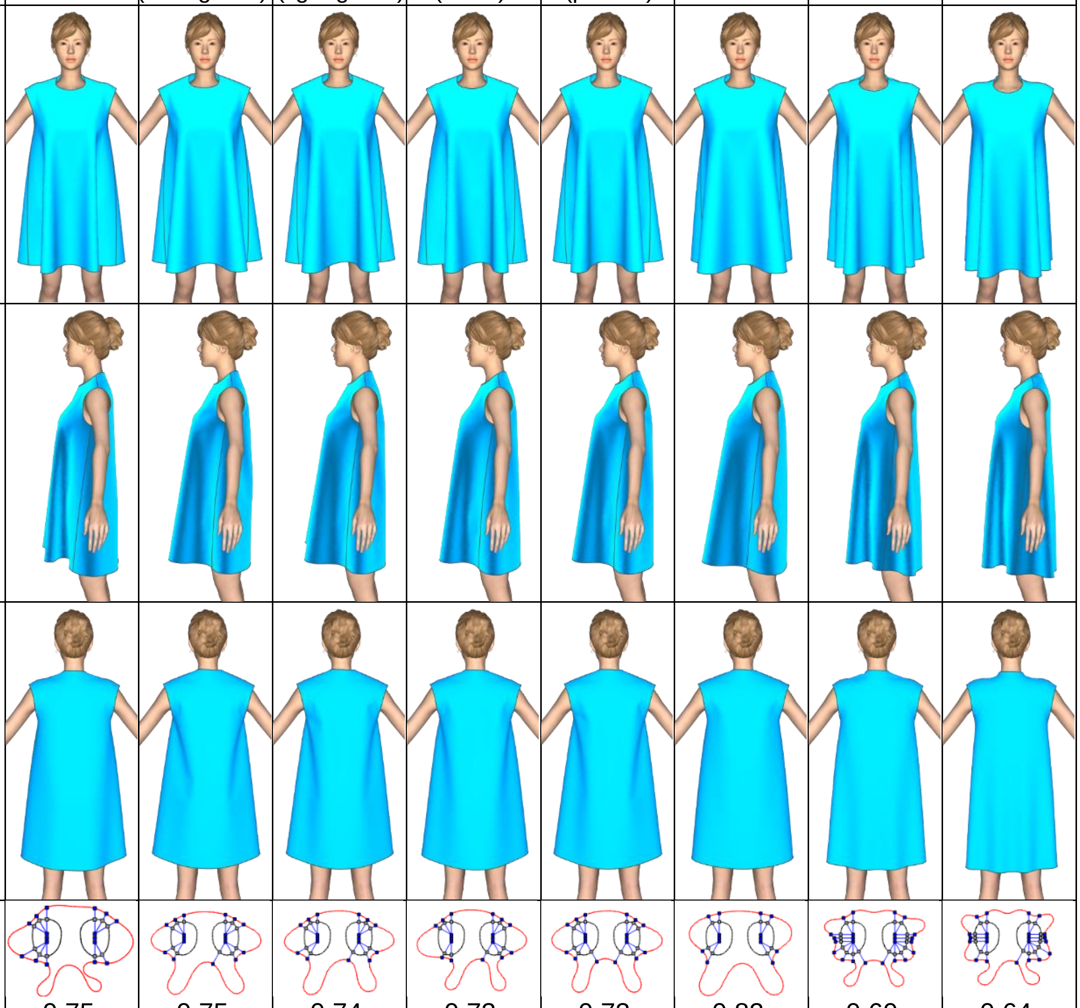
Table 7.25 Material parameter values

	C1861-3					**C1928-9**	
Fabric	Taffeta	Taffeta	Taffeta	Taffeta	Muslin	Chiffon	Crepe-de-chine
Material	Silk	Silk	Silk	Silk	Cotton	Silk	Silk
Colour	Dark green	Light green	White	Printed	Ivory	Black	Black
Weight (g/cm$^{2)}$	0.006	0.006	0.006	0.006	0.005	0.004	0.008
B (bending stiffness)	0.060	0.061	0.057	0.057	0.152	0.009	0.016
MIU (Friction coefficient)	0.135	0.138	0.139	0.128	0.185	0.174	0.177
Stretch stiffness (warp)	204.099	155.607	256.967	166.849	94.509	29.877	18.011
Stretch stiffness (weft)	127.749	103.977	111.670	121.448	24.168	3.776	11.327
Shear stiffness	76.703	96.974	64.687	60.834	20.631	8.789	6.882

Drape Simulation

The material parameter values estimated in Table 7.25 were applied into the system input and simulated with the dress used for pilot exercises to check the different drapabilty. Table 7.26 shows the images of the results and air gap ratio comparing the simulation with default values.

Table 7.26 Simulation with estimated values



	Default	Taffeta (dark green)	Taffeta (light green)	Taffeta (white)	Taffeta (printed)	Muslin	Chiffon	Crepe-de-chine
Front								
Side								
Back								
Airgap	0.75	0.75	0.74	0.73	0.73	0.82	0.60	0.64

7.3 Digital Reproduction

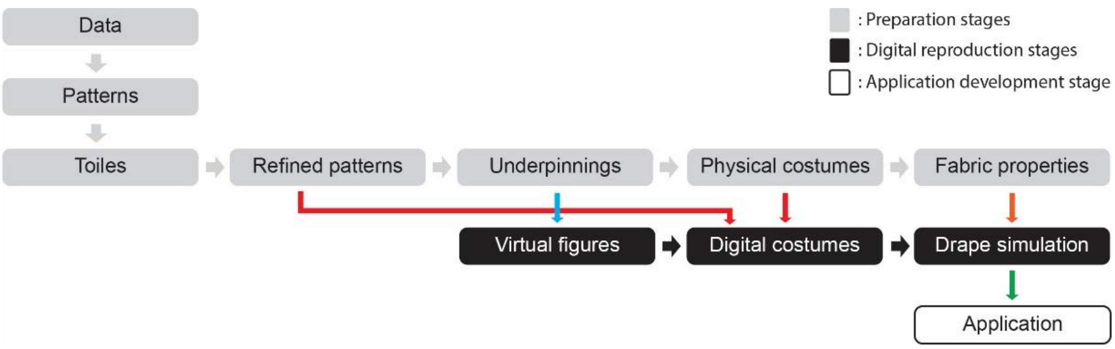


Figure 7.82 Relations between stages

The second phase of the process dealt with the digital reproduction based on the outcomes of the previous phase. The aim of this phase is to build virtual figures and digital costumes reflecting the same shape and structure of the physical objects and fabric measurement which involved three sub-stages: (1) virtual model generation, (2) digital construction of costumes and (3) simulation development. Figure 7.82 illustrates the process and outcomes of the previous phase and their influences on the digitisation phase. The data created in this phase was planned to be imported into application development phase.

7.3.1 Virtual Model Generation

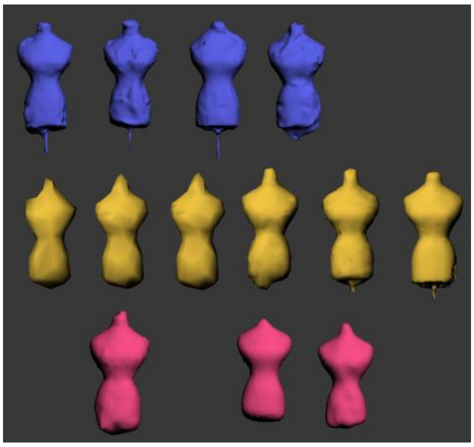
As the stand on which the clothing is worn plays a significant role in garment drape, foundation of the appropriate virtual model is important. This study aimed for generation of virtual stands which are the same as the physical underpinnings. This was not only for the achievement of the desirable garment drape but also for more objective comparison between real and digital costumes in the evaluation stage. Considering identicalness, completeness of synthetic impression and application of motion, a virtual figure with a head and limbs of each costume was created applying different techniques such as 3D scanning, modelling and rigging. This section describes how the virtual figures were prepared.

7.3.1.1 3D Scanning

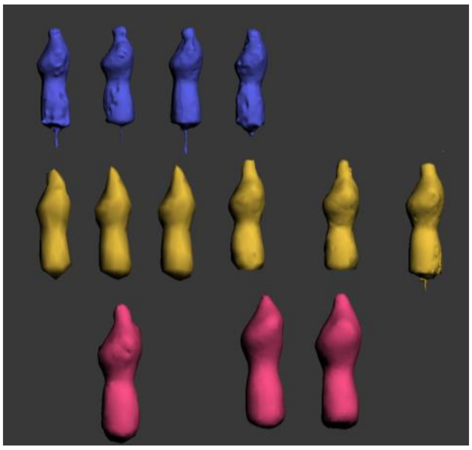
The major concern of the preparation is to build virtual torso shapes as much as identical to the physical body stands. To effectively convert the shape of the mannequins in 3D form, this study applied the 3D scanning technology. Due to the absence of the 3D scanner, this study employed the image-based modelling technique which detect and identify the traits and forms on a series of photographs of an item. This is a useful and cost-effective method which does not require any special equipment or huge installation. In order to achieve the best quality result, this study employed three different software for the first 3D object generation. The applied systems were Autodesk 123D, 3D Zephyr and Agisoft Photoscan. The photographs were taken by Galaxy S4 and the size of each image was 4128 x 3096 with 72 pixels per inch resolution.

Considering the possibility of occurrence of inappropriate results, photographs were taken six times. The images were generated in different conditions: each time, 76 ~ 144 pictures were unconstrainedly taken either in portrait or in landscape in order to attain a variety of data. The outcomes of scanning tended to be more elaborated when more images were processed. In the case of Autodesk 123D, however, only 70 images were processed each time because the application restricts the number of photographs. This study compared the scanning outcomes and chose one object each with the best quality for virtual body construction.

For example, Figure 7.83 shows the results of scanning the body stand of C1861-1863 day dress. As it is shown, the shape of each figure varied depending on the software even though the sources were same. 123D was the program which generated the roughest face of models. Using this system, four objects could be produced from the first, second, third and fourth shooting data. However the surface of all objects were too rugged to be used as a body of virtual models. Half of them had distortion in part and the other half appeared to have global distortion on the face. In the case of Zephyr, only three figures were generated from the second, fourth and fifth photo shoots. While they showed smoother surfaces than the outcomes of 123D, the necks of the mannequin were not properly modelled. The Photoscan appeared the lowest failure rate in terms of output production. A total of six objects were generated from all six shooting data. However there were huge differences in the quality of the results. While three of them had a simplified angular surface and a roughly distorted neck, the other three had real life form of the mannequin in some degree.



(a) Front



(b) Side

(Blue: 123D, red: Photoscan, yellow: Zephy)

Figure 7.83 Scanning outcomes

Amongst the outcomes, this study picked out a few processable objects with less distortion. In order to choose the most appropriate 3D object, the silhouette of the processable models were compared with the silhouette of the real mannequin (Figure 7.84). Scanning and comparison of C1928-9 evening dress and the crinoline of the day dress were conducted in the same way. From the comparison, the results from the Photoscan appeared the most approximate shape to the real mannequins. Although some deformations were found, the contour lines of the most parts corresponded roughly to the scanned subjects. These objects were adopted as the torso of the virtual model and the minor deformation were corrected through following a refinement process.

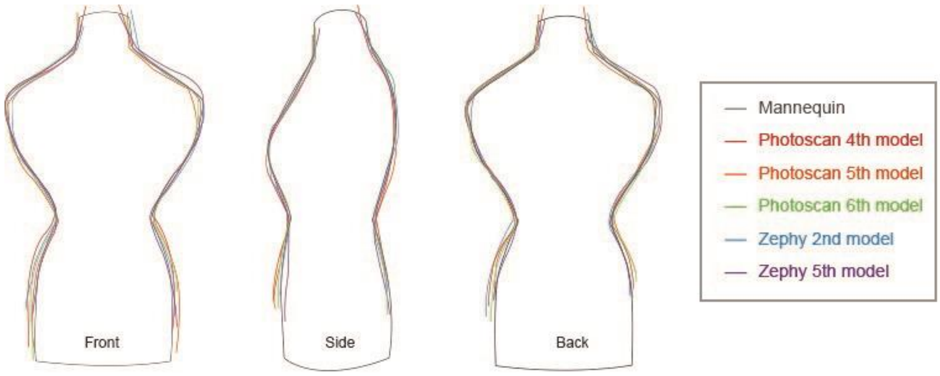


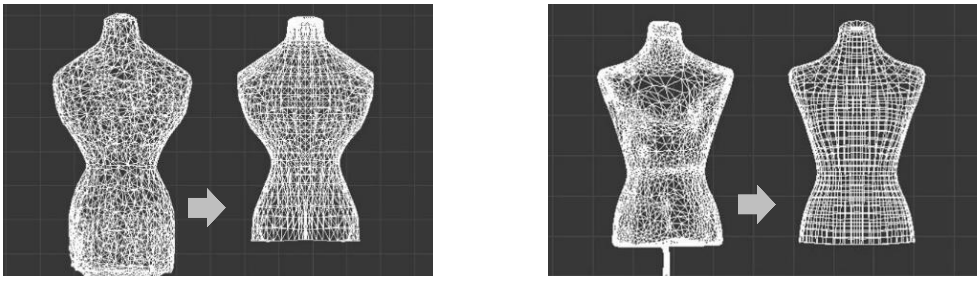
Figure 7.84 Silhouette comparison

7.3.1.2 Modelling

Additional processing was required to refine the scanned objects and improve the synthetic impression attaching a head, limbs and subsidiary items complete the virtual figures. This study applied different modelling systems considering the efficiency and the researcher's software skills.

Torsos

As it is shown in Figure 7.85, scanned body stands had some minor distortions and irregular mesh structure. To achieve even shape and structure, this study re-arranged the topology of each object using 3DS MAX software. The half of the surface of body which stands along the y-axis at the centre was re-arranged and mirrored for symmetry. The crinoline of the C1861-3 day dress was refined in the same way.



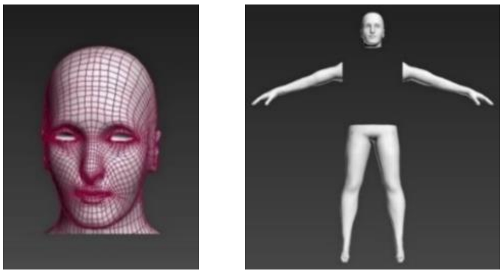
(a) Torso for C1861-3 day dress (b) Torso for C1928-9 evening dress

Figure 7.85 Refinement of scanned torsos

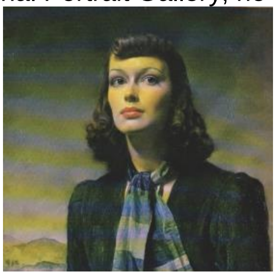
Other Body Parts

Attaching a head and limbs to the torsos was considered for better exhibition of the costumes with poses and motion and enhancement the synthetic image of virtual figures. Considering the efficiency, these parts were generated using MakeHuman software, which provides expanded adjustability of body measurements as well as facial features for virtual models. Using 3DS MAX, the generated arms, legs and heads were divided to connect to the refined torsos.

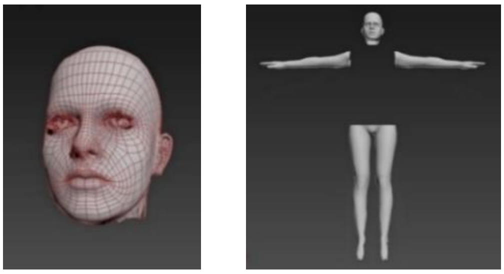
(a) Luisa Anne Beresford by Sir Francis Grant, 1859-1860 (source: National Portrait Gallery, no date-b)



(b) Face and limbs of the virtual figure for C1861-3 day dress



(c) By the Hills by Gerald Brockhurst, 1939 (ArtStack, no date)



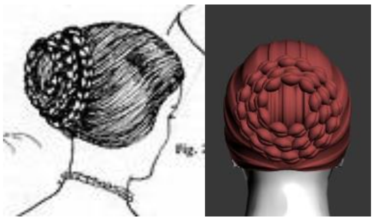
(d) Face and limbs of the virtual figure for C1928-9 evening dress

Figure 7.86 Virtual body parts and reference images

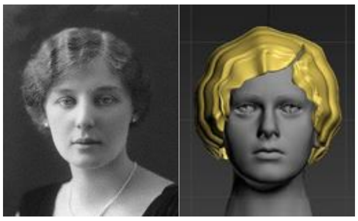
The dimensions of the body were determined based on measurements of the costumes. For the facial features, this study tried to imitate a face in portraits painted in the same era in the UK because information about the wearer was unavailable. Although the visualisation of a face may be criticised in the context of neutrality, this study tried to showcase the appearance of people from the target period. The selection of portraits was based only on clarity of the face facial features and quality of images. To compromise, grey skin tone was applied to convey neutrality of the model and to attract the audiences’ attention to the garments

Subsidiary Objects

Subsidiary objects such as hair and shoes were modelled using 3DS MAX to provide some degree of an assortment for display. Images with well specified shape of the objects of the time were selected as references.

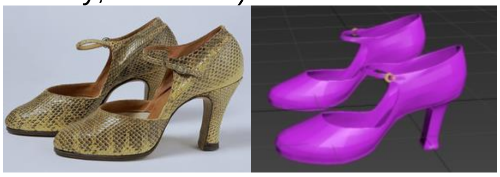


(a) Hairstyle in the 1860s

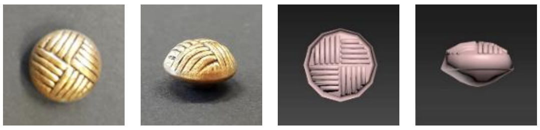


(b) Hairstyle in the 1920s (National Portrait Gallery, no date-a)

(c) Shoes in the 1860s (V & A, no date-b)



(d) Shoes in the 1920s (V & A, no date-c)

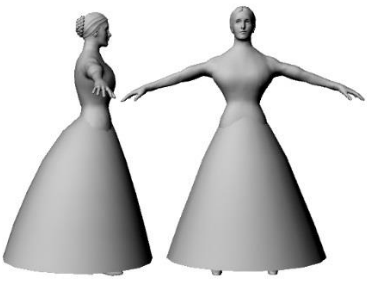


(e) Buttons for C1861-3 day dress

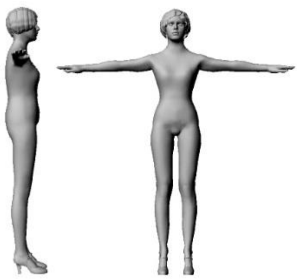
Figure 7.87 Subsidiary objects

Combining Objects

The complete shape of the virtual figures was accomplished by combining individual objects using 3DS MAX. First, the refined body stands as torsos were united with the divided heads and limbs to form the human bodies. Then modelled hair styles and shoes were attached to these virtual models. In the case of the virtual figure in the 1860s, the scanned crinoline object was additionally added around the waist.



(a) C1861-3 day dress



(b) C1928-9 evening dress

Figure 7.88 Virtual figures

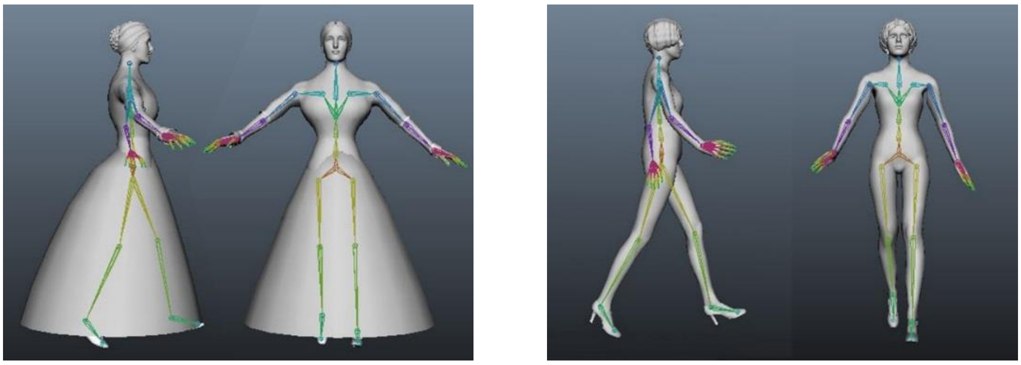
7.3.1.3 Rigging

Rigging is a process that allows motion to be applied to static meshes or objects (Zwerman and Okun, 2012). In this study, body rigging was carried out using Maya 2014. A skeleton which consisted of joints and bones with hierarchical relationships was created and aligned within each character. Then the process assigned the surface of the figures bound to the skeletons and the influences of the joints on vertices of the surface.

(a) C1861-3 day dress (b) C1928-9 evening dress

Figure 7.89 Poses of virtual figures

After rigging, a pose and motion was accommodated to the virtual figure for static and dynamic display of the digital costumes. To create more natural and plausible scenes, the poses for each model were adjusted controlling the joints of the skeleton based on a scene in a periodical TV drama set in the 1920s and an illustration of a fashion plate in the 1860s respectively. Although it would be more desirable to have motion data choreographed based on each time period, the movement of the virtual figures was adopted within motion capture data provided by Maya due to financial constraints. A motion capture data of a straight walk was imported and modified. This study adjusted the walking speed to break the stride because it was regarded as too fast for the presentation of garments. In the case of C1861-3 day dress, the position of arms was widened to avoid contact with the crinoline and the strides of the character of C1928-9 evening dress was narrowed considering the straight silhouette of the dress.



(a) C1861-3 day dress (b) C1928-9 evening dress

Figure 7.90 Motion with virtual figures

7.3.2 Digital Costumes

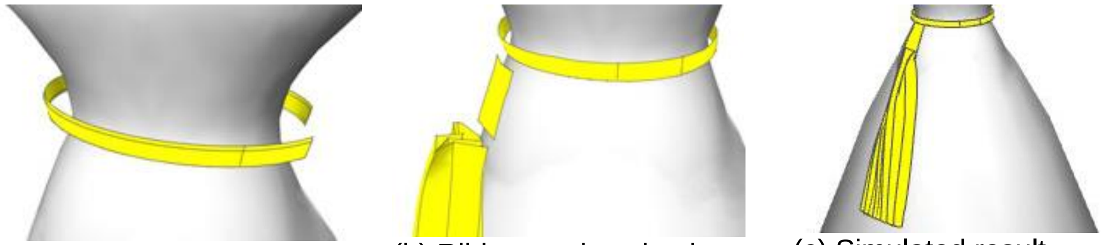
Digital clothing creation using 3D apparel CAD DC Suite is basically accomplished through the following stages: (1) body preparation, (2) pattern making, (3) assigning panels, (4) panel positioning, (5) assembly, (6) drape simulation and (7) rendering. Unlike the physical garment construction, application of colour, texture and fabric properties is flexible and can be adapted to any stage once garment panels are created. In this study, stages (1) and (2) were not needed as the virtual figures and patterns were already prepared. The garment panels were directly created using these patterns. Then construction of the costumes was accomplished by implementing stages (3) to (6) part by part according to the sequence of layers, folds and fastening and depending on the complexity of the structure. Although 3D apparel CAD has an advantage of expression of fabric materials, non-fabric objects such as buttons and beads are not strongly supported. Those are generally provided by the system's material library however the range of the objects is often very limited depending on the software. Since a specific design of buttons was applied to the costume in this study, digital costume construction was completed to stage (6) and then these additional objects were externally attached and rendered using a 3D modelling CAD system.

7.3.2.1 C1861-3 Day Dress

The bodice and the skirt of the day dress were planned to be produced separately because the large-scale and intricate garment shape may lead to large and complex meshes and there was a concern that this would cause insufficient processing of the CAD system.

Skirt

Construction of the skirt began with the waistband because it is the main part which fixes the position of the skirt and to which the other panels are clung. To facilitate assembly of the panels, DC Suite enables the user to curve the panels around the body. However this function does not apply to the folded panels. For this reason, the waistband was divided into two panels based on the folded line and curved into position around the waist of the 3D body (Figure 7.91(a)). The ribbon strap and pocket bag which are the innermost parts of the skirt were placed under the waistband. To fold the pocket, internal lines were created and fold angles were applied to pleat them inwards and outwards. Drape was simulated for several frames to fold the panel (Figure 7.91(b)) and seamlines were assigned to fix the folds and attach each panel to the waistband.



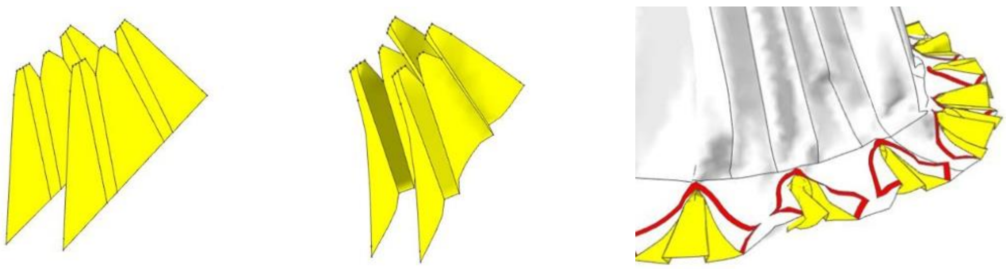
(a) Waistband (b) Ribbon and pocket bag (c) Simulated result

Figure 7.91 Waistband and pocket

The costume has five large skirt patterns which cover the lower half of the body. In physical reproduction, eight outer shells and 16 lining panels were derived from these patterns and the width of the top of the skirt was folded down to fit the waist after joining the shells and linings. During the first attempts, the digital skirt was constructed as the physical dress (Figure 7.92(a)). However, it was found that the linings and shells sometimes snagged during test dynamic simulation (Figure 7.92(b)). It was presumed that the folded parts were not stably aligned when the garment was moving. To give more clear designation of plied layers of the fabrics, this study divided the skirt panels based on the folded lines and hem lining sections (Figure 7.92(c)). They were placed according to the order of folds, and seamlines were assigned to connect the divided sections and fix the pleats. Then the top of the panels was attached to the waistband. The test simulation result of the divided panels appeared to be more stable in shape. For the same reason, the panel of the pocket bag was divided and re-assembled.

(a) Original panels (b) Snagged skirt (c) Divided panels (d) Simulated result

Figure 7.92 Skirt



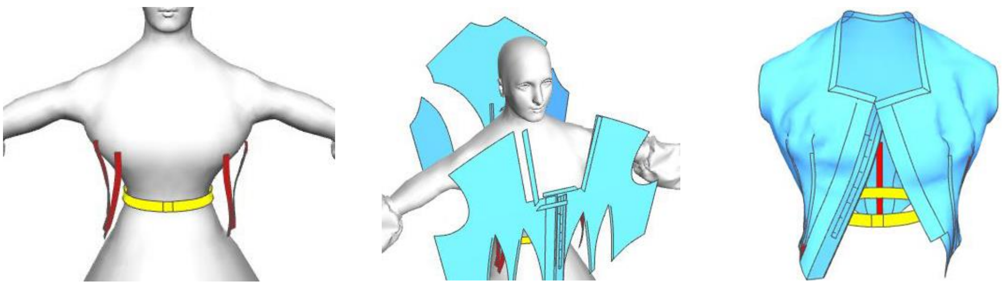
(a) Divided A-shape (b) Fold angle assignment (c) Inserts and braid

Figure 7.93 A-shaped inserts and braid panels

In the case of pleated A-shaped panels around the hem, each panel was simply divided into two sub-divided sections (Figure 7.93(a)) because the folded layers were relatively fewer and less complicated than the waist of the skirt. Also such subdivision facilitated the intuitive formation of pleats in 3D environment. To create pleats, the fold angle was applied to the internal lines (Figure 7.93(b)) and seams were assigned to the contour lines overlapped to fix the shape. While the A-shaped inserts of the physical dress needed to be added before combining the shells and linings, the digital inserts could be applied irrespective of physical construction order because trimming seams is not required in digital garment creation. Most inserts were attached before combining shells and linings but some of them which were positioned at the intersection of two hem panels were added later for convenience. Lastly, trimming braid was placed on the skirt in the form of panels (Figure 7.93(c)).

Bodice

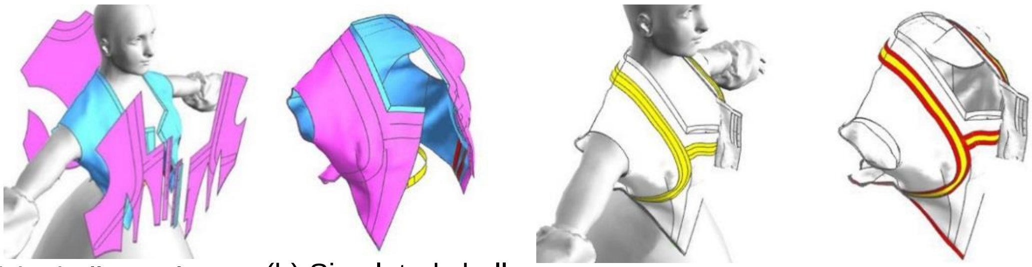
The bodice of the digital costume was constructed from centre to outer and from inner to exterior parts. First of all, the waistband which is the innermost part was adjusted around the waist applying a seam at the centre. The panels which functioned as boning were located respective to their positions and the bodice linings and ribbons around the neckline were placed over the boning. These panels were assembled and simulated as Figure 7.94(c).



(a) Waistband and boning (b) Lining panels (c) simulated result

Figure 7.94 Inner parts of bodice

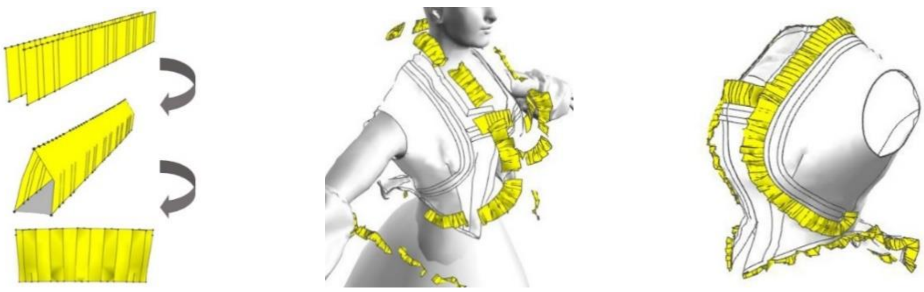
The bodice shells and reinforcing part for buttons were positioned over the lining and the pleats at the back were assigned using fold angle and seams. After assembly and simulation was carried out, facing sections at the centre front were folded and fixed. The panels which corresponded to the decorative strips and double piping were sewn on the shell, and braid was put on the decorative strips (Figure 7.95). These decorative elements were applied before attaching sleeves to minimise the collision between panels which might occur during simulation.



(a) Shell panels (b) Simulated shell (c) Decorative strip and piping (d) Braid

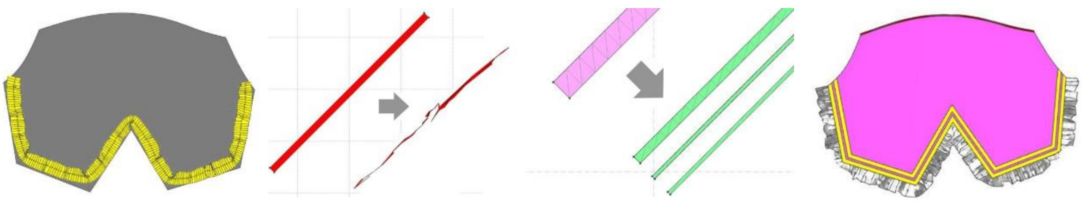
Figure 7.95 Bodice shell, decorative strip and braid

The pleated frills of the physical dress were cut on the long straight grain and folded in half. In digital construction, the frills were generated connecting small sections for the convenience of 3D positioning. Automatic pleat generation function was applied to two small panels to create box pleats and inverted pleats as a pair. These panels were joined to make a folded effect and separately simulated from the bodice. The simulated frills were duplicated and positioned around the hem and decorative strips. The dimension of the frills was adjusted depending on the sections. Then these pairs were sewn to each other to form the long frills and attached to the bodice (Figure 7.96).



(a) Divided section (b) Positioning (c) Simulated frills

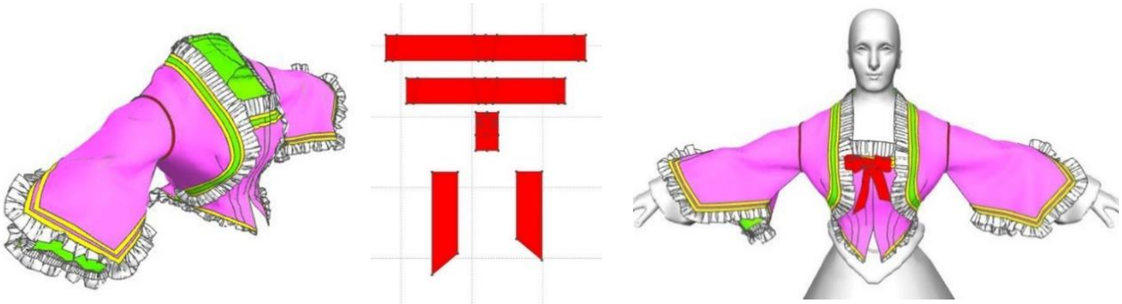
Figure 7.96 Pleated frills



(a) Lining and ruche (b) Distorted piping (c) Subdivided piping (d) Shell, frills, braid and piping

Figure 7.97 Sleeve

The ruche and pleated frills of the sleeves were constructed in the same way and attached to the linings and the shells respectively. On the physical costume, piping which contained the cord inside was decorated around the armholes. In DC Suite, however, most non-fabric materials are graphically presented. Since cord was the non-fabric material covered by the fabric, graphical presentation was not considered useful. For this reason, this study generated the shell of the piping without cord. Another problem found was that the strip-shaped panel failed to roll up as the form of the piping (Figure 7.97(b)). It was assumed that the mesh of the narrow section which comprised of a triangulated structure regularly arranged caused the problem when it was bent. As a result, this study took the approach to add more mesh by subdividing the panel (Figure 7.97(d)) and the simulation result appeared stable. Along with the frills, the piping and braid panels were attached to the sleeves and then the shells and linings were combined. To be joined to the bodice, the sleeves were firstly draped on the arms, and the seams of the underarms and armholes were sewn. Lastly, the bow was constructed by connecting five panels: two for loops, two for bottom tails and one for centre knot. This was because the virtual environment may require time-consuming control to tie up a ribbon. The bow was attached at the centre of the bodice chest.



(a) Bodice with sleeves (b) bow panels (c) Bodice with bow

Figure 7.98 Bodice

7.3.2.2. C1928-9 Evening Dress

The evening dress which required less amount of fabric for physical construction was considered smaller in volume and less complicated in details compared to the day dress in the 1860s. Digital reproduction involved no difficulty in handling two layers of garments together at one setting.

Slip

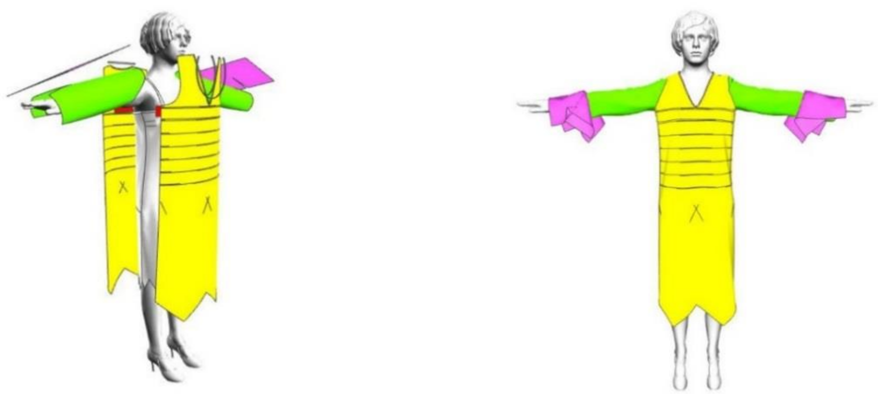
The construction of physical slip used two shoulder straps folded in half and one large bodice of which the hem on the top and side was double-folded. In digital reproduction, the folded sections were generated as separate panels and joined to the main panels after positioning. The bodice panel was placed by being rolled to wrap the torso, and strap panels were positioned above the shoulders. The seams were assigned to assemble the individual parts, joining the separated panels and darts, and then to connect the parts together into one garment.

(a) Panel positioned (b) Simulated slip

Figure 7.99 Slip

Dress

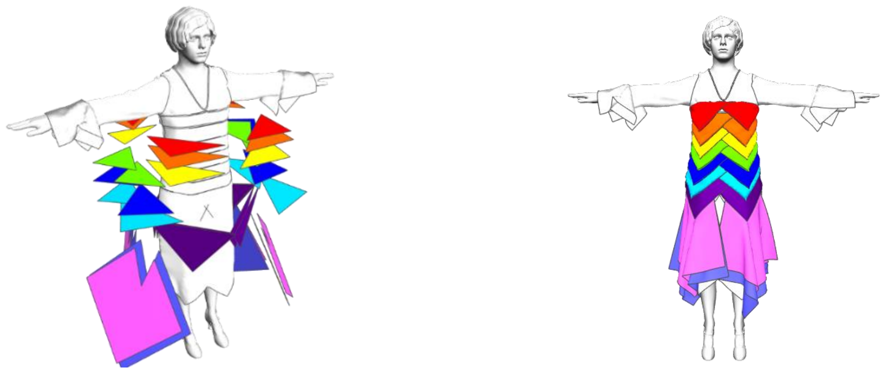
The constitution of the dress can be segregated into main parts which were hung on the body and decorative parts which were attached to the outside of the main parts. Since the assembly of digital clothing is proceeded by being draped on the virtual body, positioning of the main part panels were carried out in the following order: (1) reinforcement bands and lingerie straps, (2) bodice, (3) sleeves and cuffs and (4) neckline binding. Bodice, sleeve and binding panels were curved to facilitate draping and to avoid penetration of panels during simulation. Seams were applied to join the panels and then drape simulation was conducted.



(a) Positioned panels (b) Simulation

Figure 7.100 Bodice main parts

The decorative panels were positioned from bottom to top considering the overlaps of the layers. Double-layered floating panels were placed around the lower bottom section, and the petal shapes were arranged above them in order. Then seams were assigned to join the double layered panels, to attach the floating panels to the petal shapes, and the petal shapes to the bodice. The simulation of the dress is as shown in Figure 7.101(b).



(a) Positioned panels (b) Simulation

Figure 7.101 Decorative parts

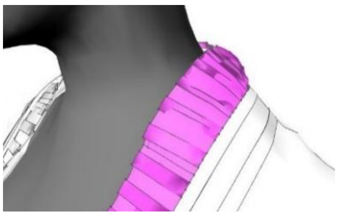
7.3.3 Simulation

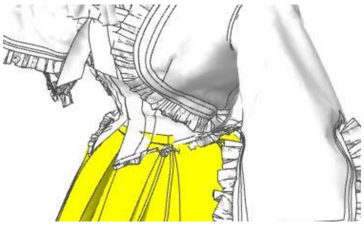
This stage was prepared to generate drape simulation by adjusting fabric properties to the garment panels and applying pose and motion to the virtual models. The material values of the fabrics were adapted from the fabric tests in section 7.2.3. However default values were applied to some specific panels which represented the subsidiary elements such as braid and bow because the methods were not able to measure non-fabric materials or fabrics with limited dimension. Four kinds of drape simulation were developed by applying different virtual underpinnings: (1) static simulation with an aesthetic pose, (2) dynamic simulation with walking motion, (3) deconstruction simulation with T-pose and (4) static simulation which re-enacted the photographs on p.183 and p.188. The first three were the simulations which were designed based on the section 5.7.2 and the last simulation was prepared for the comparison between physical and digital reproductions in Chapter 8. Due to the time constraints, deconstruction simulation was produced only with the C1928-9 evening dress. This section describes the brief simulation and revision process. The final simulation data was exported as point cache which is compatible data format for the application development in Section 7.4.

7.3.3.1 Static Simulation

The digital costumes at the previous stage were constructed on the virtual models with T-pose. To achieve static simulation with the aesthetic pose, dynamic drape of the digital costumes was generated by reflecting the transitional motion of the virtual figures from T-pose to the designed poses. Each scene where the garment drape appeared, a stationary state was selected for further processing. The simulation planned for comparison was also generated in the same way. The outcomes are shown in Figure 7.92 and this section describes some problems observed during the simulation.

In C1861-3 day dress, errors were found where sharp edges or narrow panels made contact with the surface of the garment. Figures 7.102(a) and (b) show the edges of folded sections. Unlike the physical garment, some of the edges penetrated the surface of the digital dress when collision occurred due to the movement of the virtual body. The fact that the bottom section of the skirt where the folds become less angled did not present any irregular behaviour indicated that such problems came as a result of the contact of the sharp shape. The other problem was observed in braid panels which were attached to the surface of the sleeve, decorative strips and around the hem. Some parts of the panels occasionally passed through their underlying surface as the garment drape was moved. It was assumed that direct contact of the narrowed mesh structure did not stably maintain the overlapped position. To rectify the appurtenance, this study manually pulled the dent mesh out.


(a) Pleats


(b) Waistband and folds

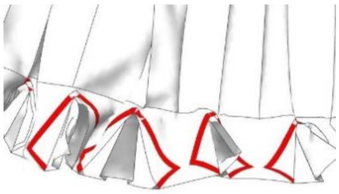

(c) Braid

Figure 7.102 Problems appeared in C1861-3 day dress

In the case of C1928-9 evening dress, the problems arose due to the nature and the pose of the virtual model. While the skin of a human body has textures and softness, the shell of the virtual models in this study was constructed with a flat surface. The system offset to avoid the intrusion of the panels into the virtual body. For these reasons, the drape of the digital garment is not stuck on the virtual body and can easily be flown down depending on its structure, and the status of the underlying body. Figure 7.103(a) illustrates that one of the straps of the slip glided due to the movement of the shoulder.

To resolve this problem, this study fixed some part of the strap to the shoulder where appropriate. Figure 7.103(b) shows the waist section of the dress pierced by close contact of the fingers, which were relatively pointed compared to the other body parts. Although the system allowed the offset distance, the pointed shape more easily tended to penetrate the garment. To evade this problem, an oval-shaped object was produced and attached to the hand to smoothen contact.


(a) Shoulder strap slid down

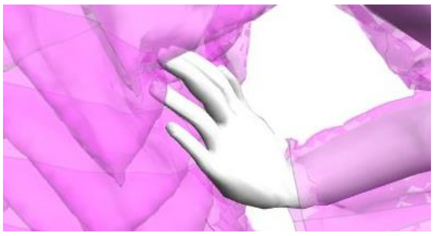
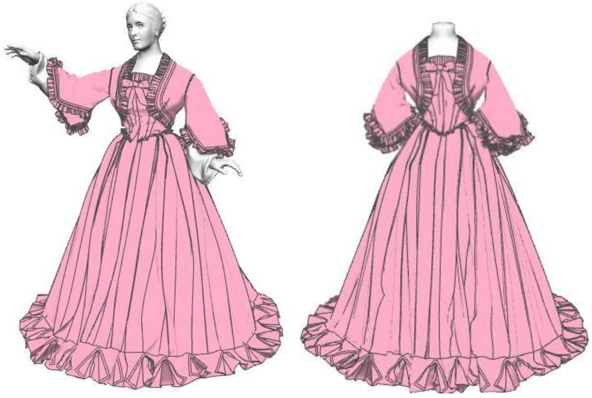

(b) Dress pricked by fingers

Figure 7.103 Problems appeared in C1928-9 evening dress


(a) C1861-3 day dress


(b) C1928-9 evening dress

Figure 7.104 Amended static simulation

7.3.3.2 Dynamic Simulation

Dynamic simulation was produced using two types of motion of the virtual figures: (1) transition from T-pose to the first posture of the walking and (2) walking motion. Due to the time constraints, the walking simulation was restricted to 240 frames which is equivalent to 10 seconds.

The same problems with the C1861-3 day dress identified in the previous section appeared during dynamic simulation. It was considered difficult to amend the dent mesh at every single frame in 3D apparel CAD because of the slow processing speed brought on by the complex and large garment construction. For this reason, the sunk edges of the pleats would be revised in the following-up stage where simulated costumes were finished and rendered using 3D CAD. In the case of the braid, this study added its image onto the panels to which braid panels were attached in the mapping stage. The 3D CAD, which specialises in modelling, was considered to facilitate manipulation of the shape. The penetration of the skirt into the bodice was prevented by inserting a supporting object (Figure 7.105) under the bodice which slightly lifted its hem to allow for space between the skirt. In C1928-9 evening dress, the shoulder straps of the slip gradually slid down due to the continuous arm and shoulder movement. The range of the position of the straps was secured by adding a ring-shaped supporter (Figure 7.105(b)) on each shoulder. In the system, the supportive objects were set up to have an influence only on the certain garment item in order to minimise factitious control over simulation.

(a) Supporter under bodice

(b) Ring-shaped supporters

Figure 7.105 Supporting objects

(a) C1861-3 day dress

(b) C1928-9 evening dress

Figure 7.106 Dynamic simulation

7.3.3.3 Deconstruction Simulation

The process of sequential disassembly was designed to visualise the garment structure and arrangement of patterns. To express both internal and external structure, this study focused on simulation which links the disassembled state to the assembled state of the costume. Two separate frames of the simulation data generated by DC Suite, which were panels of the costume before and after the drape simulation, were exported and imported to 3D CAD, Maya as objects with sequences. Use of 3D CAD was necessary because 3D apparel CAD provides limited capability of modification and manipulation of 3D objects. The simulation was generated in a form of key frame animation. In Maya, transitional processing of the different shapes can automatically be created by setting the keys to certain frames for each individual panel. Minor modification was sometimes required for some of the morphing process to clearly visualise the arrangement of the panels. The key animation of the panels was set at regular intervals to distinguish each transition.

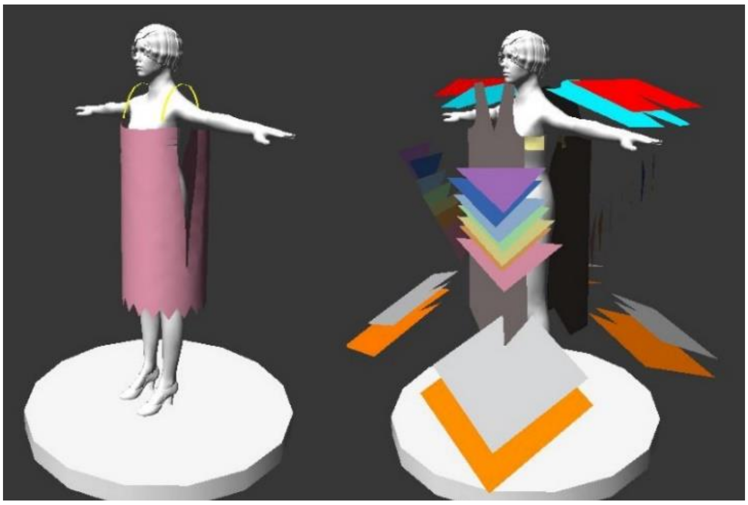
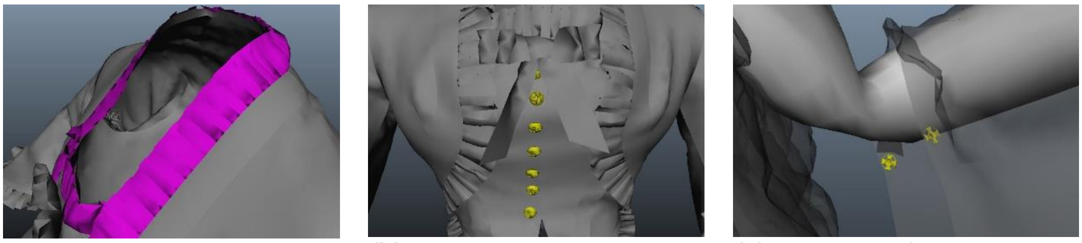


Figure 7.107 Deconstruction simulation

7.3.4 Finishing, Mapping and Rendering

Finishing and mapping stage was planned to edit the simulation data and to complete the morphological and visual components of the costumes using 3D CAD system. The simulated costumes were imported into Maya which enables facilitation of modifying the 3D objects and conversion of the data which was required at the application development phase.

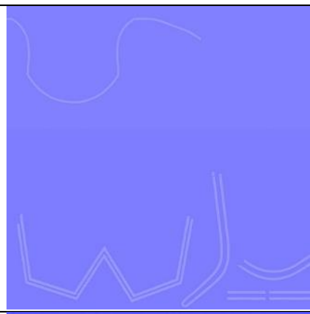
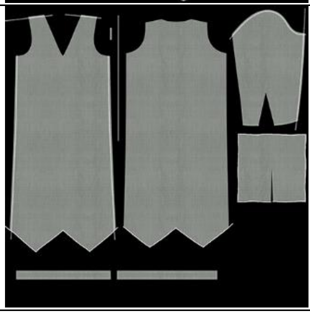
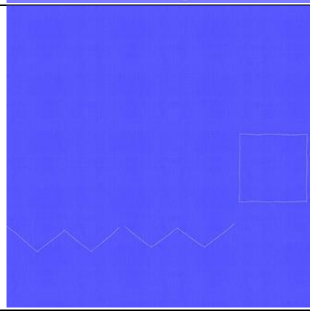
First, editing costume shape and adding morphological details were carried out. The problematic shape of the pleated frills of the C1861-3 day dress was rectified at this stage. Pulling the sunk edge of some folded parts, box pleats were regularly arranged. Then the separately modelled buttons and studs were attached to the surface of the digital costumes.



(a) Modified frills (b) Buttons (c) Press studs

Figure 7.108 Finishing

Table 7.27 Texture maps

	Colour	Transparency	Normal
C1861-3			
C1928-9			

After the settlement of the morphological elements, the texture and colour of the materials were graphically represented together with some of the details omitted in the previous stage such as braid, picot edge, top stitches and buttonhole stitches. In Maya, the material of the object is defined by shades which characterise the properties such as colour, transparency and shine (Autodesk, 2013). In this study, the graphical representation applied three types of map: colour, transparency and normal[1]. Transparency and normal maps were required to describe clear sections, holes and a semi-transparent substance and to express the texture and depth of the materials respectively. For generation of the maps, Adobe Photoshop was used editing and blending the images of scanned materials and the produced maps were applied to the

[1] Normal mapping is a technique to enable a surface to include more delicate presentation of detail, giving the appearance of dense surface (Autodesk, 2013)

surface of the digital costumes. In the case of deconstruction simulation, solid colours were used instead of shaders to help clear distinction of the patterns.

(a) C1861-3 day dress

(b) C1928-9 evening dress

Figure 7.109 Rendered digital costumes

Rendering was the final stage in the digital reproduction process which visualised the appearance of the completed outcomes. Two sets of the environments were prepared for different purposes: (1) scenes to be used for the application and (2) scenes for comparisons. For the first purpose, the digital costumes were rendered applying a camera revolving on each costume so that the audiences would be able to see the entire shape of the dresses. The second scenes were prepared to create the similar environments as the images of the physical costumes taken (p.183 and p.188). The front, side and back sides of the digital costumes were rendered.

(a) C1861-3 day dress

(b) C1928-9 evening dress

Figure 7.110 Rendered digital costumes

7.4 Application Development

A platform was designed based on the discussion in Section 5.7.2. The suggested direction for the application was a user-controlled VR system which facilitates individual access to digital costumes using new media. It was expected that the utilisation of an application with such attributes may not only highlight the significance of cultural relics through delivery and education of their historical and aesthetic value, but also contribute to the museum to be a more informative and entertaining organisation through opening and sharing of information using an interactive tool. Figure 7.111 describes the design concepts and considerations of the application.

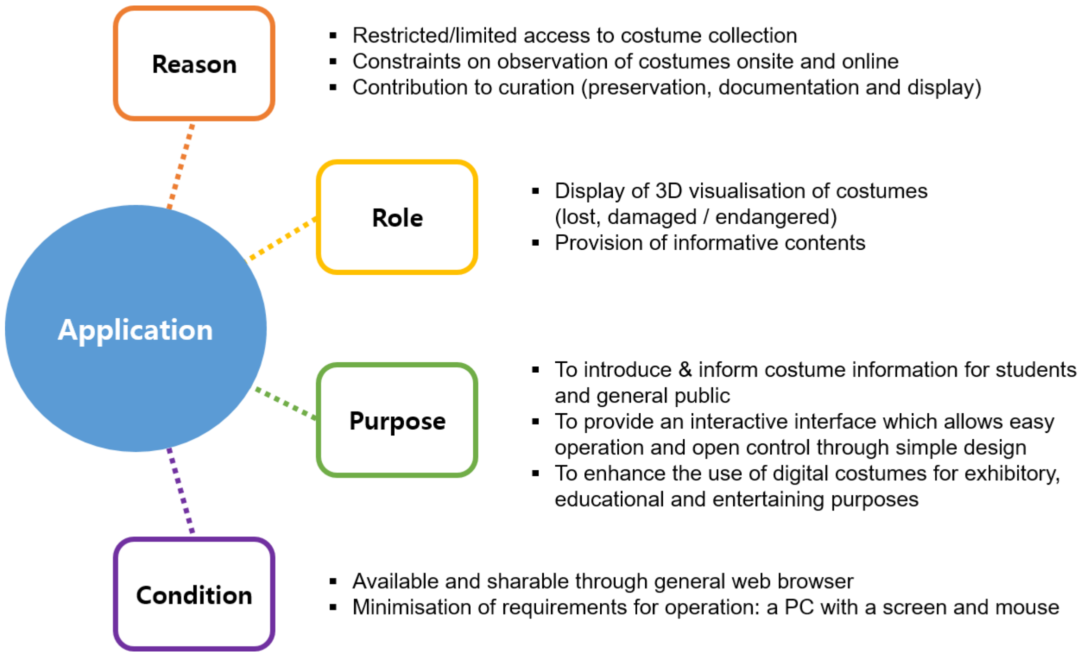


Figure 7.111 Design concepts and considerations

The main role of the application is to display a 3D visualisation of digital costumes and offer relevant informative contents. The application was intended to function to mediate between the audiences and the exhibits, making the best use of the advantages of digital costumes to compliment the constraints of costume collection and also suggest new methods for preservation, documentation, and display.

Students in fashion and costume design who may seek technical and in-depth knowledge and the general public who may be interested in more general and entertaining information were regarded as potential targets of the use of the application. For this reason, the application design considered the support for exhibitory and educational as well as an entertaining use of digital costumes.

The desirable direction of application development should focus not only on the introduction of the information, but also on the ease of navigation and operation considering the varied levels of computer literacy of target audiences. In order to increase the efficacy of information delivery, the display of data needs to be controlled by users through interaction rather than through one-sided presentation. Therefore the application aims for facilitation of its utilisation through simple design, easy operation, and open control which can easily be understood by different users.

Considering the internet as the most affordable and the least constrained new media for both developer and the users, an application which can be available and sharable through the general web browsers and a personal computer was to be developed. Also the system requirements were minimised to a screen and a mouse as the output and input devices respectively in order to facilitate easy operation.

As a main development tool, Unity 3D, which is an integrated authoring software to build 2D and 3D interactive content, was used for the application design. This software was considered appropriate as it has the advantage of a wide range of compatibility in publication across many devices. Also a wide range of editor extensions, plug-ins, and scripting available on its asset store can assist users to include various tailored functions with less effort. In this project, two extension systems written in C#, NGUI and Mega-Fier were additionally employed. NGUI is a UI system and event notification framework (ArenMook, 2011). It offers a collection of ready-made scripts and some of its scripts were directly used or tweaked for specific purposes: the interface design, execution of events and linkage and switch of functions of the application. Mega-Fier is a system which enables mesh deformation and animation and it provides around 50 modifiers including morphing, warps and UV and vertex modifiers (Chris West, n.d). In this study, a vertex modifier which allows the use of point cache data for animating physics based objects was applied to import the complex mesh animation of the digital costumes.

7.4.1 Composition of Contents

The contents which the application delivers were classified into primary and additional information. The primary contents were three different types of simulation outcomes of digital costumes: (1) static simulation, (2) dynamic simulation and (3) deconstruction simulation. On the other hand, additional information included subsidiary data such as (1) pattern diagrams, (2) photographs of original costumes, (3) links to relevant information, and (4) system information. Each category of information was designed to be displayed by the performance of an independent function of the application. This section describes the details of each contents class.

7.4.1.1 Static Simulation

The contents of static simulation were designed to include general information that physical display provides and some unconventional features. It visualises the stationary shape of the draped garments on a mannequin with text information mimicking the physical exhibition. The stationary representation of costumes was regarded essential as it enables stable observation. Unlike the conventional display, however, the visual contents offer the appearance of individual garment items as well as the ensemble on a virtual body with an aesthetic pose. Such feature allows the users to easily identify the types and number of layered garments and to appreciate the shape of each items which are sometimes not visible. As a label does in physical display, the static simulation provides text information and images such as name, maker, production date, materials and colours and description of the costumes along with the 3D images. The information on Arnold's book (1977) and the website of the Museum of London and the images of scanned original textiles were used as references.

7.4.1.2 Deconstruction Simulation

The structural information of the costumes was intended to be visualised through deconstruction simulation. The simulation contained a virtual body with a T pose and separate garment items of which the patterns were decomposed based on their types. In order to facilitate the observation, different solid colours were applied onto the surface of the pattern pieces depending on their types. The shape of constructed and deconstructed garments was visualised through the repetitive process of disassembly and assembly of pattern pieces in sequential order on a static body considering the relationship between each pattern. Along with the simulation, the contents were designed to provide the names of the patterns with coloured labels to help distinction. The contents were intended to visually provide more detailed knowledge about garment structure, which is rarely gained by displayed or preserved costumes. Understanding the garment structure is sometimes difficult without looking in the inside or holding up the layers of the garments. This feature was expected to allow all users to exploit the information without handling original costumes.

7.4.1.3 Dynamic Simulation

The contents of dynamic simulation were designed as an alternative to costume show which is not recommended in the real world due to the conservational issues. A walking body and movements of separate garment items and the ensemble were graphically presented as main contents. In order to underline that the images were a virtually created representation, the intention of the simulation, importance of dynamic garment drape and applied fabric properties were added as supplementary information. The objective of the contents was to enhance aesthetic appreciation of costumes and stimulate synaesthesia, visually expressing characteristics of fabrics such as weight, sound, and texture. It was expected that the simulation may have additional effect to provide amusement for the users while giving then an idea how the garments might move.

7.4.1.4 Pattern Diagrams

The contents in this category consisted of flat diagrams of all pattern pieces of the costumes of which errors were corrected in Section 7.2.2.2 with names and important marks such as notches and indications of front and back together with a scale. The contents were intended to deliver the morphological and structural features of the garment pattern supporting the deconstruction simulation function. This feature may especially be useful for those users who study or practice garment construction.

7.4.1.5 Photographs

As additional contents, photographs of the original costumes were designed to be provided. It was considered important to contain the photographs which show the whole appearance as well as the details of the costumes from various angles. This study applied the photographs available on the website of the Museum of London which focused on front, back and side of the overall form, texture of fabrics, and details. The photographs which could not visualise a true sense of 3D shape due to its 2D nature and digital costumes which are 3D but artificially processed images of authentic garments were considered to mutually complement the disadvantages of each other.

7.4.1.6 Links

Other relevant information and references to the costumes were planned to be complied using Links section to ease access to various source of data for the users. The specified contents at the development stage were the links which connect to the websites of the Museum of London and object information and publication information of Arnold’s book (1977). However, the contents can further be added at a future time when additional data input is required for enrichment of information connection.

7.4.1.7 System Information

The system information was prepared to introduce the purpose of the project and profile of the developer and to specify the acknowledgement and copyright. Although the contents were not relevant to the costumes, information about the application development was also considered useful for the users to understand the intention of the application and to contact the persons and organisations involved.

7.4.2 Architectural Design

Figure 7.112 illustrates the architectural design of the application. The seven types of contents stated in the previous section formed the major structural elements establishing a parallel relationship with each other and the data included in each contents group were considered as a sub-component of the application. The major structural elements and sub-components were embodied as menu and sub-menu through the interface design in Section 7.4.3. A straightforward hierarchical structure was designed for the system as it focuses on the specific purpose. Besides, such simple design can entail the advantage of less demanding operation and navigation from the perspective of the users.

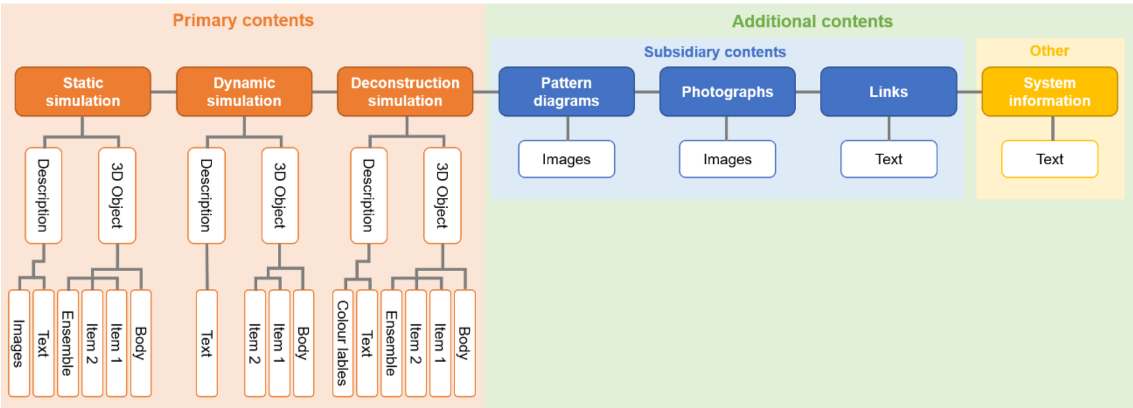


Figure 7.112 Architectural design

7.4.3 Interface Design

The interface of the application was designed based on 1920x1080 resolution which was partitioned into two sections: (1) menu which contains 2D icons in a row to enable the users selective display of the main contents and (2) details window where the contents are presented. The menu section was intended to be presented on a narrow panel on the left and the details window was planned to exhibit the contents on either a large panel which takes the entire area of the details window or a smaller panel with a 3D space.

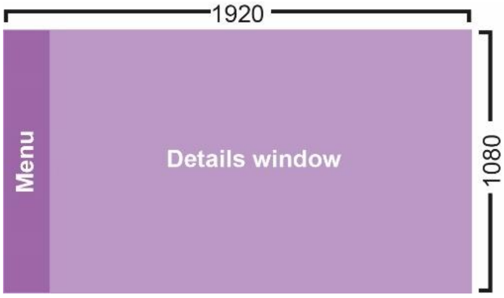


Figure 7.113 Basic interface layout

The panels were basically designed to be disposed on a single layer. In the case of primary contents, however, the details window should be able to display different dimensional components since the information consisted of 2D data as well as 3D objects. To handle those components in a more organised way, this study additionally applied one more layer. The layers were rendered by two cameras: layer 1 for the panels with planar elements such as icons, images, and text and layer 2 for projection of 3D space with virtual body and digital costumes. Figure 7.114 (a) shows the layout of the layer 1 which consists of a panel for the menu and the other panel for 2D contents which covers the half of details window allowing an empty space in the middle. This layer was projected by a fixed camera (Figure 7.114 (b)). Meanwhile, layer 2 was designed to exposed through the empty space between two panels on layer 1 and it shows the scenes that the other camera pans. As shown in Figure 7.114 (d), the camera was set to orbit the 3D objects so that the focus of the camera could stably be brought into the them.

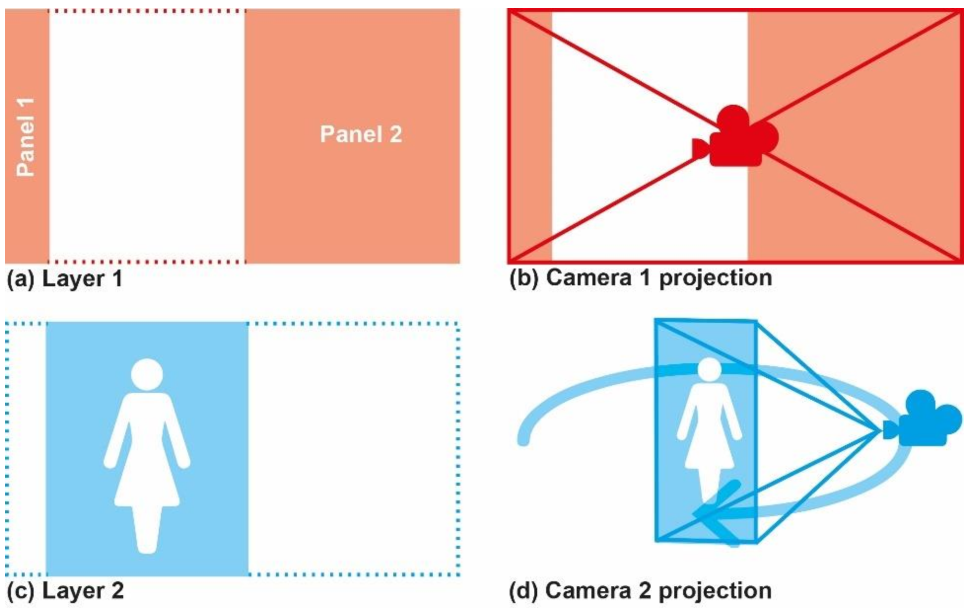


Figure 7.114 Interface layout for primary contents

Figure 7.115 illustrates more detailed layout for different contents categories in the details window section. The three types of primary contents were input based on the same format shown in Figure 7.115 (a) to have consistency. All 2D components was presented on the panel on the right together with the sub-menu. The sub-menu was designed to switch the visibility of the information depending on the type of garment items selected by the users. Based on the activated sub-menu, 3D space renders either an individual garment or ensemble while the description section on the panel shows the relevant information, including images and text.

On the other hand, four types of the additional contents are directly presented on a large panel. While pattern diagrams are spread on the entire area of the details window, the photographs and system information had two divisions. In the case of photographs, the thumbnails of all images are rendered on one of the divisions of the panel as a sub-menu and a large scale of the selected image is projected on the other division to be stressed (Figure 7.115 (c)). Two columns were applied to the system information contents for a more efficient array of information within the limited area (Figure 7.115 (d)).

In addition, 2D contents are sometimes sub-divided using contents windows within the description sections to classify the types of information.

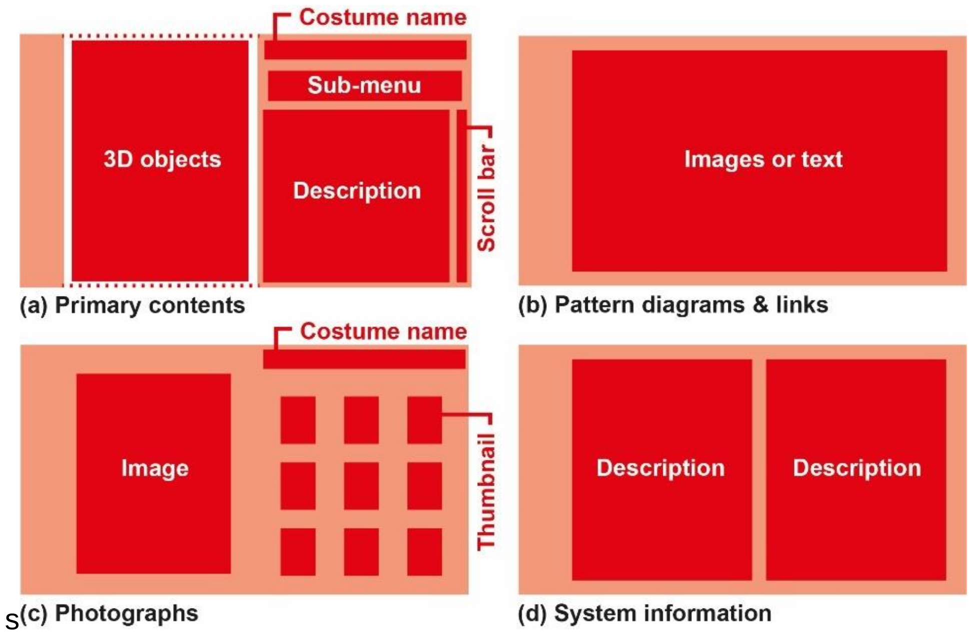


Figure 7.115 Layout of details window

The colour scheme of the interface design was determined as shown in Figure 7.116. Dark grey was adopted as background colour of the application which is universally used colour for the working area of many software such as Adobe systems, 3DS Max, and Autodesk Maya. Grey colour, which does not have a hue property, was considered to provide a neutral mood and lessen eye strain.

In general, this study applied less saturated colours into icons and contents windows in order to reduce distraction from the 3D objects and information. Two sets of colour palettes were prepared for the main menu and sub-menu icons to indicate different status: normal, over, and pressed. While normal status is represented in pale colours, the colour became more saturated when the mouse curser hovered over the icons to accentuate the selection. The icons are marked in white which is complementary of the background colour when they are pressed.

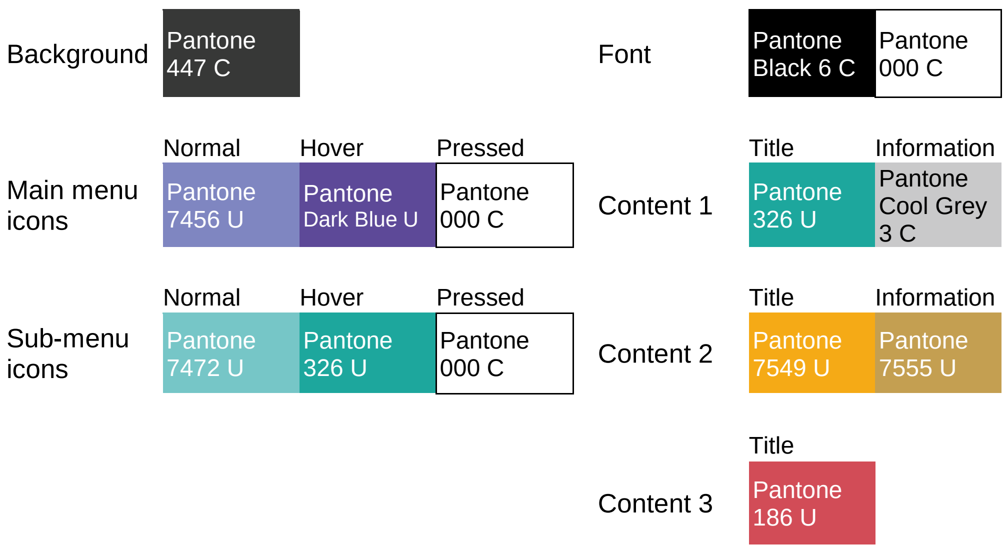


Figure 7.116 UI colour scheme

The colours of most of the content windows consist of two colours: turquoise for the title bar and cool grey for the area where contents are displayed. It was considered that the coloured title bar may catch the attention distinguishing the types of information and the cool grey window may redound to text separating its area from the background colour. In addition, extra colours were used for the contents windows in system information to highlight the copyright and introduction of the developer.

Black and white were chosen as font colours and selectively applied depending on the colour of the area where text was input. Arial was selected as the font type and applied sizes were 40, 30, and 26 pt for the costume names, title bars, and descriptions respectively.

The icons for the main menu and sub-menu were designed using the colour palettes in Figure 7.116. The key features of the seven major structural elements were symbolised to signify the types of the information as the main icons. For the static simulation, a circular shape of an arrow with 360° mark was used to indicate full range of display of the 3D objects. Also a symbol with disjointed bodice and skirt parts of a garment was designed to imply a deconstruction simulation. In the case of dynamic simulation, a simplified body shape with a walking posture was employed. The photographs, pattern diagrams, links, and system information were represented by the abstract form of camera, flat patterns, links, and a question mark respectively.

Since the sub-menu controls the types of garment displayed, the design of the icons applied simplified shape of the individual and layered garments items. The sub-menu for the evening dress in the 1920s consisted of three icons which represent the dress, slip, and ensemble.

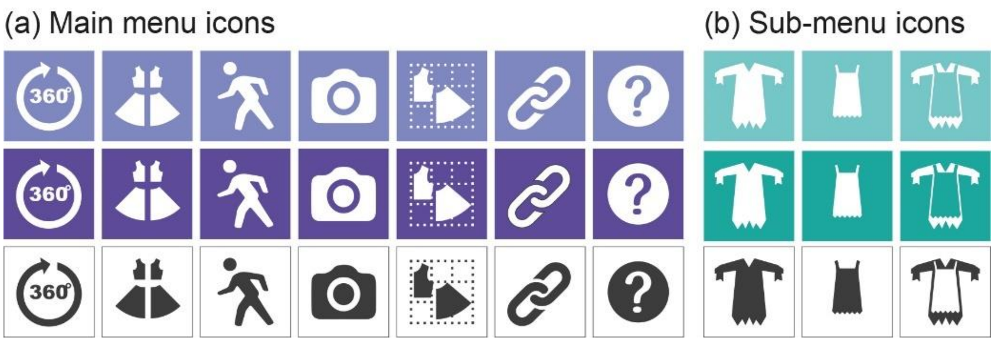


Figure 7.117 Icon design

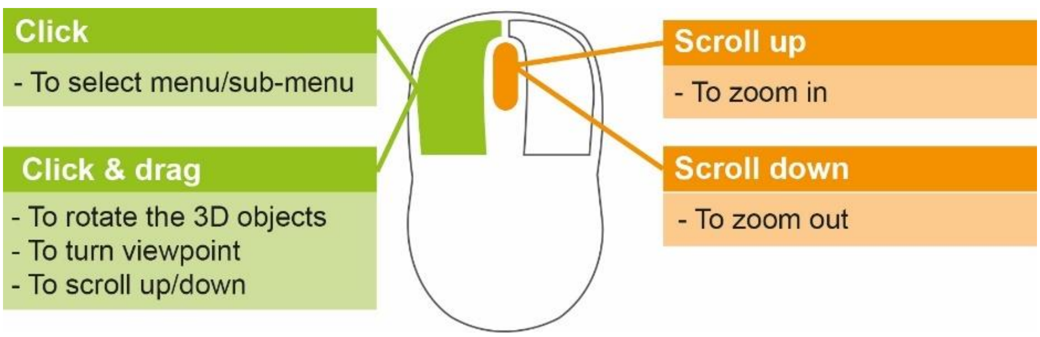


Figure 7.118 Mouse interaction

The application was designed to communicate with the users through simple manipulation of the mouse. In order to minimize the complexity, interaction was allowed using two mouse buttons: the left button and wheel as shown in Figure 7.118.

7.4.4 Procedural Design

The straightforward parallel relationship of the major structural elements was directly reflected into the procedural design of the application which allows simple and unconstrained flow of the use and switch of each function. The initial screen of the application was set to display the static simulation. By selecting the main menu, the application enables the users to access the other types of contents from the scene currently viewed by the users as shown in Figure 7.119.

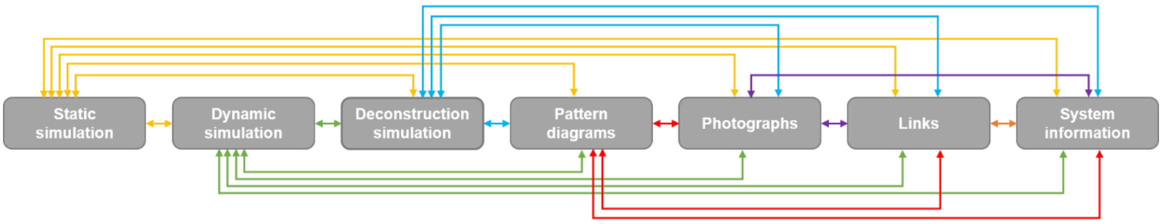


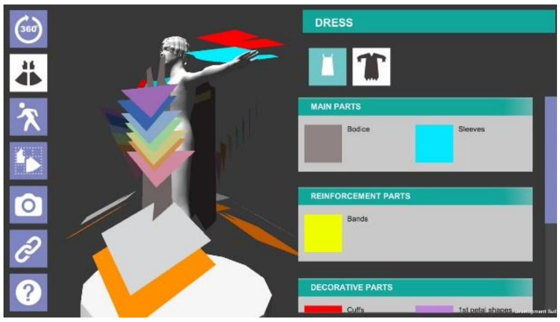
Figure 7.119 Procedural design

7.4.5 Applied Data and Publication

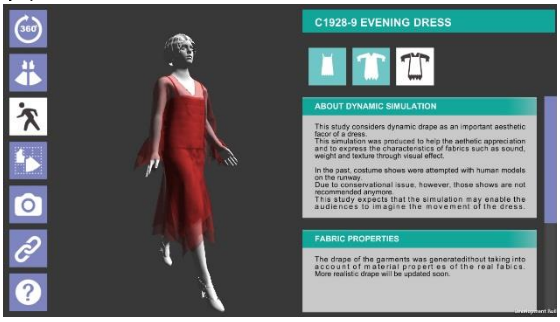
In the development of application, the simulation data of C1928-9 evening dress was applied since the application design was accomplished before the completion of simulation of C1860-3 day dress. Also relevant information to C1928-9 evening dress collated from the Museum of London website, Arnold's book (1977) and physical reproduction practice in Section 7.2 was compiled to be presented on the application.

The application developed in this study can be displayed on the museum website using Unity web player or published as an independent system for PC, Mac, and mobile devices, such as tablets and smartphones. However, considering consumption of time and expense in designing a website and securing an online server for sufficient data processing, the system was designed in a form of PC platform which can be downloaded through a museum website. Since computers are very common electronic devices that most people use in daily life, online distribution of a PC application was considered appropriate. Figure 7.120 shows the completed UI design of the application with data integrated.

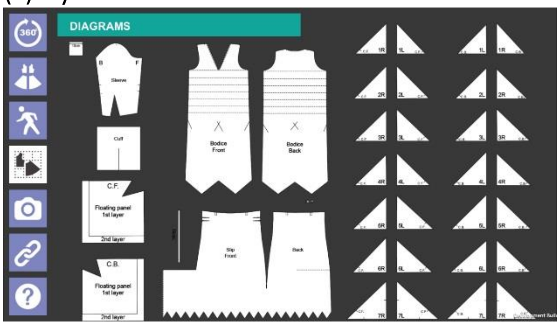
(a) Static simulation



(b) Deconstruction simulation

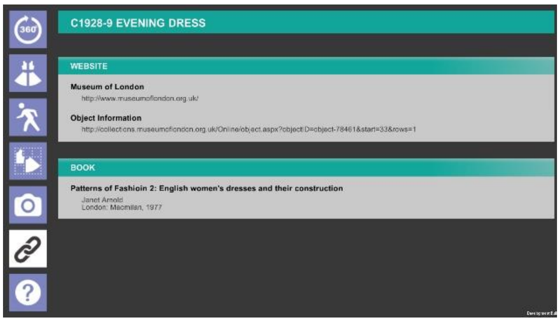


(c) Dynamic simulation



(d) Pattern diagrams

(e) Photographs



(f) Links

(g) System information

Figure 7.120 Completed interface design

7.5 Summary

This chapter described the development process of digital artefacts which adopted two costumes in the Museum of London as the samples to applied the concepts identified in Section 5.7.2. The process consisted of three main phases.

The first phase was a preparatory stage where fundamental foundation was established prior to digitisation practice. This included (1) data collection, (2) physical production and (3) measurement of fabric properties. In data collection, information related to structure, dimension, colour, pattern, material detail techniques and others were measured and recorded through the investigation of original costumes for foundation of historic references. The physical production involved pattern making and revision, toile generation, preparation of underpinnings and costume reproduction and all these stages synthetically formulated the objects to be digitised. The fabric measurement stage tested some properties related to 3D apparel CAD system input for drape simulation.

The results of the first phase were exploited at the second phase which entailed (1) virtual model generation, (2) digital reproduction of costumes, (3) simulation and (4) other finishing process. Various methods were applied into the digitisation process: 3D scanning for intergradation of the shape of the physical underpinnings into virtual models, 3D apparel CAD for duplication of the physical dresses into digital forms and for simulation, 3D CAD for preparation of subsidiary objects and rendering and 2D graphic design CAD for mapping sources.

At the final phase, digital application was developed as a platform which is compatible with online use and three types of simulation data which visualise static and dynamic costumes and deconstruction process were incorporated into the system.

Through elaboration of the process, this study attempted to provide design knowledge in physical and digital costume construction. The evaluation of the outcomes and the validity of the study were separately discussed in the following chapter.

Chapter 8: Evaluation

8.1 Evaluation of Application

The subjects of the appraisal include digital costume data which portrays the features in the appearance and structure of costumes and the application which presents the 3D data along with other useful information. The objective of this evaluation was to understand the effectiveness and efficiency of the application and the users' perception in digital artefacts and application. Although the digital costumes were completed at a prototype level at this evaluation stage, the data was considered to have a sufficient capability of visualising the concepts (static and dynamic simulation, and facilitation of costume deconstruction). Through the evaluation of the platform conveying the 3D data, this study attempted to discuss the value and prospects of the digital costumes as well as the implications of the system.

As participants, a total of 11 students of the M.A. in Fashion Management programme at the University of Huddersfield volunteered. Since the evaluation focused on a general assessment of the usability of the system, the sample was recruited based on convenience regardless of their specializations and personal histories. The participants were randomly divided into two groups to facilitate the moderation.

8.1.1 Evaluation Design

The evaluation was designed to assess three subjects: system quality, system quality in use, and information quality. The main criteria of this evaluation, and their definitions are as follows.

(1) System quality

- Understand-ability: easiness to understand the functions of application
- Operability: ability of the application to be easily operated by a user
- Satisfaction: comfort and acceptability of the interface

(2) System quality in use

- Effectiveness: the capability of the application to facilitate acquisition of specified knowledge

(3) Information quality

- Suitability: the appropriateness of 3D visualisation of information on costume structure and silhouette
- Learnability: easiness of acquisition of knowledge
- Satisfaction: comfort and acceptability of 3D contents

This study explores these aspects through the application of a numeric rating standard and descriptive assessment through different methods. The evaluation conducted a user opinion study based on human subjects and taking place in a real setting. The procedure of the evaluation was designed to go through three stages as shown in Table 8.1. The first stage was a preparatory phase meant to introduce the purpose and process of the evaluation and to demonstrate how to operate the application. The practical use of the application was proposed to the participants in the second stage, where the exploration and completion of task and questionnaire were required. The final stage consisted of a discussion section in which participants exchanged their thoughts. In this evaluation, while the questionnaire and discussion dealt with the measurement of the overall criteria, the emphasis of task completion as on the assessment of individual understanding of the degree of information in order to examine the effectiveness of the system.

Table 8.1 Evaluation process

Stage	Activity	Partaker	Duration
1	Introduction	Moderator	
	Demonstration	Moderator	5 min
2	Exploration	Participants	10 min
	Questionnaire	Participants	10 min
3	Discussion	Moderator and participants	15 min

The composition of the questionnaire consisted of questions regarding personal information of the participant’s background, experience, and computer literacy, as well as the statements describing above attributes as shown in Table 8.2. The questionnaire was designed to be answered through short-answers and a five point Likert scale was used where 1 represented strongly disagree and 5 represented strongly agree.

Meanwhile, a group discussion was planned for the purpose of collecting extensive opinions from participants. The discussion aimed for a casual and free expression of ideas from the individuals regarding the digital costumes and application. In order to stimulate participants' active participation and a smooth process, the moderator led the discussion in a way that encouraged participants to specify different issues, as shown in Table 8.3. Throughout the discussion, it was expected that qualitative data will be acquired, as well as feedback to improve current outcomes.

Table 8.2 Questionnaire compositions

Subject	Criteria	Questions or statements
Personal information	Background & experience	What is your background? How long have you studied in that area?
	Computer literacy	How comfortable are you using computer applications?
System quality in use	Effectiveness	The application provided visual information effectively.
System quality	Understand-ability	The menu and functions of the system were easy to understand
	Operability	The control of the system was simple/easy.
	Satisfaction	The overall interface of the system was pleasing.
Information quality	Suitability	The visual information of the costumes was intuitive.
	Learnability	The 3D costumes helped to understand their structure.
	Satisfaction	The visual information of the costumes was overall enjoyable

Table 8.3 Main issues in discussion

Subject	Issue
Information quality	Suitability of 3D costume as information delivery method Clarity of visualisation Utility of deconstruction animation Intuitiveness of understanding garment features Improvements required
System quality	Suitability of interface and functions Operability of system Improvements required
System quality in use	Satisfaction in searching information
Others	Intimateness of digital information and system Value and prospects of 3D costume and digital medium

8.1.2 Implementation of Evaluation

The evaluation was carried out on 17th February in 2015 at the University of Huddersfield. To set up the evaluation, a PC with the application was prepared in a room, and participants were asked to use the system by group. The evaluation process proceeded as demonstrated in Table 8.1. Although the PC was shared with a number of people due to the constraint of the equipment, the moderator encouraged each student to individually take part in trying out the application.

8.1.3 Results

8.1.3.1 Findings of Questionnaire

Table 8.4 shows the average and standard deviation of responses to the questionnaire with results rounded off to two decimal places. The findings of the questionnaire show that most participants had a good level of computer literacy. Three people out of 11 responded that they were uncomfortable using the computer application, while all the others answered that they possessed more than an average level of understanding. The overall criteria of system quality, system quality in use, and information quality were positively rated. Operability of the system and satisfaction of the information had the highest score (3.89). On the other hand, understand-ability of the system (3.33) received a relatively low mark, but was still positive above the average point 3.0.

Table 8.4 Questionnaire result

Criteria \ Group		A		B		Overall	
		AVG	SD	AVG	SD	AVG	SD
Personal information	Computer literacy	4.50	0.84	2	0	3.67	1.41
System quality in use	Effectiveness	4.33	0.52	2.67	2.08	3.78	1.39
System quality	Understand-ability	4.17	0.75	1.67	1.15	3.33	1.50
	Operability	4.50	0.55	2.67	1.15	3.89	1.17
	Satisfaction	4.17	0.41	2.33	0.58	3.56	1.01
Information quality	Suitability	4.17	0.41	3.00	0.58	3.78	0.83
	Learnability	4.33	0.82	2.00	1.00	3.56	1.42
	Satisfaction	4.17	0.41	3.33	1.15	3.89	0.78

(A: good computer literacy, B: less computer literacy)

Although the number of participants with less computer literacy was few, this study analysed the findings depending on the results of the group whose computer literacy level was below and above medium levels, as there were differences in responses between the two groups. Therefore this study reconstituted the groups by separating the responses of those three participants from the others. The average computer literacy score of the group with good and lesser levels were at 4.5 and 2.0 respectively (Figure 8.1).

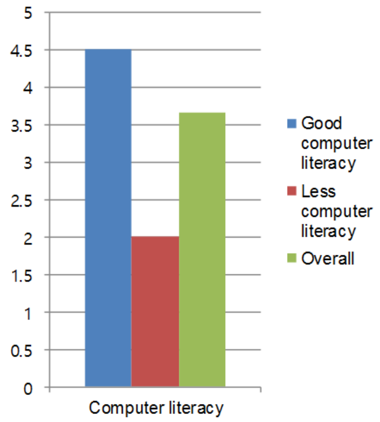


Figure 8.1 Computer literacy level

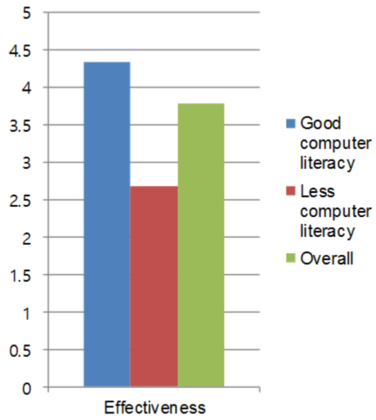


Figure 8.2 Effectiveness of system quality in use

Figure 8.2 shows the responses regarding the effectiveness of system quality in use. While the group with good computer literacy skills agreed that the application was effective (4.5), the participants with a lesser level showed somewhat negative results. However, a large standard deviation (2.08) of this group indicated that their opinions were not consistent with each other's.

Figure 8.3 presents the average rates in respect to system quality. The respondents with high computer literacy skills showed very positive results in all three qualities, and they seemed most satisfied with the operability (4.50). However, participants with low computer literacy appeared to respond negatively, and their understand-ability was rated remarkably low. Likewise, there was a huge disparity in these attributes between the two groups.

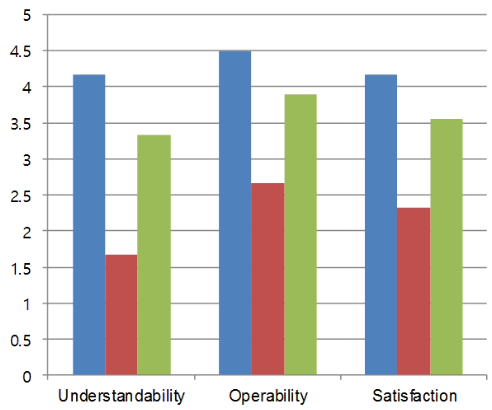


Figure 8.3 System quality

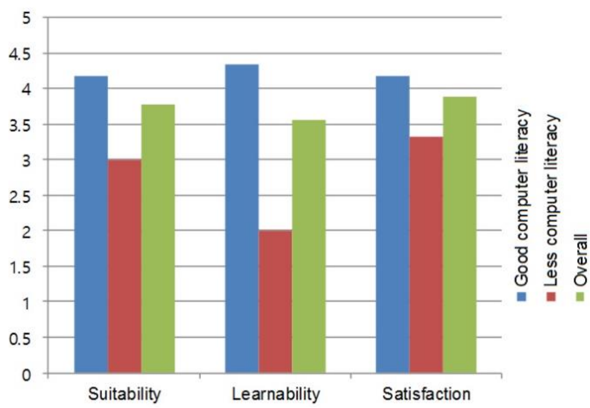


Figure 8.4 Information quality

Information quality was more highly evaluated than system quality and system quality in use; however, learnability was rated low by participants with less computer literacy, and there was a large difference in opinion from those with good computer literacy. Suitability and satisfaction received average or positive reviews by both groups.

8.1.3.2 Findings of Discussion

The key opinions and ideas of the participants expressed and exchanged were as follows: First, the information quality was positively evaluated by all participants. Many of them stated that the virtual costumes effectively functioned as an information source, emphasising how it enabled the visualisation of full 3D garment shape as well as individual items. They thought that the costume features were more easily understood through the observation of the costume from various angles and perspectives. The 3D shape of the visual elements was considered to have greater advantages of immediate recognition than descriptive information of the publication. Besides, the deconstruction simulation received good reviews. Some participants pointed out that the deconstruction process clearly presented not only the geometrical features of each pattern, but also the complex arrangement of the multi-layered fabric pieces. They highly regarded the digital costumes in respect to the realisation of garment decomposition, which is impossible in reality. Also, many participants showed favourable responses to the dynamic factor of the digital costumes, and stated that the digital movement of the garment was more amusing and interesting than in pictures.

Second, the design, function and the operation of the application were reviewed suitable to present the digital costumes. All participants agreed that the exploration of the application itself was comfortable and pleasing and the interface design in terms of the use of symbols and colours was simple, and associated well with the functions. They also explained that the types of functions were acceptable and properly incorporated various types of information for users. Although most participants were satisfied with the current concepts and contents of basic functions, several pointed out some technical improvements which could be made to the costume display: user adjustable background colours, simulation speed control, and pausing. As facilitation of observation of the costumes is primarily important, adding these control functions is considered necessary to practically apply the digital application to the museums. With regard to the system’s operation and control, the participants were satisfied with the use of a mouse. However, using a touch screen was suggested as an input device to enhance intuitive manipulation. Application of a touch screen is considered feasible since a wide range of personal digital devices such as PCs, laptops, tablets and smart phones supports a touch screen nowadays. It is expected that the introduction of a touch screen may not only provide more intuitive operation but also improve engagement of audiences as Henning (2006) stated.

Third, all participants showed favourable attitudes towards digital artefacts and applications, particularly towards using new media. They thought that digital media was more interesting than traditional means of costume display. The participants especially valued the attributes of digital costumes for several reasons. Firstly, the digital costumes enable convenient access and offer a more interesting display method. Secondly, digital costumes allow for dynamic and deconstruction simulation. The participants expressed that 3D costumes were effective for exhibitory and informative purposes, and complemented the traditional limitations of fragile garments. One of the participants estimated that the digital costumes and applications may have a great impact in the museum alongside traditional collections.

8.1.4 Discussion

The overall positive results of the evaluation support the utilisation of digital costumes. The findings of the 3D visual data confirmed the suitable performance of virtual garments compared to traditional ones for displaying garment features in an intuitive and satisfactory way. Additionally, favourable responses of questionnaire and discussions regarding the suitability and satisfaction of information quality positively suggest the possibility for 3D costumes themselves to be exhibits for all people regardless of computer literacy. The system was also considered to be effective as an information delivery method, with its design and functions properly supporting this role in general.

However, relatively low comprehension of the system and low learnability of information were observed among the group with less computer literacy. This may imply some potential trouble with beginner computer users, as this activity requires a good understanding of system functions irrespective of the suitability of digital information. Therefore, a proper explanation of the system needs to be offered whenever help is required. This may also improve the learnability of 3D information and accordingly the effectiveness of the system in use and system operability. In addition, minor technical improvements regarding subordinate functions such as user-controlled display settings were suggested. Nevertheless, the concept of the system's functions was evaluated as suitable for exhibitory and educational purposes during the discussions.

The 3D costumes and application were reviewed as effective informative materials on exhibitory and educational purposes in general. However, relatively low understand-ability of system and learnability of information of the group with less computer literacy left room for further improvement. Although the evaluation of the system was mainly positive, this study at the present stage has some limitations. The 3D data submitted to evaluation was a prototype digital costume which was simulated without taking into account the material properties and visualisation of fabric colours/textures. Since this study focused on the development of digital costume data as an effective information delivery method, the costume drape was generated with the default property values that the 3D CAD system provided. In application of colour, red was applied to the whole costume surface to be distinct. Also, visualisation of texture was disregarded because some fabrics with bumpy textures might have masked the recognition of complex garment structure during the assessment. In this study, the presentation of garment drape and surface were assessed in the following evaluation to discuss realistic and aesthetic aspects.

8.2 Evaluation of Digital Costumes

The evaluation primarily focused on the appearance of digital costumes was conducted separately to examine the faithfulness of the artefacts from a professional viewpoint. As the assessment required advanced technical knowledge, the recruitment of the participants was confined to experts in fashion or costume. By the support of the Museum of London, a group of seven experts, including two curators and five costume and fashion specialists, participated in the assessment. Such purposive sampling was considered critical for more rigorous evaluation.

The subjects of the appraisal were morphological components of digital costumes and the similarities between physical and digital costumes were also compared. Through the professional opinions, this study is aimed at verifying the validity of the digital costumes as well as to discover the shapes which appeared congruence and incongruity in order to clarify the improvements for future study.

8.2.1 Evaluation Design

The evaluation was designed to assess the digital costumes based on three categories: overall shape, structural features and details. Each category was planned to be evaluated in sections as follows.

(1) Overall shape

Overall silhouette: overall shape and volume

Garment drape: falling behaviour of the garment

(2) Structural features

Neckline: top edge of a garment which besieges the neck

Bust and shoulder: upper body around the chest and upper joints of arms

Sleeve: parts which cover the arms

Waist: part around the waist

Bottom edge: part around the bottom hem

(3) Details

The assessment items for the details were determined by considering the distinctive elements of the costumes. The pleated frills and ruche, and the folded waistline of C1861-3 day dress, and the petal shapes and cuffs of C1928-9 evening dress were chosen as the evaluation items.

Based on these sections, two types of questionnaires were developed applying a five point Likert scale where 1 represented completely dissimilar and 5 represented very similar. Three pairs of images of physical and digital costumes taken at the front, side and back (Figure 8.5) were prepared for comparison along with the questionnaires. To minimise visual distraction, the colour and texture of the digital costumes were not applied in this evaluation and the photographs of the physical costumes were processed into a greyscale.

(a) C1861-3 day dress (b) C1928-9 evening dress

Figure 8.5 Costume images for comparison

The evaluation process consisted of two stages as shown in the Table 8.5: introduction stage which explains the purpose and method of the evaluation and the assessment stage where the participants' opinions are collected using questionnaires.

Table 8.5 Evaluation process

Stage	Activity	Partaker	Duration
1	Introduction	Moderator	
2	Questionnaire	Participants	15 min

8.2.2 Implementation of Evaluation

The evaluation was conducted on 20th November in 2015 at the Museum of London. Each individual evaluator was given three paired images of costumes and questionnaires and the physically reproduced costumes were also set up to offer a close physical observation. The participants were asked to observe and compare the physical and digital costumes and to measure the degree of their similarities.

8.2.3 Result

8.2.3.1 Findings

The average and standard deviation of the responses are shown in Table 8.6. The results were rounded off to two decimal places. Although details of the costumes were rated lower than other sections in general, the results appeared be overall positive in similarities of both costumes.

In C1861-3 day dress, overall shape, structural features and details of the garment were evaluated and noticed to possess an extensive degree of similarities and there was not a section which presented below the median value. The components which showed the highest similarities were the neckline, the bust and the shoulder of the structural features (4.86). On the other hand, the lowest similarities appeared in the bottom edge of the structural features, pleated frills and ruche and folded waistline of the detail (4.14).

The assessment result of C1928-9 evening dress also presented a high level of similarities. The overall result was slightly higher than C1861-3 day dress and the average response of all components was higher than the median value. The silhouette of the overall shape, neckline and waist of the structural features were reviewed and found to have the most similar components (4.86) and the garment drape of the overall shape and petal shapes of the details were considered the least similar in parts (4.14).

Table 8.6 Evaluation result

Category	Section	C1861-3				C1928-9			
		AVG	SD	AVG	SD	AVG	SD	AVG	SD
Overall shape	Overall silhouette	4.71	0.49	4.57	0.51	4.86	0.38	4.5	0.65
	Garment drape	4.71	0.53			4.17	0.69		
Structural features	Neckline	4.86	0.38	4.63	0.56	4.86	0.38	4.66	0.54
	Bust and shoulder	4.86	0.38			4.67	0.76		
	Sleeve	4.71	0.49			4.57	0.53		
	Waist	4.57	0.79			4.86	0.38		
	Bottom edge	4.14	0.38			4.29	0.49		
Details	Pleated frills & ruche	4.14	0.38	4.14	0.36	-	-	-	-
	Folded waistline	4.14	0.38			-	-	-	-
	Petal shapes	-	-	-	-	4.14	0.69	4.36	0.63
	Cuff	-	-	-	-	4.57	0.53		

8.2.3.2 Discussion

The results of the evaluation which showed the high level of similarities between the physical and digital costumes indicates the faithful appearance of the digital costumes. This study considered the fact that the digital costumes possess a good level of validity to represent the morphological aspects of the original costumes. However, some components, particularly details of the costumes which appeared relatively less similar to the physical costumes were considered to need further improvements for a far stronger authenticity. This study supposes the reasons of a less similarity of some elements as follows.

First, in C1861-3 day dress, the subdivision of the skirt patterns caused angled, folded lines. Due to the problem in simulation, this study divided the skirt patterns based on the folds around the waist and hem lining sections. The garment drape of the attached subdivisions did not present smooth connections but sharp vertical and horizontal edges. It is assumed that the shape of the folded waistline and bottom edge of the skirt can be improved to achieve less angled connections if the patterns were horizontally divided in the middle. In the case of the pleated frills and ruche, the physical dress displayed more rigid forms compressed by an iron. Whereas the pleated sections of the digital costume did not have stability in shape.

Secondly, it is considered that the biggest differences in C1928-9 evening dress were generated because of the adjustment of fabric properties. The garment drape and petal shapes of the digital costume with lowest similarity rate appeared more structured and less irregular than the physical dress. More accurate adjustment of the material parameters will be required to express the limp behaviour of the dress.

Although some differences were derived from the technical capability of the 3D apparel CAD applied in this study, further refinement of some components may be accomplished through manipulation of patterns and reflection of more accurate fabric properties. This signifies that consideration on good balance between efficiency and faithful representation is dependent on the basis of the proficiency of the system user which can sufficiently handle the problems and accurate estimation methods of the material properties.

8.3 Evaluation of Digital Costumes and Application

The comprehensive evaluation which assessed the final digital costumes and application was carried out. The evaluation had two main purposes. First, to examine the faithfulness of the digital costumes in detail. Secondly, to assess the possibility of utilisation of digital costumes and application for exhibitory and educational uses.

This study attempted to understand the effect of the digital artefacts and to discuss their implications from the perspective of the people regarded to be the main users in the real-life situation. This study considered the students in fashion or costume studies and the general public as major users of interest. Thus, it employed two groups of participants: group A, which included six fashion design students in their 2nd or 3rd year and group B, which consisted of six people from the general public. It was assumed that the recruitment of these two groups would enable highly informative discussions from both academic and general viewpoints

8.3.1 Evaluation Design

The final evaluation was designed to assess the outcomes in three aspects embracing the main issues assessed in previous evaluations: (1) usability of digital costumes with application in terms of exhibition and education, (2) realistic description of the digital costumes, and (3) faithfulness of digital costumes. The first aspect is related to the verification of the effectiveness of the desirable concepts of digital costume suggested in this study. The second and third aspects involve rating the reproducibility and expressiveness of the digital costumes.

Table 8.7 Evaluation process

Stage	Activity	Partaker	Stimulus	Duration
1	Introduction & demonstration	Moderator		
2	Exploration	Participants	Digital costume simulation and application	5 min
	Discussion	Moderator & participants		10 min
3	Observation	Participants	Physical costumes, digital costume simulation and fabric samples	5 min
	Discussion	Moderator & participants		10 min
4	Questionnaire	Participants	Images of physical and digital costumes	10 min
	Discussion	Moderator & participants		5 min

A real setting was prepared with PCs which displayed digital costume simulation and the application, physical costumes, and fabric samples in a room. Controlling the exposure of the stimuli, the evaluation process proceeded as Table 8.7. The evaluation mainly took a form of discussion which induces free expression of participants' opinions. However, the moderator's mediation and use of questionnaires were prepared to interpose between discussions in order to narrow down the focus and to intensify more concrete data collection.

The first introductory stage was planned to deliver the procedure of the evaluation and demonstrate the way of using digital application. Since the application was developed applying a prototype digital costume, it was intended to give an instruction to assume the digital costume simulation separately produced was incorporated into the application.

The other stages were prepared for the evaluations of different subjects through the group discussion on the issues shown in Table 8.8.

Table 8.8 Discussion issues

Stage	**2**	**3**	**4**
Subject	Digital costume with application	Reality of simulation	Faithfulness of digital costumes
Issues	▪ Information delivery method ▪ Information quality ▪ Usability ▪ Functionality ▪ Educational use ▪ Exhibitory use ▪ Improvement	▪ General reality ▪ Static simulation ▪ Dynamic simulation ▪ Expression of fabric features	▪ Expression of major features ▪ Similarity ▪ Dissimilarity ▪ Application ▪ Acceptance

The second stage was designed to discuss the usability of the artefacts after individual exploration of the simulation and application using PCs. Through the user experience, this study intended to examine the effectiveness of the concepts of the digital costume.

The third stage was designed to expose the costume simulation along with the physical costume to induce participants to predict the shape of physical costumes associating it with the posture and motion of the virtual models. To help the prediction, fabric samples were prepared to allow handling. The discussion was planned to assess the sense of the realism of the static and dynamic simulation based on the fabric touch and the look.

At the fourth stage, comparisons between the physical and digital costumes were planned, exposing the printed images to assess faithfulness of the digital artefacts. Due to the environmental variables such as lights in the room and quality of the screens, evaluating printed images was regarded to be more objective than comparing real costumes to costumes on the screens. The images of each costume at the front, side and back were printed on A3 paper (Figure 8.6) and the evaluation took the form of a questionnaire and discussion. Based on the evaluation items and the same five point Likert scale in the previous evaluation, the following two items were added to the questionnaire design to take into account the assessment of the fabric features.

(a) Physical reproduction (b) Digital reproduction

Figure 8.6 Costume images for comparison

- Colour: visual property of reflecting light which has attributes such as hue, saturation and brightness
- Texture: feel of the fabric surface

Through the use of questionnaires which provided the numeric standard for each section of the costumes, it was intended to specify the degree of faithfulness of the dresses avoiding ambiguous appraisal. The discussion was arranged after the questionnaires to further define the opinions of the evaluators discovering important design elements and the reasons for positive or negative review. This study expected that the quantitative and qualitative data may provide detailed explanation for the viable elements and improvement of the digital costumes.

Through the use of questionnaires which provided the numeric standard for each section of the costumes, it was intended to specify the degree of faithfulness of the dresses avoiding ambiguous appraisal. The discussion was arranged after the questionnaires to further definitise the opinions of the evaluators discovering important design elements and the reasons for positive or negative review. This study expected that the quantitative and qualitative data may provide a good explanation for the viable elements and improvement of the digital costumes.

8.3.2 Implementation of Evaluation

The evaluation by the fashion design students group and the general public group was separately arranged at the University of Leeds on 8th and 11th of March in 2016 respectively. For the real setting, two physically reproduced costumes with underpinnings were exhibited in the middle of a room, so that both garments could be viewed by all participants at the same time. The C1861-3 day dress and C1928-9 evening dress were designated as costumes A and B respectively for convenience. Also, the following equipment and materials were provided to each participant:

- A PC displaying the digital costume simulation and the application
- A set of seven fabric samples which were used to physically reproduce costumes
- A set of printed images of the costumes both physically and digitally reproduced in Figure 8.6

These materials were exposed or hidden based on the process plan in Table 8.7.

8.3.3 Result

8.3.3.1 Usability of Digital Costumes and Application

Table 8.9 shows the summaries of the discussion of the groups. The negative views are stated in red to help the separation of different opinions.

Table 8.9 Summary

	Group A	Group B
Information delivery method	▪ Interesting, interactive and intuitive method ▪ Good exploration of space to see how the shapes come together and the overall silhouette of the garment ▪ Provides integrated information ▪ Novel way to explain garment assembly	▪ Interesting, interactive, intuitive, direct, descriptive and exciting ▪ Enables visual learning about garment shape ▪ Good remedy for young generation who do not like reading books ▪ Does not provide some atmosphere or emotional factors
Digital costume as information	▪ More interesting and intuitive ▪ Movement and colours are not life-like	▪ More interesting and intuitive ▪ Organic shape and movement provides natural and realistic images ▪ Presentation of costume movement is the most effective factor
Usability	▪ Tracking and moving visual simulation facilitate observation ▪ A good way of looking at garments and how a garment is made ▪ Convenient observation without the need to travel to different places ▪ No constraints of access archives ▪ Comprehensive acquirement of integrated information	▪ Interaction by simple control helps to focus on certain parts ▪ Easy and free observation without wandering physical space
Functionality	▪ Helps learning about garment structure ▪ Gives a good idea to learn how to make the right pieces ▪ Provides basic and limited information. Detailed information on finishes, seams and lining are required for research	▪ Informative simulation and contents ▪ Good description of patterns for students who study professional garment design. ▪ Helps general audiences to understand what patterns were used and how the garment was made .
Satisfaction	▪ Prefer real samples to see how exactly it looks ▪ Watching screen is not seeing garments in real life ▪ Loss of quality ▪ Deconstruction simulation is good to know the information that people cannot see ▪ Good for garments which cannot be displayed	▪ More pleasing and enjoyable ▪ Very satisfied with general appearance
Educational use	▪ The simulation can be used to have a look at how the garment will look like before students make it ▪ Pattern deconstruction provides educational information effectively. ▪ Being able to see how the flat patterns fit together and work on the body and seeing finished garment would help	▪ Good educational material for both general people and design students ▪ Fashion student may need to see 3D shape of digital costumes. ▪ Suitable as teaching materials

Exhibitory use	▪ Digital costumes cannot replace the original garments ▪ Prefer to see the real garments ▪ Can partially replace the real costumes ▪ Better delivery of more comprehensive information ▪ The biggest advantage would be presenting how the costumes move and what fabrics were used ▪ Will support observation	▪ Digital costumes can be used for exhibition. ▪ Digital costumes can replace the original dresses ▪ Digital costumes enable appreciation of garments without exploring the rooms. ▪ Physical exhibition provides better understanding of the garment scale
Improvement	▪ Very detailed photographs ▪ Video of real garment walking	▪ Glitches in time lag
Others	▪ Use of technology for prototyping is a good way to reduce consumption of time, cost and materials ▪ Digital clothing can be applied to display of costumes as well as to iconic garments	▪ Presentation of costume drape on bodies with different measurements will be interesting. ▪ Use of technology for online shopping will help consumers to know how garments look

Both groups assessed the information delivery method of the application positively. Most participants agreed that the display and exploration of the information are more interesting, interactive and intuitive than the textbooks. Some students of the fashion student group pointed out the use of virtual environment as a sufficient and new way of visualising of the information on garment shape and structure. The general group highlighted that the application provides direct and visual information display to stimulate learning and one of the participants in the group stated that:

> *It's more descriptive and it's more exciting for the user to watch this rather than just the book. Especially for younger generation, … this would be more interesting and exciting because they don't like reading books.*

The findings imply that this method may not only stimulate information search but also facilitate understanding making a favourable impression than conventional ways. In addition, one of the participants was concerned that the virtual space does not express some atmosphere and emotional factors which are created by the physical environment such as the effects of light and the surrounding people who appreciate the object together, though she reviewed the digital method has more advantages.

In review of digital costume simulation, the participants of two groups appeared to have differences in opinions. While the collective idea of both groups agreed that the digital costumes themselves are more interesting and intuitive information than traditional data such as photographs and description, the degree of realistic depiction was differently perceived. From the perspective of the fashion student group, the colours and movement of the garment do not look life-like compared to the physical costumes displayed. On the other hand, the overall view of the general public group rated the drape and movement of the garments highly natural and realistic. Particularly, most of them considered the dynamic simulation as the most effective factor in distinctive information delivery.

The usability of the application and simulation was rated high in facilitation of observation by both groups. Good presentation of appearance and construction of the garment, easy mouse interaction, tracking and moving functions were mentioned as the major features which enhance usability. Some participants underlined that the digital artefacts provide more convenient appreciation without physically moving the audience’s body to different places. One of the participants further detailed the advantages of the online application which not only lessens the physical movement of appreciation of an object but also eliminates the procedure to visit the fashion archive. Meanwhile integration of digital simulation with the other information was considered as another useful aspect which links partial data to form complete knowledge.

> *I actually think like the best bit about this is all the information and like the patterns. … You know, like when you go to a museum, instead of having a little thing with the information there could be these and you can look through all the information while you’re looking at simulation.*

Different opinions were shown in terms of the functionality. The general public group agreed that the outcomes well perform an informational role however the level of information that the application provides was differently assessed in relation to learnability. Some participants stated that the simulation, particularly deconstruction process, may be more useful for design students than the general public. One of them stated that:

> *That would be like an informational video for pattern making for fashion students … who study on design on garment, profession design work garment. It would be really helpful to get exactly what pattern they used because I can look into …*

Whereas the other participants expressed that the contents will effectively assist general audiences' understanding even though they might not be aware of technical knowledge. One participant explained that:

> *Maybe they don't think this as a pattern but they will want to know how … this garment … can be made. That's really – we can't imagine it from the garment but without this kind of simulation, how they were made into a garment.*

The opinions of the fashion student group can be divided into two views. Some students thought that the outcomes perform an instructive function to help learning garment structure and construction stating that:

> *If you were looking to get an idea, like to learn how to make the right pieces and stuff, then it would give you a really good idea.*

The other participants pointed out the visual information is too basic and limited to sufficiently support higher learning such as research or garment construction practice stating that:

> *Basic in the sense ... it was maybe to children who didn't need to know exactly how a garment was going to be put together. It's great because you see. But I think if you're looking at it from a more sort of research, if you were really looking into garment construction, then it is limited. Because it doesn't show you how they finish it.*

The participants asserted that more detailed information is required to assist more technical study as follows:

> *Maybe a bit more detail like the finishes of the garment, like how a seam is finished and, you know, lining and things like that.*

The overall opinions of the groups signify that the application and simulation functions the informative and instructive role, however, more specified improvement of contents is demanded considering the need and interest of the target audiences.

The most contrasting views of the two groups were found in satisfaction. There was a general consensus among the general public group that the digital artefacts are more pleasing and enjoyable than existing forms and media of information. Also they assessed the overall appearance of the digital outcomes very satisfactory and highlighted dynamic simulation and interactivity as the most satisfactory elements. On the other hand, the use of digital artefact was rated less satisfactory by the fashion student group. Their collective idea indicated that the exploration through the screen provides less realistic experience and they prefer to see the physical reproduction or original garments for better understanding. One of them explained that:

> *It is ... kind of lose a bit of the quality of it. And it's not necessarily like a fault in the computer programme, it's just ... always nicer seeing the real thing.*

Although the appreciation of the real garments was considered the best, use of technology for the garments which cannot be exhibited and for the presentation of the scenes which people cannot see in general display were positively advocated by the students. The findings of the discussion indicated improvement of more accurate representation of the costumes and consideration on media to create more liveliness and realism.

The applicability of the digital artefacts for educational purpose was positively reviewed by both groups. The general public group considered the outcomes as suitable educational materials for both design students and general audiences. The 3D nature of the digital costumes was highly acclaimed which reinforces learnability. One participant emphasised that:

> *Fashion students need to see 3D shape, back of the garment and details. Display normally does not show the back.*

The fashion student group thought the outcomes contain educational information to help understand garment structure and completed shape, which will be useful before conducting practice. One student stated that:

> *We want to see how it would fit together and how it would work on the body, being able to see the flat pieces and then being able to see it as being put together and then seeing the finished garment, that would really help.*

These opinions imply that the three-dimensionality and garment deconstruction which are not fully achieved in reality, increase intuitivism.

The opinions on the applicability of the outcomes as exhibitory materials appeared different complexions. The general public group viewed that the digital costumes can play a role not only as supportive materials but also as exhibits which can be a substitute for original objects. One of the participants highlighted the positive potential of digital reproduction as replacement which has an additional advantage of reducing the physical pain of exploring spaces as follows:

> *Really good for students not just for general people, visiting museum. Really amazing. I think if you're using such kind of software. Definitely it (digital costume) will replace it (original costume). You can explore the museum and instead of going in a room where all those physical costumes and they just have it display somewhere where you can see.*

Although the collective views welcomed the introduction of the digital display, a disadvantage was concerned in terms of real-life scale.

> *I think if you're watching these costumes in a museum, that would make you get a get a sense of proportions in a better way. Because if you're just watching it online, you don't know what's the height of that female. So if you're going to the museum, you can actually see the height of the person and how the costume is adjusted on her body.*

Meanwhile the fashion student group considered that digital artefacts can better support collection objects or partially replace the original garments. They emphasised that the digital technology cannot completely substitute the real objects and they prefer to see the actual dresses. One student stated that:

> *I think it would contribute like within a museum environment so that you can actually see the real thing at the same time and then like obviously like spin it around on there …, but if it was just this on its own I don't think it would ever be the same as seeing it in real life.*

The majority of this group thought that the strength of using digital artefact is to provide more comprehensive information integrating visual and other types of data, which is not entirely offered by the exhibition labels but usually by multiple sources.

> *I think you'd need multiple books just to get the information. … You can find a picture of a dress or something but then to get all the information for that dress, they might have a bit of written information and then it might be another book that you've got all the patterns.*

Also, 3D observation and expression of garment movement appeared as good factors which may better explain the characteristics of the costumes.

> *With this you really get to like spin it and look at it and see it move, and I think especially with clothing, it's so important how things move and that you really get an idea of what fabric they used, like how heavy it was, if there's underlay or things like that. For me I think, would be the biggest advantage.*

The findings imply that the digital costumes have the potential to be used as exhibits for general audiences. However, the current outcomes have limits such as lack of reality and expression of actual scale. Nevertheless, good applicability of the outcomes as supportive materials was positively reviewed due to the comprehensiveness of information and visualisation of the dynamic movement of which existing information sources are generally constrained.

In addition, some improvement points were suggested for further development. First, time lag was observed in simulation which caused a mismatch between the movement of the garment and the body. This problem did not emerge on a PC with higher specification. It is concerned that the application may not be smoothly run on some devices and reducing data resolution may be required for universal use. Second, inclusion of visual data of the original garments such as a photograph was recommended to help better appreciate how the original garment looks and giving a sense of reality, if more detailed photographs and a video which shows the movement of the costume are available.

8.3.3.2 Reality of Digital Costumes

Summary of the discussion is shown in Table 8.10.

Table 8.10 Summary

	Group A	Group B
Reality in general	▪ Very similar. ▪ Realistic without comparison ▪ Costume A looks more realistic but pleats are more defined ▪ Costume B is good but creases badly and falls heavier	▪ Realistic but some differences ▪ Costume A looks more realistic: drape and creases, sleeves and skirt ▪ Costume B looks less soft and heavier
Static simulation	▪ Drape reflects the body shape and pose ▪ Physical reproduction may drape in similar way as simulation	▪ Drape reflects the body shape and pose ▪ Physical drape might look similar with same underpinnings
Dynamic simulation	▪ Costume A moves more like prediction ▪ Costume B moves less realistic: too bouncy, less side movement, stiff bodice and sleeves.	▪ Good presentation of how garments flow on the body ▪ Movements look plausible ▪ Drape reacts well to motion
Expression of fabric features	▪ Stiffness, weight, texture and lustre are expressed ▪ Some characteristics not same as physical garments ▪ Good expression of weight and lustre ▪ Costume B looks stiffer, heavier, bulkier and less floaty	▪ Softness, smoothness, stiffness, reflection, lustre, comfort and weight are expressed ▪ Some characteristics not the same as physical garments ▪ Good expression of weight ▪ Costume B looks stiffer, less soft and less floaty ▪ A sense impression associated with inaudible sound
Others	▪ Good reflection of hair style of the time	▪ Display problem depending on graphic system ▪ Historic research is required to develop motion of virtual body

The overall assessment of the reality of the costume simulation appeared similar between the two groups, however there were subtle differences in their views. From the perspective of the general public group, the digital costumes were perceived as being realistic but with some differences from the physical dresses. Meanwhile, the fashion student group appraised the digital costumes themselves look realistic, and they considered the digital costumes very similar to the physical dresses. Some participants further articulated that:

> *It looks very, very similar. If you weren't given that (physical dresses) I would probably imagine they are realistic.*

> *.. we all study fashion so obviously nit-picking. if someone didn't know, they probably wouldn't pick up on it, I don't think.*

The findings imply that the digital costumes do not have fatal flaws in appearance and have a positive degree of resemblance. In terms of exhaustive duplication, however, the current outcomes are considered not up to the mark. All participants of the two groups stated that costume A looks more realistic than costume B. More defined pleats of costume A and stiffer and heavier fabric expression of costume B were pointed out as the major differences.

The collective view of both groups on static simulation positively rated the drape of the dresses. The participants considered that drape was well developed, reflecting the shape and pose of each virtual model and the physical dress may look similar if they are worn on the mannequins with the same pose. Meanwhile, different opinions were observed in the discussion on dynamic simulation. The general public group overall agreed that the simulation provides believable movement of the dresses. One of them underlined that:

> *I think I like the movement. I am saying the drape the way … it moves. I think I'd show how the garment flows on body, someone's walking.*

On the other hand, the fashion students group assumed that simulation of costume B would differ from the real movement of the physical dress. They explained that:

I think costume A looks more like I'd expect it to in the simulation. I think costume B looks a bit too bouncy. It is still quite stiff, like all of the layers separate, and I don't think that would necessarily actually happen on costume B.

It's like it's going up and down so it should be going side to side a bit more, so just not as much movement in the layers maybe. The bottom of the skirt looks good though, it's just the bodice and the sleeves, I think.

The participants agreed that the costume simulation visualises some characteristics of the fabrics: stiffness, weight, lustre (reflection) and texture (softness and smoothness) were detected in common by both groups and comfort was additionally mentioned by the general group. However, both groups pointed out that some features were not authentically expressed as the materials of the physical dresses. The fashion student group viewed weight and lustre as the well-expressed factors in general, however stiffness and weight were considered not realistically expressed for costume B. The general public group also agreed that the weight of the materials was properly presented, helping the audiences to understand differences between costumes. One of participants stated that:

This especially showed us two different materials obviously. Two materials are different. … I'm not a professional, but there are very obvious differences between two materials, so easy to get that idea.

Like the fashion students, the collective idea of the general public group indicated that fabrics of costume B were visualised less realistically. They stated that stiffness and softness were the most contrasting features. Additionally, there was an individual opinion that colours and comfort were not expressed realistically.

Interestingly, some of the participants in this group commented that the simulation evokes auditory experiences and one participant described the sound as follows:

I can imagine the sound of the fabrics. It's like a crispy sound (costume A) and some lighter sound (costume B).

The opinions on reality of the simulation indicate that the current outcomes need improvement in morphological and material aspects for more specified expression. Particularly, the findings suggest that thin and limp fabric may appear less authentic in shape. It is considered that more appropriate methods for fabric measurement and data conversion may be required to solve these problems. Nevertheless this study regards the following facts suggest good potential of the digital clothing: good degree of resemblance of digital costumes in general aspects, plausible appearance of the static simulation, partially good reviews of dynamic simulation, realistic expression of some fabric characteristics and stimulation of synaesthesia.

Besides, some additional comments pointed out that use the hair style of the time as a good element for implication of certain period of the costume. However application of the modern walking data into the virtual models was considered as a minus point which diminish a historic atmosphere. Also some participants claimed that the resolution of the screens was not good enough to see the details therefore the online users may not be satisfied with the image quality depending on their display devices at home.

8.3.3.3 Faithfulness of Digital Costumes

Observing the printed images, comparison between physical and digital costumes were made at the last stage. The summary of the comparison and other issues discussed are shown in Table 8.11 and the results of the comparison with questionnaires are shown in Tables 8.12 and 8.13.

Table 8.11 Summary of discussion

	Group A	**Group B**
Expression of major features	▪ Costume A: big sleeves, rounded shoulder, small waist, frills and bow are well presented. Frills are not naturally expressed. ▪ Costume B: triangle shapes, layers on the hem, bodice, sleeve, sheer against solid fabric are well expressed. Differences are observed due to stiffer drape.	▪ Costume A: elegant mood, mix of colours, pattern, texture and detail are clearly expressed. ▪ Costume B: straight and flat silhouette, layers, soft texture and lightness are well reflected. Differences are observed due to stiffer drape.
Most similarities	▪ Costume A: neckline with pleats and colours ▪ Costume B: hemline, colour and texture	▪ Costume A: Overall silhouette, fabrics, colours and pattern ▪ Costume B: colour and texture

Most dissimilarities	▪ Costume A: more structured folds on the skirt and pleats around sleeves, broader back and cotton-like bow ▪ Costume B: structured petal shapes, striking sleeves and cuffs	▪ Costume A: Strong folds ▪ Costume B: Regular shape of petal and stiffer drape
Expected application	▪ Interactive information for museums ▪ Database as a reference ▪ General enjoyment purposes	▪ Application for portable devices such as tablets and smartphones
Acceptance	▪ Physical materials are preferred ▪ Useful digital asset for study ▪ More fun	▪ Favourable to use digital assets ▪ More interesting and futuristic ▪ Capturing imagination
Others	▪ Use digital clothing for fashion sales or marketing ▪ Virtual fitting for online shopping	▪ Application of eye tracking method to digital costumes ▪ Virtual costume fitting ▪ Use of background music to enhance periodic atmosphere ▪ User adjustment of light and skin colour of virtual models.

While the fashion students tended to capture more detailed elements of the dresses, the general public group perceived the overall impression of the costumes as the important aesthetic elements. This group viewed the mood, colours, pattern, texture and detail and straight and the flat silhouette, layers, texture and light weight as the predominant traits of costume A and B, respectively. The opinions of this group accorded that digital costumes evidently present those characteristics; however, the stiffer drape of digital costume B was also pointed out as the factor which made an incorrect expression on the shape. It is considered that the digital costumes have the capability to construct the features but lack expressiveness which makes some elements look artificial or causes them to be more prominent.

To encourage the detailed observation, the discussion started with major aesthetic features of each of the costumes. The fashion student group chiefly considered the features of the bodice such as big sleeves, rounded shoulder, small waist, frills and bows as the most distinctive elements of costume A. Although the group agreed that the digital costume also possesses such distinctness, they pointed out that some of the features such as frills and sleeves are too prominent on the physical dress. In the case of costume B, petal shapes, layers, sleeve and use of fabrics with contrasting sheerness were mentioned as the major aesthetic factors. The collective opinion of this group expressed that the features were clearly visualised on digital costumes; however, differences in petal shapes and drape were also indicated. The group alleged that the wrong expression in fabric drape produced differences in other evaluation items.

Table 8.12 Comparison results of C1861-3 day dress

Category	Section	Fashion student group				General public group			
		AVG	SD	AVG	SD	AVG	SD	AVG	SD
Overall shape	Overall silhouette	4.33	0.52	3.92	0.79	4.33	1.21	4.17	0.94
	Garment drape	3.50	0.84			4.00	0.63		
Structural features	Neckline	4.50	0.55	3.90	1.03	4.33	0.47	4.00	0.69
	Bust and shoulder	4.00	1.10			4.17	0.69		
	Sleeve	3.67	1.03			4.00	0.58		
	Waist	4.00	1.10			3.83	0.69		
	Bottom edge	3.33	1.21			3.67	0.75		
Details	Pleated frills & ruche	3.83	0.98	3.42	1.24	4.00	1.00	3.92	0.79
	Folded waistline	3.00	1.10			3.83	0.37		
Fabric	Colour	4.33	0.82	4.25	0.75	4.50	0.76	4.42	0.79
	Texture	4.17	0.75			4.33	0.75		

Table 8.13 Comparison results of C1928-9 evening dress

Category	Section	Fashion student group				General public group			
		AVG	SD	AVG	SD	AVG	SD	AVG	SD
Overall shape	Overall silhouette	4.50	0.55	4.00	0.95	4.00	0.89	4.00	0.85
	Garment drape	3.50	1.05			4.00	0.89		
Structural features	Neckline	4.50	0.55	4.03	1.34	4.50	0.55	4.13	0.78
	Bust and shoulder	4.50	0.55			4.50	0.55		
	Sleeve	3.33	1.03			3.67	0.82		
	Waist	3.67	0.82			4.33	0.82		
	Bottom edge	4.17	0.75			3.67	0.82		
Details	Petal shapes	3.67	0.82	3.67	0.65	3.67	1.03	4.00	1.13
	Cuff	3.67	0.52			3.00	0.89		
Fabric	Colour	4.83	0.41	4.50	1.00	4.83	0.41	4.75	0.45
	Texture	4.17	1.33			4.67	0.52		

The similarity between physical and digital dresses was further evaluated in detail through questionnaires and discussion. The results of the questionnaires showed that the fashion student group rated the neckline in structural features most positively (4.50) followed by the overall silhouette and fabric colours (4.33) in costume A. The collective opinion in the discussion also indicated the neckline with pleated frills and colours are the most similar components. The lowest-rated element was the folded waistline (3.00) and one student explained that:

> Folds on the skirt; I think in the actual costume it's quite soft. …whereas on the computer generated one it looks almost like knife pleats all the way down, it's very sharp edges.

The bottom edge of the skirt (3.33) and sleeves (3.67) in structural features and garment drape (3.50) were underscored. Pleated frills around the sleeves, back silhouette and texture of the bow were additionally pointed out as dissimilarities through the discussion. However, the questionnaire results imply that those components did not have a huge impact on the general review of the overall silhouette and fabric texture. In the case of pleated frills, the assessment of the shape was controversial depending on the garment sections they were applied to.

> *The pleats, they are very similar, around the neckline.*

> *The skirt looks a lot more structured than it is. It's the same with the pleats around the sleeve edge, they just look a lot more structured.*

The frills, which scored 3.83 through the questionnaires, seemed to affect the assessment of the neckline (4.50) and sleeves (3.67), both positively and negatively.

Meanwhile, the general public group assessed the colour as the most similar element (4.50) followed by overall silhouette, neckline in structural features and fabric colour (4.33). The lowest-rated section was the bottom edge (3.67) and waist in structural features and folded waistline in details scored 3.83. These results coincided with opinions stated in the discussion.

In costume B, colour (4.83) was the most highly rated by both groups. Also there was a tendency for the results to appear similar in the groups in components which were positively evaluated: (1) overall silhouette, neckline, bust and shoulder (4.50) by the fashion student group and (2) texture (4.67) followed by neckline and bust and shoulder (4.50) by the general group. Correspondingly, the discussions of the groups pointed out colour as the most similar element and texture and hemline are further stated as important factors.

On the other hand, sleeves were given the lowest score (3.33) followed by garment drape (3.50), petal shapes, and cuffs and waist (3.67) by the fashion student group and the cuff was lowest-rated (3.00) followed by bottom edge and petal shapes (3.67) by the general public group. In discussion, the petal shapes were viewed as the most dissimilar section by both groups and sleeves and cuffs were further added by the fashion student group. Although the ranking scores in the results of the questionnaire appeared to be a different order of negativity from the discussion, a consistency in negative opinions was observed.

The discussion with fashion students highlighted that the neckline with pleated frills and colours as the most similar part and the folds around the waist, pleated frills around the sleeves, back bodice silhouette and texture of the bow as the most dissimilar components.

Although the general public group rated the digital costumes slightly higher than the fashion student group, differences in the average scores were not notable. Also the opinions of both groups regarding the most similar and dissimilar components roughly agreed with each other. The overall responses appeared more negative than a previous evaluation with costume and fashion specialists discussed in section 8.2. However, rated scores for all evaluation items were more than the median value. On average, the items in fabric were more positively reviewed and the items in the details categories were less positively rated by both groups.

The discussion further developed an extended issue regarding the application of digital costumes. The fashion student groups considered their possible use for interactive information at museums, for the establishment of a database and for general entertainment.

> *I think the things where you're looking for a lot of information, like a lot of things this is perfectly good. I think just for the general like enjoyment purposes it's probably nicer to see the real ones but I think this is really good as like a reference; like a database I think it's good.*

Also, a more portable application was suggested by the general public group. They explain that the development of apps for personal devices such as tablets and smartphones will facilitate the exploration of digital costumes as the graphic options of those devices becomes stronger.

In acceptance of digital assets, different opinions were observed between the groups. The general public group welcomes the introduction and use of digital objects. They considered digital assets exciting, futuristic and stimulating. Meanwhile, the fashion students expressed that they prefer physical objects such as books and magazines over digital assets because digital assets are not tangible. It seems that they regard the sensation as an important quality that is created during the exploration or use of materials. One student described that:

It's almost like you can buy a magazine and you can read it online, I mean, normally you can get the same information online but I still buy a magazine because I like to have it and touch it and physically feel it and have it in front of me. But I think for like research, … a dissertation or something, it would be really good material.

However, this group agreed that digital materials can positively be accepted as handling good quality of information and with the facilitation of delivery. As an example, one participant described the potential of the digital costumes in this study as follows:

> It's a lot more concise as well, you can just flick through and find what you need. The kind information is very relevant. And it's fun, spinning and zooming in and out.

In addition, the discussion added other comments related to improvements of the application and their wishes. Extra functions for the enhancement of the application were recommended such as an eye tracking method, virtual costume fitting, use of classical music and adjustment of the light and colour of virtual models. Among those ideas, the functions to adjust the light in the virtual environment and colour of the virtual models are regarded essential as these factors can support high visibility of the garments. To accommodate these functions, the user interface should carefully be designed to help the audiences to easily control the light and colour in response to the different textures and colour of a range of costumes. Meanwhile, the virtual costume fitting and use of classical music are not directly engaged with the quality of the garment display. However these factors may help engrossment of the audiences in exploration of costumes by granting the experience of historic atmosphere. The application has the potential to affiliate with the virtual fitting system in a 2D, 2.5D or 3D form. However sophisticated virtual try-on which provides interactive dynamic simulation on an individual body can only be feasible at a museum level as it requires special installations for scanning, tracking and display. The improvement of the application should take into account these elements to practically be used in reality. On the other hand, the application of the eye tracking method is considered less feasible for the online application used by home users. Because the method requires dedicated devices such as a remote or head-mounted tracker. It may be more applicable within the museum to analyse audiences' visual attention or to facilitate the operation of the system.

8.4 Discussion

The findings of the evaluations suggest that the concepts of the effective digital costume can be used as the guidelines for the development of educational materials. The value of the digital costumes and application was positively reviewed in their functions and effects however the digital costumes as realistic and faithful objects were considered to need improvements. The participants' attitudes about digital artefacts are varied. In general, more active acceptance appeared among fashion management students and the public groups, and the negative stand was observed among fashion design students. However, the participants with negative views also agonised the partial acceptability of the technology and its potential contribution to exhibitions and education. This section summarises the findings of overall evaluations and discusses the improvement points for further research and development.

The evaluations in sections 8.1 and 8.3 confirmed the usability of the digital artefacts which applied the concepts of practical digital costume. The opinions of the participants were positive in total and offered the insights into the role and characteristics of the outcome. The digital costumes and application were perceived as an effective information delivery method and their attributes were typified into the following three aspects:

- Methodological features: interactive and direct
- Information characteristics: intuitive, integrated and descriptive
- Encouraging characteristics: attractive, amusing, exciting and comfortable

In terms of application, good operability was responded and the design and functions were reviewed appropriate to support the display and exploration of the digital costumes without physical constraints. However, the findings suggested several limitations. First, there was concern about low understand-ability and learnability that the users with low computer literacy might have. Second, the current outcomes give an indication that the use of the application will be under the technical restrictions. The participants' opinions on time lag and blurred presentation of costume details and contradictory results of evaluation of colour in sections 8.3.3.1 and 8.3.3.3 suggested that sufficient visualisation may not be supported depending on the specification of a PC and screen. Third, the absence of atmosphere which is created by a physical environment including space and people and tactile sensation which is developed by the touch of physical materials such as books and magazines were pointed out as the disadvantages. The limitations imply that considerations are required for more user-friendly design which facilitates understanding and control of all users, technical strategy to minimise the constraints of varied computer specifications for online users and use of display methods which better appeals to emotions.

Meanwhile, the usability of digital costumes was positively assessed in a provision of visual information and inducement of interest due to the three-dimensionality and the ability to visualise a plausible or unrealisable garment state. First, full 3D shape was viewed that it enables complete exposure of the costumes so that the audiences could observe them from any perspective. This nature was considered to facilitate more intuitive understanding and immediate recognition. Second, the static simulation which recreates garment drape based on the pose was accepted as a plausible expression of garment drape and considered to support safe exploration of overall garment silhouette. Third, dynamic and deconstruction simulation was viewed as the most advantageous factors of the technology which can illustrate the information that people cannot see. The dynamic simulation which visualises the movement of costumes was perceived to offer an exciting experience and make audiences feel some characteristics of fabrics such as stiffness, weight, texture, lustre and sound. The deconstruction simulation was reviewed that it describes the internal structure of the garment such as geometric features of patterns and arrangement.

Although the digital costumes themselves were evaluated as good information sources and the types of information were regarded satisfactory in general terms, the quality of information was controversial to the degree of providing technicality and lifelikeness of garment shape and movement. While the fashion management students and general public groups viewed the deconstruction simulation providing useful educational information, the fashion design student group claimed that the information needs to be more detailed to assist garment construction practice sufficiently though the majority agreed that the information was suitable for the purpose of general research or the audiences without professional knowledge. Those opinions indicate that the simulation needs to be designed depending on the target audiences with more specified purposes considering their demands. For the people who require more technical information, simulation with seams, finishes and lining may be applicable as suggested by the fashion students.

In garment shape and movement, the digital costumes were reviewed to present expression of plausible appearance in general however the degree of their reality was perceived partially positive. Some participants viewed the digital costumes realistic cognising some differences and some participants who assessed them very similar explaining they would have thought them realistic if they did not see the physical garments. The opinions imply that the technology has the capability to create digital garments, however, with a lack of precise expression. Overly structured shape, less irregularity and wonderful material properties were pointed out as the factors which looked the most different. This study regards that modification of garment panels, use of supportive objects and estimation of fabric properties conducted might have an influence on insufficient reality and faithfulness together with the technical limitations.

To examine the faithfulness of the costumes, more careful comparison in parts was made with costume and specialist fashion group in section 8.2 and fashion student and general public groups in section 8.3.3. Compared to the evaluation results by the costume or fashion experts in Table 8.6 (p.253), overall lower opinions of the other groups in all categories were observed in Tables 8.12 and 8.13. However, the high standard deviation of the fashion student and the general public groups, in general, indicates that the individual opinions were very varied. Figures 8.7 and 8.8 illustrate the results of common questionnaire items. Although there was the gap in the level of the scores, the responses of the specialist and the general public groups presented a similar tendency in the assessment of each item. Meanwhile, the fashion student group appeared to give less consistent responses than the other groups. It seems that the first two groups may have a similar focus for the judgment but with a different standard. Although the fashion student group appeared different tendency, the items in details were relatively lower-rated by all groups in common.

Figure 8.7 Average scores of three groups in evaluation of costume A

Figure 8.8 Average scores of three groups in evaluation of costume B

Table 8.14 Differences of opinions on costume A

<table>
<tr><th></th><th>Small differentials</th><th>Large differentials</th></tr>
<tr><td>Fashion students</td><td rowspan="2">▪ Pleated frills & ruche: 4.14 / 3.83 / 4.00
▪ Neckline: 4.86 / 4.50 / 4.33</td><td>▪ Garment drape: 4.71 / 3.50
▪ Folded waistline: 4.14 / 3.00
▪ Sleeves: 4.71 / 3.67</td></tr>
<tr><td>General public</td><td>-</td></tr>
</table>

(: Costume & fashion specialists, : fashion students and : general public)

Table 8.15 Differences of opinions on costume B

<table>
<tr><th></th><th>Small differentials</th><th>Large differentials</th></tr>
<tr><td>Fashion students</td><td>▪ Bottom edge: 4.29 / 4.17
▪ Bust & shoulder: 4.57 / 4.50
▪ Overall silhouette: 4.86 / 4.50
▪ Neckline: 4.86 / 4.50</td><td>▪ Sleeves: 4.57 / 3.33
▪ Waist: 4.86 / 3.67</td></tr>
<tr><td>General public</td><td>▪ Bust & shoulder: 4.67 / 4.50
▪ Garment drape: 4.17 / 4.00
▪ Neckline: 4.86 / 4.50
▪ Waist: 4.50 / 4.33</td><td>▪ Cuffs: 4.57 / 3.00</td></tr>
</table>

(: Costume & fashion specialists, : fashion students and : general public)

Tables 8.14 and 8.15 show the sections of each the following which appeared to have the least and the most disparity in responses from the specialist group. Based on the findings, this study draws the following summary:

(1) The items which appeared consensus about good similarity by all groups are considered faithful: neckline of costume A and bust and shoulder of costume B.

(2) Following cases are regarded to have some degree of faithfulness, however, need minor enhancement.

- The item which was positively rated but with less high scores by all groups: pleated frills and ruche of costume A
- The items which were highly rated by two groups: bust and shoulder of costume A and overall silhouette, garment drape, bust and shoulder, neckline, waist and bottom edge of costume B

(3) Following instances were considered as the parts which have partial similarities, however, require critical improvement.

- Items which presented large differential in score by two groups: garment drape, folded waistline and sleeves of costume A and waist, sleeves and cuffs of costume B
- Items which were lowest-rated by one group: wrapped waistline of costume A and cuffs of costume B

Besides the evaluation of colour and texture of fabrics was rated high in both costumes. It is considered that those attributes were faithfully expressed but may need minor improvement.

The findings in discussions indicate that the digital costumes in this study gave a realistic or similar impression in global cognition however the deficient factors were found in meticulous comparison in parts through the questionnaires. Nevertheless, the results presented more than a median value in all evaluation items, and participants' opinions support the positive feasibility of digital costumes as educational and exhibitory materials. The general views are summarised as follows.

First, supportive roles as educational materials were predicted highlighting inclusiveness and an ability of visual description of digital costumes. The rich visual data was viewed to cover a broad range of information scattered in multiple references and to facilitate learning without wandering various sources. The simulation was considered as a 3D visual explanation of completed and deconstructed garment shape which offers a helpful understanding for garment construction. The applicable areas were expected to include general study, research and garment construction practice.

Second, contribution to exhibitions use was expected to diminish various restrictions. The advantages of digital costumes such as facilitation of appreciation and providing comprehensive information were regarded as appropriate attributes for the exhibition which reduce constraints such as spatial migration and physical exercise and limited description on exhibit labels. Also, the dynamic simulation which expresses prohibited movement of costumes was considered as a useful factor for the enhancement of display. Use of digital costumes was deemed to be able to alleviate conversational concerns. As possible application, full or partial replacement of original costumes, interactive information and a database were suggested.

Meanwhile the findings entail the concern for the negative factor in use of digital costumes. Strong belief that digital costumes cannot substitute real garments were observed in some opinions. The following reasons were mentioned to explain why physical exhibition is preferred: (1) display on screen gives different impression from seeing real-life, (2) real garments can provide a better understanding of garment shape and scale and (3) digitisation can cause a loss of quality. This study considered that the quality of the current outcomes and insufficient display methods used in evaluations may have influenced a negative attitude of the participants to some degree and expects that the concern for quality and shape of costumes can be alleviated by an improvement of the digital costumes and application of better display. Also providing visual information about actual scale can be compromised using a large screen displaying real-size images. However requirement for certain hardware or special installation is not regarded as the individual level of consideration for home-based online audiences. This means that the digital costumes should provide better quality of images and understanding through improvement and their development should consider the use of hardware based on more specified use purposes such as optimised graphic information allowing for a certain degree of technical constrains for online users or high quality presentation for exhibition or education. The critical weakness of the digital costumes is their virtual attribute that they cannot be directly presented without media accordingly they make a less natural and less vivid impression. Likewise the limitation of digital application previously pointed out, the virtual and intangible digital costumes may also lack emotional and sensory stimulation. In digitisation, the important future task will be seeking for the solution to include sensitivity aroused by physical attributes into digital artefacts.

Following improvement points were further proposed for enhancement of digital costumes and application:

- Supplement of information: photographs and video of original costume
- Addition of interesting factor: virtual fitting of costumes
- Reinforcement of historic atmosphere: movement based on historic research and background music which represents certain periods
- Application of sensible operational methods: touch screen
- User-adjustment of display options: background and skin colours, light and speed
- Suggested medium: portable personal devices

In addition, positive prospect of digital clothing technology was expected by participants in garment design practice, communication for fashion sales and marketing and virtual fitting for online shopping.

8.5 Summary

This chapter described how evaluations were carried out and the results. Based on the findings, this study attempted to examine not only the quality of outcomes but also the applicability of the design of the outcomes to the research purpose and predictive effects of their use.

The overall usability of the digital artefacts was positively reviewed. The application with digital costumes was considered as an effective information delivery method in three aspects: methodological features, information characteristics and encouraging characteristics. In reality and faithfulness of digital costumes per se, however, the assessment appeared to yield different degrees of positiveness between groups and individuals and need for improvements. In general, more negative reviews were observed from the fashion design student group. They expected more technical information from the simulation and they tended to be more sensitive to reality and faithfulness of the digital costumes. Nevertheless, the questionnaires showed more than the average score in all assessment items and discussions confirmed formal resemblances between physical and digital costumes to some degree. For more faithful and accurate reproduction and supplementation of the flaws, this study considered that technological improvements of the system, minimisation or optimisation of garment panel modification and estimation of more appropriate material parameter values will be required.

Although the outcomes of the study were considered to be improved in terms of faithful reproduction, the value of the digital costumes were highlighted due to the advantages of taking a complete 3D form and enabling imaginary presentations such as deconstruction and dynamic simulation to provide educational and interesting information. The virtual simulations as well as interactive and stereographic display method also evaluated as appealing elements in exploration of information. The overall findings indicated that the concepts of the effective digital costume proposed had suitability and applicability for exhibitory and educational use with the curational purpose for which this study is aimed.

Moreover, the reviews suggested following effectiveness on exhibition which application of digital costumes may bring:

- Complete or partial replacement of costume relics
- Presentation of concealed or prohibited garment features
- Release of physical constraints on appreciation
- Provision of integrated and comprehensive information

In addition, the findings implied that further considerations and improvements are required for concerns related to the display which depended on the specification of the system and virtual and intangible nature of digital artefacts which may hinder stimulation of emotional and sensual factors together with enhancement of faithfulness and reality of the digital costumes.

Chapter 9: Conclusion

This chapter reviews how the aim and objectives of the study have been addressed and synthesises conclusions reflecting on the design development process and findings. Also limitations and suggestions for future work are presented.

9.1 Addressing Aim and Objectives

The aim of the study was to explore the applicability of recreating costume relics in a digital from using digital clothing technology, especially 3D apparel CAD which has the potential to supplement the various constrains on costume resources. This study set an aim of identifying the desirable factors for digital costume development, producing accurate reproductions of digital clothing from historical sources and investigating the implications of developing it for online exhibitory and educational materials. As shown in Table 9.1, the aim was realised through conducting research activities to satisfy the objectives in Chapter 1.

Table 9.1 Addressing research objectives

Research objective	Chapter
(1) To establish a theoretical understanding on digital clothing technology and 3D apparel CAD	2 and 3
(2) To understand the importance and constraints of costume collection (3) To provide an overview of the influence of new media and clarify the status and problems of museums' current practice of applying websites	4
(4) To review methods, strengths and weaknesses of earlier digital costume projects and establish key concepts for the development of effective digital costumes and application	5
(5) To develop digital costumes and application	7
(6) To evaluate the effectiveness and faithfulness of the outcomes	8

Objective 1 was achieved through a literature review clarifying the concepts, features and possibility of the technology and techniques. Chapter 2 provided understanding of what digital clothing is and what kind of qualities are basal. Also, it discussed the possible techniques and a feasible method for the purpose of the study analysing the characteristics on a bigger scale. Chapter 3 offered more narrowed down insights into the capability of 3D apparel CAD to represent potential effects on costume reproduction. The chapters established a theoretical understanding of digital clothing technology and provided the implication of what the contribution that the technology brings to the costume reproduction method.

Objective 2 was addressed in Chapter 4 reviewing the concept and role of the museum and costume collection and identifying the constraints from the viewpoints of the museum staff and students. In this chapter, a museum and costumes were emphasised as repositories of information to store, preserve, disseminate, educate and promote culture and science and as a valuable resource to be collected, exhibited and studied respectively. Difficulties in management due to the vulnerable nature of costumes, temporal and spatial constraints on admission, limitations of physical display methods and restricted access to fragile costumes were discerned as major constraints on a costume collection.

Chapter 4 also contributed to satisfying Objective 3. The chapter investigated the general impact of new media in museums to characterise the universal phenomenon. Various changes in museum practices were outlined and digital database construction and network and expansion of curational areas into the online domain were highlighted as a notable shift. To specify the problems of the costume and fashion museums' online practice, an observation of their websites was carried out as a case of typical new media application. The findings displayed problematic conditions of the websites underlying the absence of the in-depth information of costume, particularly visual data, to perform as virtual museums or an online costume collection.

Objective 4 was fulfilled in Chapter 5 through the critical review of literature, websites, and relevant videos and images of eleven earlier digital costume projects. The chapter analysed the features of each project and discussed the general tendency and advantages and disadvantages of various methods. Based on the analysis, desirable factors for digital costume development were investigated considering the constraints of costume collection and limitations of museum websites. Three concepts for effective digital costume development which were faithfully reproduced, virtual fabrication and interactive and stereo graphic display were drawn and feasible methods were addressed to realise the concepts.

Chapter 6 addressed the research strategy and the selection and rationale of the methods outlining the structure of the study.

Objective 5 was realised by conducting three design activities described in Chapter 7 applying the proposed concepts. The first activity was preparation which provided a physical foundation for the digitisation such as costume data, physical costumes and underpinnings and fabric property data. Based on these outcomes, the second activity, digital reproduction was carried out to generate digital costumes and figures and eventually to produce static, dynamic and deconstruction simulations. The simulation data was then incorporated into the last activity, development of digital application. Throughout three design phases, digital application with digital costumes and physically reproduced dresses were generated as the primary and subordinate outcomes respectively.

In fulfilment of Objective 6, focus groups and questionnaires were applied for the evaluation of digital applications and costumes and comparison with physically reproduced dresses as counterparts to verify effectiveness and faithless of digital artefacts. The overall assessments provided the results of positive usability of current outcomes with the need for improvements in faithfulness. Also the feasibility of the proposed concepts for exhibitory and educational purposes was supported by the user discussion highlighting the various effects such as complete or partial replacement of costume relics, presentation of concealed or prohibited garment features, release of physical constraints on appreciation and provision of integrated and comprehensive information.

9.2 Conclusions

This study has addressed the capability of digital clothing technology and its potential possibility of costume reproduction for exhibitory and educational purposes to supplement the existing constraints of costume collection. To underline the gap, diverse perspectives of digital clothing becoming ubiquitous and the lack of its expanded use in an aspect of costume curation were discussed through the exploration of current applications of the technology, which has mainly inclined to clothing sector, film and animation, game and social network.

In order to deal with the costume reproduction from the perspective of expanded application of the technology, 3D apparel CAD was suggested as a suitable tool for the research purpose due to its efficient usability for complicated garment construction, accommodation of conventional principles and the potential for diverse utilisation. It was considered that the various advantages of 3D apparel CAD in garment design such as rapid and easy design process, reduction of material, labour, cost and time, less-constrained revisions and alleviation of dependence on skills and experiences of an expert may be applied into the costume reproduction.

Reproduction of costumes was regarded worth consideration in application of the technology due to their significance. Costumes were weighted as valuable resources which represent the style, identity and culture of the past for a range of fields of study and give inspiration and pleasure. However, various constrictions such as difficulties in management, temporal and spatial constraints on admission, limitations of physical display methods and restricted access to fragile costumes were identified as the hindrance to the research and appreciation of the costume collections. Hereupon this study highlighted the benefits of new media which enables the expansion of curation area of the museums into the online domain to alleviate the physical constraints and contribute to the democratisation of knowledge. However the observation of current costume and fashion museum websites pointed out the problematic situation which was a dearth of detailed information in exploration of individual costumes and underlined the necessity of enriched visual data.

As a remedy to supplement the problematic situation of the museum websites and constraints of costume collections, utilisation of digital costumes and its directional elements for effective design were suggested through the analysis of methods, advantages and disadvantages of earlier digital costume projects. First, faithful reproduction through reflection of historic resources, use of 3D apparel CAD and a clear definition of design elements. Second, virtual fabrication with static, dynamic and deconstruction simulation. Third, interactive and stereographic display through user control, virtual reality and new media.

For the development of design which applies proposed concepts, two costumes in the Museum of London were selected as subjects and physically reproduced with underpinnings to prevent potential damage during handling of the original garments. Also properties of the fabrics used for costume reproduction were carried out for the generation of drape simulation. Based on these digital costumes, virtual models and simulation data were created applying various techniques including 3D apparel CAD, 3D scanning and 3D modelling. Lastly, digital application was developed to display costume simulations.

The outcomes were evaluated through three stages of assessment with different groups of participants: (1) evaluation of digital application by fashion management students, (2) evaluation of digital costumes by costume and fashion specialists and (3) overall evaluation with fashion design students and the general public. The overall results indicated that the digital application and costumes were perceived as an effective information delivery method and allowed the users to explore the intuitive, inclusive and descriptive information in an interactive and direct way providing an attractive, amusing, exciting and comfortable experience.

The digital costumes produced in this study appeared to give a realistic impression[1] to some participants, however, were considered as a very similar representation[2] by the other participants. Especially detailed comparisons by garment sections pointed out some dissimilarities between digital and physical costumes although the deviation of opinions appeared large. It was inferred that some factors such as use of alternative methods in fabric measurement, division and modification of garment panels to avoid errors in simulation and omission of seam allowance and non-fabric materials due to limitations of 3D apparel CAD may affect the incompleteness to some degrees.

Nevertheless, the findings implied the positive usability of digital costumes in a provision of visual information and inducement of interest due to the three-dimensionality and the ability to visualise plausible or unrealisable garment state having specific values: (1) the full 3D shape enabled intuitive and direct understanding through observation from any angle, (2) static simulation generated plausible drape and silhouette, (3) dynamic simulation expressed some characteristics of fabrics, and (4) deconstruction simulation

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[1] The adjective “realistic” was stated by some participants in the context of a positive aspect of the digital costume to describe almost the same image as the original costume by comparison. It is argued that the vocabulary did not mean “identical,” as the participants pointed out some differences. The vocabulary was understood as a very good degree of representativeness of an object in this study.

[2] Compared to “realistic,” the adjective “very similar” was used to underline less accuracy and truthfulness of the digital costumes. The word implied having a resemblance that might not be noticed without direct comparison.

visually delivered internal structure and geometrical features and arrangement of patterns.

The evaluation indicated positive effects of the outcomes as educational materials. Particularly, inclusiveness of information and the capability of visual description were featured to cover a wide range of references and offer a better understanding of garment shape. Also possibility as exhibitory materials were positively assessed in elimination of constraints on physical exhibition and appreciation and providing comprehensive information. Moreover, digital costumes were considered to enhance display enabling visualisation of unattainable expression in reality. It was predicted that they can be used for complete or partial substitution of original costumes and for the establishment of a digital database.

The findings suggest some considerations for practical utilisation of digital costumes. First, improvement of garment shape and lifelikeness is required for more accurate representation. Second, provision of more technical information may be needed for the audiences who want more advanced knowledge. Third, the complementary method to lessen the repulsion toward the virtual and intangible nature of digital artefacts need to be considered.

In addition, the findings implied some needs for further development of the digital application in reinforcement of supplementary information, entertaining factors, historic atmosphere and display options, application of sensible operational methods and portable medium.

Although the drawbacks and considerations denoted the current outcomes had incompleteness to be instantly employed as online materials for museums, the digital artefacts were capable of improvement and feasibility of the concepts of the effective digital costume were affirmed. It is regarded that the study demonstrated the application process of 3D apparel CAD exploring the phenomena appeared as the example models to guide future development. Considering the rapidly progressing technology, the introduction of more advanced digital costumes into museums is expected to be realised in the near future. The key benefits that digital costumes may bring to the museums compared to the conventional methods are shown in Figure 9.1.

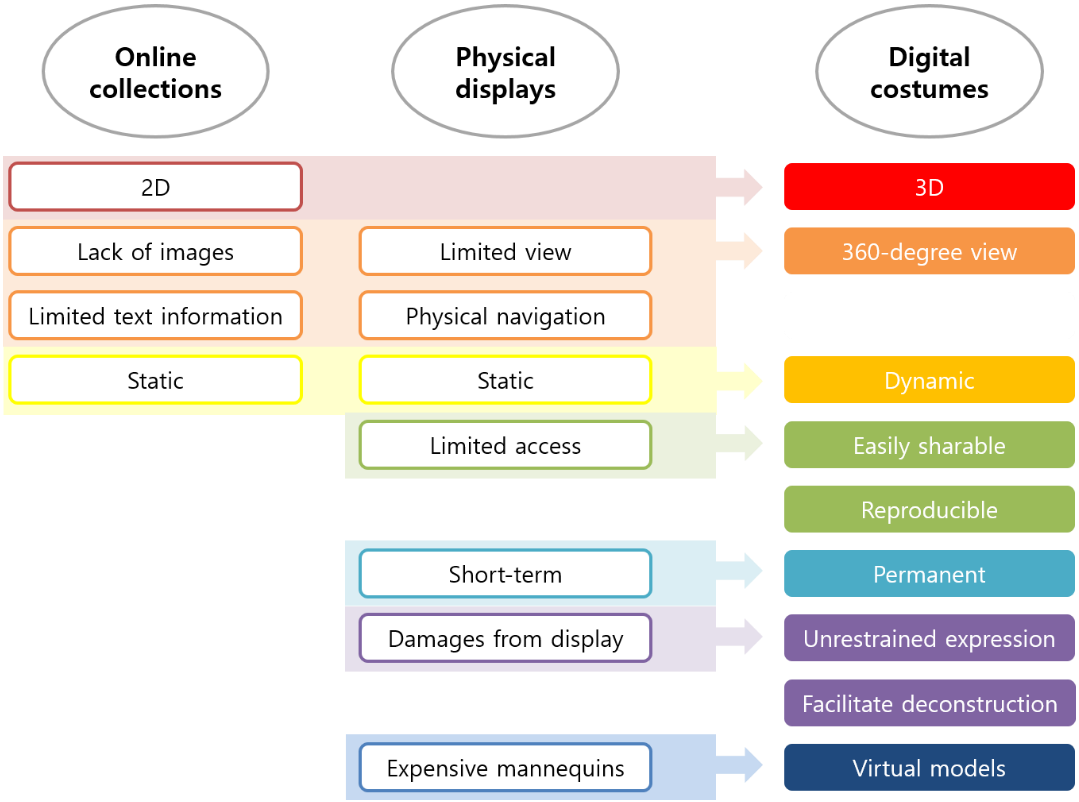

Figure 9.1 Advantages of digital costumes

First, 3D digital costumes render multitudinous images which portray the garment shape from 360-degrees. This feature may strengthen the fragmentary images and explanation for costume collections appeared in museum websites through rich visualisation. Also fully exposed digital costumes in virtual space are not restrained by any obstacle and do not require special and physical movement as the exhibition. It is considered that digital costumes not only provide abundant images but also devise ways to make the observation more convenient.

Second, dynamic simulation may animate the costume display. According to Buck (1958, p.3), "the beauty of dress, always ephemeral, is so closely connected with the living, moving body which wore it and gave it final expression, that a dress surviving, uninhabited, may appear as an elaborate piece of fabric, an accidental repository of the textile arts, but little more." While the garment draped on static forms cannot arouse the human experience connected to the wearing (Taylor, 2012), digital costumes on virtual bodies which are able to perform a variety of movements can visually deliver the feeling of wearing through simulation stimulating synaesthesia. The animated digital costumes may be used as the factor which interest audiences providing more rhythmic as well as sensual information.

Third, virtual nature of digital costumes enables their exploitation. Such characteristic can allow creation of a range of scenes which are avoided in the real world to prevent excessive handling such as the depiction of deconstruction, partial dressing or undressing of the ensemble and sequential process of wearing from underwear to outer garments. This feature can present the in-depth information which is hardly exhibited through the physical display strengthening the educational use.

Fourth, digital costumes have the merit of facilitation of dissemination. Once the costume is constructed, the data is easily sharable and reproducible and accordingly can be used for many purposes. Applying new media, digital costumes can be accessed anywhere at any time by anyone online. Also digital costumes can be used in physical exhibitions enabling multiple simultaneous displays and virtual costume shows through a variety of mediums allowing permanent display free from the ephemeral exhibitions.

Additionally, use of digital costumes lessens a load of preparation of customised mannequins which are often costly applying virtual models.

This study highlights that those advantages may help museums overcome conservative and managerial constraints giving new opportunities to the garments particularly damaged and lost costumes to be introduced.

9.3 Review of Digital Reproduction

The digital reproduction in Chapter 7 revealed some phenomena which was not observed during the physical reproduction. This section reviews the distinctive factors in the aspects of construction, simulation and overall process.

9.3.1 Digital Construction Method

The use of the non-physical fabrics without threads and physical treatments of 3D apparel CAD is the most distinct factor that distinguishes between digital and physical garment production. In addition, the process of construction in this study entailed some other distinctiveness such as the division of patterns, omission of seam allowance and non-fabric materials and a less restricted assembly process which did not pertain to the physical production stage. From the practice of the digital construction, this study could draw several reasons to explain such phenomena.

First, the assembly method led to differences in the sewing process and the internal shape of a garment. While the physical needlework was mainly done on a flat table sometimes checking the fit using the body stands, the assembly in the system was carried out thoroughly relying on the virtual models in the 3D environment. Therefore the construction process tended to start from the innermost parts considering the draped status. Also the 3D apparel CAD system which joined the panels without seam allowance brought about no constraint on the sewing order to which the physical sewing process had to comply. Such feature may not be disadvantageous for prototyping since the seamless garments do not appear to show huge dissimilarities in the external appearance, and the proportion of the seams is minor in most cases. However when it comes to more accurate cloning which this study aims for, the absence of the seams concerned the imperfection of the shape inside the dresses and the less accurate garment behaviour due to the negligence of physical properties of the seams.

Second, the division of patterns was needed (1) to facilitate panel positioning or more stable simulation, (2) to clearly define the folds and (3) to cope with the case which the system could not apply the physical techniques. One of the general principles of the 3D apparel CAD is that the construction of the garment implemented on the virtual body required positioning of the panels close to the relevant body section. In the arrangement of large panels and layered or folded structure convergence, the penetration of the panel into the body or into the other panels was a concern. The division of the patterns as well as their placement in 3D facilitated evasion of such problems. Additionally, division was sometimes inevitable when a curved panel required bending or folding before the simulation. The folded waistband of the day dress placed around the waist is one such example. The panels were also split when simulation appeared to render an unstable shape. This study found that dividing a panel which had multi-layered folds or which had simple mesh structure generated a more stable outcome. The second case of division was applied to the frills folded in half for clear definition of pleats. Since the pleating direction of the folded-side was reversed to quadrate the pleats of the other side, a pair of two panels was generated to form the frills: one with box pleats and one with inverted box pleats. In this way, the layered pleats appeared to be folded in the same direction. Also 3D apparel CAD has limits on realisation of some physical techniques such as knot and bow, for which the shape is formed by tying rather than sewing. To give a similarly shaped bow for the day dress, the ribbon panel was divided into pieces and sewn together into the form of a bow.

Third, the expression of non-fabric elements such as buttons, hooks and eyes, cord, braid and stitches were not authentically supported by the 3D apparel CAD. The garment making and simulation in the 3D apparel CAD were principally founded on the visualisation of the assembled fabric pieces and the non-fabric materials and details are often regarded as additional components. To add those elements, the user may need to choose the most suitable elements among the resources provided by the software, or give a graphic effect using an image of the element. Unlike when prototyping modern clothing design, the use of software resources was considered less desirable as the details in costumes could carry distinctiveness which enhances the peculiarity of a dress. To resolve this and to reflect the uniqueness of each element, the digital costume reproduction in this study adopted the graphical presentation option and attached external objects using 3D modelling CAD in the later stage. However the materials which were not externally visible such as the hooks and eyes and cord were disregarded.

To summarise, the digital process in this study presented some differences compared to the physical method due to the principles of digital construction, limitations of the system and constraints arisen from the purpose of costume reproduction. Minor differences appeared in the relatively simpler design of the costume, C1928-9 evening dress. It is considered that such discrepancies may not appear in modern garment design with simpler elements and whose physical and digital process can closely correspond to each other. Despite the undesired process of dividing patterns, digital construction proved advantageous by significantly reducing the time required for construction compared to physically cutting and sewing the fabric. Two aspects, non-physical seam assignment and less restricted sewing order due to the absences of seam allowance, accelerated the assembly of the garments. However the system’s processing speed declined considerably during the construction of the C1861-3 day dress with large volume and complicated structure. There is a concern that digital construction may be protracted depending on the size and complexity of the dress as well as the specifications of the computer. Also, dealing with unexpected problems such as unstable simulation may require additional time for a less experienced user to achieve satisfactory results.

9.3.2 Limitations of Simulation

The drape simulation in this study has limitations which were induced by two main reasons: constrained application of material properties and technical capability of the system. Although the objective comparison was not made at this stage, this study regards these limitations as the factors which caused discrepancies in garment drape.

In terms of material properties, this study had following restrictions. First, the drape simulation took into account five material parameters which have major impact on static simulation and which could be applied through objective measurement. Due to this reason, expression of drape, especially dynamic drape was presumed to have some limits. Second, material properties were omitted or imprecisely applied when the measurement of the materials was not applicable or when the materials could not be constructed within 3D apparel CAD. Those components were graphically expressed without structural shapes or some shapes were built with panels but with default values were used for the simulation. Although these elements were considered less influential compared to the main structure, it would have made a difference to the simulation.

The limitations caused by the technical capability were related to the stability of the garment shape and the interaction between virtual body and the clothing. The instability in shape appeared on some parts of the garment which had the sections folded or on narrowed structures when they collided with other surfaces. Those elements tended to hinder the rational behaviour presenting penetration or subsidence. Such problems were considered to require technical improvement of the system in order to be solved. The other problems were the glide of the garment on the virtual body and the penetration of body into the garment. If strong strain or close contact with body is applied to a physical garment, the garment is pulled pressing soft human skin, whereas digital clothing can penetrate into the body due to the force. To prevent the penetration, some minute space between body and the garment is allowed in DC Suite. For this reason, the digital clothing in DC Suite seemed to cling less tightly to the body than the real clothing on textured human skin and sometimes slide down more vulnerably responding the change of the postures. Also this study observes that the penetration of the body into the digital garment occurred by close contact with a pointed shape. Although this study only focuses on the use of DC Suite, such problems were as a general phenomena are also shown in other 3D apparel CAD and 3D CAD packages.

To supplement the problems, the following methods were applied. First, the omitted materials and the subsided details were graphically expressed by applying a mapping technique or separately modelled using 3D CAD. Second, where the costume mesh appeared dented was manually restored using 3D apparel CAD or 3D CAD. Third, supportive objects were applied to prevent the penetration and sliding of the dress. This admits that these methods are regarded as artificial resolutions but unavoidable cost-effective means which can make up for the system's limitations.

This study considers that the use of 3D apparel CAD for its true purpose may be less problematic unless the virtual prototyping requires the expression of small details and which has complex structures of folds. Moreover the poses and motion of the virtual models which 3D apparel CAD provides are usually designed to take into account minimising the potential problems. However when the system is utilised for other purposes, particularity for the design which accurate expression of fine details and delicacy are regarded indispensable, the designer may need to be flexible in their abilities to minimise the problems and suggest applicable solutions.

9.3.3 Differences between Physical and Digital Process

The digital method which demonstrated costume construction with rapidness and ease required relatively time-consuming process in the finishing stage than the physical reproduction involving the use of several CAD systems. While the finishing of the physical costumes simply entailed minor treatments such as adding fastenings and a small detail, the digital reproduction covered expression of subsidiary materials and details which were omitted at the construction stage. Depending on the appearance of the materials and efficiency, the elements were visualised applying modelling or mapping techniques. In this study, the components with prominent depth such as buttons were modelled and the elements which were adhered to the costume surface such as stiches and braid were graphically represented. Those factors are regarded as superficial presentation which did not influence the drape simulation however the necessary in the completion of the costumes. In prototyping, application of details may not be problematic as it can be supported using the material library of 3D apparel CAD. However costume reproduction which requires expression of original aesthetics as much as possible is more likely to engage with a range of possible techniques to supplement the capability of 3D apparel CAD and enhance the originality of the dresses. The consideration on the components which will be omitted and expressed using what kind of technique should carefully be given as it affects the efficiency and effectiveness of the process.

The differences between physical and digital methods are also evidently appeared in expression of textiles. Whereas the characteristics of the fabrics immediately applied to the garments during the physical construction, the digital method required additional process to visualise the features of the physical materials. Although digital methods facilitate the change or revision of the materials than physical construction, realistic representation involves elaborate manipulations of various attributes. In the 3D image industry, research and experimentations have been carried out by specialists for more lifelike representation. However this study has limitations on intuitive control of limited material attributes due to the constraints that the whole process was implemented by the researcher within the given time. This study considers that improvement of authenticity can be achieved thorough more study for objective setting for the textile representation.

9.3.4 Application of 3D apparel CAD into Costume Reproduction

Figure 9.2 compares the processes between physical and digital costume development based on Chapter 7. Use of 3D apparel CAD induced the application of the similar process of the design development method described in Section 3.7. The main advantages of 3D CAD which can be achieved in costume reproduction are as follows.

First, the costume construction can proceed faster and simpler than the physical method. Table 9.2 shows the approximate time consumed during the construction process in this study. While the physically reproduced C1861-3 day dress and C1928-9 evening dress took around one and half months and three and half months respectively, 3D apparel CAD only took around one month for construction of both costumes. A further reduction of time could be achieved if 3D apparel CAD was used from the toile generation stage. It is considered that the remarkably reduced construction time can be applied to most garment construction cases.

Second, physical materials are not consumed during the process. In the physical reproduction of this study, considerable expense was incurred for the preparation of materials. Particularly, obtainment of a large amount of the fabrics which were mainly made of silk came expensive. If a large number of costumes are to be reproduced or if reproduction is carried out by an individual, the financial difficulty may be considered as the major factor. Digital construction may bring economic effect in such cases.

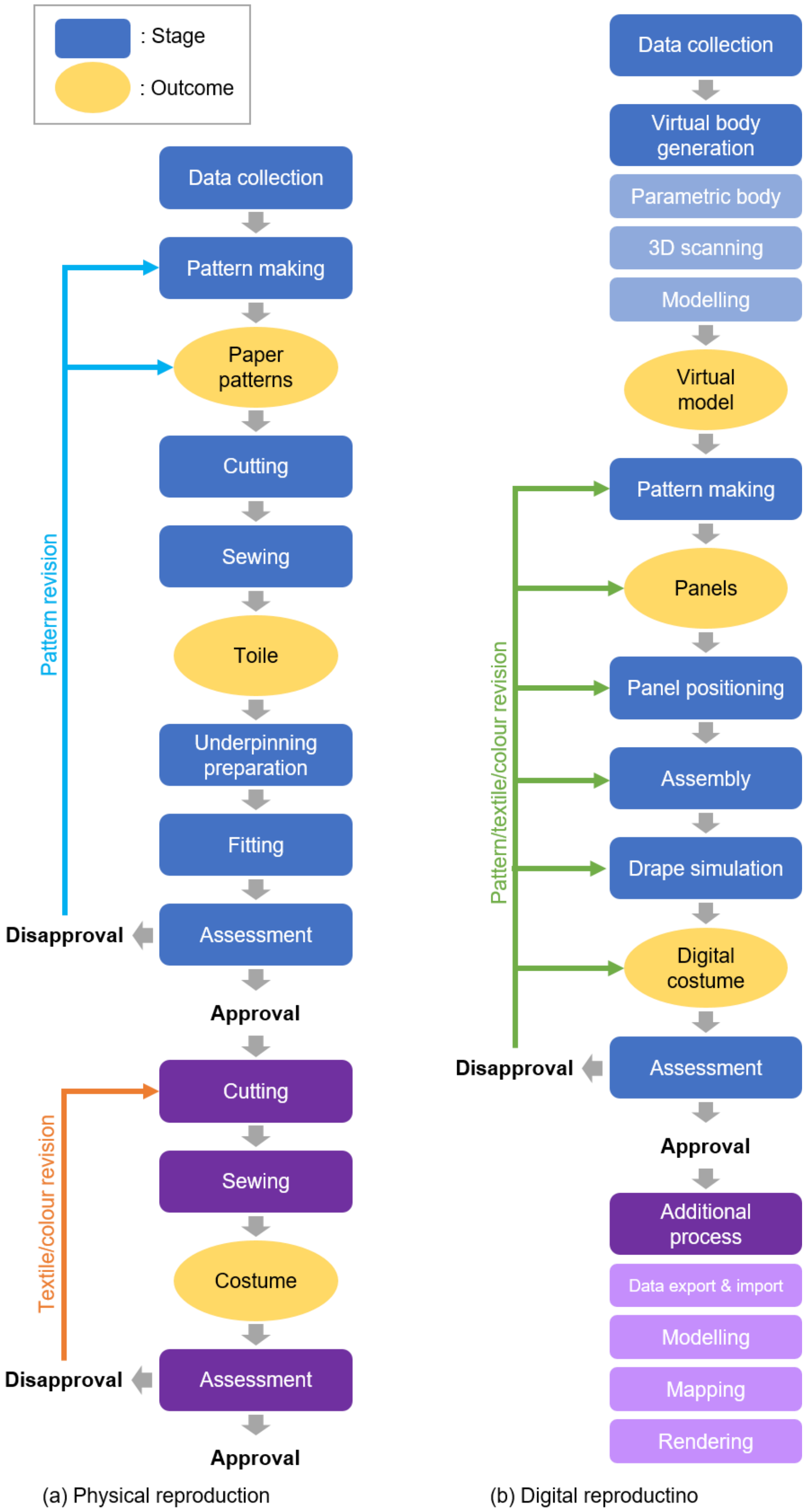

Figure 9.2 **Physical and digital costume development process**

Table 9.2 Time required in construction

	C1861-3 day dress	C1928-9 evening dress
Toile by physical method	3 weeks	1 week
Costume by physical method	1.5 month	3.5 month
Costume by 3D apparel CAD	1 month	

Third, revision of costumes is less constrained in 3D apparel CAD. This study adopted the toile method to refine the garment patterns for the preparation of the underpinnings. To apply the modifications of the patterns into toile, however, disassembly and resewing were required in most cases which resulted in substantial time consumption. Besides, if a change of the textile or colour is needed in the physical production, extra cost and time are inevitably required for the preparation of the fabrics and fabric cutting and sewing. On the other hand, the revision of pattern, textile and colour can be more freely be involved during the process in 3D apparel CAD and disassembly and reassembly are not necessarily required if fundamental modifications of a pattern are not made. This merit may be further emphasised when costume reproduction is conducted based on 2D resources such as illustrations and photographs that precise measurement and analysis of garment patterns are not feasible. Such cases possibly require more revisions as interpretation of 2D images to 3D is not an easy task.

In this study, however, the development of the digital costumes had to entail the use of various techniques and software apart from 3D apparel CAD for several reasons: (1) application of distinctive silhouette into virtual body, (2) use of non-fabric materials and (3) development as exhibitory and educational materials. Except for the costume construction stage, difficulties may lie in covering the whole development process by a garment or costume designer alone. For instance, 3D modelling, shading, rendering and application development in this study demanded tasks for the researcher. Also much time was spent in dealing with the technical problems and errors in simulation and other processes than costume construction. In order to sufficiently fulfil the concepts of effective digital costumes and provide secured quality of the outcomes, cooperation with professionals including 3D modelling, rigging and animation, shading and rendering and application development is considered essential.

In terms of the generation of digital costumes itself, it is expected that a garment specialist will be able to accomplish the completion solely using 3D apparel CAD. Especially digital construction can be more straightforward and successful without the use of external systems in the following cases: (1) the costumes which can be accommodated with the modern body silhouette, (2) the costumes of which main materials and details are fabric-based and (3) costumes with subsidiary materials which are similar to standardised modern designs. The outcomes of 3D apparel CAD which are typically in the form of images or animations are considered to be used as a unilateral visual data to display and as a documentation method to establish a database.

9.3.5 Discourse with Curators

The Museum of London supported this project in data collection and evaluation accompanying discussion each time. Their overall view on this project is described in the letters in Appendix A and B. This section summarises the comments of the curators on the application of the digital costumes from the viewpoint of the museum. Following positive aspects were addressed.

First, the use of digital costumes was considered as a new and interesting information delivery method and the digital costumes were estimated to have possibility to be published as museum exhibits. The 3D images which illustrated the movement and deconstruction process of the garment were viewed as a distinctive approach to costume display which cannot be applied to physical costumes.

Second, the most outstanding contribution was expected to be open opportunities of scholarly research on costumes for everyone particularly for students. The patterns of fashion award by the Costume Society was mentioned as an example which requires a minute observation of a costume for both study and practice to produce a reconstructed garment. To investigate the structure and features of a garment inside and outside, handling is inevitably accompanied. However, meticulous care is required in handling and the number of costumes of which access is restricted is gradually increasing by time. Curators anticipated that the visual description of the digital costumes may assist restricted observation of the costumes without neglecting academic demands and the conservational concerns.

Third, application of the technology into the costumes, which have some parts destructed, was proposed for the visualisation of their restored shape. It was considered that the capability of the 3D apparel CAD which facilitates creation and duplication of the garment panels can be employed to fill the destructed sections analogising the shape based on the remaining parts.

On the other hand, feasibility of the technology for reconstruction of other costumes was concerned in a practical sense. In order to routinise the application of digital costumes in the museums, purchase of 3D apparel CAD, involvement of experts in garment construction, possibly 3D graphics and others and consumption of a substantial amount of cost and time are predicted. Though the digital reproduction may be more cost-efficient than the physical reconstruction, the introduction of the digital method requires further considerations from the point of view of a museum. Although the curators admitted the advantages of using 3D apparel CAD, 3D scanning technique was also considered as an applicable method.

In addition, some experts expressed that they put a high value on physically reconstructed garments than digital costumes. Although the simulation of the costume movement and deconstruction process was underlined as a positive aspect of digital costumes, physical existence of the dresses seemed more meaningfully recognised. They showed more interest in the techniques applied to physical reconstruction which contributed to the realistic representation such as the surface reproduction method and digital printing.

9.4 Limitations and Future Research

This study is considered as a foundation of using digital clothing technology for cultural and educational application dealing with the reproduction of costumes and has some limitations to be improved in the future. This section reflects on the limitations of study and suggests recommendation for future work.

First, the subject matter of the study was under a bias towards a local aspect of use of new media. The focus of this study concentrated on the development of online materials for museum websites which may have constraints on specification of the hardware depending on the individual PCs in digital costume display. In a true sense, the purpose of the study can attain the significance if utilisation of digital costumes is assured in a universal environment from the position of audiences. In general, however, more sophisticate presentation of a 3D object requires more high specification. Focusing on the provision of good quality of visualisation, it is regarded more desirable to consider the applicability of different types of new media. Also the aspects of new media in affiliation with physical exhibition, concerns for threating relics and compromising methods of virtual and intangible attributes of digital artefact needs to be further investigated.

Second, the adoption of bricolage facilitated execution of the research objectives through flexible application of various methods and materials however there were several limitations in conducting bricolage and application of the method. The process of bricolage has characteristic to constantly circulate for further re-appropriation. However this study undertook primary round which resulted in evaluation of produced outcomes and suggested concepts. Foundation of more advanced research model should be challenged for continuous improvement and development. In application of the method, questionnaires did not take a significant part in evaluation. Although the questionnaires were applied to assist analysis of descriptive findings by providing numeric standards, the number of samples was too small and the standard deviation appeared large to draw consistent results. In order to generalise collective opinions, evaluation with a large number of respondents is required using this method.

Third, design development was carried out with a small number of samples and the produced outcomes had some defects to be improved in faithfulness. The process and observed phenomena which were reflected on this study are confined to two costume cases. Therefore there can be unexplained phenomena in digitisation of other costumes. More diverse samples with different features should be investigated to establish a stable and efficient process and to introduce the method into museums. In improvement of faithfulness, the digital costumes should be enhanced in several aspects: (1) morphological improvements of digital costumes through manipulation of garment panels and application of more accurate material properties, (2) application of choreographed movement into virtual figures based on the historical research and (3) improvements of technical precision in rigging, shading, lighting and rendering.

Fourth, further examinations on virtual garment drape in relation to application of objective fabric measurement is required. In this study, fabric measurement was conducted partially adopting an alternative method due to being out of commission of a tester. The data collected by the alternative tester was processed to be compatible with the recommended method based on the mathematic calculation. However, there can be differences between theoretical estimated values and actually measured values. More accurate estimation of material property values needs to be established for drape simulation. Above this, accuracy of virtual drapability should fundamentally be scrutinised in respect of verification of the capability of 3D apparel CAD.

Fifth, application of digital costumes was not addressed in-depth the at the museum level. Although curators were engaged with evaluation of digital costumes, applicational aspects were not covered and discussions were not systematically made to closely inquire into practical considerations. Future study is required to explore feasibility of the introduction of digital costumes considering how to produce, display and database from the side of museums in a way that harmonise with existing costume collections.

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Appendix A

18 September 2014

Zi Young Kang
University of Leeds
School of Design
Leeds LS2 9JT

Zi Young Kang:

I hope this letter finds you well. I would first like to say a very big thank you and congratulations on your wonderful presentation to the staff at the Museum of London. Even now, a week later, the staff are still talking about your presentation. You've inspired me and many of my colleagues to think about how digital simulation can assist our work with historical objects.

As I mentioned to you when we met last, the Museum of London would like to publish, if you agree, some of your work on costume simulation within the Museum's Collections Online. As you know, the Janet Arnold dresses in the Museum's archive are coveted items that receive a lot of attention. Unfortunately, due to this high volume of requests, we've restricted the availability of these items in order to preserve their fragile condition; It pains us greatly to decline these research requests.

However, the work that you have done on the two Janet Arnold dresses gives us high hopes that we may be able to provide access to these items in a creative way that doesn't cause harm to the original material. If we were able to publish some of your work within Collections Online, we would be able to offer scholars, students and general costume enthusiasts the opportunity to gain access to these items in a very fresh and exciting way.

I understand that this request will bring up many questions, which we are glad to discuss with you and the University of Leeds to make sure that everyone agrees on the best solution. Of course, this should wait until you are finished with your work! But please know that when you are ready to consider this, we would be thrilled to pick up the conversation again.

Thank you for the inspiration and best of luck completing your work.

Sincerely,

Timothy Long

Timothy A. Long
Curator of Fashion & Decorative Arts
Museum of London

Appendix B

30 August 2016

Zi Young Kang
University of Leeds
Woodhouse Lane
Leeds LS2 9JT

To Zi Young Kang:

I hope this letter finds you well. Thank you for sending me a copy of your thesis and for the links to view the .avi files of the digital costumes you simulated from the Fashion Collection at Museum of London. May I quickly take a moment to say congratulations. I am so pleased with the outcome of your thesis and feel quite proud to have been involved. Thank you for allowing me to be a part of this.

From the beginning of the project, your professionalism, determination and focus on the subject was clear, and so the decision for the Museum of London to be a part of your project was easy to make. With each of the paramount challenges that you faced, your solutions were impressive and made such a difference in the final outcome. I am particularly impressed with your handling of the body for both the 1860s and 1920s dresses. Each of these figures/silhouettes had to be different (and appropriate for that period), including the waistlines, facial structure and hair styles. Furthermore, you were able to animate these figures in a way that works appropriately for their period. Bravo.

Additionally, the reproductions you made of the two garments made such a difference in your understanding of how the garments were constructed and how they moved on a moving body. I know I speak for my colleagues when I say it was difficult for us to know which dress was original and which one was made by you. Again, bravo.

As I've mentioned to you before, we would like to publish some of the results of your work on the Museum of London's Collections Online. It would be ideal to share your .avi files of the dresses on their entries for Collections Online. Your work is clearly the future of how we can better engage our visitors with the objects in the collection.

Your work for this project will most certainly assist in shaping the future of the study of dress and its relationship with the digital world. I am eager to see how your immediate future unfolds and am so happy to have been a part of your studies.

Thank you, again, for thinking of the Museum of London and I wish you the best as you complete your studies and begin your career.

Sincerely,

Timothy A. Long
Curator of Fashion & Decorative Arts
Museum of London

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