HISTORIC COSTUME SIMULATION AND ITS APPLICATION

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ABSTRACT

This study highlights the potential of new technology as a means to provide new possibility for costumes in fragile condition to be utilised. The aim of this study is to create accurate digital duplicates of costumes from historical sources, and to explore the possibility of developing them as an exhibitory and educational method applying 3D apparel CAD and new media. To achieve this, three attributes for qualities of effective digital costumes were suggested: faithful reproduction, virtual fabrication, and interactive and stereographic appreciation. Based on these qualities, digital costumes and a PC application were produced and evaluated.

Key Words: *3D apparel CAD, digital clothing, garment simulation, costume reproduction, digital curations*

1. INTRODUCTION

Costumes may offer insight into a significant cultural heritage. This can include sharing information such as social status, occupation and lifestyles as well as reflecting the socio-cultural background and aesthetic tendency from the people of the past. Also the beauty and distinctiveness of a costume can be considered important qualities to share pleasure and artistic inspiration for creativity. However very old costumes are often limited with their use due to their fragility and potential harm from being exposed for study or exhibition. They generally compose of organic matter and constantly degrade by environmental factors such as light, dust, temperature, humidity and physical stress (Ahn, 2007). In the case of severely damaged dresses, display of those garments would not be allowed and they would have to be permanently stored in the archive. Publications and internet contents could function as alternative methods to study or appreciate such costumes; however they often have limits to thoroughly deliver the stereographic and detailed features of the costumes. In this regard, this study highlights the potential for technology to offer a more distinct method which may supplement learning when access to the costumes is limited as well as enhance information delivery.

The technological progress and digital revolution have brought many changes to society. Especially in the world of the fashion industry, various computer-aided design (CAD) systems have been introduced and improved. Most promisingly, 3D apparel CAD is receiving attention as an outstanding technology which facilitates more efficient garment design. This reduces consumption of materials, time and human labour through virtual simulation. The technology behind this system is being used in varying ways. Now we can see fashion brands providing virtual fitting rooms and individual designers showing their digital fashion shows on the internet. Besides, this simulation technology is heavily utilised in the film, animation and game industries.

Meanwhile, advances in technology have brought about changes in museums. In particular, improvements in visualisation techniques have influenced the display methods of exhibits, approaches to operational procedures, and the way in which exhibitors establish

relationships with audiences (Henning 2006). Also the introduction of new kinds of media has accelerated the use of digitised information in museum collections. The distinctive attributes of new media can be characterised by programmability, modularity, automation, variability and transcoding (Manovich 2001). Due to these qualities, it appears that various forms of new media have the potential to be an attractive and efficient information delivery method.

In these contexts, this study considered that advancement of technology showed the possibility for effective application of digital costumes. Optimising the advantages of a 3D apparel CAD system, this study aims to create faithful digital duplicates of costumes from historical sources and to explore the possibility of developing them as exhibitory and educational materials. To achieve this, the following objectives were set: (1) identify desirable factors for producing effective digital costumes, (2) develop digital costumes and an application, and (3) evaluate the effectiveness of the outcomes. The project is still in progress and this paper deals with several issues for further study: exploration of features of existing technologies, suggestion of desirable directions, and assessment of effectiveness of the technology through prototype outcomes of a suggested design process.

2. EARLIER COSTUME SIMULATION WORK

This section explores earlier simulation projects on the reproduction and recreation of a garment using 3D computer graphic technology. The subjects of investigation were limited to the following: (1) projects that replicated existing garments or costume design and (2) projects that produced the costume design based upon historical references. Personal fashion design work based on individual creativity was excluded from this study. A total of ten projects on the following list were selected for analysis.

- Flashback (Thalmann et al. 1996; Magnenat-Thalmann et al. 2004; MIRALab 2007a)
- Virtual Hagia Sophia (Papagiannakis et al. 2003; Papagiannakis 2010)
- ERATO (Magnenat-Thalmann et al. 2007a; MIRALab 2007d)
- Virtual life in Pompeii (Magnenat-Thalmann et al. 2004; Magnenat-Thalmann et al. 2007a; MIRALab2007b; MiraLab 2011)
- High fashion equations (Thalmann and Volino 2005; MIRALab 2007c)
- Turandot cosutmes (Sparacino 2004a; Sparacino 2004b)
- Empress's new dress (Harris 2004)
- Fashion curation '13 (Capacete-Caballero et al. 2013)
- Digitisation project of DHCC (Martine and Mauriello 2013; Martin 2013)
- Rococo costumes (Wu et al. 2013)

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.

The results of the analysis are presented in Tables 1 and 2. Most costume simulations in the tables were produced for exhibitory purposes. The majority of the costumes appeared as the main object to be displayed, and showed 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 like historic monuments. The costumes in these projects tended to be less detailed and less realistic, probably for cost reasons.

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 cloth simulator plug-in. However, costumes in this work did not express accurate structural features and details. Some layered structures and decorations were just 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 because 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 as it is hardly realised in the physical 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. However measurement and determination of property values were not specified.

From the findings of the comparison exercise, this study can draw several considerations which are addressable and feasible for more effective digital costume generation. First of all, more faithful reproduction can be attempted through reinforcement of structural components. In some cases, the lack of reality in shape and details was observed, and this problem mainly derived from the absence of structural foundation or the purpose of the projects showing other objects as main exhibits. Considering the structural aspect of garments, 3D apparel CAD was regarded as an effective method in digital costume generation because its construction is based on actual patterns. Although 3D scanning techniques may have more accuracy in appearance, the structural factors of garments are not incorporated to the outcomes. The outcome of this method merely unifies superficial features into a single shape and accordingly separation of individual items and generation of dynamic drape cannot be achieved. This study expects that sufficient reproduction of costumes will be possible using 3D apparel CAD if historic references are clearly interpreted into 3D objects and 2D visual data. Additionally, the capability of a 3D Apparel CAD system allowing adjustment of fabric properties may have the possibility of more realistic simulations.

Secondly, dynamic elements can be applied to the costumes. 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 with a stationary state. Besides, there is more potential to express other experimental effects using a simulation method based on imagination. The utilisable aspect of virtualisation suggests boundless potentialities for digital costumes.

Thirdly, interactive and stereographic appreciation of costumes can be realised applying various display methods. There were some cases applied open control 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 advantages and weaknesses, selection of method will need some consideration depending on the purpose and main functions of digital costumes. However display methods which require great expense or specific equipment and installations were not considered in the design plan of this study due to the financial constraints.

(a) Flashback (Source: Magnenat-Thalmann et al. 2005)

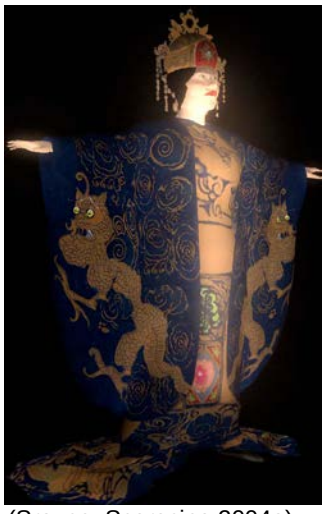
(b) Hagia Sophia (Source: Magnenat-Thalmann et al. 2004)

(c) ERATO (Source: Magnenat-Thalmann et al. 2007)

(d) Pompeii (MIRALab 2007b)

(d) High fashion equiations (Source: Magnenat-Thalmann et al. 2005)

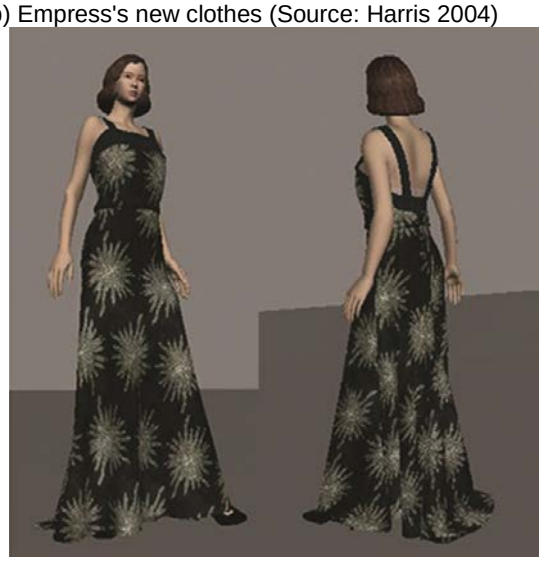
Figure 1. Ealier virtual costume projects



(a) Turandot (Srouce: Sparacino 2004a)

(b) Empress's new clothes (Source: Harris 2004)

(c) Fashion curation '13 (Srouce: Capacete-Caballero et al. 2013)



(d) DHCC (Source: Martin 2013)

(e) Rococo costumes (Source: Kang et al. 2013)

Figure 2. Earlier virtual costume projects

Table 1. Comparison of ealier 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**	Hovie "The Seven Year Itch (1955)"	Historical information (pattens, & textile images)	Historical information (fresco, mosics, scultures, literature, etc)	Historical information (fresco, mosics, scultures, 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	Peformance based on frescos & scenario by archeologists & 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	Realtime simulation	Realtime simulation	Realtime simulation	Animation
	Features	-	Open control	Open control	Argumented reality	-

Table 2. Comparison of earier 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 costuems, 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 Stuit, Maya & Qualoth plug-in	DC Stuit
	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 samles	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	Choreogrphy 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	-	-

In addition, many of the projects appeared to use several auxiliary factors 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.

Based on the main concerns mentioned above, this study suggests three desirable attributes for effective digital costume development: faithful reproduction of the original garment to give authenticity, virtual fabrication to realise impractical factors and interactive and stereographic appreciation. Applying 3D Apparel CAD as key development system, digital costumes were developed as described in the following section.

2. VIRTUAL COSTUME PRODUCTION AND APPLICATION

The findings of the previous section clarify the directions of an effective presentation of virtual costumes. This study fulfils the three desirable aspects focusing on the enhancement of the exhibitory and educational efficacy, as well as an entertaining factor applying the following elements as shown Figure 3: (1) faithful reproduction based on historical sources; (2) a 3D display which allows observation from different angles and distances; (3) the visualization of dynamic drape; (4) the facilitation of deconstruction to enlighten garment structure. Additionally, the advantages of open control shown through previous projects were adapted to the display system of this study to enable user's interaction.

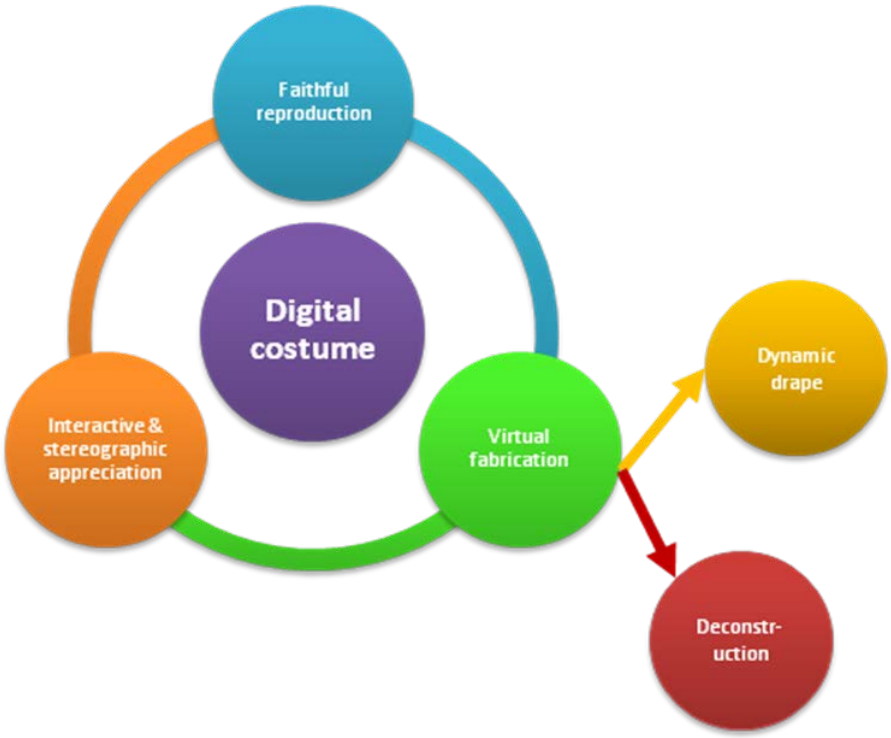


Figure 3. Development concepts with Three desirable factors

2.1 3D Costume Generation

The consideration and implementation of costume object selection and data collection were carried out by the support and help of the Museum of London. Two dresses were chosen among the costume collection of the museum of which patterns were presented in Arnold's book (1977): a day dress in the 1860s (p.20) and an evening dress in the 1920s (p.76). The

process of digital costume generation went through several stages: (1) preparation: costume data collection, pattern revision and mount preparation; (2) digitization: virtual model generation and virtual costume reproduction; (3) 3D data development: static and dynamic simulation and deconstruction simulation.

(a) Day dress in the 1860s (Source: Arnold 1977)

(b) Evening dress in the 1920s (Source: Arnold 1977)

Figure 4. Subjects of the study

2.1.1 Stage 1: Preparation

For faithful reproduction, foundation data was established through the actual measurement of the original costumes, pattern revision, and mount preparation. The data collection was conducted in the Museum of London: structure, materials, colours and other information were measured, illustrated and photographed. Information on patterns was provided based on the diagrams in Arnold's book (1977). However the diagrams manually drawn appeared to have some errors in dimension and shape, and therefore the refinement of patterns was required. In order to examine the appropriacy of the revised patterns, toiles were generated (Figure 5). The toiles were also used for the preparation of costume mounts in order to provide an appropriate foundation for digital costume drape (Figure 6).

(a) Toile for day dress in the 1860s

(a) Toile for day dress in the 1860s

Figure 5. Toiles

(a) Mount for day dress in the 1860s

(b) Mount for day dress in the 1920s

Figure 6. Costume mounts

2.1.2 Stage 2: Digitization

The second phase involves converting previous data into a 3D digital form. In order to generate virtual figures on which garments were properly draped, the costume mounts in the previous stage were transferred into 3D objects using 3D scanning systems. In this way, the virtual models could have the same volume and dimensions as the torsos of the physical mannequins. Next, heads, arms and legs were modelled and attached to the scanned objects to form human figures. In addition, facial features, hair styles, shoes and other subsidiary items like crinoline were modelled based on actual objects or historic illustrations of the time to reflect historic plausibility (Figure 7).

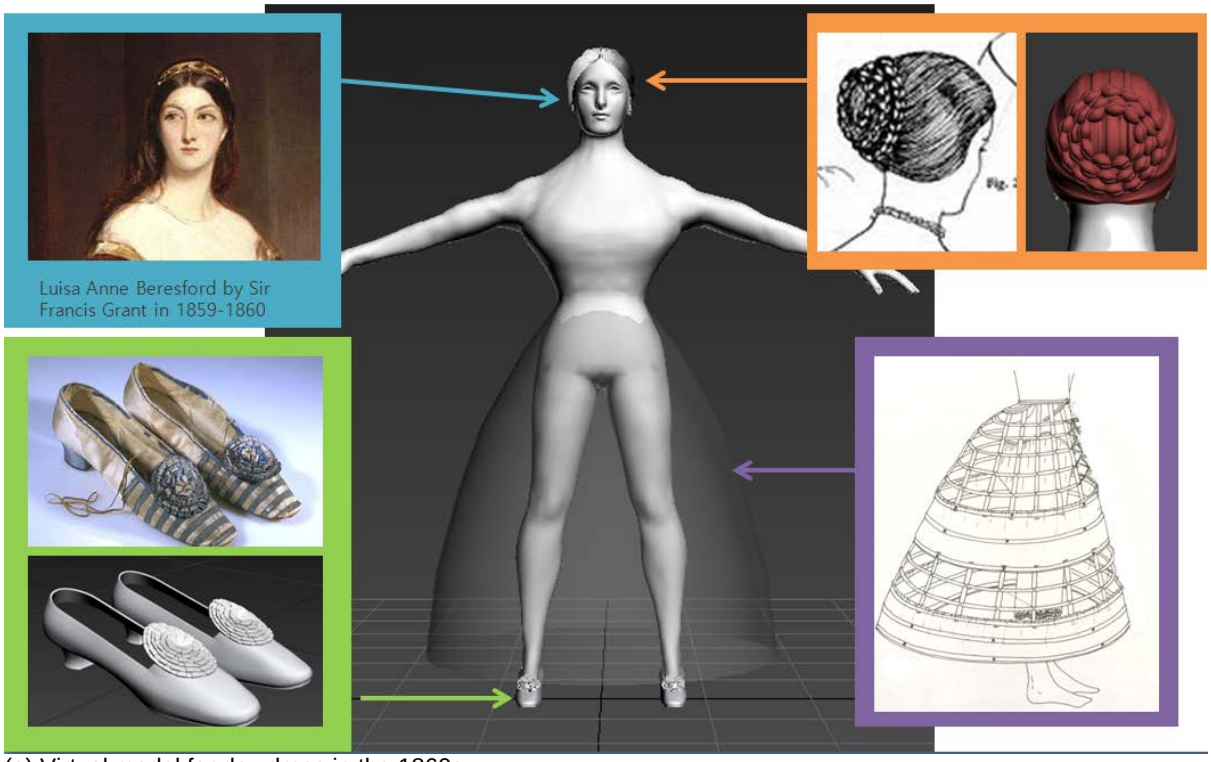
The virtual costumes were then created using the 3D apparel CAD system DC Suite 3.0 which integrates drafting methods of pattern CAD and 3D garment draping simulation. The process of production was as follows: (1) pattern drafting; (2) pattern positioning; (3) assembly; (4) drape simulation; (5) mapping and rendering (Figure 8).

2.1.3 Stage 3: 3D Data Development

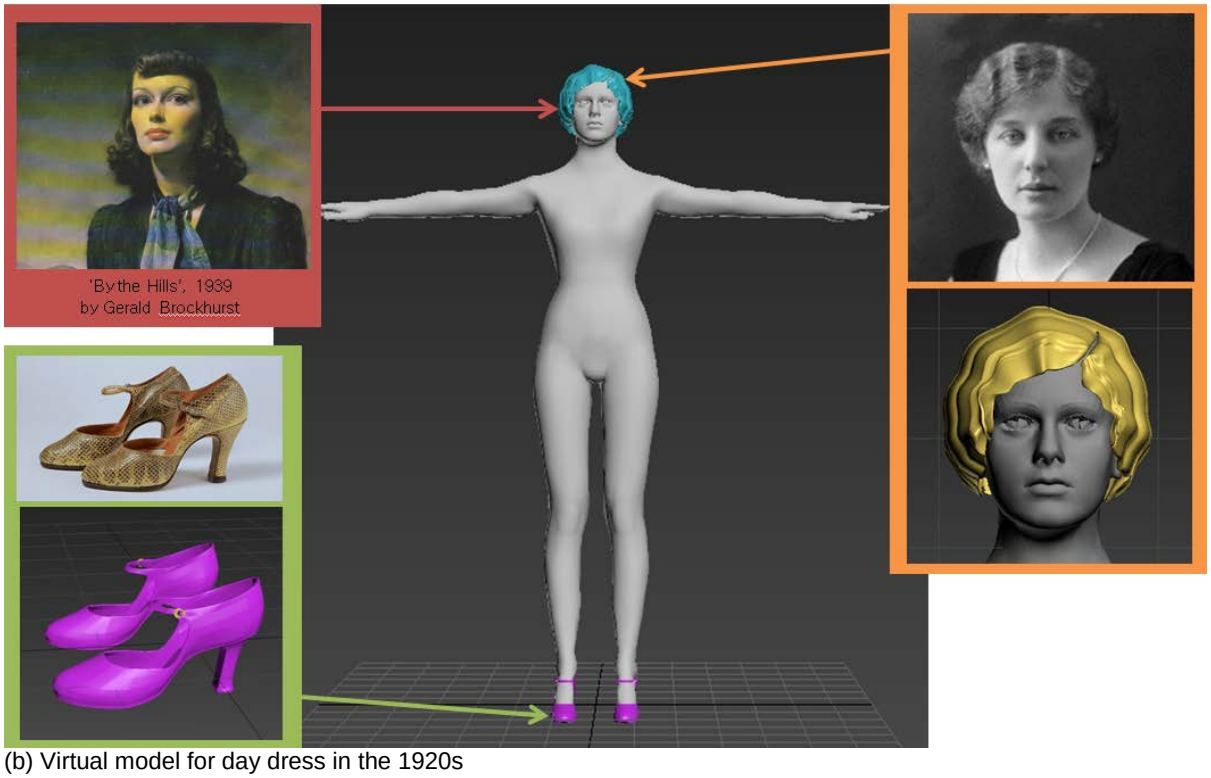
The aim of this stage was to further develop the digital costumes to effectively perform a role as exhibits, which helps aesthetic display, and as learning materials, which deliver the structural information of the costumes. Based on design directions, key data of this study was planned and produced as follows: (1) static simulation with aesthetic poses for stereoscopic observation of whole garments; (2) dynamic simulation for appreciation of garment movement; and (3) sequential deconstruction process to show structural features. The static posture of each model was based on the pose of an illustration of the Fashion plate (Figure 9) and a character in a historic period television drama (Figure 10).

For the dynamic simulation, it may be ideal to employ a certain manner of movement that the female of the time typically took. Due to the constraints of cost and time, however, this study applied general walking motion in order to capture data for Autodesk Maya 2014 in the models (Figure 11).

The deconstruction simulation could be generated by creating key animations between two costume data before assembly and after draping, and then making intervals for the animation of each fabric piece (Figure 12).

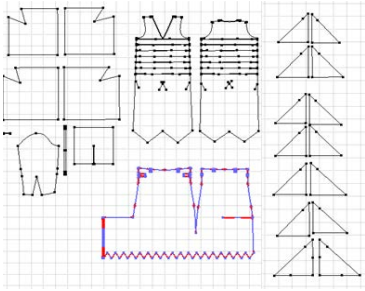


(a) Virtual model for day dress in the 1860s

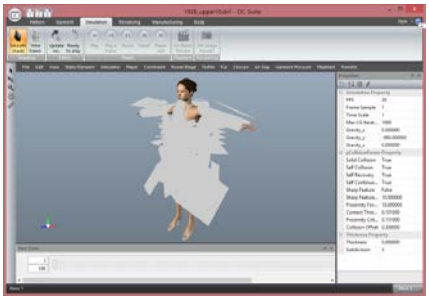


(b) Virtual model for day dress in the 1920s

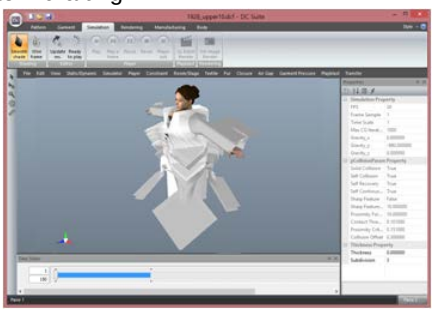
Figure 7. Virtual models



(a) Pattern drafting

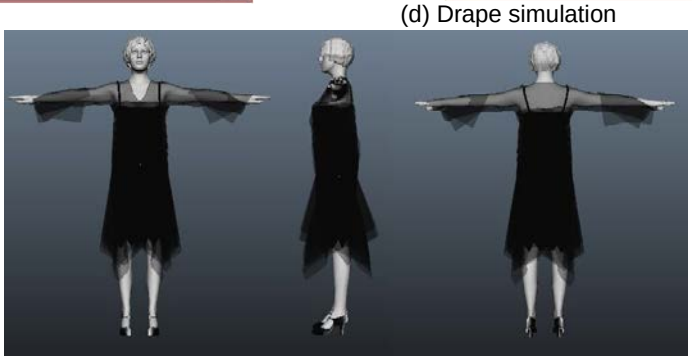


(b) Pattern positioning



(c) Assembly

(d) Drape simulation



(e) Mapping & rendering

Figure 8. Digital costume generation process

(a) Fashion plate (Source: University of Washington Libaray)

(b) Static pose of virtual model with day dress

Figure 9. Static pose for day dress in the 1860s

(a) Figure in Television drama "Downton Abbey"

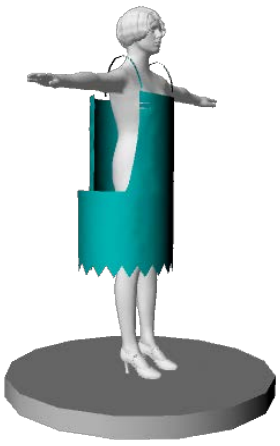
(b) Static pose of virtual model with evening dress

Figure 10. Static pose for evening dress in the 1920s

(a) Day dress in the 1860s

(b) Evening dress in the 1920s

Figure 11. Dynamic simulation



(a) Slip

(b) Dress

Figure 12. Deconstruction simulation of evening dress in 1920s

2.3 Application Development

The desirable direction of application should focus not only on the display of 3D visualisation of costume, but also on the ease of observation and operation from the users' perspective. In order to increase the efficacy of visual 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 the provision of informative contents through simple design, easy operation, and open control, which enables users with low computer literacy.

The integration of digital costume data was carried out using Unity 3D 4.6.2, and the system was designed as a PC platform, as computers are very common electronic devices that most people use in daily life. The main functions of the system consisted of exhibiting 3D costume data with other major information such as visual and textual data contained on museum websites and in Arnold's book (1977). This data was categorised to display discrete items and a costume ensembles simulated as primary functions, and provide pattern diagrams, photographs of original costumes, links to relevant websites and publications, and information on application as supplementary functions. The application was designed to show different types of data through symbolised icons arranged on the left side of the screen in a row. In general, the interface was designed to show the main or selected visual data on the left and the subordinate or descriptive information on the right (Figure 13). For ease of operation of the system, a mouse was chosen as the input device. The system only enables the left button and wheel of the mouse: click to select, click and drag to rotate or scroll, and roll the wheel to zoom in and out respectively.

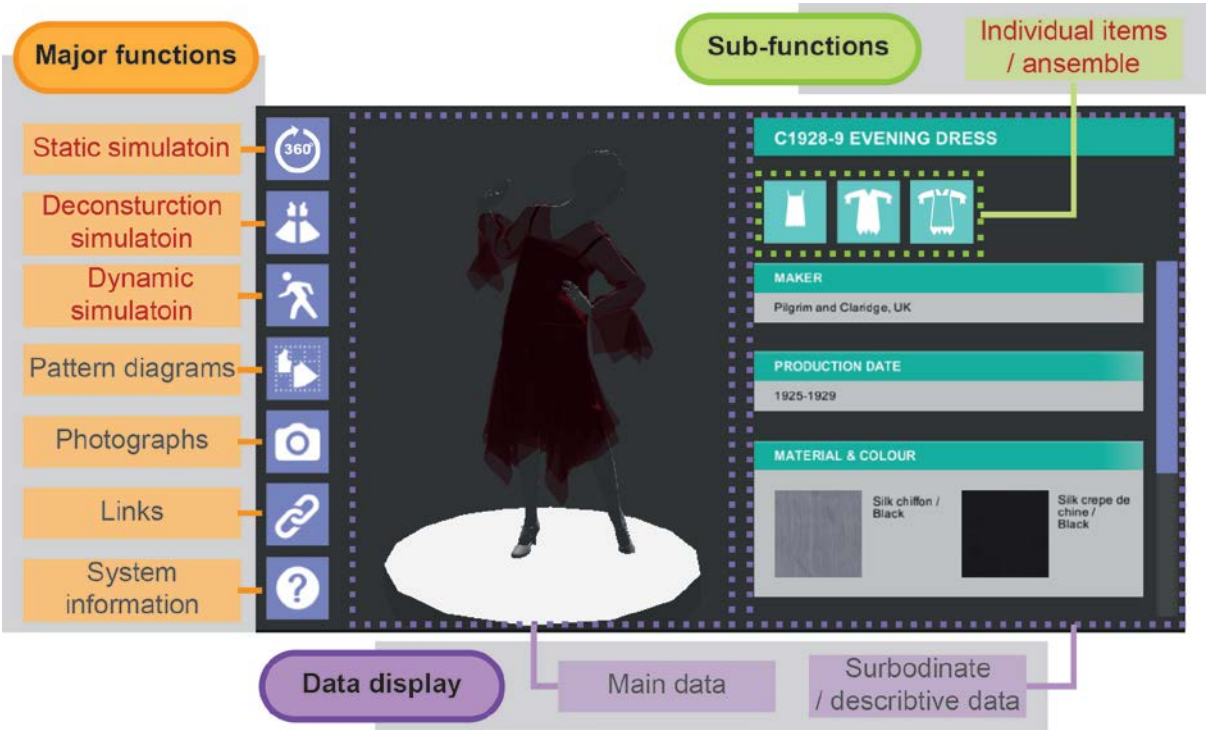


Figure 13. UI design for application

3. EVALUTATION OF APPLICATION

The design results of this study 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. Although the digital costumes were completed at a prototype level for the present, the data was considered to have a sufficient capability of visualising costume concepts (static and dynamic simulation, and facilitation of costume deconstruction) to some degree. 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 implication of the system, and to suggest a more improved framework for a follow-up study later on. The object of this evaluation was to understand the effectiveness and efficiency of the application and the users' perception in digital artefacts and application.

3.1 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, were as follows.

(1) System quality
- Understandability: 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 attempted to explore 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 3. 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 competition of task and questionnaire were demanded. 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 3. Evaluation process

Stage	Activity	Partaker	Duration
1	Introduction	Moderator	
	Demonstration	Moderator	5 min
2	Exploration	Participants	10 min
	Task	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 4. The questionnairewas designed to be responded to through short-answers or a five point Likert scale where 1 represented strongly disagree and 5 represented strongly agree.

Table 4. 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	Understandability	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

In the case of the task, the evaluation focused more on the measurement of the capability to deliver the in-depth information about costume. The task required a good understanding and analysis of the morphological and structural aspects of the costumes. In order to check the degree of the users' comprehension, different types of questions were applied as shown Table 3.

Table 5. Task compositions

Task type	Attribute	Questions
True & false	Structure	The costume has 2 bands attached on the bodice for reinforcement.
	Structure	A total of 24 petal shapes are mounted on the bodice
	Structure	The petal shapes lap over and under each other alternatively.
	Shape	The dress has a rectangle-shaped neckline.
Short-answer	Structure	How many fabric pieces were used to construct the slip?
	Structure	What is the name of patterns that the floating panels are attached?
Recognition based questions using pattern diagrams	Shape	Specify the front and back of the sleeve.
	Shape	Find the diagram which indicates cuff and fill inside with diagonal lines.
	Structure	Draw circles on the patterns which constitute the slip.

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 6. Throughout the discussion, it was expected that qualitative data will be acquired, as well as feedback to improve current outcomes.

Table 6. 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

3.2 Implementation of Evaluation

The evaluation was carried out on 17thFebruary in 2015 at the University of Huddersfield with two groups of volunteer students in the M.A. fashion management program. The participants consisted of three Europeans and six Chinese students, each having different experiences with different backgrounds including international fashion management and students from the cultural creative industry, among others.

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 3. 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.

3.3 Result

3.3.1 Findings of Questionnaire

Table 5 shows the average and standard deviation of responses to the questionnaire with results rounded off to decimal places. The findings of the questionnaire show that most participants had a good level of computer literacy. Only three participants responded that they were unconfortable with computer applications. Three people out of nine responded that they were uncomfortable using the computer application, and all the others answered that they had 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, understandability of the system (3.33) received a relatively low mark, but was still positive.

Table 7. Questionnaire results

Criteria \ Group		Good computer literacy		Less computer literacy		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	Understandability	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

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. The average computer literacy score of the group with good and less levels were at 4.5 and 2.0 respectively (Figure 14).

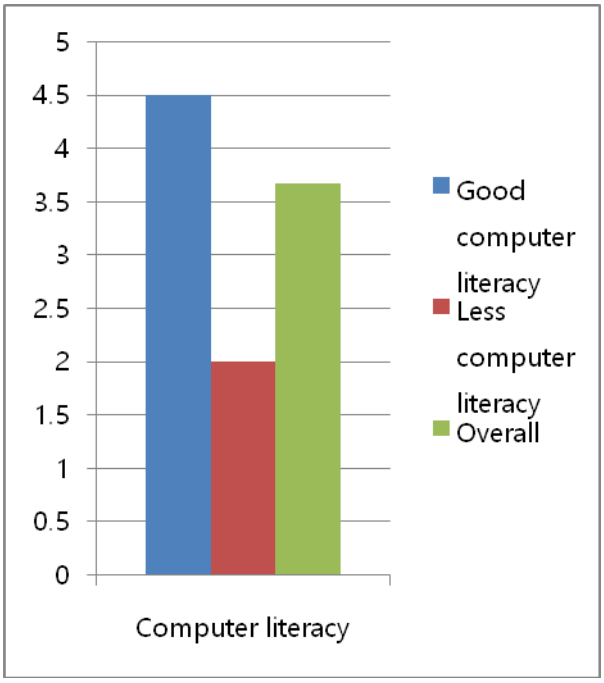


Figure 14. Computer literacy level

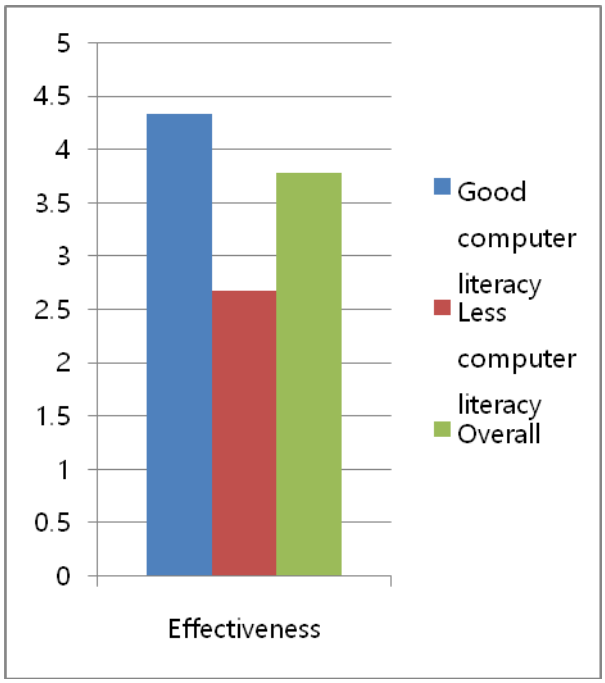


Figure 15. Efffectiveness of system quality in use

Figure 15 shows the responses regarding the effectiveness of system quality in use. While the group with good computer literacy skills answered that the application was effective (4.5), the participants with less 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.

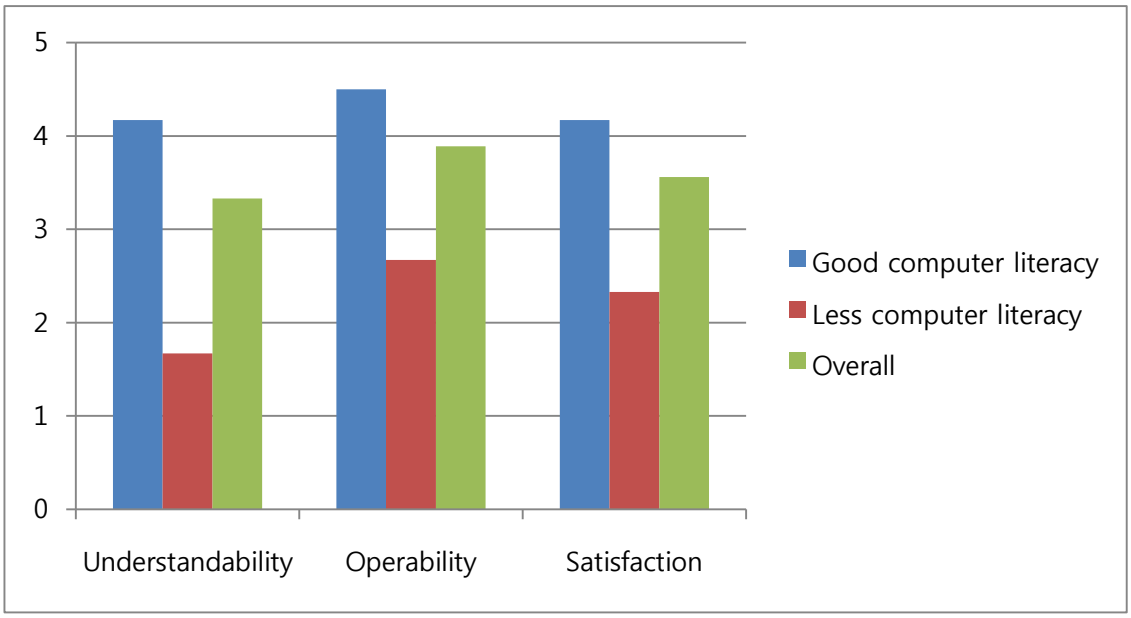


Figure 16. System quality

Figure 16 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 understandability was rated remarkably low. Likewise, there was a huge disparity in these attributes between the two groups.

Figure 17. 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.

3.3.2 Findings of Task

The task was designed specifically to assess the effectiveness of the application by demanding the users to find specific information. The effectiveness metrics focused on whether or not the tasks accomplished specified objectives, and provides numerical marks on task effectiveness, task completion, and error frequency using the Eq. (1). Each attribute X indicated the proportion between the total number of tasks and the number of tasks with correct answers, the number of tasks attempted, and the number of tasks with errors divided by the total number of tasks respectively.

$$X = \frac{A}{\text{total number of the tasks}} \tag{1}$$

Table 8. Task results

Attribute \ Participant		Good computer literacy								Less computer literacy					Overall	
		A	B	C	D	E	F	AVG	SD	G	H	I	AVG	SD	AVG	SD
Shape	Task effectiveness	0	0.33	0	0	0	1	0.22	0.40	0.33	0	0.33	0.22	0.19	0.22	0.33
	Task completion	0.33	0.33	0.33	0.67	0.67	1	0.56	0.27	0.33	0.33	0.67	0.43	0.34	0.5	0.30
	Error frequency	0.33	0	0.33	0.67	0.67	0	0.33	0.30	0	0.33	0.33	0.22	0.19	0.3	0.26
Structure	Task effectiveness	0.5	0.5	0	0.5	0.5	0.5	0.42	0.20	0.5	0.5	0.33	0.44	0.10	0.40	0.17
	Task completion	0.67	0.67	0.83	0.67	0.83	1	0.78	0.13	0.83	0.67	0.67	0.72	0.09	0.8	0.12
	Error frequency	0.17	0.17	0.33	0.17	0.33	0.5	0.11	0.13	0.33	0.17	0.33	0.28	0.09	0.3	0.12
Overall	Task effectiveness	0.33	0.44	0.33	0.33	0.33	0.67	0.40	0.14	0.44	0.33	0.33	0.37	0.06	0.39	0.11
	Task completion	0.56	0.44	0.33	0.33	0.33	1	0.50	0.26	0.67	0.22	0.33	0.41	0.23	0.47	0.24
	Error frequency	0.22	0.11	0.33	0.33	0.44	0.33	0.29	0.11	0.22	0.22	0.44	0.29	0.13	0.29	0.11

Unlike the findings from the questionnaire, the results of the task appeared to suggest that the effectiveness of the application was quite low in general. The low task effectivenessvalue (0.39) shows that only a few tasks were achieved by most of the participants. E; especially, the tasks which required recognition of the detailed shape of the costumes were less correctly answered by both groups. The task completion rated low (0.47), however the group with good computer literacy showed better completion levels (0.50) than the group with less computer literacy (0.41). Also Likewise, tasks related to garment structure showed a higher rate (0.8) than tasks related to garment shape (0.5). It is assumed that the low task

effectiveness and task completion derived from the lack of specialised knowledge of garment design and construction.

3.3.3 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. 3D shape of visual elements were considered to have great 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 operation of the application was reviewed suitabe to present the digital costumes. The discussion groups agreed that interface design in terms of the use of symbols and colours was simple, and well associated with the functions. They also explained that the types of functions were acceptable and properly incorporated various 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. 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. Although some participants mentioned that they had difficulty completing the technical tasks, all participants agreed that the exploration of the application itself was comfortable and pleasing.

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.

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 to 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 without experiencing a sense of repulsion. 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 learnablility 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.

Besides, this study found inconsistent evaluation results of the effectiveness of the system. The results of the task section showed lower values of system effectiveness than the questionnaire and discussions. During the discussions, some participants expressed that they could not understand several technical terms such as slip and cuff. Although the participants were studying fashion management, they had difficulty completing the tasks which required the ability to interpret the 3D garment shape into 2D pattern pieces, and to associate specific pattern pieces to be assembled without practical experience and background knowledge of garment construction. For more accurate measurement in future studies, the selection of the human subjects will need to target a specific group with basic knowledge of garment design, as this study concentrates on the delivery of in-depth costume knowledge.

Nevertheless, considering the results of the evaluation, this study expects that the digital costumes generated by 3D garment CAD can be developed as useful exhibitory and educational materials through the design process shown in Figure18. This process embraces the three factors required for effective digital costume data.

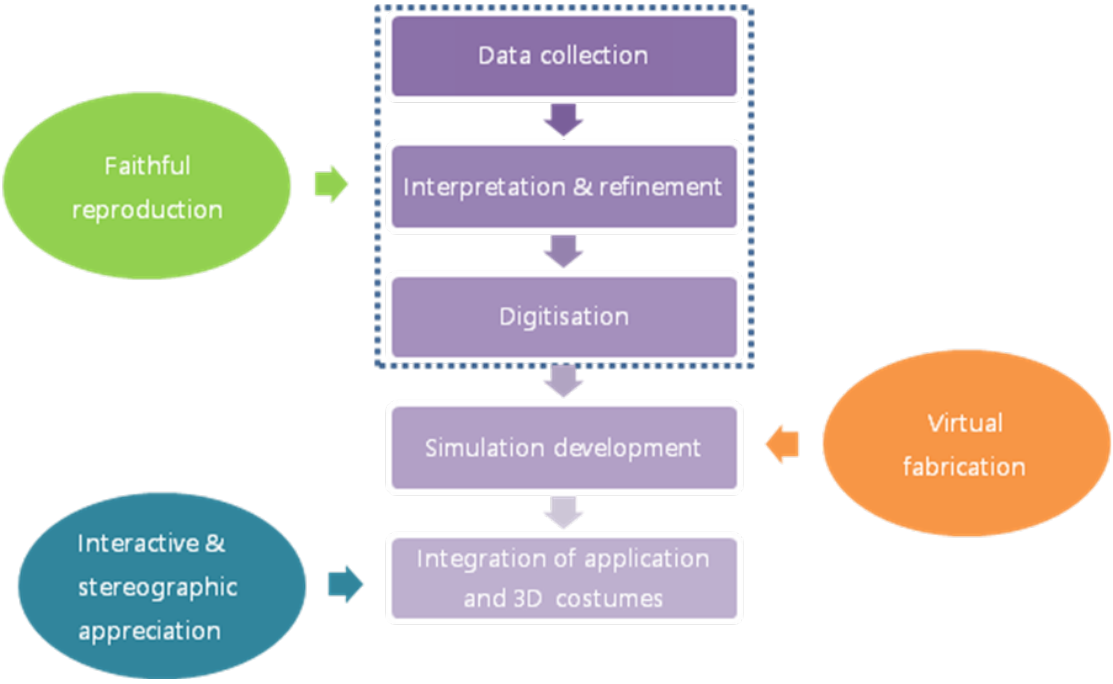


Figure 18. Digital costume development process

The first quality is faithful reproduction of the original garment. This relies on the foundation of historic data and original costume measurements. It will be desirable to collect both actual

measurement data of the original garment and other historic data such as anthropometric features and historical background. If access to the actual costume is not available, the design process needs to rely only on historic references including images, literature, and sculptures. Before digitisation, these data required interpretation to be of 3D form and possibly iterative refinements to correct the errors and produce samples more identical to the original costumes. In this study, the physical refinement approach was applied through toile production and mount preparation. However, 3D garment CAD can be directly applied to the refinement process with less time and no material consumption. The refined data then goes through the full digitisation stage. This phase converts not only structural features, but also the physical and visual characteristics of fabrics. This study expects that application of fabric properties and visualisation of texture data onto the virtual garment surface will further reinforce faithful presentation.

The second desired quality of digital costume is the ability to virtualise impractical factors. For example, the ideal way to investigate costume structure is to disassemble the garment into individual pieces; however, in practice this would cause fatal damage to costumes. Also, dynamic drape, which is an important aesthetic element of a garment, cannot be displayed due to conservational issues. Simulation techniques can remedy such problems. Once digital garments are accomplished, they have an advantage of diversifiability in simulation. Although this study only conducted garment movement and deconstruction simulations, digital costumes are capable of being applied to diverse simulations for different purposes.

The third aspect is the feasibility of effective display with interaction and stereographic exhibition. This means that users are able to determine the type of 3D costume items to be exhibited and the direction and distance to the objects. The digital costumes produced by 3D apparel CAD innately have the 3D nature. In order to be interactive materials, however, digital costumes need association with new media to allow users' involvement. For the better use of digital displays, selection of media will need consideration of the advantages and disadvantages of different methods. In the case of this study, a PC application was adopted and as a result of which some constraints of physical exhibition such as restricted access, limited view points and non-selective display of individual or assembled items became inhibited.

3. CONCLUSION

This paper presented the development process of digital costumes and an application using 3D apparel CAD and new media. As fundamental criteria, three significant elements for effective digital costume were characterised by faithful reproduction, virtual fabrication and interactive and stereographic appreciation through the investigation of previous works. Based on these, digital costumes with static and dynamic drape simulation and deconstruction simulation were generated through a process of preparation, digitisation and simulation. The PC application was then developed to display 3D simulation data to facilitate interaction and observation.

In order to evaluate the effectiveness and applicability of the digital costumes and the system quality, system quality in use and information quality were assessed employing a questionnaire, task and focus group discussions with a real-setting. Although the results of task did not show valid data, the 3D costumes and application were reviewed as effective informative materials on exhibitory and educational purposes in general. However, relatively low understandability 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 several limitations. Firstly, the digital costumes submitted to evaluation were 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 the case 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. Hence, presentation of garment drape and surface will require further adjustment and evaluation in follow-up studies to reinforce realistic and aesthetic aspects.

Secondly, the degree of efficacy of the outcomes in in-depth information delivery and assistance of learning was not properly investigated in task evaluation section. To collect more valid data, reassessments will be required based on purposive sampling with practical experience and knowledge of garment structure to achieve the specialised goals of the tasks.

In addition, there are some considerations for the practical implementation of the digital costume development process. First of all, a substantial amount of time may be required for the generation of digital costumes. Although the virtual garment design process of 3D apparel CAD takes much less time compared to real garment production, complex structures and decorative elements of costume and refinements can add additional time requirements. Secondly, sophisticated generation of digital costumes and the development of applications will require involvement of specialists in different areas, including garment design, graphic design, 3D modelling, animation and programming. Accordingly, the use of such human labour may entail high expense in reality. Therefore cost-time efficiency will be priority a issue to put digital costume data to practical use.

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