Ministry of Science and High Education of Russian Federation
Ivanovo State Polytechnic University

Trial print

Zhang Shichao

DEVELOPMENT OF HISTORICAL MEN’S CLOTHING VIRTUAL RECONSTRUCTION BY MEANS OF REVERSE ENGINEERING

Scientific specialty 05.19.04 − Technology of sewing garments

Dissertation for the degree
of PhD (technical sciences)

Scientific adviser -
Doctor of Sc., Prof. Victor Evg. Kuzmichev

Ivanovo – 2021

CONTENT

LIST OF ABBREVIATIONS

CAD – computer aided design
CGP – computer graphics packages
HCP – pattern of historical clothing
AOI – areas of interest
FE – forward engineering
RE – reverse engineering
HCC – historical costume complex
DT – digital twins
DF – dimensional feature
M_P – the result of measuring the clothing pattern block of the selected historical period, cm
IT_M – an increase in the thickness of the material of underlying layers of clothing (corset, linen), cm
In – ease allowance to the n-th dimension, cm
T_M – the thickness of the package materials, cm
ΔDF – changes in the girth of the chest, waist and hip, under the influence of compression effct of the corset, cm
P_b – position of the body
d_{tra} – changes in transverse under the influence of corst
d_{an} – changes in anteroposterior diameters under the influence of corset
CG – chest girth
WG – waist girth
HG – hip girth
AG – arm girth
BW – back width
BL – back length
FW – front width
FS – front shoulder
OS – over shoulder
B – blade
ND – neck diameter
SL – shoulder $length_1$
DS – depth of scye
WS – width of scye
BMo – the result of girth measuring by tape around the body in underwear
BM – body measurement
$\sum T_{TF}$ – the sum of thicknesses of textile fabrics,cm

$\sum AG$ – the sum of air gaps which formed between body and undergarments, cm

K_A – the coefficient of filling the textile fabrics with air gap

BNP – back neck point

FNP – front neck point

AN – anthropometric net

SNP – side neck point

APB – armpit back

APF – armpit front

SP – shoulder point

Back length – distance between bnp to waist level

Back length1 – distance between snp to waist level

Back width – distance between apb to the central of back

Shoulder length – distance between snp to sp

Front width – distance between apf to the central of front

Back neck girth/2 – girth between snp to bnp

Depth of scye – distance between sp to axilla

Width of scye – width between apf to apb

Neck diameter – width between left and right sides snp

$E_{\text{Back length}}$ – ease to the distance between bnp to waist level

$E_{\text{Back width}}$ – ease to the distance between apb to the central of back

$E_{\text{Shoulder length}}$ – ease to the distance between snp to sp

$E_{\text{Neck diameter}}$ – ease to the width between left and right snp

$E_{\text{Front width}}$ – ease to the distance between apf to the central of front

$E_{\text{Depth of scye}}$ – ease to the distance between sp to axilla

$E_{\text{Width of scye}}$ – ease to the width between apf to apb

PB_{CG} – width along the chest level of pattern block

PB_{WG} – width along the waist level of pattern block

PB_{HG} – width along the hip level of pattern block

PB_{BW} – back width of pattern block

PB_{FW} front width of pattern block

PB_{BL} back length of pattern block

PB_{ND} neck diameter of pattern block

PB_{SL} shoulder length of pattern block

PB_{DS} depth of scye of pattern block

PB_{WS} – width of scye of pattern block

PB_{AL} – armhole length of pattern block

PB_{FS} – front shoulder of pattern block

PB_{OS} – over shoulder of pattern block

PB_{B} – blade of pattern block

E_{CG} – the total ease allowance to the chest girth

E_{CGh} – the historical ease allowance to chest girth

k – the coefficient of quantitative differences between the same body measurement in different anthropometric software

Δ – the difference between the body measurements measured by historical and modern anthropometric software

BM_h – the body measurement of the historical body

E_m – ease allowance to body measurements of contemporary male body

E_h – ease allowance to body measurements of the historical body

BM_m – body measurements of contemporary male body

BL – bust line

WL – waist line

LIST OF TABLES

LIST OF FIGURES

FULL INTRODUCTION

Актуальность исследования. Историческая одежда как объект культурного наследия может быть оценена в полном объеме только на человеческой фигуре, имеющей характерные антропометрические и иные имиджевые признаки того же времени. Разница между исторической одеждой, помещенной на манекене и этой же моделью одежды, изображенной на картине или запечатленной на фотографии в виде системы "фигура-одежда", огромна по причине того, что внешний вид и объемно-пространственные формы будут являться результатами проявления разного количества отличающихся друг от друга факторов.

Современное состояние и возможности компьютерных технологий, применяемых для проектирования современной одежды, позволяют расширить область их использования и включить в нее те объекты дизайна, которые были получены ранее исключительно на основе некомпьютеризированных действий и ручного труда. В таких областях накоплен огромный опыт, который не формализован и окончательно не систематизирован, но который представляет огромный интерес для развития современного дизайна. Такой перспективной областью является реконструкция в виртуальной среде исторических костюмных комплексов (ИКК) как объектов художественного и инженерного творчества. Для развития этого направления существуют несколько объективных причин: необходимость сохранения и широкого использования культурного наследия; сложности с материальной реконструкцией и экспонированием ИКК; частое обращение современных дизайнеров к ИКК как источнику творчества; важность сохранения национальной идентичности.

Перечисленные факторы могут быть реализованы за счет цифровизации и замены материальных костюмов их цифровыми двойниками (ЦД), что позволит повысить доступность исторического костюма для изучения, демонстрации и применения. Воссоздать ЦД ИКК можно с применением систем автоматизированного проектирования и компьютерно-графических пакетов, которые обладают инструментарием для выполнения всех этапов художественного и инженерного проектирования одежды в виртуальной среде. Виртуальная реконструкция ИКК - это генерирование (воссоздание) компьютерными средствами фотореалистичных ЦД систем "фигура - костюм" на основе сохранившихся изображений, описаний внешнего вида, художественно-конструкторских решений материальных артефактов (полным или фрагментарным).

Степень разработанности темы. Научные проблемы виртуальной реконструкции являются объектом исследования многих зарубежных ученых. Kang (Южная Корея) разработал цифровые копии исторических костюмов для создания виртуальных экспозиций. N.Magnenat-Thalmann и P. Volino (Switzerland) заложили принципиальные подходы к виртуальному прототипированию исторической одежды разных стилей согласно характеристикам текстильных материалов. В нашей стране такие исследования выполняют А.Ю.Москвин и М.В.Москвина (СПбГУПТД) и кафедра КШИ ИВГПУ. К настоящему времени разрабатывают научные, методологические и технологические основы виртуальной реконструкции ИКК, проводят активную работу по включению в состав музейных экспозиций ЦД. Заложенные в этих исследованиях базовые принципы реконструкции позволяют увеличить количество видов виртуальной одежды.

Однако широкому применению такого подхода мешает отсутствие систематизированной и параметризованной информации о конструктивном устройстве исторической одежды, которая является обязательным условием получения фотореалистичных цифровых двойников. Структура исторического гардероба представлена на уровне вербального описания без антропометрической "привязки" к морфологии фигуры. Непосредственное использование сохранившихся исторических чертежей сопряжено с большими проблемами ввиду полного отсутствия информации о размерной принадлежности, приемах конструктивного формообразования, заложенных конструктивных прибавках. Кроме того, степень формализации и глубина изучения мужского костюма значительно ниже, чем женского.

Слепая попытка изготовить по имеющимся чертежам исторической одежды (ЧИО) копию исторической одежды и сформировать историческую систему не может считаться успешной при отсутствии утраченных знаний. Базы данных, необходимые для адекватной реконструкции ИКК, должны содержать информацию, с помощью которой будут раскрыты механизмы действия разных факторов и даны ответы на вопросы, относящиеся к условиям повторного проектирования и изготовления:

- на этапе *измерения* фигуры

1. Реконструировать значения размерных признаков и особенности морфологии фигуры, для которой был предназначен ЧИО.

2. Восстановить условия измерения размерных признаков.

- на этапе *конфекционирования* материалов

3. Реконструировать показатели свойств текстильных материалов.

- на этапе *формообразования* одежды

4. Воссоздать гардероб ИКК, а именно количество и виды одновременно носимой одежды.

5. Формализовать количественные признаки объемно-пространственной формы, которую приобретет одежда вокруг фигуры.

6. Восстановить критерии, с помощью которых оценивали качество посадки одежды на фигуре.

При отсутствии перечисленной информации сложно оценить правильность конструкторских решений и выбор типа фигуры. Поэтому реконструкции ИКК по имеющимся ЧИО должен предшествовать комплексный анализ всех перечисленных факторов.

Это исследование позволит заложить научно-обоснованные принципы виртуальных примерок исторической одежды и ввести в культурный оборот утраченные исторические костюмы на основе их 2D изображений (картины, фотографии), количество которых неизмеримо больше по сравнению с сохранившимися материальными объектами. ЦД ИКК позволили бы экспонировать зрителю не только внешний вид одежды, но увидеть внутреннее конструктивное устройство, сложное с инженерной точки зрения и знание которого усилило бы полноценное восприятие ИКК. Использование цифровых реплик вместо материальных аналогов, подверженных старению, позволит в некоторых случаях сохранить натуральные текстильные материалы, исключить их повреждение и решить проблему музейных фондов, которые пока недоступны для зрителей ввиду ветхого или фрагментарного состояния экспонатов.

Работа выполнена на кафедре конструирования швейных изделий Ивановского государственного политехнического университета в 2018-2020 гг. в рамках научного направления кафедры "Анализ и синтез материальных и виртуальных систем "фигура-одежда" и двух международных проектов: "Разработка цифровых двойников исторического костюма с помощью технологий реверсивного инжиниринга" при поддержке Министерства науки и высшего образования РФ и Партнерской программы Юбера Кюрьена - А.Н. Колмогорова с участием Университета Верхнего Эльзаса, Франция (уникальный индентификатор проекта: RFMEFI61619X0113); "Виртуальная реконструкция исторических костюмов России и Словении" при поддержке Агентства научных исследований Словении с Университетом Марибор (номер проекта BI-RU/19-20-023).

Работа выполнена в соответствии с пунктами паспорта ВАК научной специальности 05.19.04 – Технология швейных изделий (технические науки): 2. "Совершенствование процесса и методов проектирования одежды на основе использования рациональной размерной типологии населения, требований ЕСКД и широкого применения современной вычислительной техники". 5 «Совершенствование методов оценки качества и проектирование одежды с заданными потребительскими и технико-экономическими показателями». 12. "Разработка методов получения оптимальных технологических решений применительно к одежде разнообразного ассортимента, обеспечивающих применение современной технологии, рациональное использование оборудования и др.".

Целью диссертационной работы является создание методики получения фотореалистичных цифровых реплик мужских исторических костюмов на основе технологии реверсивного инжиниринга.

Для достижения поставленной цели в диссертационной работе необходимо решить следующие **задачи:**

1. Сформировать базу данных о структуре мужского гардероба и применявшихся для его изготовления текстильных материалах конца XIX - середины XX вв.

2. Изучить приемы формообразования, использовавшиеся для получения объемно-пространственной формы исторической одежды при ее проектировании и производстве.

3. Провести антропометрические исследования современных мужских фигур для формирования базы данных, необходимой для генерирования цифровых двойников мужских модных исторических фигур.

4. Разработаны алгоритмы генерирования виртуального двойника исторической мужской фигуры, нахождения толщины пакета материалов носимой одежды и величин конструктивных прибавок к размерным признакам фигур.

5. Разработать методику параметризации, графоаналитического анализа и идентификации размерного варианта чертежей исторической одежды.

6. Разработать метод адаптации ЧИО к антропоморфным особенностям современных фигур.

7. Разработать технологию получения виртуальных двойников исторических костюмных комплексов на основе сохранившихся материальных прототипов или их изображений.

8. Выполнить экспериментальную проверку разработанных методик на примере материальной и виртуальной реконструкции следующих видов мужской одежды: мундир российского профессорский парадный сюртука XIX века, русская народная рубаха XIX века, словенский костюм молодежного движения "Соколы" первой половины XX в., европейское повседневное пальто конца XIX - начала XX вв.

Объекты исследования – мужские исторические фигуры, мужские исторические костюмы (мундир российского профессора XIX века, словенский мужской костюм молодежного движения "Соколы" первой половины XX в., русская народная рубаха XIX века, европейское мужское повседневное пальто конца XIX - начала XX вв.), процесс проектирования мужской одежды.

Предмет исследования – размерные признаки торса мужской фигуры, показатели свойств тканей, конструктивные параметры исторических чертежей.

Методы и средства исследования. Для исследования отдельных элементов и всей системы "мужская фигура - историческая одежда" использовали метод реверсивного инжиниринга, метод аналитической реконструкции исторической одежды, бесконтактный метод измерения мужских фигур и толщины текстильных материалов, методы генерирования многослойных виртуальных объектов.

Для проведения экспериментальных исследований был сформирован аппаратно-программный комплекс под условным названием "Цифровая реплика исторической одежды", обеспечивающий генерирование и передачу цифровой информации, получаемой на каждом этапе исследований, в который вошли шесть компонентов: (1) лазерный бесконтактный 3D бодисканер VITUS Smart XXL для получения сканатаров мужских фигур согласно стандарту ISO 20685-2010(E); (2) программа Anthroscan (Human Solutions, Германия) для обработки антропометрической информации; (3) САПР (BUYI Technology, Китай) для оцифровывания исторических чертежей; (4) компьютерная программа CLO 3D, версия 5.0.156.38765 (CLO Virtual Fashion, Республика Корея), для генерирования статичных и динамичных виртуальных объектов.

Статистическую обработку результатов измерений проводили с помощью программы SPSS (IBM, США).

Положения, выносимые на защиту:

1. Закономерности формирования модных мужских исторических фигур под влиянием корсета.

2. Методика идентификации размерной принадлежности и запроектированных конструктивно-технологических приемов в исторических чертежах мужской плечевой одежды.

3. Методика бесконтактного измерения в виртуальной среде толщины пакета текстильных материалов, принадлежащих одновременно носимым нескольким видам одежды.

4. Алгоритм пересчета конструктивных прибавок, содержащихся в исторических чертежах, для реконструкции исторических костюмных комплексов с учетом типологии современных фигур.

Научная новизна работы в разработке совокупности методик реконструкции и генерирования аватаров фигур, конструктивного устройства и приемов формообразования, необходимых и достаточных для генерирования цифровых двойников исторических костюмных комплексов.

Практическая значимость работы состоит в создании новых баз данных, методики идентификации размерной принадлежности исторического чертежа, генерировании цифровых двойников с высокой степенью реалистичности. Разработан алгоритм адаптации ЧИО к современным фигурам с целью генерирования основных признаков объемно-пространственной формы системы "мужская фигура - историческая одежда". Результаты работы прошли проверку путем виртуальной реконструкции трех комплексов из разных материалов, отличающихся конструктивным устройством и разными показателями объемно-пространственной формы.

Теоретическая значимость состоит в установленных закономерностях преобразования материальных исторических костюмных комплексов и их изображений в виртуальные двойники систем "мужская фигура-одежда".

Получен патент на промышленный образец № 123089 "Мундир для торжественных случаев" (заявка № 2019505136 от 18.11.2019).

Степень достоверности результатов подтверждена идентичностью внешнего вида исторических костюмных комплексов и их виртуальных двойников благодаря применению двух групп информации: первой - полученной после аналитических исследований 70 практических руководств по конструированию исторической мужской одежды, 17 исторических изданий по текстильному материаловедению, второй - полученной после графоаналитического анализа 47 конструкций мужских пальто, бесконтактных антропометрических исследований 41 мужской фигуры, испытаниям 16 современных тканей, виртуальных экспериментов. Проверка обеих групп информации проведена во время виртуальной реконструкции четырех видов исторических костюмных комплексов, отличающихся конструктивным устройством, объемно-силуэтной формой и приемами формообразования..

Апробация работы. Основные результаты исследования докладывались и обсуждались на следующих конференциях: 17th World Textile Conference AUTEX 2017- "Textiles - Shaping the Future", 21-23 июня 2017 года (**Корфу, Греция**); XXIV международная научно-технической конференции "Информационная среда вуза", 22-23 ноября 2017 года (**ИВГПУ, Иваново**); Aegean International Textile and Advanced Engineering Conference (**AITAE 2018**), 5-7 сентября 2018 (**Mytilene, Greece**); Всероссийская (с международным участием) молодёжная научно-техническая конференция "Молодые ученые - развитию национальной технологической инициативы ПОИСК 2019", 24-26 апрель 2019 года (**ИВГПУ, Иваново**); XXII международном научно-практическом форуме "Физика волокнистых материалов", 25-27 сентября 2019 (**ИВГПУ, Иваново**); 2019 3rd International Conference on Advanced Education and Management Science AEMS2019, 24-25 ноябрь 2019 года (**Пекин, Китай**); 6th ICAET 2020 International Conference on Advanced Engineering and Technology, 13-15 декабря 2019 года (**Инчхон, Южная Корея**); национальная молодёжная научно-техническая конференция "Молодые ученые - развитию национальной технологической инициативы ПОИСК-2020", 22-24 апрель 2020 года (**ИВГПУ, Иваново**); международная конференция "Техника, технологии и образование" (International Conference on Technics, Technologies and Education) ICTTE 2020, 5-6 ноября 2020 г. (**Ямбол, Болгария**).

Материальные и виртуальные объекты, полученные в ходе выполнения диссертационной работы, были продемонстрированы на первом Всероссийском конкурсе молодых дизайнеров "Мода 4.0", декабрь 2018 (**Иваново**); выставке "Историческая реконструкция. Промышленный дизайн одежды. Цифровые технологии в моде", 27-28 ноября 2019 года, Министерство науки и высшего образования Российской Федерации, (**Москва**). В коллаборации с Университетом Марибора и Музеем Национального освобождения выполнена реконструкция мужской униформы 1937 г. (**Марибор, Словения**), а с Гаврилово-Посадским краеведческим музеем - реконструкция мужской рубахи конца XIX века (**Ивановская область, Гаврилов Посад**). Аналитическая реконструкция профессорского мундира заняла первое место в номинации "Костюм" на конкурсе #Узнай Россию. Донское слово в рамках II Международного конгресса волонтёров культуры и медиа, 2020 (**Ростов-на-Дону**).

Публикации. По результатам диссертационного исследования опубликовано 11 печатных работ, из них две статьи в журнале "Известия вузов. Технология текстильной промышленности", входящем в перечень ВАК, четыре статьи в зарубежных изданиях, индексируемых в международных цитатно-аналитических базах данных Web of Science и Scopus, пять материалов конференций и форумов различных уровней, одном патенте на промышленный образец.

Структура и объем диссертационной работы. Диссертация состоит из введения, пяти глав, заключения, списка литературы и приложений. Содержание работы изложено на 204 страницах машинописного текста, включая 87 рисунков и 35 таблиц. Список использованных источников насчитывает 168 наименований.

BRIEF INTRODUCTION

As an object of cultural heritage, historical costume can be only appreciated on the human body with characteristic anthropometric and other image features at the same time. The difference between historical costume dressed on a mannequin or the same model of clothing depicted in a picture or captured in a photograph in the form of a body-clothing system is enormous because the appearance and spatial forms will be the result of the manifestation of a different number of factors that differ from each other.

The current state and functionality of computer technology for designing modern clothes allow us to expand its scope of use and include those design objects which were previously obtained based solely on non-computer operations and hand-making. In such areas, lots of experience has been accumulated, which has not been formalized and not systematized ultimately but is greatly interested in the development of modern design. Such a promising field is the reconstruction of historical costume in the virtual environment as an object of art and engineering work.

There are several objective reasons for the development of this direction: the need to preserve and extensively use the cultural heritage; difficulties in material reconstruction and exhibiting natural objects; modern designers advocate historical costume as a source of creativity; the importance of maintaining national identity.

These factors can be achieved through digitalization and the replacement of historical costume with their digital replicas, which will increase the accessibility of research, display and application. Digital twins of historical costume can be reconstructed by using computer-aided design system and computer-graphic packages, which have the tools to perform all stages of the clothing art and engineering design in a virtual environment. Virtual reconstruction of historical costume is the reconstruction by computer by computer means of photorealistic digital replicas of "body - clothing" systems based on preserved images, descriptions of appearance, artworks and design solutions of material artifacts (complete or fragmented).

The scientific problem of virtual reconstruction is the subject of many foreign scientists. To date, as a part of the “Historical Figure Avatar - Historical Clothing” system, the scientific, methodological, and technical foundations have been developed for the virtual reconstruction of historical costume, and active work is been done to include virtual objects with material prototypes together in the museum exhibition. These studies have laid the basic principles of reconstruction and increase the types of virtual clothing.

However, the lack of systematic and parametric information about the construction of historical costume has hindered the widespread use of this method, which is a prerequisite for obtaining realistic reproductions. The structure of the historical wardrobe is presented by verbal description without anthropometry "attached" to the morphology of the body. Using the preserved historical patterns directly will encounter many problems due to the complete lack of information about the size, methods of shaping, and the layer of garments. In addition, the degree of formalization and depth of study of men's clothing is much lower than women's.

The aim of this research is developed a method for obtaining photorealistic digital replicas of historical men's clothing by meanings of reverse engineering. This research is devoted to the development of theoretical and methodological foundations of the virtual reconstruction historical men’s clothing by meanings of reverse engineering, which a promising field is the reconstruction of historical costume in the virtual environment as an object of art and engineering design.

CHAPTER 1. THE DEVELOPMENT ABOUT VIRTUAL RECONSTRUCTION PROBLEM OF HISTORICAL MEN'S CLOTHING

"Material culture is the conventional name for the tangible yield of human conduct. We have things to study, and we must record them dutifully and examine them lovingly if the abstraction called culture is to be compassed." "The design is a record of the process of design and … of the designer's mind and provides a resource for the historian and scholar created in time and shaped to cultural pattern [1]." Historical clothing not only offers a rich source of inspiration for contemporary fashion designers, but also provides opportunities for sociologists, anthropologists and historians to study fashion design from concept to realization; the social environment in which clothing is produced and worn; and the evolution of body type and posture. For now, however, full appreciation of historical clothing still affected by many restrictions, such as the costume were usually exhibited on the mannequins in museum instead of on real human bodies. At the same time, the historical clothing were difficult to preserve with modern technology, even in the optimum environment, it degrades by the influence of light, temperature and humidity, pressure and other factors. Therefore, we urgently need a new way to permanently protect these cultural heritages and to convey the material and spiritual culture of each era [2]. Virtual clothing simulation is the result of a vast array of technologies developed over the past 25 years which not only on the realistic simulation of fabric mechanical properties but also virtual garment on the synthetic avatar.

However, this technology was extensively used in contemporary industrial garments currently and seldomly used in historical clothing, which is causing by lack of awareness of relationship between historical male body morphological features, historical pattern block structure, historical textile material, etc. This review is aimed to analyze the current scientific research situation in real and virtual clothing reconstruction and to enlighten a new method to reconstruction of historical costume with high precision, which will have a huge impact on the historical costume and its related branch industries, and will push the traditional professional treasure to a higher level.

The results obtained in this Chapter published in three papers [158-159].

1.1. Scenario technologies for obtaining 3D HCC based on their 2D images

In the contemporary fashion market and industry, the historical European costume has been one of the most essential inspiration of designing. Especially on the runways of yearly fashion weeks in Paris, Milan, New York, London, the relevant elements and features of historical clothing have been appeared in many notable brands' designs [3]. Meanwhile, some luxury brands also showing digital fashion show to express their brand characteristic. Such as Alexander McQueen and Burberry who showed the holographic fashion show, and even Ralph Lauren showed the 4D style to feel the smell and the wind, unlike the previous 3D fashion show. In addition, Ecole de Paris, Fnc. Kolon, new designer Harriette Kim, etc. used the same costume as a real one to implement a 3D digital fashion show on a virtual model with image effect [4-6].

N. Magnenat-Thalmann and P. Volino reviewed the development of virtual clothing scenario simulation technologies from 1994 to 2004 and detailed a framework for meeting the needs of the fashion industry of virtual clothing design and prototyping. Virtual simulation would greatly help fashion designers not only to speed up their creative work, but also to bring their creations to life through high-quality mechanical simulation on animated characters (Fig. 1.1) [7].

a b c d

Figure 1.1 – Recreating animated haute couture garments based on 2D sketches: a – 2D sketches from Marc Bohan in 1946; b – 3D analogue; c – Hubert de Givenchy in 1946; d – 3D analogue [7]

In addition, they developed a system to reproduce haute couture garments from the 1940s based on sketches. The system successfully simulates garments close to the body as well as loose and complex garments with realistic folds and localized rigidities (Fig. 1.2). The result obtained shows the versatility and the robustness of the Fashionizer software for the creation and simulation of fabric in various contexts.

Figure 1.2 – Creating a 3D garment based on sketch of Serge Guerin in 1950 [7]

J. Juanfen initially studied the method of generating three-dimensional clothing based on two-dimensional hand-drawn drawings in the same structure, with the purpose of creating a three-dimensional virtual clothing CAD suitable for clothing designers system [8].

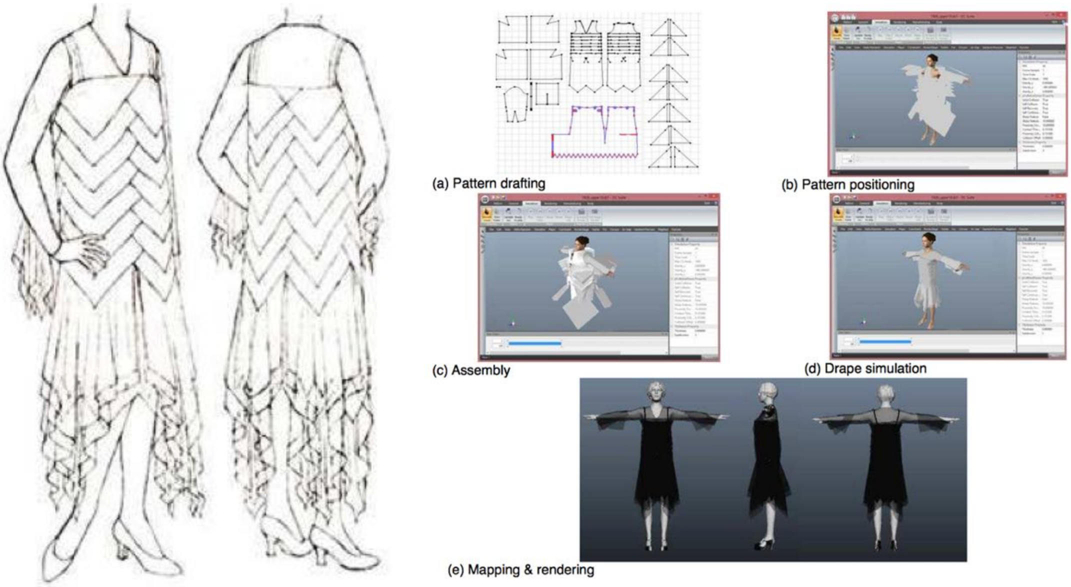
With the popularization of virtual scenario technology in women fashion design, the reconstruction of HCC has been optimized consequently, virtual scenario of historical costume can be applied to movies, theaters and online museums. To increase access to and conserve their collections many institutions are creating websites that do more than advertise the physical collection but provide images and data for selected pieces from their collection. K. Martin described an evolutionary prototype for a historic clothing archive project that is developing a process to incorporate these standards into an online searchable database, so that the high quality images and brief archival data about the objects in their collection online meet their defined user groups' requirements as well as conserving the garments from undue handling and conserving the curator's time [9]. In order to achieve this, many researchers have conducted the researches about 3D virtual reconstruction of historical men's clothing according to the 2D images.

Kang et al. did the exploration about virtual and real reconstruction of historical clothing [10-12]. They presented the development process of digital costumes and an application using 3D apparel CAD and new media. The process of digital costume generation went through several stages:

(1) preparation: clothing object selection as Fig. 1.3, a and data collection, pattern revision and mount preparation;

(2) digitization: virtual model generation and virtual clothing reproduction;

(3) 3D data development: static and dynamic simulation and deconstruction simulation.



a b

Figure 1.3 – Evening dress in 1920: a – sketches [11]; b – stages of the digital double generation scenario [12]

Based on these, digital clothing with static and dynamic simulation and deconstruction simulation were generated through a process as follows: (1) pattern drafting; (2) pattern positioning; (3) assembly; (4) drape simulation; (5) mapping and rendering as Fig. 1.3, b. Moreover, two 19th-century Rococo HCC were generated based on 2D photography, which is considered as an example of the period with the most 3D glamorous dresses in history (Fig. 1.4).

a b c d

Figure 1.4 – Digital reproduction of historical costumes in Rococo era based on 2D photo: a – woman's 2D photo; b – 3D analogue; c – man's 2D photo; d – 3D analogue [10]

This study examined the capabilities of two programs - DC Suite and Maya Qualoth-to create digital clothing, which can be a reference experiment for improving social services and online clothing museums. DC Suite was used for creating drawings and virtual sample tests, while Maya Qualoth was used for simulation and rendering. In the above-mentioned study, the developers encountered some difficulties. For example, woman's dress was decorated with Watteau pleats at the neck line at the back and waist line, but the function of generating such pleats was not included in the software. Therefore, the Watteau pleats were omitted, and the pleats at the waist were replaced with an assembly [10].

Kuzmichev V.E. et al. made significant contributions to the virtual reconstruction of historical clothing, this research team applied 2D and 3D CAD to reconstruct the historical pattern block and get the virtual image in accordance with the prototypes. The conformity between the style of several HCC and their DT from two resources – images silhouette and pattern block – has been achieved. Here is diagram of the reconstruction of this research group for three groups of clothing, based on the image of the clothing and the adapted pattern (Fig.1.5)

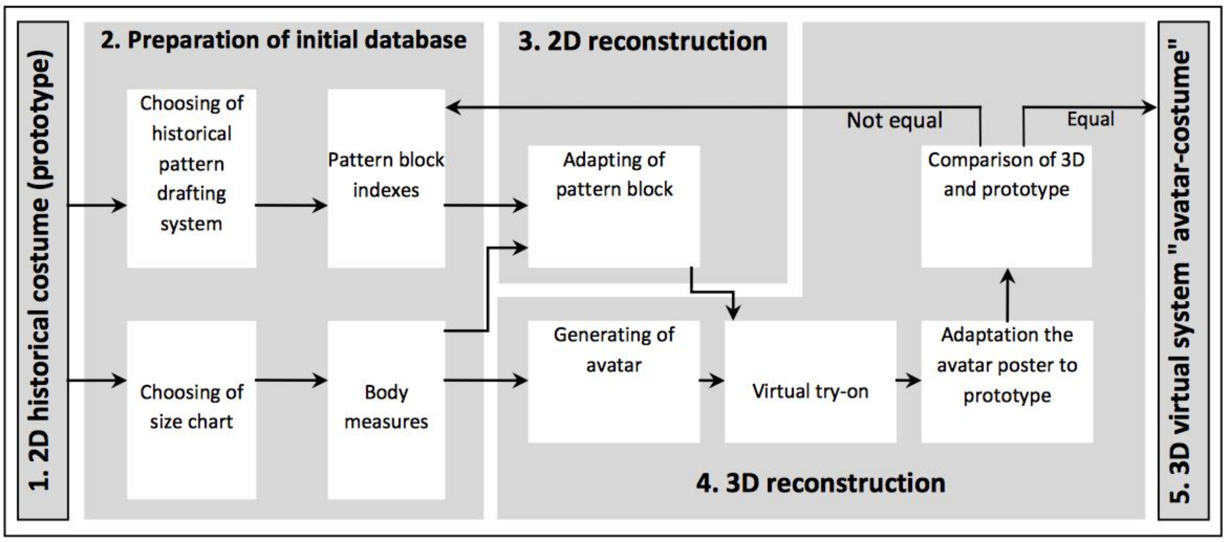
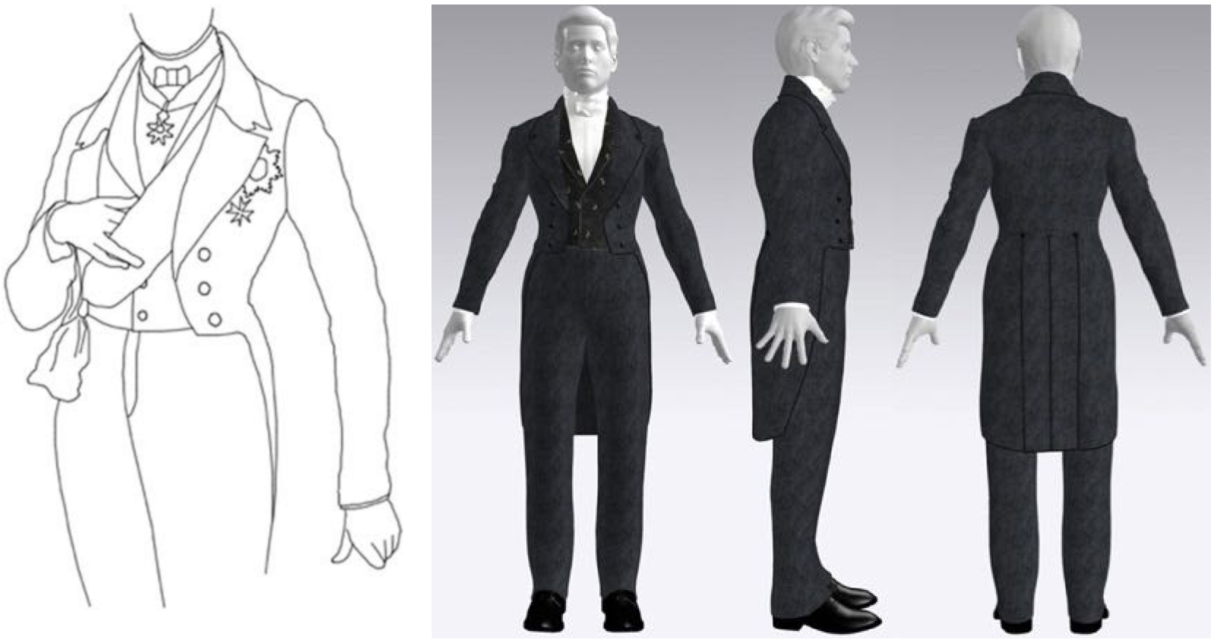


Figure 1.5 – Flowchart of virtual reconstruction of historical costume [13]

The first group and HCC are the men's full-dress suite of the XIX century. This method involves five steps to transform historical image into a virtual "avatar – clothing" system: 1) a 2D image of clothing (Fig. 1.6, a); 2) preparing the source database; 3) 2D reconstruction; 4) 3D reconstruction; 5) 3D virtual "avatar-clothing" system (Figure 1.6, b).



a b

Figure 1.6 – Reconstruction of the costume of Prince Albert of Saxony:
a – technical drawing based on a painting by William Ross, 1840;
b – virtual double [13]

The second group of HCC - skirts of the 1850s - 1860s. They developed a method for generating numerical copies of skirts based on photographs, as shown in Fig. 1.7, a. They used two-dimensional and three-dimensional software to parameterize all the elements of skirts and reconstructed the structure of all the layers of the petticoat (Fig. 1.7, b). The simulation of the DT of the historical women's skirt was performed and the similarity between the historical prototype and its DT was proved [14].

a b c d

Figure 1.7 – Virtual DT based on 2D image: a – 2D photo of woman's HCC; b – 3D DT [14]; c – 2D image of man's trousers; d – 3D DT [3]

The third group is the men's trousers of XIX century. They reconstructed the historical pattern block and got the virtual image (Fig. 1.7, d) in accordance with the prototypes (Fig. 1.7, c) by means of CAD. Finally, they proposed scheme for testing the results of the virtual fitting, which helped to determine the differences between the HCC selected as a prototype and the DT reconstructed using 3D CAD [3].

1.2. Database for reconstruction of historical clothing

Compared with 2D CAD, 3D virtual technology is an innovative technology for historical costume reconstruction and redesign, which allows researchers to use simulation in the virtual environment of "body-clothing". Draping and fluidity of the fabric are delicately imitated in the work at 3D CAD. In order to reconstruct the HCC , it is necessary to create databases that include the morphological characteristics of the historical male figure, the structure of the wearable wardrobe, indicators of the properties of historical fabrics, methods of shaping clothes, etc. Otherwise, the simulation of replica of historical men clothing will not be the "digital twin" with the prototype. For example, Y. Kim et al. used 2D pattern block from historical pattern manuals to reconstruct three style men's coat in the second half of 19th century directly as shown in Fig. 1.8 [15].

Figure 1.8 – Three groups of simulated DT [15]

It can be seen that their virtual DT are not similar to the prototypes. Obviously, it is impossible to get DT HCC based on historical pattern without additional databases.

1.2.1. Historical male body

To accurately reconstruct the HCC and improve the efficiency of construction, the primary factor is to establish the identical avatar which is consistent with the historical male body. In the virtual system "historical costume-body", the avatar should be as an exact replica of historical prototype. That is to say, the real-looking image, the anthropometric indicators, and morphological features of the reconstructed virtual avatar should be the same as the original fashionable European body [13].

N. Magnenat-Thalmann et al. described body modeling techniques about how to assist the designers effectively locate joint centers by reusing existing bone-to-skin data (i.e. converting it to an animatable model) based on a surface model from any external source. Fig. 1.9 shows two groups of their results [16].

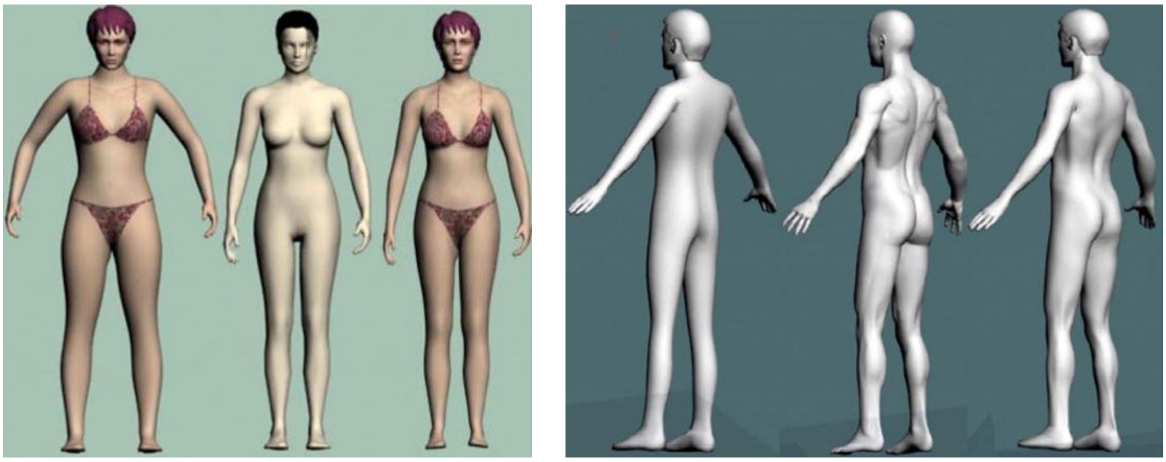
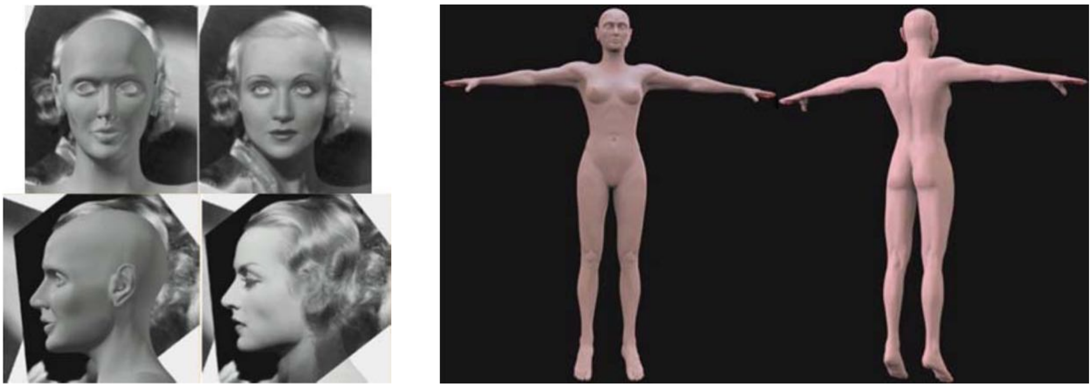


Figure 1.9 – Transform the stationary source avatar (left) into a mobile one by leveling the surface (middle), and localizing bone formations (right) [16]

Additionally, they investigated that the body shape of the average woman of the 1940s was different from today's. The post-war period was characterized by the typical wasp waist. In virtual environment, it became possible to model a shape according to the parameters of fashionable shapes of different time periods, since the shape is just a shell of polygons. Ranging between a very realistic and a more abstract body, they created a combination of both was chosen for the virtual mannequin for the Robert Piguet exhibition. The waist is overly slim, mixed with a typical feminine curved body from the 1940s [7].

K. Martin et al. did the exploration about 3D simulation of historical costume, particularly on creation of virtual humans[17, 18]. Because of no photographs of the original owner of the garment, they created a 1930's virtual model (Fig.1.10) inspired by the iconic 1930's film star Carole Lombard in collaboration with Dave Mauriello, Digital Media faculty, Drexel University, and his students.



a b

Figure 1.10 – 3D avatar reconstructed by Dave Mauriello: a – virtual actress Carole Lombard's body; b – virtual 1930's body [17]

In Kang et al. earlier research, they reconstructed men and women body which was imitating the appearance of people in the 18th century. In order to express the huge shape of a women dress with a skirt, the waist of the women figure is attached to a panier - shape object (Fig. 1.11) [10].

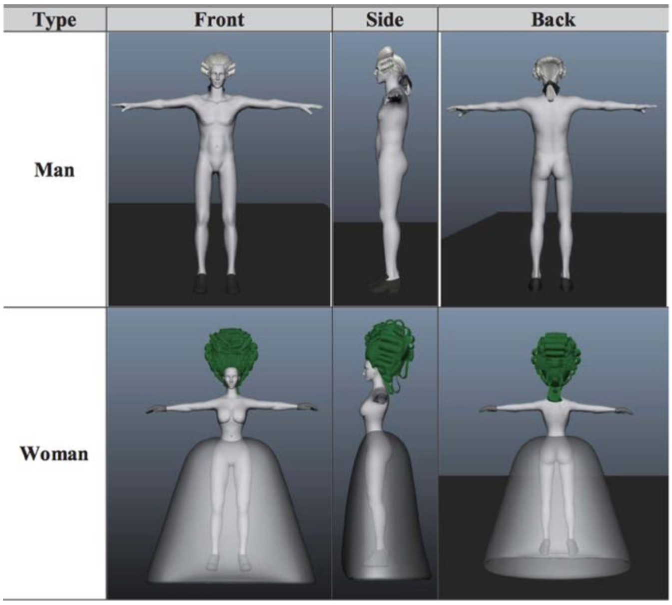
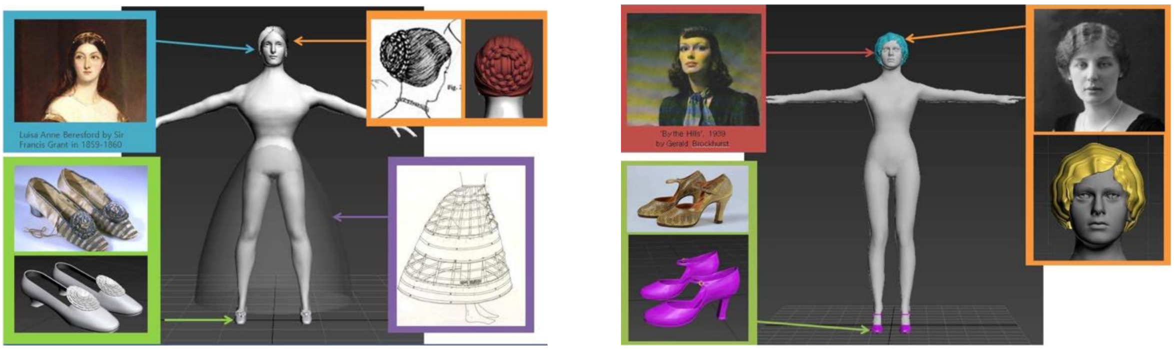


Figure 1.11 – Virtual body generation in Maya [10]

This team developed a new method which can use 3D scanning system to generated 3D model objects. Thus, the virtual model may have the same volume and size as the torsos physical mannequin. Next, modeling the head, arms and legs and attach them to the scanned object to form the body character. In addition, facial features, hairstyles, shoes and other auxiliary items such as crinoline were modeled based on actual objects or historical illustrations of the time to reflect the authenticity of history (Fig.1.12) [12].



a b

Figure 1.12 – 3D virtual model: a – for day dress in 1860; b – for day dress in 1920 [12]

1.2.2. Structural of Wardrobe

The HCC includes the appropriate undergarments to support the silhouette of the full dress suite. Additional deforming characteristics, created by layers of garments and underlying support garments [2]. Meanwhile, in contrast to the offline museums, using DT opens the possibility to presenting each item of costume from underwear to outer clothing, as well as the way of wearing it [10]. Therefore, in the process of generating DT HCC, the layers of undergarments and the wearing ways is also needed to investigate.

K. Martin et al. introduced the world class Drexel Historic Costume Collection from the Civil War era. In addition to the uniforms and gowns, both Collections have the complex undergarments worn with these ensembles. They chose the pattern specifications from selected collections, and then create 3D avatar to adapt the costume, dress them from the inside out in complete ensembles of the period and demonstrate how the bodies moved in this dress during [2].

To reconstruct delicate and elegant costumes of the 18th century Rococo period using three-dimensional technology, Kang et al. made a complete men's suit of coat, waistcoat, breeches, cravat, etc., as shown in Fig. 1.13 [10].

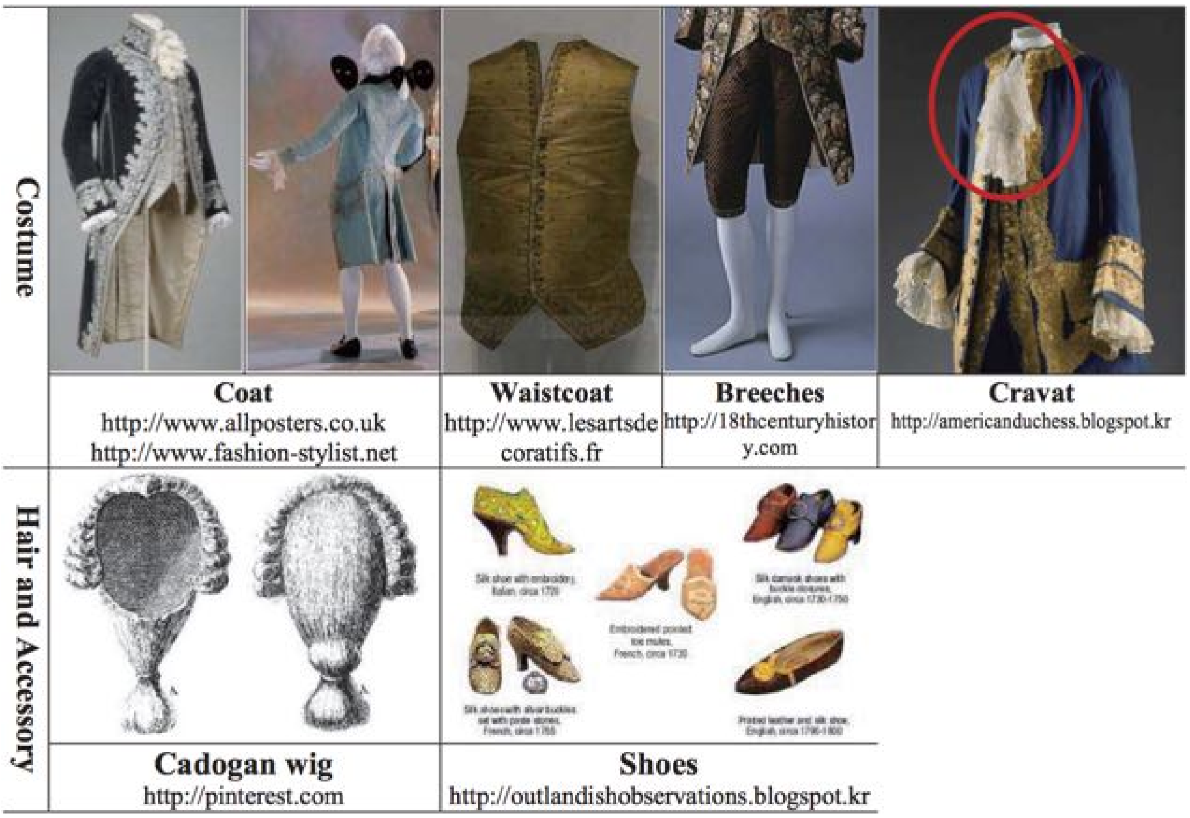


Figure 1.13 – Wardrobe of clothing of the Rococo period in the XVIII century [10]

Moskvin A. Y. et al. coped the order of Prince Albert' dressing for the selected garments (shirt - trousers - vest - coat) and simulated the interactions between the garments under virtual try-on. Fig. 1.14, a shows the virtual systems "avatar - full dress suit 1840" formed on different layers of wearing [13]. Fig. 1.14, b shows the sequence of studies of clothing and elements for simulating a woman's dress of the 1860s from six 6 layers: 1) pantaloons or breeches (underwear shorts); 2) chemise (underdress worn under a corset and crinoline); 3) round or elliptical crinoline; 4) petticoat (one or more petticoats placed on top of the crinoline cage); 5) lining (this layer was used to extend the life of the skirt and get the desired shape); 6) upper skirt.

a b

Figure 1.14 – The structure of the HCC: a – the DT of the men's suit, completed in layers [13]; b – the structure of the women's skirt in 1860 [14]

For most of the 19th century, clothing on the streets of Boston, New York, Philadelphia, or Washington was no different from clothing in London, Paris, or Berlin due to the emergence of international styles [19] .

a b c d

Figure 1.15 – Men suit in XIX century: a – 1815-1820 [20]; b – 1852 [21]; c – 1890 [22]; d –1895-1915 [23]

From the beginning of XIX century, a variety of coat styles, with flamboyant accessories and in a wide color range, showed how untrimmed cloth could command its own distinctive style. Men would wear a high-collared shirt with stock and sometimes with a bowknot. Generally, shirts were made of cotton or linen with flat front. Waistcoats were usually worn the fashion waist length and the standing collar was seen until 1830. Men wore long trousers and flat shoes. The tailcoat was of different colors, and black was the standard of elegance. The top hat was the most popular type of headdress [19, 24, 25]. In Fig. 1.15, and shows the men's dress suit of 1815-1820, which was in one of the collections of the Victoria and Albert Museum, museum No. T. 118-1953, in 1815-1820 [20].

From 1850 to 1890, named the dawn of modern clothing. The Romanticism (1850-1890) is a mixture of the three early styles of the Renaissance, the Gothic and the Rococo [26]. During this period, although women's clothing were becoming more complicated, men's wear has begun to simplify and emphasize functionality. Standard and international styles of clothing began to appear [19]. During these 40 years, uniformity, quiet elegance and adherence to standards were very important in men's clothing. High-quality fabrics distinguished better clothing and revealed the wealth and social status of the wearer. They preferred costume in dark colors, such as black, dark blue, brown and gray. A standard suit was composed of shirt, trousers, waistcoat and coat. The shirt had detachable collars and sleeves turned tightened slightly ending in a buttoned cuff. There were many forms of neck wear including four-in-hand ties, stocks, ascots, string ties, bow ties, and lavalieres. The trousers were slightly loose around the hips, with pleats at the waist and tapering at the bottom, created a fitted and slim effect. Double-breasted waistcoats little below the natural waist line were popular. The tight, smooth fit was achieved through precise cutting and a strap and buckles or ties in the back. The coat had revers and turned down collar, looser fit and less material in the skirts gave it a much straighter line [24, 19, 25]. Fig. 1.15, b shows men coat and trousers in 1852, which was one of the collections in Los Angeles County Museum of Art [21].

At the late of 19th century, men's costume had become practical and uniform, the everyday suits are similar to contemporary styles, emphasized quality tailoring, practicality and well-dressed. Men's suit usually consists from shirt, drawers, trousers, waistcoat and coat. And men started to wear corset to achieve "soldierly bearing." Shirts were usually white with stiff detachable collars and were cut quite high on the neck from 1900-1910. The trousers were narrowed, with flat fronts and a sharp central crease. Some had cuffs, customary length was fairly short and ends above the instep. The coat did smarten up again with more fitted with body and long skirts which looks in slim silhouette. Both single-breasted and double-breasted coats were extremely cut with nipped-in waistlines and narrow sleeves. A well-groomed mustache and monocles slung on long ribbons. Fig. 1.15, c presents men suit, 1890, which was one of the collections in The Metropolitan Museum of Art [22].

At the turn of century, named Art Nouveau (1890-1914) and after the First World War (1918), the rapidly development of science and technology has affected people's lifestyle in all aspects depending on different purpose and occasion, kinds of fabrics, colors and styles could be chosen. No man who was properly dressed without an appropriate hat, well-polished shoes and a distinctive walking stick [26], as shown in Fig. 1.15, d.

For example, men usually wear fitted suit during daytime and dress tailcoat for official evening events. The structure of a fashionable men wardrobe included five garments - shirt, drawers, trousers, waistcoat and coat [24, 25, 26]:

1. Corset. Men started to wear the corset to achieve "soldierly bearing" sometimes.

2. Shirt. The shirt was usually made of white cotton or linen fabric with a detachable collars which were cut quite high on the neck. Sleeves were covered with small pleats over the sleeve crown and ending with a buttoned cuff.

3. Drawers. Length of drawers were near the knee horizontal line.

4. Trousers. Trousers were cut narrowed and structure changed slightly, with flat fronts and a sharp central crease by using the iron. The trousers had a silhouette of stovepipe and ends above the instep.

5. Waistcoat. Waistcoat was the second most important garment in men's suit, usually plaid wool for front and silk for back were popular. The differences between popular styles were created by length under waist level, single or double-breasted and collars.

6. Coat. There were many kinds of coats since the second part of the 19th century. Among them, as for a daily wear, frock coat was the most prevailing, they did smarten up again with more fitted with body and long skirts, emphasizing a slim silhouette. The coats were extremely cut with nipped-in waistlines and narrow sleeves.

1.2.3. Textile materials

Cultural heritage consists of many forms: material, such as objects, buildings, landscapes; intangible, such as memories, emotions, values, and customs [27]. However, to date, the full evaluation of historical clothing is still subject to many limitations, for example, HCC have a relatively short service life, since clothing is usually composed of organic fibers that are vulnerable to the environment and degrade rapidly compared to other relics [28]. To this end, many scientific researchers are working on the reconstruction of historical clothing using 3D technology, which is based not only on a realistic simulation of the mechanical properties of the fabric, but also virtual clothing on a synthetic avatar and some other aspects.

The 3D CAD system reproduces not only the appearance of the fabric surface, but also indicators of its physical and chemical properties, such as the bending coefficient, bending stiffness, density, internal damping, bending, etc.Kang et al. created accurate DT of women's dresses from historical resources and developed them for online exhibitions. However, the database they obtained was not enough to accurately reconstruct the clothing. They did not take into account the features of historical fabrics. It can be seen that the folding of the tissue is more rigid in the modeled CD result than in the real material, as shown in Fig. 1.16 [10].

Figure 1.16 – The touch of the fabric and puckering of the woman robe [10]

An overview of academic collections of historical textiles and clothing and recommendations for the management of such collections is presented in the monograph of Welters L. M. [29]. Kang et al. demonstrated the way about how to created design and fabric image in Photoshop CS5, used shader and lighting in DC Suite and MAYA to naturally express surface detail and adjusted the capabilities of different fabrics in simulation tab of DC Suite [4, 11]. Cybulska M. conducted a study of the properties possessed by archaeological textiles in the past, and developed a method for virtual reconstructions of textiles [30, 31]. The details of the fabric, such as textures, prints, structures or decorations, as well as physical parameters (such as tensile stiffness, mass density), which are important elements for physical reproduction in the works of Seoul National University, are established [2]. The research team, led by N. Magnenat-Thalmann, has made substantial contributions on the virtual modeling approach, especially the elaboration of simulation techniques for historical garments, they developed a method of 3D modeling and simulating for different styles of historical costume according to the characteristics of textile materials [32].

Moskvin A. Y. et al. chosen the same rare fabric as the XIX century and pre-adjusted the physical and chemical properties of the fabric, such as bending, buckling ratio, buckling stiffness, internal damping and density to ensure that virtual costume will consistent with the prototype. In addition, they also considered the position of supportive trims and accessories [13]. And in their research the DT of historical skirts, they selected 13 contemporary fabrics of type, weight and fiber content similar to historical fabrics in software library of CLO 3D and Marvelous Designer as shown in Fig. 1.17.

		Properties							
Fabric id	Type	Weight (density) (g/m^2)	Thickness (mm)	Stretch-weft stiffness (g/s^2)	Stretch-warp stiffness (g/s^2)	Bending-weft stiffness (g/mm^2/s^2/grad)	Bending-warp stiffness (g/mm^2/s^2/grad)	Buckling ratio-weft (0-1)	Buckling ratio-warp (0-1)
Skirt, silk									
SS001	Crepe de Chine	66.1	0.18	17,315	21,157	156	195	0.70	0.70
S007	Taffeta	66.1	0.15	700,000	700,000	1406	153	0.01	0.01
S002	Charmeuse	81.1	0.19	9672	48,714	156	375	0.01	0.01
S003	Duchess Satin	113.3	0.26	709,685	518,307	3500	2500	0.90	0.90
S009	Faille	129.3	0.23	1,700,000	1,700,000	17,500	1094	0.85	0.85
Lining, cotton									
M008	60s Muslin	74.6	0.19	87,354	138,904	586	1602	0.90	0.90
M007	30s Muslin	113	0.28	188,301	147,113	1132	2226	0.90	0.90
C010	Cotton Sateen	136.9	0.27	594,694	1,600,000	742	1601	0.90	0.90
M006	20s Muslin	143.5	0.35	356,725	467,417	1367	2773	0.90	0.90
Petticoat, cotton									
C004	40s Chambray	103.1	0.23	378,944	486,772	750	1078	0.90	0.90
C003	50s Cotton Poplin	105.3	0.21	280,769	356,091	938	1289	0.90	0.80
C009	40s Cotton Poplin	125.8	0.24	1,363,880	877,343	976	1445	0.90	0.90
M005	Oxford Muslin	217.5	0.52	674,371	459,432	14,101	18,242	0.90	0.90

Figure 1.17 – Properties of digital textile materials in CLO 3D library [14]

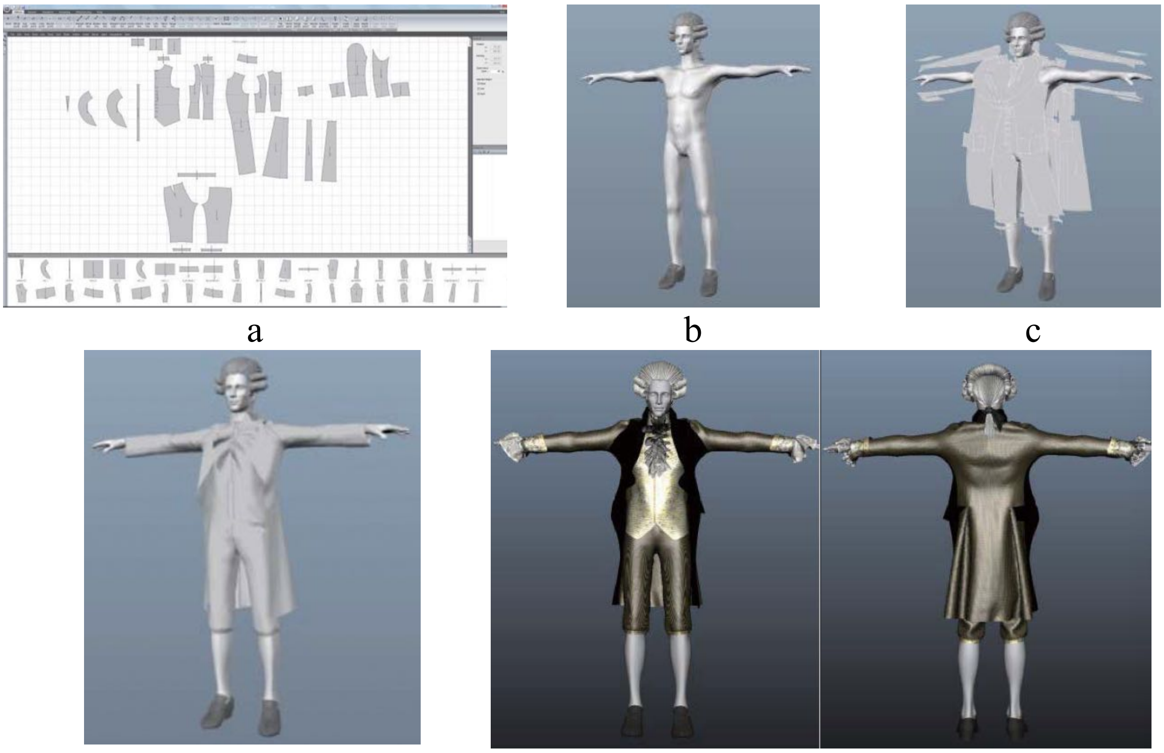
According to Emanuel (1920) [33], Grace (1923) [34], Dyer (1923) [35], Waugh (1964) [27], Cole and Deihl (2015) [25], the fibers and type of typical fabrics for each item of men's clothing are presented in Table 1.1.

Table 1.1 – Textile material for men's suit in the late of 19th century

Garment	Type	Classification
Shirt & drawers	Cotton, linen	Madras, percale, oxford, white cambric, linen-cotton mixed half bleached plain
Trouser	Wool	Usually lighter in weight than for the coat, high quality wool, jersey-weaves, merinos, doeskins, cassimere, kerseymere, ratiné.
Waistcoat	Wool, cotton, silk	The front was wool (in plain colors, checks, tweed, or plaid) or cotton pique. Back was silk satin or brocade, and cotton in different weaves and finishes.
Coat	Wool, silk	Black or blue-black superfine wool, worsteds, cassimere, tweeds, vicunas. Velvet and silk facings to collars and revers.
Linings for coat	Wool, silk, cotton	Mohair, serge, flannel, khaki, satin, drill and sateen, cotton and silk, silk and linen mixtures.

1.2.4. Method of shaping

Kang et al. used the pattern block from the published books directly without consider the methods of clothing shaping during pattern block drafting and sewing in history. Fig. 1.18 shows their steps of garment production in DC Suite.



a b c

d e

Figure 1.18 – Garment production in DC Suite: a – pattern making; b – avatar; c – positioning; d – 3D simulation; e – textile and texture mapping [10]

In Fig.1.18 there are visible defects in the fit on the back and area of the shoulder.

N. Waugh pointed out how to change the proportions of virtual clothing, make it longer, reduce the volume in the waist area with the help of darts, pads in the chest area, around the armhole and sleeve head [24]. Scott et al. provided a brief description of working with the shoulder girdle to demonstrate the various clothing modeling techniques and their respective capabilities to produce an expressive and well-proportioned belt [36]. K. Ryu identified the patterns, sewing, and design techniques by examining the pattern books on men’s clothing in the early 19th century, and analyzed the preserved costumes to restore the selected models. Table 1.2 presents their database of shaping and sewing photos of one coat in 1840s, which is took from the Museum of Decorative Arts, Paris. Table 1.3 shows their way of 2D production making by hand [15].

Table 1.2 – Method of shaping and sewing in the 1840s [15]

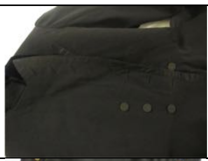
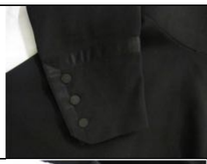
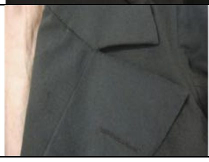
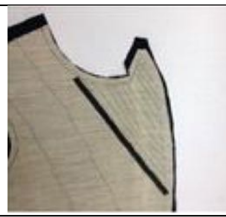
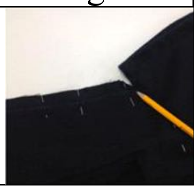
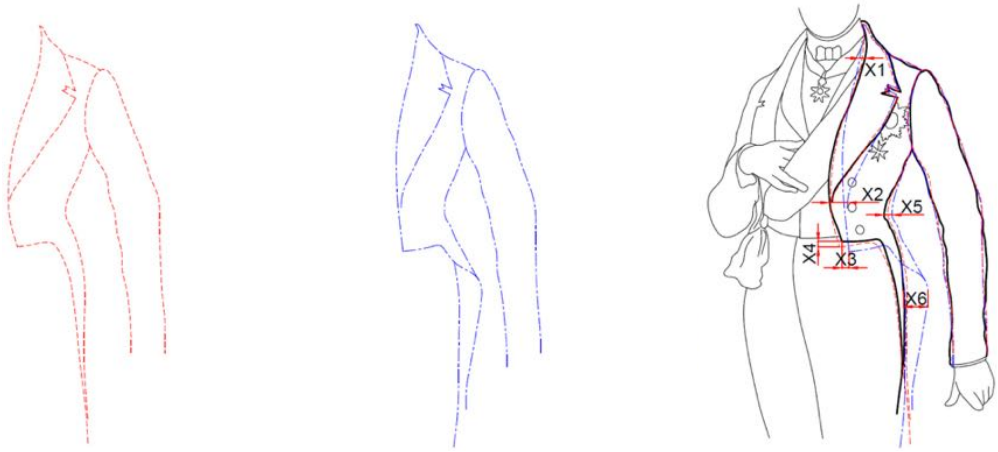
	Front and back	Collar and lapel	Pocket and button hole	Sleeve	lining
Photo					
					
					

Table 1.3 – Techniques for sewing each part of the coat of the 1840s [15]

<table>
<tr><td colspan="3">Collar</td><td colspan="3">Lapel</td></tr>
<tr><td></td><td colspan="2"></td><td colspan="2"></td><td></td></tr>
<tr><td rowspan="2">Back center connection</td><td colspan="4">Back tail</td><td rowspan="2">Seam line between body part and collar</td></tr>
<tr><td>Cut the angle</td><td colspan="2">Seam folding</td><td>Wrinkles</td></tr>
<tr><td></td><td></td><td colspan="2"></td><td></td><td></td></tr>
</table>

Moreover, N. Waugh also indicated the tailor's iron was used with great skill and the cloth and canvas molded by stretching and shrinking throughout the whole process of making a coat [24]. This process was also mentioned by W.D.F. Vincent [37]. Moskvin A. Y. et al. considered this technics in 3D simulation research, replaced it with darts, which were added in the areas of intensive heat-moisture treatment. To evaluate the precision of method, they compared three contours of 3 objects as shown in Fig.1.19. 1) DT with moisture-heat treatment; 2) DT without moisture-heat treatment; 3) HCC. After measuring and comparing six horizontal and vertical distances between the contours (X1-X6), they came to the conclusion that the DT generated from the drawings with simulated deformations during steam pressing has a greater similarity to the original HCC [13]



a b c

Figure 1.19 – The contours of the suits: a – with simulation of deformations during heat-moisture treatment; b – without simulation of deformations during heat-moisture treatment; c – combination of contours and measurement scheme [13]

In order to reconstruct historical costume with high-precision, it is essential to know the methods of pattern drafting, sewing and shaping, including the special knowledge related to craftsman skills which have been lost in the past. For example, in the 1830’s and 40’s the fronts of waistcoat were padded and a small dart into the armhole and another under the lapel helped to give the fashionable rounded-chest look [24].

In the first half of the XIX century, woolen fabrics were used for fashionable coats. The central parts of the shelves, sometimes the backs on the shoulder girdle and the collar were reinforced with linen or other sides. The collar was reinforced and molded, reinforced with a canvas lining cut out at the slant and set up on the collar of the coat with many small "padding stitches". Around 1818, fashion demanded that the tailcoat should have a longer length and a tighter fit in the waist area, called the “fish”. When the waistline dropped again, the tucks were used to fit in the hip area and below the armhole, and by

1840 the tucks were laid in relief seams. The upper part of the coat consisted of six separate parts and had five vertical seams. This method of shaping was also used in all coats of the XIX century, which had a tight bodice and a separate skirt or tails. The sleeves were usually reinforced with white linen, and the front parts of the skirt with dense cotton, and sometimes with a richer material of the same or contrasting color as the coat. The back of the coat and skirt were unlined: the skirt was always open at the back, and the front of the skirt had a slight crease [24].

Since the middle of the XIX century, manufacturing and finishing technologies have made great progress. In the 1880s, the lower edges of the dress and the back tails began to be wrapped inside [24]. Fig. 1.20, a shows a tailcoat made before the First World War [38].

a b c

Figure 1.20 – Schemes of shaping of men’s costume in the late of XIX century: a – view from the front side [38]; b –view from the inside out [39]; c – the areas of heat-moisture treatment [13]

In order for the tailcoat in the chest area to have a convex shape, the shelf was reinforced with a side gasket and a cut-off edge of the side was designed. Armhole coat was free, so the size of mill lining and the lining of the sleeves were enlarged, cotton lining, echoing the shape of the shoulder area, were placed around the back and the front of the armhole, shoulder seam supported shoulder pad triangular in shape, made of two or three layers of canvas, and podomatic placed in the sleeve head. This treatment of the shoulder girdle was known as"American shoulders". Men's coats were completely lined, for the front part usually used the fabric of the top. Heavy fabrics were used for the sides, skirts, and tails. Silk, satin, or light cotton was used for lining the sleeve. Fig. 1.20, b shows a man's evening coat turned inside out [39].

Moreover, the tailor's iron was used with great skill by stretching and shrinking throughout the whole process of making men’s coat [24, 37]. Fig. 1.20, c shows the places of wedges which would be shaping by iron of men’s coat. The length of edges would be elongated or shorten after the heat moisture treatment. The range of area 1 was 0 to 0.9cm, area 2 was 0.6 to 1.3cm, area 3 was 0.6 to 6.4cm, area 4 was 0.6 to 2.5cm [13]. So, without these values, the DT which is exactly same with the HCC can not be reconstruction.

1.3. Dimensions measuring of historical male body

To build the avatar for historical costume and compare the dimensional typologies and sizes of dimensional characteristics of typical body between the second half of the 19th century and modern times, the sizing system, content and conditions of body dimensions measuring, collecting body dimensions which were used to draft the pattern block during that time should be known.

Since the middle of the 19th century, with the continuous development of urbanization, the garment industry has grown stronger by the day. The number of tailors in Europe, the USA, and the Russian Empire had been increased significantly between 1841 to 1871. Early drafts were very important, because tailors ideas and methods of approaching the problems of sizing system for pattern making formed the basis for the later more sophisticated methods and created the technical means to provide the mass-produced clothing of the twentieth century [40]. Bespoke tailors published a huge number of size charts for men. For example, this dissertation investigated more than 70 pattern manuals which were published in Europe, the USA, and the Russian Empire from 1809 to 1979 has been explored [24, 36, 37, 41-108].

To better understand the method of body measuring for each garment in men's suit and definition of historical anthropometric database, it also should to know tools used by tailors during the period. Every dressmakers had special tools for drafting system in the 19th century. They were produced of various materials in diverse forms and made of paper, cardboard, wood, metal or a combination of these. They took the form of nearly square rectangles, rectangular strips, squares (similar to carpenter's squares), irregular curves or combinations. They could be perforated, adjustable and/or compliant [101].

Fig.1.21 shows the special tools of tailor's system in the XIX century. The inch tape measure was the first and most significant improvement upon the strip of notched parchment used by generations of tailors (Fig. 1.21, a) [43]. The square was probably the next to become common (Fig. 1.21, b) [101]. Some had a level or plumb line as an important feature (Fig. 1.21, c) [43].

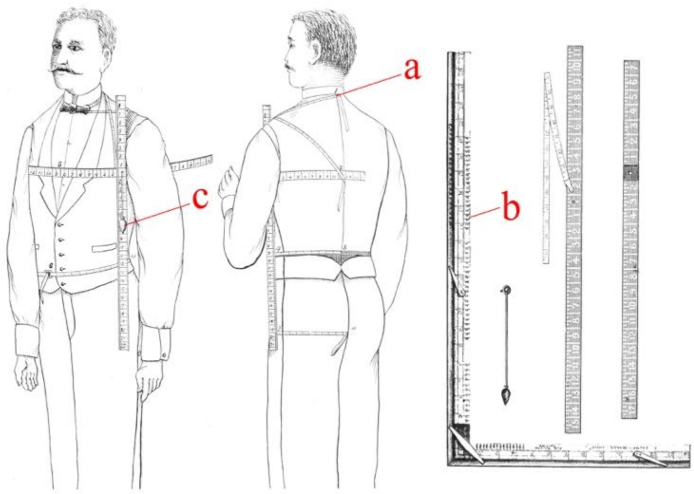
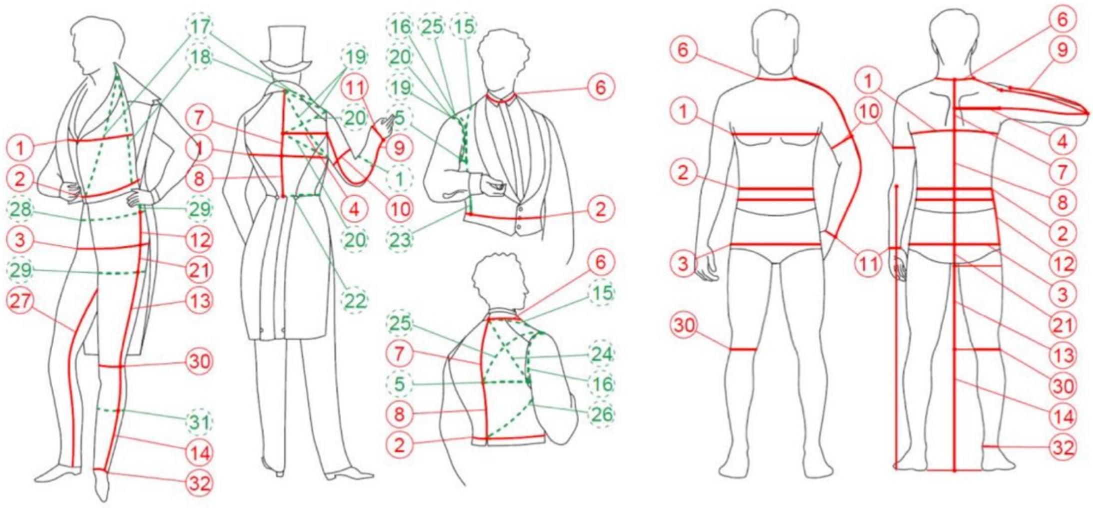


Figure 1.21 – Historical measuring tools: a – tape [43]; b – square [101]; c – plumb line [43]

Fig. 1.22 shows the measurement schemes of body in the XIX and XXI centuries [13].



a b

Figure 1.22 – Measurements over clothes and body: a – used in XIX century [13]; b – W. Aldrich' system [109]

Fig. 1.22, a shows the body measurements from the drafting system 1840， 1867 and 1891 [41 - 43]. Fig. 1.22, b shows the contemporary measurements of W. Aldrich's drafting system [2]. Similar measurements are indicated by solid lines and belong to historical and contemporary anthropometric dimensioning systems; outdated measurements are indicated by dotted lines. Contemporary anthropometric programs do not include some historical measurement data, such as 5, 15-20, 22-26, 28, 29, 31, (the numbers 1, 2, 3 ... 32 are following Fig. 1.22).

The men’s shirt was made up with surplus width and length. Fig. 1.23 shows the schemes of body measurements for men’s shirt from Vincent and Gibson’ drafting systems 1898,1913 [77, 93].

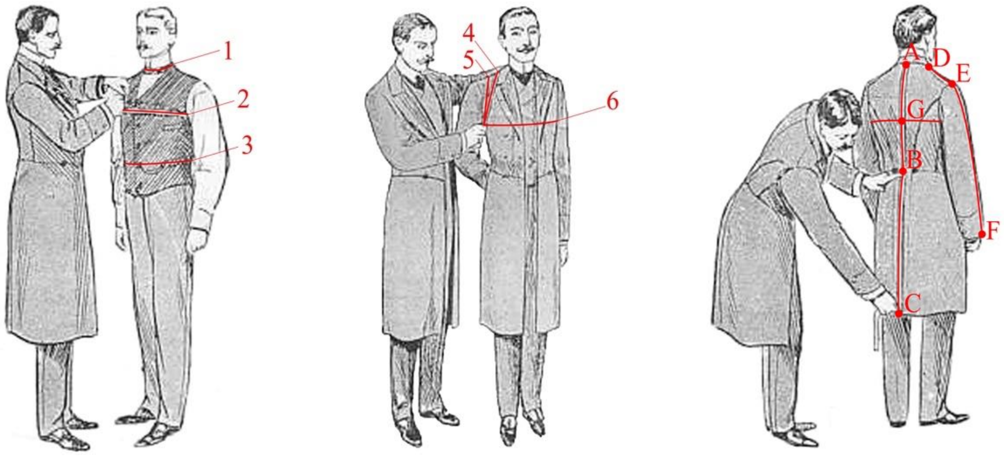


Figure 1.23 – Content and conditions of male body measurements for shirt designing

Table 1.4 contains the anthropometrical measurements used in the XIX century and its contemporary analogues for men's shirt.

Table 1.4 – Measurements for men's shirt designing

No.	Measure		Item	Definition
	Historical	Contemporary		
1	Neck girth	Neck girth	Line 1	Round the neck, across back neck point, side neck point and front neck point
2	Chest girth	Bust girth	Line 2	Round the breast, up to the armpits
3	Waist girth	Waist girth	Line 3	Round the waist, over the smallest part
4	Front shoulder	—	Line 4	Back neck point over the front shoulder to the bottom of armhole
5	Over shoulder	—	Line 5	Point G over the front shoulder to the bottom of armhole
6	Across-chest	—	Line 6	The front armhole on the one side to the other side armhole
7	Back length	Back length	AB	Back neck point to the central waist
8	Full length	Full length	AC	Back neck point to the bottom of shirt
9	Shoulder width	Shoulder width	DE	Side neck point to shoulder point
10	Sleeve length	Sleeve length	EF	Shoulder point to bottom of cuff
11	Depth of scye	Armscye depth	AG	Length of AG which point G is the central of back

Fig. 1.24 shows the schemes of body measurements of men's trousers from the drafting systems 1841 [36], 1871 [59], 1898 [79], 1913 [93].

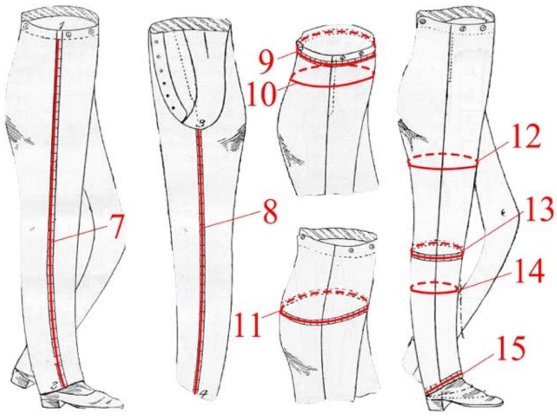


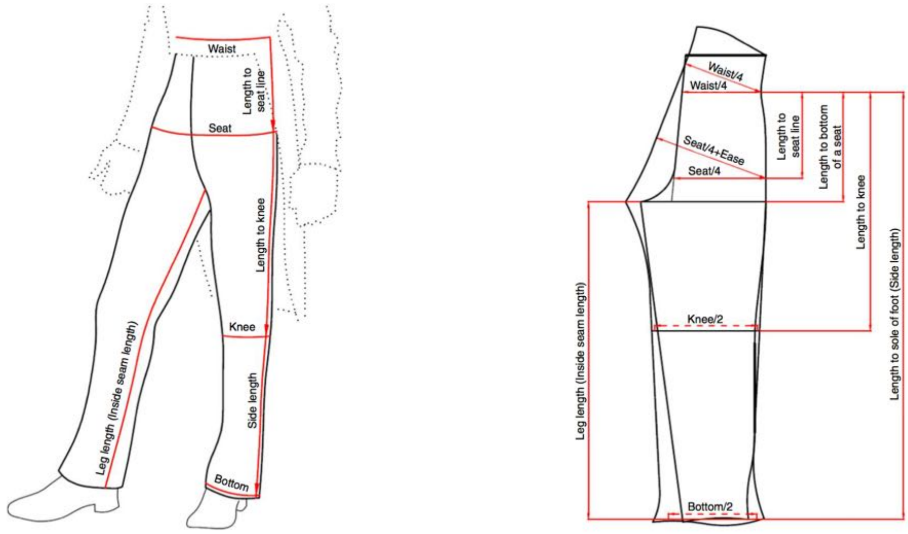
Figure 1.24 – Content and conditions of male body measurements for trousers designing

Table 1.5 contains the anthropometrical measurements used in the XIX century and its contemporary analogues for men's trousers.

Table 1.5 – Measurements for men's trousers desining

No.	Measure		Item	Definition
	Historical	Contemporary		
12	Outside length	Side seam	Line 7	Top of the hip bone to the sole of shoe, not from top of trouser
13	Inside length	Crotch height	Line 8	Crotch to the sole of shoe
14	Waist girth	Waist girth	Line 9	Raise the vest, round the waistband, up above the hip bone
15	Upper hip girth	—	Line 10	Waist at the smallest place between the lower rib and hip
16	Seat girth	Hip girth	Line 11	Put heel and toes together, round the hip, over the largest part
17	Thigh girth	Thigh girth	Line 12	Round the thigh at fork
18	Knee girth	Knee girth	Line 13	Round the knee
19	Calf girth	Calf girth	Line 14	Round the calf
20	Bottom girth	Ankle	Line 15	Taken over the shoe, from just above the sole on the heel to in front, the tape meeting in front over the instep the width desired

The trousers cutting systems used a set of body measurements named "widths" and "lengths". Fig. 1.25, a shows how the tailor measured the body dimensions of the male body. Fig. 1.25, b shows how the measured dimensions were used in pattern block drafting [3].



a b

Figure 1.25 – Body dimentions for drafting trousers pattern: a – body measurements; b – for drafting trousers pattern [3]

Fig. 1.26 shows the schemes of body measurements for men's waistcoat from the drafting system 1841 [36], 1871 [59], 1891 [43], 1898 [77, 78], 1913 [93].

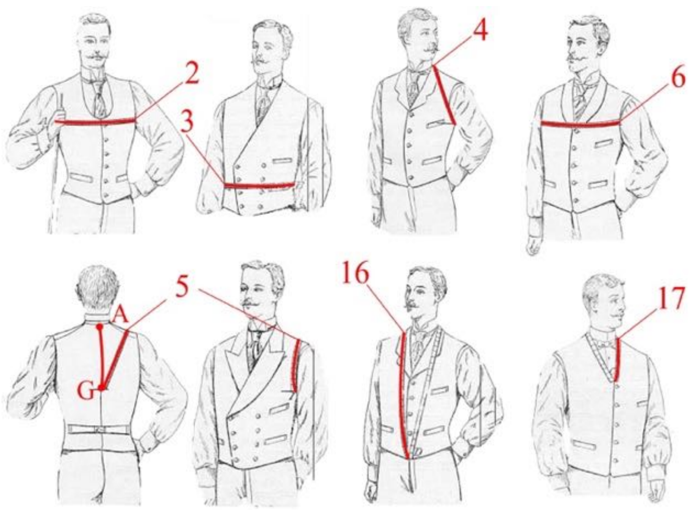


Figure 1.26 – Content and conditions of male body measurements for waistcoat designing

Table 1.6 contains the anthropometrical measurements used in the XIX century and its contemporary analogues for men's waistcoat.

Table 1.6 – Measurements for men's waistcoat desining

No.	Measure		Item	Definition
	Historical	Contemporary		
2	Chest girth	Bust girth	Line 2	Round the breast, up to the armpits
3	Waist girth	Waist girth	Line 3	Round the waist, over the smallest part
4	Strap / Front shoulder	—	Line 4	Back neck point over the front shoulder to the bottom of scye
5	Over shoulder	—	Line 5	Point G over the front shoulder to the bottom of scye
6	Across Chest	—	Line 6	The front of scye on the one side to the other side scye
8	Full length	Full length	Line 16	Back neck point over front and down to the bottom of vest
9	Opining	—	Line 17	Back neck point over front and down to the first button
11	Depth of scye	Armscye depth	AG	Length of AG which point G is the central of back

Fig. 1.27 shows the schemes of body measurements for pattern drafting of men's coat 1841 [36], 1871 [59], 1891 [43], 1892 [74], 1898 [77], 1906 [88], 1913 [93].

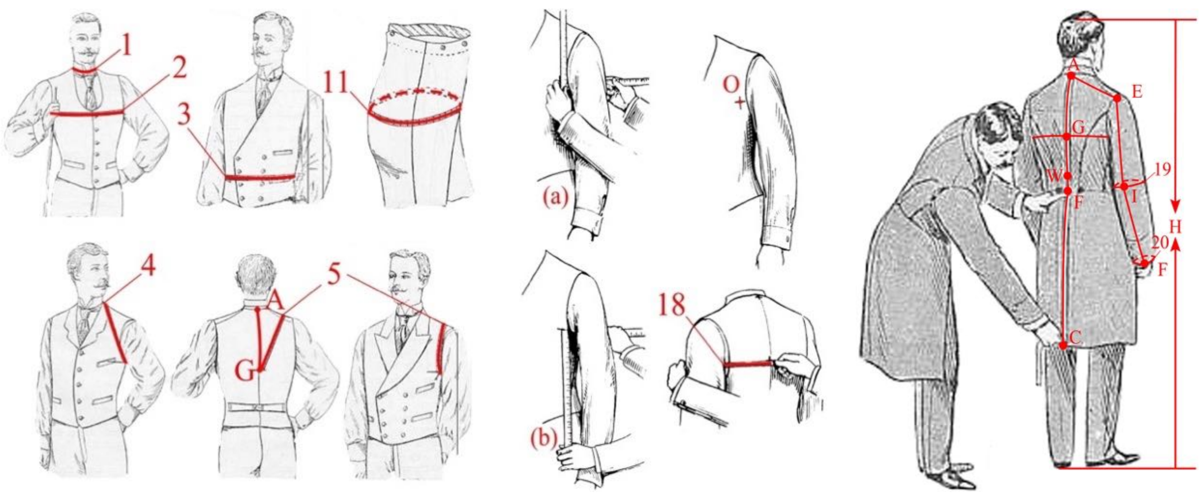


Figure 1.27 – Content and conditions of male body measurements for coat designing

Table 1.7 contains the anthropometrical measurements used in the XIX century and its contemporary analogues for men's coat. The manner for the coat are the same as for the shirt and waistcoat. However, there are additional measurements: arm length internal poverhnosti, the distance from the middle of the back to the front corner of the armpit, back length to natural waist level and fashionable Tali, height, etc. [43].

Table 1.7 – Measurements for men's coat desining

No.	Measure		Item	Definition
	Historical	Contemporary		
1	Neck girth	Neck girth	Line 1	Round the neck, across back neck point, side neck point and front neck point
2	Chest girth	Bust girth	Line 2	Round the breast, up to the armpits
3	Waist girth	Waist girth	Line 3	Round the waist, over the smallest part
4	Strap / Front shoulder	—	Line 4	Back neck point over the front shoulder to the bottom of scye
5	Over shoulder	—	Line 5	Point G over the front shoulder to the bottom of scye
11	Depth of scye	Armscye depth	AG	Length of AG which point G is the central of back
16	Seat girth	Hip girth	Line 11	Put heel and toes together, round the hip, over the largest part
21	Natural waist	Neck to waist center back	AW	Back neck point to the hollow of waist
22	Fashion waist	—	AF	According to the style of coat, usually about 2 inches lower than natural waist
23	Blade	—	Line 18	From the cross-mark in front (point O), measure under the arm in a straight line over the blade to the center of the back
24	Full length	Full length	AC	Back neck point and down to the bottom of coat
25	Back width	—	AE	Measure from the centre of back to the shoulder joints
26	Upper sleeve to neck	—	AI	Back neck point to the elbow, across shoulder joints

27	Sleeve length to neck	—	AF	Back neck point to the wrist, across elbow and shoulder joints
28	Elbow girth	—	Line 19	Round the elbow
29	Wrist girth	Wrist girth	Line 20	Round the wrist
30	Inside sleeve	—		Armpit to the root of thumb and deduct 1 inch
31	Height	Height	H	Overhead to the ground

Obviously, the dimensional features measured in this way cannot be directly used to generate an avatar in 3D software.

For pattern block drafting in 2D CAD, all mentioned measurements will be used. However, some of the historical measurements (4 - 6, 9, 15, 22, 23, 25 - 28, 30) which were involved in the above tables do not the analogues in contemporary anthropometrical system.

Moskvin A. Y., Kuzmichev et al. analyzed the relationship between body measurements and pattern block parameters. They presented the common rules of rectangular net drawing after comparison of all methods of pattern drafting which were existed in the XIX century as shown in Fig. 1.28, which are important to ensure the relations with contemporary methods of pattern drafting [13].

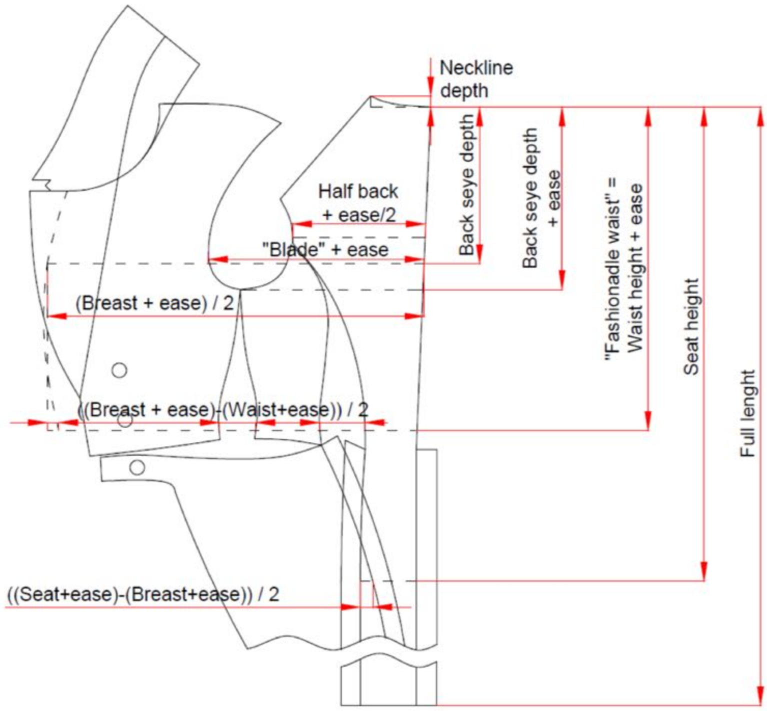


Figure 1.28 – The adaptation of historical coat patterns to contemporary pattern drafting rules [13]

Moskvin A. Y. et al. compared the size typologies and typical body dimensions of the second half of the XIX century and modern times. The main differences between modern dimensional typologies and the principles of formation of their historical analogues are determined. In addition, the values of deviations of historical and modern figures were obtained. It is determined that for any typical figure of the XIX century, such a modern figure can be chosen that the deviations of its leading dimensional features will not exceed the interval of indifference of modern dimensional typologies [110]. They found that it is possible to compare each typical male body of the XIX century with modern typical counterpart, the deviation of the value of the leading body measurements (bust, waist, height) does not exceed half the interval of these measurements lessness in modern typology (±2 cm).

1.4. Software and hardware for virtual reconstruction

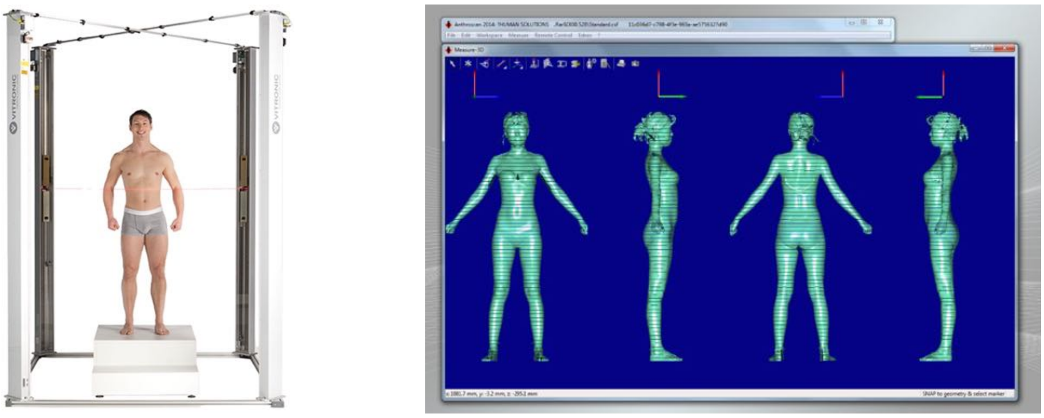
1.4.1. 3D body scanning technology

With the advancement of technology, anthropometric instruments and techniques are constantly improving. Body measurements was mainly measured by tailors or consumers with tape both in history and in modern daily life. One of the biggest problems is that the accuracy of measurement highly depends on their experiences. Besides, some special instruments and methods have been invented, such as Martin anthropometer, cross-section anthropometer, plaster method, Moiré interference fringes [111].

Nowadays, the introduction of 3D human body scanners revolutionized the way of capturing anthropometric data because they can collect data automatically, quickly and without contact [112, 113]. Compared with historical and traditional manual anthropometric measurements, these significant advantages have led to numerous anthropometric surveys worldwide [114, 115].

For example, VITUS Smart XXL laser non-contact 3D body scanner with four laser sensors and two cameras in each column for obtaining scanned male body according to ISO 20685-2010 (E) , more than 100 key dimensions of the body could be measured automatically.

Anthroscan software is specifically designed for 3D body scanning image, data processing, development and design. Its main functions include scanner scanning control, clone generation, automatic measurement of body size, arbitrary extraction of body image cross-section and analysis, input and output CSF, STL, OBJ. Anthroscan is based on interactive measurements of the human body. Fig. 1.29 shows the 3D body scanner and interface of Anthroscan software [111].



a b

Figure 1.29 – Hardware and software of 3D body scanner: a – VITUS Smart XXL 3D body scanner; b – Anthroscan software user interface [111]

As a result, the number of anthropometric databases based on 3D scanning data is constantly growing. Therefore, it is particularly important that these data have a high degree of accuracy [116]. ISO 20685 is the standard for 3D scanning methods for internationally compatible anthropometric databases, which defines the accuracy, that is, the degree to which measurements extracted from 3D scans are close to reference values [117].

Most manufacturers offer their 3D body scanning systems as packages, including scanners, controllers for operating scanners, and IT for data processing and storage. In most cases, they also offer proprietary software packages dedicated to data acquisition, anatomical sign detection and automatic measurement of body dimensions [118].

The usual practice that the scanner operator verbally instructs the subjects how to adopt the scanning posture. According to the research work by Lu and Wang, Han et al., to achieve higher accuracy in body scan data capture, the main focus should be on the replication of consistent postures [114, 116, 119, 120].

However, few researchers use 3D body scanners for historical costume virtual reconstruction. In fact, 3D body scanning technology is very useful in this research. For example, it helps to study the parameters of system "body-clothing" between historical costume and the human body, to study the changes of the human body under the pressure of the corset and so on. Thus, 3D body scanning technology brings many new possibilities not only in anthropometric work but also historical costume virtual reconstruction.

1.4.2. CAD technology

Computer-aided design (CAD) refers to the use of computers and its graphics devices to help designers create, modify, analyze or optimize. As an outstanding engineering technology achievement, CAD technology has been widely used in various fields of engineering design. At present, CAD technology research hotspots include computer-aided conceptual design, computer-supported collaborative design, massive information storage, management and retrieval, design method research and related issues, and support for innovative design [121].

2D CAD systems have been developing rapidly for several decades. There is a gradation of CAD for several generations: the first, converting manual drawing into computer graphics, with simple instrumental functions; the second, linking a single application software into an organic whole, supporting and calling each other; the third, intelligent.

The commonly used 2D CAD software includes Assyst (Assyst GmbH, Germany), AccuMark (Geber Technology LLC, USA), PAD System (Pad System International Limited, Canada), Richpeace (RICHPEACE AI CO. China), TUKACAD (Tukatech, USA), ET SYSTEM (BUYI Technology, China), Modasoft (Liu Hesheng Technology, China), etc.. Fig. 1.30 shows the representative technology of the latest intelligent era, ET CAD invented by China Shenzhen BUYI Technology Co., Ltd. [122].

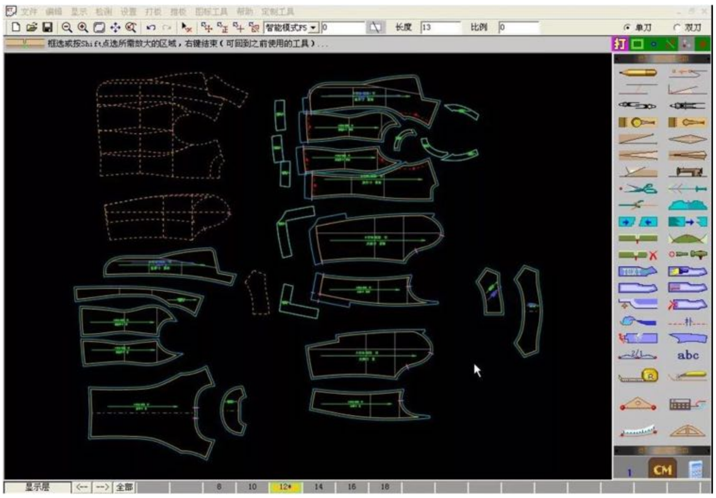


Figure 1.30 – The user interface of third generation of intelligent clothing 2D CAD system – ET CAD [122]

In general, 2D CAD has functions such as creation design (style, color, clothing accessories, etc.), sampling, grading, and layout. Using this technology to draft pattern block will greatly reduce the manual labor of the designer, and the professional level requirements of the designer can also be relatively reduced. The fashion design information is stored in the computer and can be called up at any time for easy management. Information can also be transferred through the network.

The clothing industry quickly turned to virtual simulationin nowdays. 3D clothing and virtual try-on are the most interesting topics in textile engineering, 3D clothing CAD and computer graphics areas [123, 124]. 3D clothing simulation is currently being used in various fields such as film, game, animation and fashion industry. 3D clothing simulation is a technique that creates 3D clothing shape by applying various sewing conditions to flat patterns pieces [125].

The popular 3D CAD software for clothing virtual try on are CLO 3D and Marvelous Designer (CLO Virtual Fashion Inc., Korea), 3D Vidya (Assyst GmbH, Germany), AccuMark 3D (Geber Technology LLC, USA), Assol (Russia), etc.. Fig. 1.31 shows the computer program CLO 3D, version 5.0.156.38765 which invented by CLO Virtual Fashion, Korea.

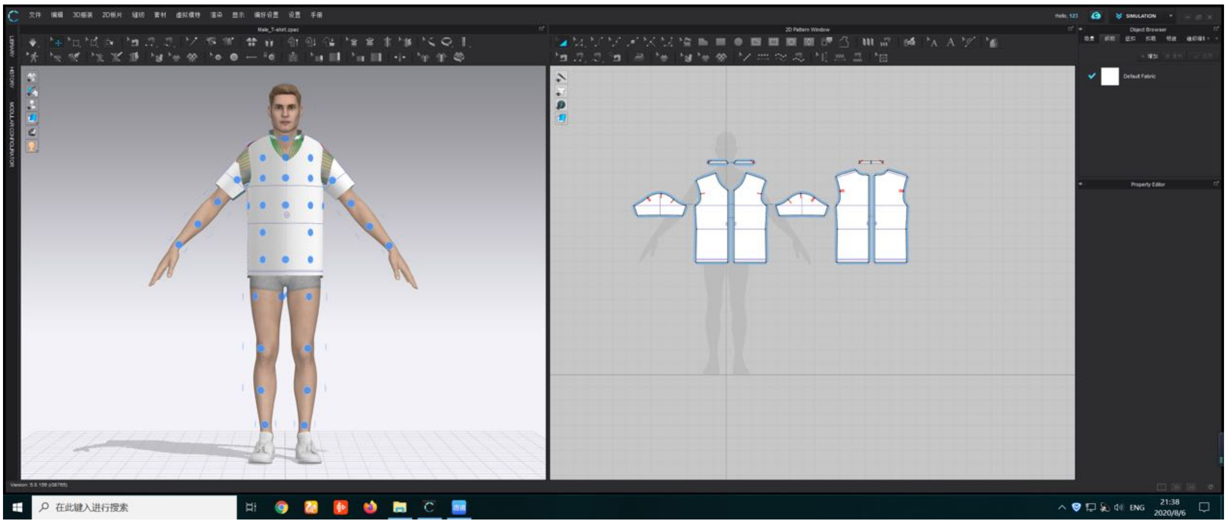


Figure 1.31 – The user interface of CLO 3D Standalone 5.0

The general process of 3D CAD and its corresponding main functions are:

a. Avatar: edit style, size, pose and arrangement point of avatar, skin offset, make body measurement;

b. 2D pattern design: create/edit pattern block, AI curve, symmetric/instance design, dart/pleats fold, notch, trace, symbol/annotation, seam allowance, reference lines;

c. 3D arrangement: gizmo, arrangement point, direct positioning, fold arrangement, arrange as flat/curved, flip patterns, superimpose, smart arrangement;

d. Sewing & tacking: segment sewing, free sewing, M:N sewing, sewing notch, symmetric sewing, tack on garment/avatar, pleats sewing;

e. Fabric: fabric kit, emulator, image open/save, edit color swatch, physical properties, nonlinear simulation, set fabric thickness;

f. 3D simulation & layer: real time sync/simulation and garment move, high-definition garment, pattern layer and sublayer, sewing layer, fold pattern and seam lines;

g. Fit check: 2D pattern measure, 3D garment measure, check 2D sewing length, transparent map, pressure points, strain/stress map, fit map, 1:1 view, 3D state history;

h. Animation (runway): record, play, edit, animation video capture.

Many foreign scientists use 2D and 3D CAD technology to reconstruct historical costumes in virtual environment. As our previous introduction, Kang (Korea) developed digital replicas of historical costumes for virtual exhibitions [10-12]. According to the characteristics of textile materials, Nadia Magnenat-Thalmann and Pascal Volino (Switzerland) laid the foundation for virtual prototypes of historical clothing in different styles [16]. In Russia, this type of research is conducted by Moskvin A. Y. and Moskvina M. V. of the St. Petersburg State University of Industrial Technology and Design and the department of Ivanovo State Technical University [3, 13, 14]. In conclusion, CAD technology laid methodology and technical foundation for the simulation of replica of historical men costume.

1.5. Application of reverse engineering method

Engineering is the process of designing, manufacturing, assembling, and maintaining products and systems. It is the one that efficient, reliable and useful to human beings with the shortest time and the least manpower and material resources. There are two types of engineering, forward engineering (FE) and reverse engineering (RE). FE is the traditional process of moving from high-level abstractions and logical designs to the physical implementation of a system. In some situations, there may be a physical part/ product without any technical details, such as drawings, bills-of-material, or without engineering data. Oancea et al. presented the process of duplicating an existing part, subassembly, or product, without drawings, documentation, or a computer model is known as RE [126].

A common explanation of the phase "reverse engineering" , was first used in publications in the 1970s revolves around copying originals [127]. The process of digitally capturing the physical entities of a component, referred to as

RE, is often defined by researchers with respect to their specific task [128]. Abella et al. described RE as, “the basic concept of producing a part based on an original or physical model without the use of an engineering drawing” [129]. Yau et al. define RE, as the “process of retrieving new geometry from a manufactured part by digitizing and modifying an existing CAD model” [130, 131].

Generally, material articles deteriorate over time, a particular artefact may represent its last one, and history shows that unique and authentic parts are not always reserved for future generations. Reverse engineering can be easily used to preserve inanimate objects of anthropological or cultural importance in virtual or replicated form. The comprehensive 3D digital archive is durable and immutable, so it can be used as a reference for monitoring the degradation or restoration of works [127]. According to Vinesh et al. here are several reasons for using RE in our research:

• The original manufacturer no longer exists or no longer produces the product, but HCC to enrich the profession treasure is needed.

• Part of the original HCC design documentation has been lost.

• Creating data to refurbish or manufacture a part for which there are no CAD data, or for which the data have become obsolete or lost.

• Fitting HCC [131].

As the application of RE becomes more extensive and diverse, it is widely used in many applications such as manufacturing, industrial design, computer arts, cultural heritage and reproduction. Kevin et al. introduced a general process of RE and redesign methodology is a three-stage process, as shown in Fig. 1.32 [132].

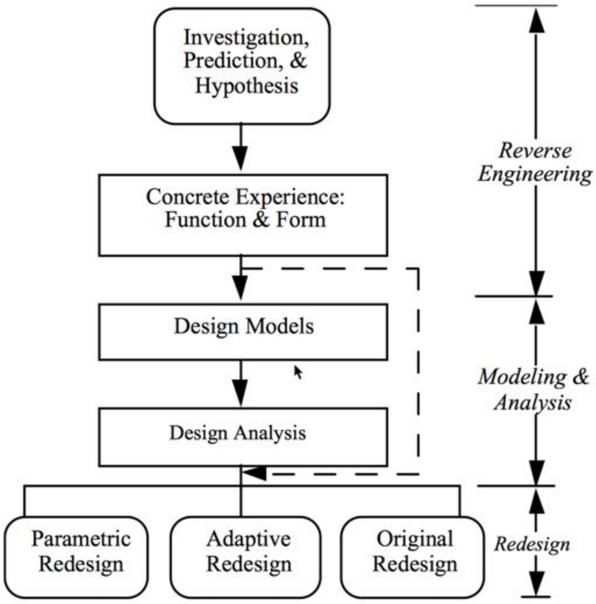


Figure 1.32 – Overall process of RE and redesign methodology [132]

Realistic visualization of cloth has many applications in computer graphics. Kai et al. put forward a pipeline for fabric by using RE and estimate the parameters from a single image of the cloth model. Fig. 1.33 explicates the key steps [133].

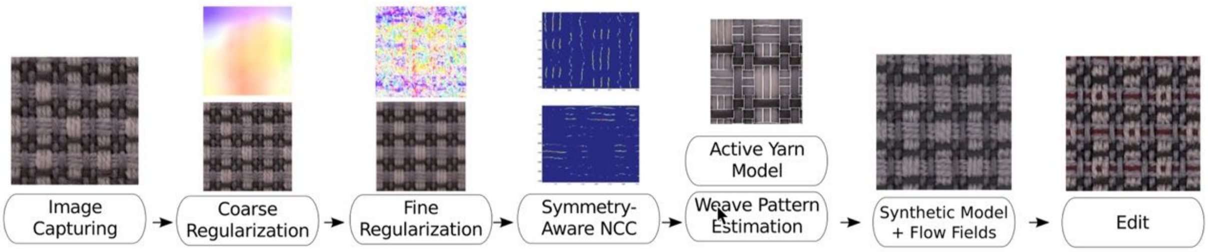


Figure 1.33 – Algorithm for obtaining the DT of fabric from its image (visual prototyping) [133]

Several examples of their research proved that they are able to simulate the appearance of the original samples (Image-based reverse engineering and visual prototyping of woven cloth). Italy is a hot bed for European art and historical sculpture, the IBM T.J. Watson Research Center involved the nightly set up a portable scanning system to produce Michelangelo's Florentine Pieta [134]. Based on an original algorithm, Pescaru et al. developed a new method for designing of the shoe by using RE [135].

RE provides possibilities for virtual reconstruction of historical male costumes. In this strategy, must perform the following main steps: digitization of male body and costume, processing of acquired database such as textile material, pattern block etc., costume redesign, 3D reconstruction and verifying the physical product. RE and redesign methodology will be helpful to accurately exhibit the features of historical costumes.

Aim and steps of research

Historical clothing as cultural heritage can be evaluated only on human body with similar morphological and image features as historical prototype. The difference between two objects - first system "manikin + clothing" forming from and second system "body - clothing" pictured on photo or painting will be very huge because two outline and 3D shapes are the results of various factors acting. If copy the historical pattern block to sew the clothing, the result couldn't be successful without special knowledge related to craftsman skills which have been lost in the past.

The main aim of this research is to develop a method for obtaining photorealistic digital replicas of historical men's clothing by meanings of reverse engineering.

To do the adequate reconstruction of historical clothes, the special data bases and create the method of historical clothes adapting for contemporary male bodies and to get the similar image nowadays as in the past was needed. In order to achieve this, the necessary tasks should be conducted following the framework of this research:

1. Create a database on the structure of men's clothing and the textile materials used for its manufacture in the late XIX - mid XX centuries.

2. Study the method of shaping which used to obtain the three-dimensional form of historical costume in its design and production.

3. Conduct anthropometric studies of contemporary male body to form a database which is necessary for generating digital twin of men's fashionable historical body.

4. Develop an algorithm for generating of virtual twin of historical man body, find the thickness of the package wearable garments and values ease allowance to the dimensional characteristics of shapes.

5. Develop a method for parameterization and graphic analysis of the HCP.

6. Develop a method for identifying the size variant of the HCP which was developed for men.

7. Develop a method for adapting HCP to the anthropomorphic features of contemporary body.

8. Develop an algorithm and method for obtaining photorealistic digital replicas of the "male body - historical costume" system based on preserved material analogues or their images.

9. Develop a method for evaluating the photorealism of virtual replicas of historical costumes.

10. Perform an experimental test of the developed methods on the example of material and virtual reconstruction of the following types of men's clothing: the uniform of Russian professorial formal coat of the XIX century, Russian folk shirt of the XIX century, European frock coat of the late XIX - early XX centuries, Slovenian uniform of the youth movement "Falcons" of the first half of the XX century.

By completing the above steps and tasks, this research will make it possible to lay down the science-based principles for the virtual simulation of historical costume, and introduce the lost historical costume into cultural circulation based on their 2D images (painting, engraving, photos) the number of which is immeasurably greater in comparison with the preserved material objects. Virtual replicas of clothing would allow the viewer to not only appreciate the appearance of the clothes but also to see the internal structure, which is complex from an engineering point of view and knowledge of which would enhance the full perception of the historical costume.

CHAPTER 2. DEVELOPMENT OF A DATABASE OF BODY AND TEXTILE MATERIAL FOR VIRTUAL RECONSTRUCTION

Up to now, historical costume is still affected by many limitations in preservation. Therefore, the new knowledge to restoration or reconstruction these cultural heritages was urgently, so that can better convey the material and spiritual culture of this period. This knowledge also creates database that will be useful for creating digital counterparts of the HCC as part of a virtual museum.

The results obtained in this Chapter published in three papers [160-161].

2.1. Material of research

2.1.1. Instrument and software

To conduct experimental research, a system of hardware and software was established under the conditional name "Digital replica of historical clothing", which provides generation and transmission of digital information received at each stage of research.

To measure and analyze the body measurements of male body, the scanning was performed with a VITUS Smart XXL contactless 3D scanner (Human Solutions GmbH, Germany).

The compatible, powerful, professional Rhinoceros software for 3D modeling on a PC, developed by Robert McNeel & Assoc (USA), was used. This is not only a set of professional software for creating 3D models, but also the tools provided can accurately obtain cross-sections of the scanner and measure the necessary length, height, volume, etc. Adobe Photoshop for image processing. CLO 3D was used to compare the properties of digital counterparts of modern textile materials with their historical counterparts.

To study the materials of historical men's clothing, thickness gauge was used to measure the thickness of fabrics and 8-fold fabric analyzing glass was used to analyze the weave and count the threads in the fabric.

2.1.2. Subject of research

41 young men (average age 22) were selected for measuring by using Human Solutions scanner (Germany).

2.1.3. Object of research

As HCC for the formation database selected four types of historical men's clothing: Professor's formal coat of the nineteenth century, Russian male folk shirt XIX century from the collection of Gavrilovo-Posadsky Museum of Ivanovo region, the Slovenian youth uniform 1937 from the Museum of National Liberation of the city of Maribor (Slovenia) and European men's frock coat of the late XIX - early XX centuries from the collections of the Department of designing of garments, Ivanovo state Polytechnic University.

2.2. Method of formation of fashionable male historical body under the influence of the corset

For virtual visualization of historical clothing and the construction of avatars of historical body, modern solid-state digital twins (DT) of real body cannot be used. The DT of a historical body should be soft, since in different historical periods men resorted to correcting the plasticity of their torso with the help of corsets. To date, there are no scientifically based principles for generating soft-body avatars, but thanks to computer technologies, the problem of their formation can be solved at a new level [3, 13, 14, 136].

The purpose of this work is to develop an algorithm for constructing avatars in the form of soft digital twins of historical body.

The reconstruction of DT requires additional databases that combine historical and contemporary database. The algorithm should includes the sequence of formation of the DT of the historical body using the initial database, studying the features of deformation of body using body scanning technology and integrating the results into the software environment for performing a virtual fitting.

Historical pattern manuals for clothing design contain recommendations for measuring dimensional features on the surface of the clothed body, rather than on the nude body [137]. Therefore, the measurements include the dimensional feature, the thickness of the underlying clothing, and in the case of wearing a corset, and the original dimensional feature could be increased or decreased under the influence of compression and displacement of soft tissues. In general, the value of the true dimensional feature DF, which was used for pattern block drafting, can be written as:

without corset:

$$DF = M_P - IT_M \pm In, \quad (2.1)$$

where M_P - the result of measuring the clothing pattern block of the selected historical period, cm; IT_M - an increase in the thickness of the material of underlying layers of clothing (corset, linen), cm; In – ease allowance to the n-th dimension, cm;

when under corset:

$$DF = M_P - 1.57 \cdot T_M + \Delta DF \pm In, \quad (2.2)$$

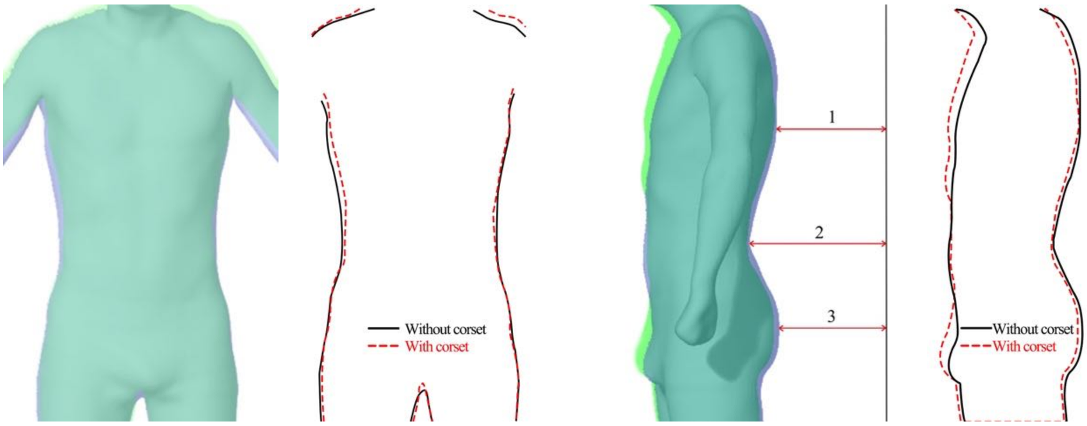
where T_M is the thickness of the package materials, cm; ΔDF – changes in the girth of the chest, waist and hip, under the influence of compression effct of the corset, cm.

Thus, in order to determine the DF value from the pattern block, it is necessary to know the values of the four components.

The second component - the thickness of T_M material packages which was calculated based on database from published sources about the structure of the package formed by the lower shirt, upper shirt, vest, drawers and trousers, and the thickness of the materials used [138]. It was adopted as follows, cm: at the level of the chest 0.5, waist 1.1, hips 0.6.

The third component - the change in the dimensional features of ΔDF was calculated from the results of body scanning. For the study, selected the bodies of contemporary Chinese and Russian men, marked according to the current Chinese standard [139] by the difference between the bust and waist as Y types (difference 17...22 cm), A (difference of 12...16 cm), B (difference of 7...11 cm). These groups are analogous to Russian full-length groups. To study the compression effect of the corset on the plastic of men's body, measured 41 young men (the average age is 22 years old) using body scanner. With the consent of the subjects, scanned them twice in the main anthropometric position-without a corset and in a corset to the maximum tightening of the waist area, which was determined by the subjective sensation of each wearer. The corset was made of non-stretchable material and the thickness was 0.32 cm.

Fig. 2.1 shows the combined outlines of scanned Y - type body as an example of the effect of corset on plastic 187.4 – 104.6 – 85.2, oriented relative to a vertical plane parallel to the centerline through the center of gravity, at distances of 1, 2, 3, respectively, at the chest, waist, and hip levels.



a b

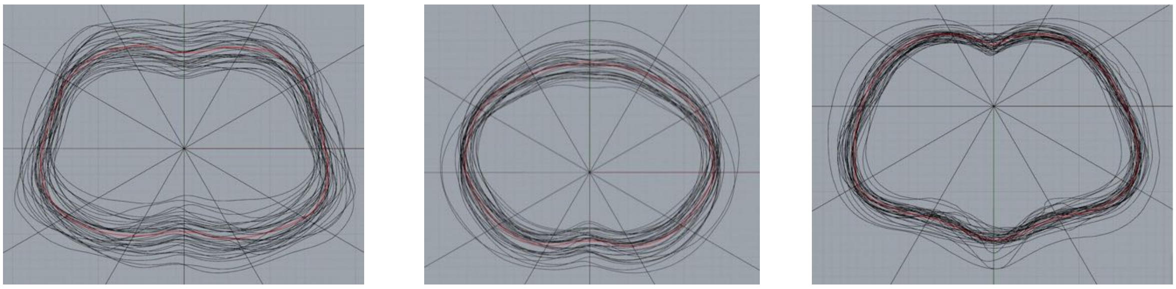
Figure 2.1 – Combined outlines of male body scanned without corset (black solid line) and in corset (red dotted line): a – front view; b – side view showing the projection measurements required for the correct positioning of the DT in space

Fig. 2.1 shows that under the influence of the corset, soft tissues move up and down from the waist area, which leads to a change in posture, diameters and profile contour.

The fourth component-the value of In - can be calculated using the methodology of the Department of Garment Design of Ivanovo State Polytechnic University [140].

Thus, all the components included in (2.1) or (2.2) can be measured or determined experimentally.

The algorithm for modifying the original standard shapes available in the modern CAD library into the avatar of historical body is particularly difficult. To set the DT of a typical avatar in space, it is necessary to know the coordinates of points located in the middle sagittal plane, and changes in the position of the body P_b, diameters of transverse d_{tra} and anteroposterior d_{an} under the influence of the corset and the position of the body center of gravity. To determine the coordinates of such points for typical body, obtained cross sections for each scanned body in the Rhinoceros software, combined them in a single center of gravity, and then built averaged horizontal cross sections [141]. Fig. 2.2 shows the sets of combined cross-sections at three anthropometric levels, the scheme for finding the coordinates of the points at the intersection of the rays from the center of gravity of the body, and the average girths obtained from them for typical body. The coordinates of the points and the values of random errors ε were determined according to [141] for a 95% confidence probability for the sample size n = 35 bodies. The cross sections are given for a typical male body Y / 180 (height) - 92 (CG) - 84 (WG) - 95.4 (HG) at the level of the chest (a), waist (b) and hip (c).



ε = ± 0.95...0.28 cm   ε = ± 0.25...0.43 cm   ε = ± 0.19...0.79 cm

a   b   c

Figure 2.2 – Averaging scheme for horizontal cross-section for typical male body Y / 180 (height) - 92 (CG) - 84 (WG) - 95.4 (HG) at three level: a – chest; b – waist; c – hip

ΔDF for girths, transverse and anteroposterior diameters at the same levels and the position of the body P_b under the influence of the corset was measured. The measurement results are presented in Table 2.1 and Table 2.2, detail information in Appendix A.

Table 2.1 – Changing in the girth of men's body under the influence of the corset

No.	Body type	Change in the dimensional feature under the influence of the corset ΔDF (in the numerator) and the interdimensional interval according to the Chinese standard [148] (in the denominator), cm					
		CG	important influence	WG	important influence	HG	important influence
1	Y	1.76 / 2	-	-1.26 / 1	+	2.65 / 0.8	+
2	A	2.33 / 2	+	-2.36/ 1	+	1.24 / 0.8	+
3	B	3.20 / 2	+	-1.13 / 1	+	0.86 / 0.7	+

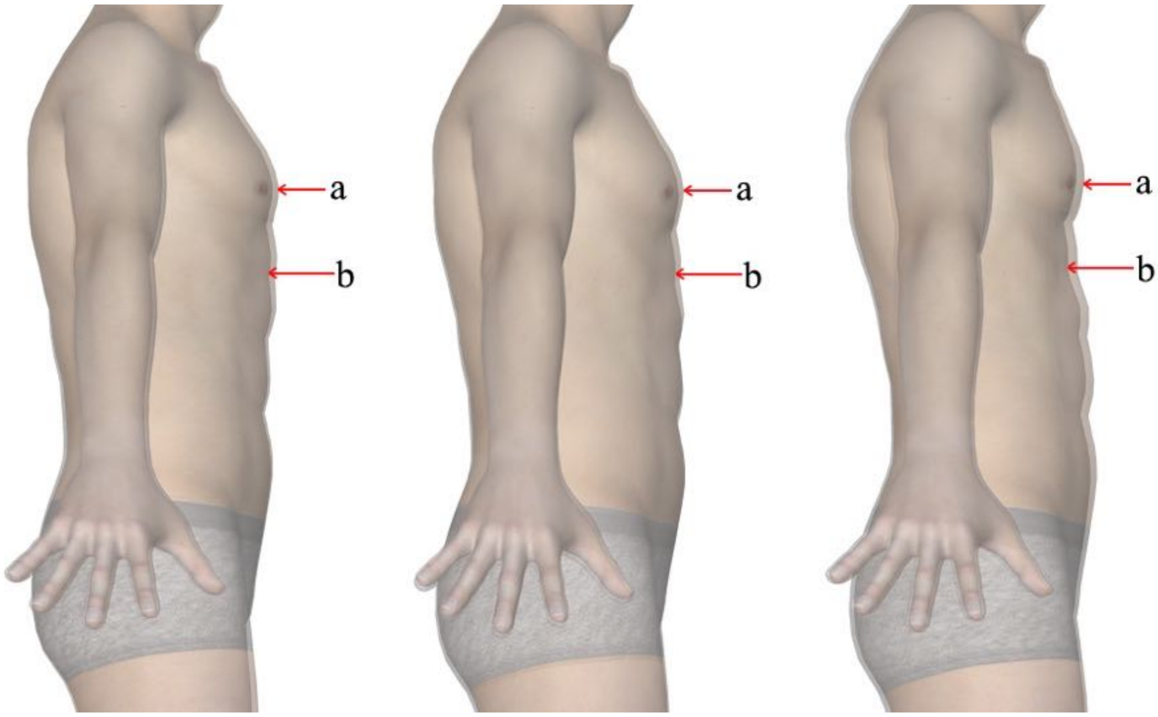
Table 2.2 – Changes in the transverse and anteroposterior diameters of male body and the position of the body under the influence of the corset

Body type	Change in diameters ΔDF under the influence of the corset, cm (in the numerator-without the corset, in the denominator - with the corset)													
	Chest level CG = 92cm				Waist level WG = 84cm				Hip level HG = 95.4cm				Position body P_b	
	$d_{tra.B}$	Δ	$d_{an.B}$	Δ	$d_{tra.W}$	Δ	$d_{an.W}$	Δ	$d_{tra.H}$	Δ	$d_{an.H}$	Δ	P_b	Δ
Y	$\frac{35.8}{36.3}$	-	$\frac{25.41}{25.5}$	+	$\frac{29.4}{29.0}$	-	$\frac{21.9}{22.3}$	-	$\frac{35.0}{35.2}$	+	$\frac{24.7}{25.0}$	+	$\frac{8.3}{7.6}$	-0.68
A	$\frac{35.0}{35.7}$	+	$\frac{24.6}{25.4}$	-	$\frac{30.4}{29.8}$	-	$\frac{22.9}{22.8}$	-	$\frac{36.0}{36.1}$	+	$\frac{25.4}{26.1}$	+	$\frac{8.4}{7.8}$	-0.62
B	$\frac{30.3}{31.7}$	+	$\frac{22.8}{23.8}$	+	$\frac{28.3}{28.6}$	-	$\frac{20.8}{22.5}$	-	$\frac{35.0}{34.7}$	+	$\frac{25.1}{25.6}$	+	$\frac{8.7}{8.5}$	-0.25

Table 2.1 shows that the change in body measurements under the influence of the corset in eight cases out of nine exceeds the values of inter-dimensional intervals, which is certainly important for the design of the DT of soft avatars. Under the influence of the corset, all diameters has changed in the direction of increase or decrease (Table 2.2), and a decrease in diameters is characteristic of the waist area. Knowing the changes in the diameters, then combining the original and modified contours for deforming and adjusting the solid avatar, as shown in Fig. 2.1 (b).

Thus, the formed anthropometric database of men's body, which includes the values of changes in girth under the influence of the corset, the shape of their cross sections and the coordinates of the points of the spinal contour, is sufficient to build DT and its transformation into soft DT in the CLO software.

Fig. 2.3 shows the examples of Y, A, B three body typies DT in the CLO software, which the body contour a is under corset, body contour b is without corset.



a b c

Figure 2.3 – Digital twins of historical male body: a – Y type; b – A type; c – B type

2.3. Graphic structure of men's clothing simultaneously worn in the late XIX - first half of the XX centuries

According to previously researched literature and real clothing from museums, it is possible to collect the database needed for a 3D simulation. The real historical men's clothing as shown in Fig. 2.4.

a

b

c

Figure 2.4 – HCC: a – Russian men's folk shirt; b – European men's coat; c – Slovenia young men's uniform consists of shirt, waistcoat, trousers and jacket

Fig. 2.5 shows the researchers analyzed and measured the unique geometric structure, textile materials, and technics.

a b

Figure 2.5 – Data collection: a – Russian men's folk shirt; b – Slovenia young men's uniform

Fig. 2.6 shows the location and structure of the professor's formal coat.

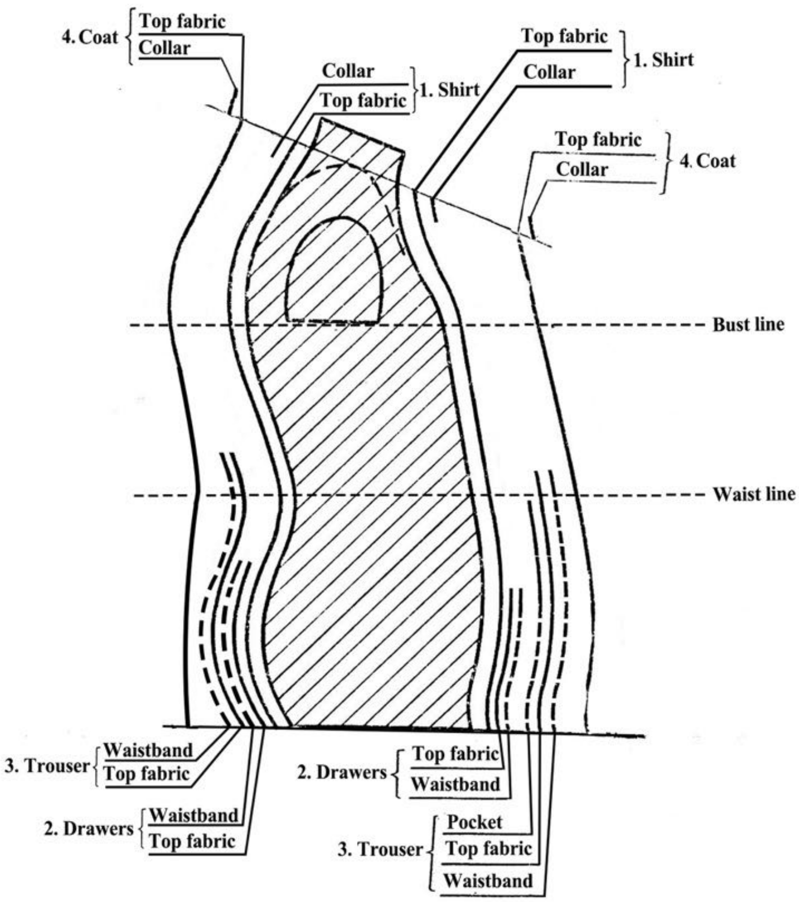


Figure 2.6 – Structure of the package materials of the HCC "Professor's formal coat"

Fig. 2.7 shows the location and structure of Russian men's folk shirt.

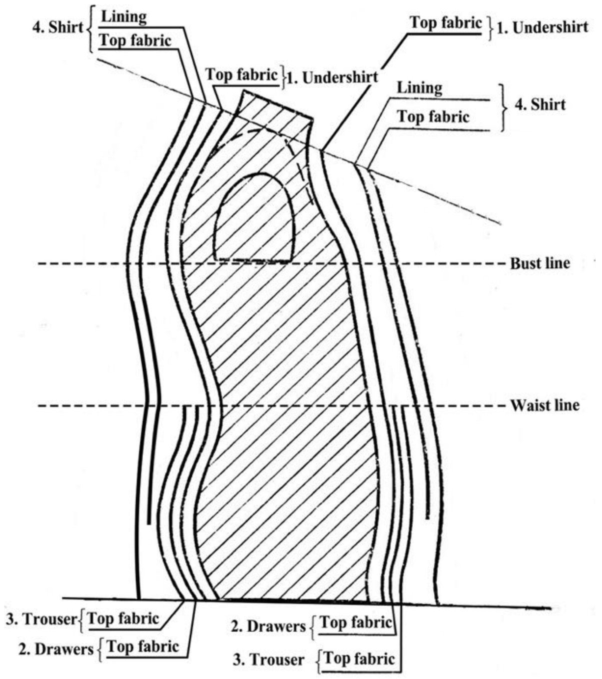


Figure 2.7 – Structure of the package materials of the HCC "Russian men's folk shirt"

Fig. 2.8 shows the location of four garments which were formed the Slovenia young men's uniform.

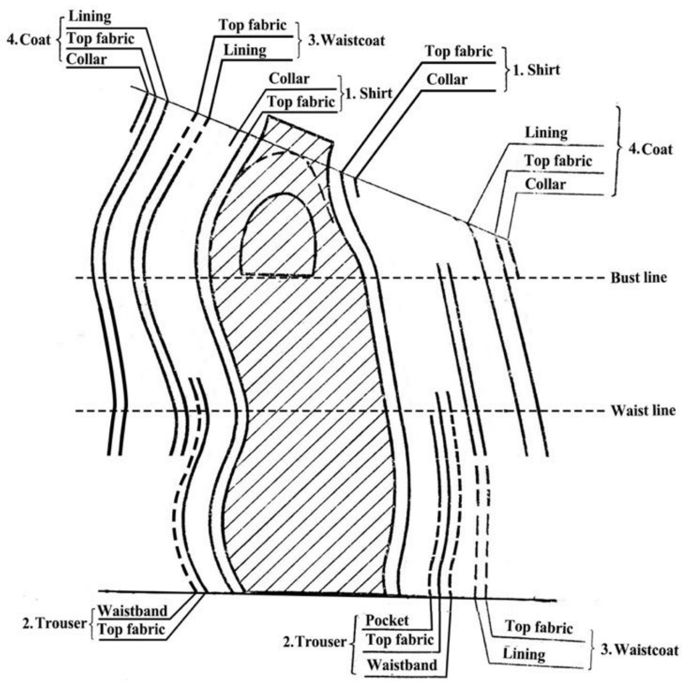


Figure 2.8 – Structure of the package materials of the HCC "Slovenia young men's uniform"

Fig. 2.9 shows the location of five garments which were formed the HCC European men's frock coat.

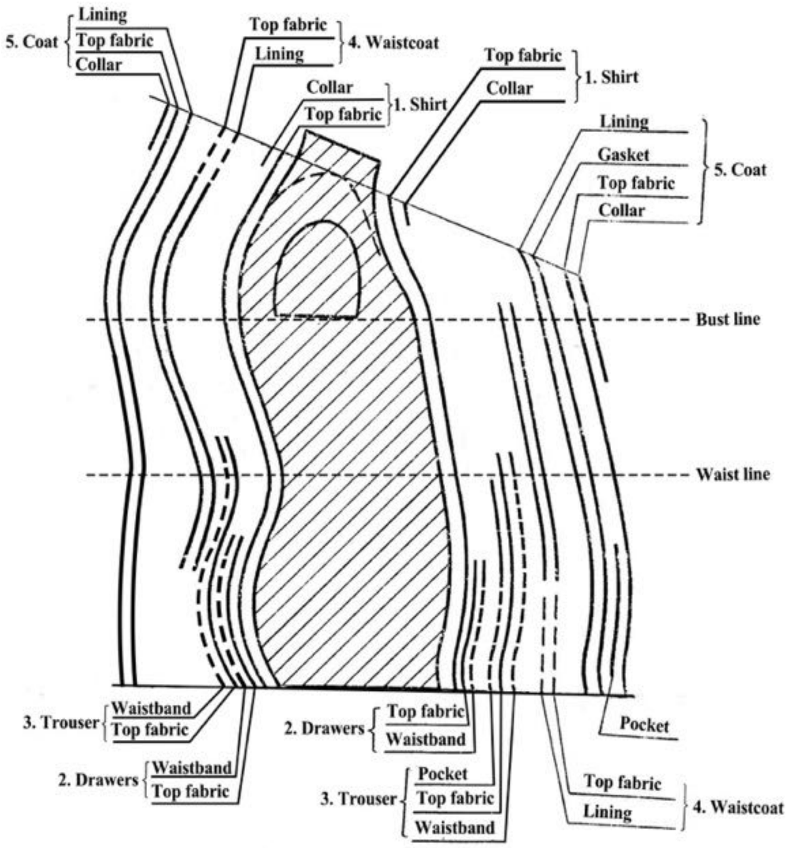


Figure 2.9 – Structure of the package materials of the HCC “European men's frock coat”

2.4. Textile materials for men’s clothing

It is very difficult to find modern prototypes of historical textile materials for the selected HCC. In order to choose the perfect substitute for historical textile materials, it is necessary to conduct a study in the following order. First, the design and layer of each piece of men's clothing should be analyzed. Secondly, it is necessary to establish information about textile materials from books and historical prototypes to search for modern substitutes in the DT. Thirdly, it is necessary to select the DT of textile materials in CLO 3D to prepare for virtual reconstruction. This approach will be useful not only for traditional museums, but also for 3D clothing technology and new digital media.

2.4.1. Type of textile materials

Information about the professor's formal coat was very limited, except for the type of basic material (cloth).

The Russian men's folk shirt was made of one fabric of the top and one lining fabric (for the waist, sleeves and collar).

As shown in Fig. 2.8 and Fig. 2.9, the Slovenian Youth uniform and men's frock coat were made of many types of fabrics, such as cotton, silk, wool, etc., which can allow each garment to have different functions. Throughout this century, the shirt, trousers, vest, and coat were of various colors and materials. [24].

To reconstruct HCC, the virtual fabrics were selected according to the historical fabrics. For example, cotton - for a shirt, cotton pique-for the front of the vest, silk satin-for the back of the vest, wool-for trousers and coats. In addition to the fiber composition, it is necessary to take into account the thickness and physical and mechanical properties [14]. The thickness of the fabric was different around the torso, so to get a real-looking DT, it should be known that the construction of each garment and the properties of textile fabrics used. For example, Slovenian HCC has eight types of upper fabrics.

According to the research of the structures of the selected four HCC, 16 types of textile materials should be studied, as shown in Table 2.3.

Table 2.3 – Types of historical textile fabrics for selected HCC

<table>
<tr><th>HCC</th><th>No.</th><th>Type of clothing</th><th>Fabrics</th></tr>
<tr><td>Professor’s formal coat</td><td>1</td><td>Coat</td><td>Top fabric</td></tr>
<tr><td rowspan="2">Russian men's folk shirt</td><td>2</td><td rowspan="2">Shirt</td><td>Top fabric</td></tr>
<tr><td>3</td><td>Lining</td></tr>
<tr><td rowspan="5">Slovenia young men's uniform</td><td>4</td><td>Shirt</td><td>Top fabric</td></tr>
<tr><td>5</td><td>Trousers, waistcoat, coat</td><td>Top fabric</td></tr>
<tr><td>6</td><td>Trousers, coat</td><td>Lining on trousers waist and coat sleeves</td></tr>
<tr><td>7</td><td>Waistcoat</td><td>Lining</td></tr>
<tr><td>8</td><td>Jacket</td><td>Lining on bodypart</td></tr>
<tr><td rowspan="8">European men's suit</td><td>9</td><td>Shirt, drawers</td><td>Top fabric</td></tr>
<tr><td>10</td><td>Trousers</td><td>Top fabric</td></tr>
<tr><td>11</td><td rowspan="2">Waistcoat</td><td>Front</td></tr>
<tr><td>12</td><td>Back, lining</td></tr>
<tr><td>13</td><td rowspan="4">Coat</td><td>Top fabric, lining on forepart</td></tr>
<tr><td>14</td><td>Paddings on forepart</td></tr>
<tr><td>15</td><td>Lining on Side, skirt and tail</td></tr>
<tr><td>16</td><td>Lining on sleeve</td></tr>
</table>

2.4.2. Methods of determining the properties

For each textile material of HCC in XIX century, the information could be find was limited. Here are two methods for us to speculate the contemporary fabrics which are similar with historical fabrics:

1. Finding properties from report of museum or historical books (fiber content, type and density).

2. Simple testing and measuring of real historical men’s clothing such as fiber, thickness, weave and thread count (linear density).

Results from the 1st method

According to the report of museum, the information of textile materials of Slovenia young men's uniform was shown in Table 2.4. (the number of each fabric are same with Table 2.3.

Table 2.4 – Information about historical textile materials for the Slovenia young men's uniform and its contemporary substitutes

HCC	No.	Historical prototype			Contemporary analog from CLO 3D library
		Fibre	Thickness, mm	Weight (density, g/m^2)	Fibre, density, g/m^2
Slovenia young men's uniform	4	Cotton	0.6	163	Cotton, oxford, 165
	5	Wool	1.957	192.2	Wool, worsted, 160 - 200
	6	Cotton	0.478	120.8	Cotton, poplin, 125
	7	Cotton	0.475	192.3	Cotton, twill, 191
	8	Cotton	0.474	193.4	Cotton, twill, 191

The density of the tissues was calculated using the Emanuel method (1920) [33]. Based on these three main properties (fiber composition, thickness, density), similar modern textile materials were selected.

Information about the textile materials of European men's clothing can be found in historical books. Table 2.5 shows the results of choosing modern fabrics instead of historical ones (the numbers of each fabric coincide with Table 2.3).

Table 2.5 – Information about historical textile materials for the European men's suit and its contemporary substitutes – Part 1

HCC	No.	Historical prototype			Contemporary analog from CLO 3D library
		Fibre	Type	Weight (density, g/m²)	Fibre, density, g/m²
European men's suit	9	Cotton/Linen	Linen, half-bleached, madras, percale, oxford, white cambric	107.39	Cotton, linen, percale, 103~113
	10 & 11	Wool	Usually lighter in weight than for the coat, high quality wool, jersey-weaves, merinos, doeskins, cassimere, kerseymere, ratiné	337.85	Wool, worsted, 150~337.84
	12	Silk	Silk satin or brocade, and cotton in different weaves and finishes	82.09	Silk, brocade, 83.33
	13	Wool	Superfine wool, worsteds, cassimere, tweeds, vicunas	506.79	Wool, worsted melton, 300 ~ 506.67
	14	Linen	Canvas, cotton and linen mixtures	-	-
	15	Cotton	-	-	-
	16	Cotton	-	-	-

• Results from the 2nd method

Indicators of the properties of the five fabrics (No. 1- No. 3, No. 14 - No. 16, Table 2.3) cannot be determined using the first method, so they used instrumental methods to determine the fiber composition, thickness, weave, and fabric count.

Fig. 2.10, a presents the cloth thickness gauge for measuring the fabric thickness. This tool has an error of ± 0.01mm. Fig. 2.10, b presents the 8-fold fabric analyzing glass for observing the weave and fabric count. Cotton and wool fabrics are expressed in terms of metric density, that is, the number of warp or weft yarns within a width of 10 cm [142]. For example, 236×220 means that the fabric has a warp density of 236 threads/10 cm and a latitudinal density of 220 threads /10 cm.

a b

Figure 2.10 – Tools for measuring: a – thickness gauge; b – fabric analyzing glass

Table 2.6 presents the results of No. 1 to No. 3 and No. 14 to No. 16 historical fabrics and their modern analogues.

Table 2.6 – Information about historical textile materialsfor the Russian men's folk shirt and European men's frock coat and its contemporary substitutes – Part 2

	Historical prototype				Contemporary analog from CLO 3D library
No.	Fibre	Thickness (mm)	Weave	Linear density	Fiber, thickness, density
2	Cotton	0.45	Plain	100×110	Cotton, canvas, 0.46mm, 227 g/m^2
3	Cotton	0.19	Plain	320×260	Cotton, muslin, 0.19mm, 100 g/m^2
14	Linen	0.34	Plain	130×110	55% linen, 45% cotton, plain, 0.35mm, 162.5 g/m^2
15	Cotton	0.34	Twill	320×290	Cotton, twill, 0.35mm, 189.19 g/m^2
16	Cotton	0.21	Plain	320×260	Cotton, plain, 0.21mm, 100 g/m^2

2.4.3. Selection of textile material in CLO 3D for virtual reconstruction

After comparing historical information about textile materials with modern analogues in virtual software, the DT were determined. The selected DT textile materials from the CLO 3D library as shown in Table 2.7.

Table 2.7 – Properties of digital textile materials in CLO 3D

No.	Type	Name of DT	Weight (density, g/m^2)	Thickness (mm)	Tensile strength, g/s^2		Bending stiffness, g/mm^2 /s^2 /grad	
					Warp	Weft	Warp	Weft
1	Knit	Ponte Knit Jersey	330. 9	0.86	112,983	286,453	3000	2500
2	Cotton	Cotton Canvas	238.9	0.46	823,217	613,716	10000	5000
3	Cotton	40s Chambray	103.1	0.23	486,772	378,944	1078	750
4	Cotton	Cotton Oxford	165	0.37	440,584	217,880	1289	1445
5	Wool	Super 120s Wool	157.5	1.9	182,216	165,263	976	976
6	Cotton	40s Stretch Poplin	122.5	0.23	502,405	114,036	1835	585
7 & 8	Cotton	Cotton Twill	190. 8	0.41	493,986	231,271	3000	1800
9	Cotton	50s Cotton Poplin	105	0.21	356,091	280,769	1289	938
10 & 11	Wool	Coatweight Twill	345	0.84	489,034	368,706	1300	1300
12	Silk	Silk Charmeuse	81.1	0.19	48,714	9672	375	156
13	Wool	Coatweight Twill	345	0.84	489,034	368,706	1300	1300
14	Linen	Linen	173.4	0.36	799,917	215,456	1500	850
15	Cotton	Cotton Gabardine	189	0.35	1700,000	1700,000	4500	2200
16	Cotton	50s Cotton Poplin	105	0.21	356,091	280,769	1289	938

2.5. Structural arrangement of clothing

In order to reconstruct historical costume with high-precision, it is essential to know the methods of pattern drafting, sewing and shaping, including the special knowledge related to craftsman skills which have been lost in the past.

Professor's formal coat

The main material for making coat is knitted. When building a structure, should take into account the features of the fabric. For better shaping, the main parts were duplicated with serpentine. Lining was used on the collar and sleeve cuffs.

Russian men's folk shirt

Fig. 2.11 shows the inside-out of the shirt. The lining was used on collar, sleeves, front and back body part. All seams are hidden by exquisite craftsmanship.

a b c

Figure 2.11 – Inside-out of Russian men's folk shirt of the XIX century: a – front view; b – collar; c – armpit

Slovenian youth uniform

The shirt of the uniform is light grey with long rever. The neckline with a trim should be closed to the chest with three red buttons on each side (Fig. 2.4, a). The back is longer than the fore and is etched in a arc at the bottom. There's a crack in the bottom on either side.

The inside of the trousers is lined with a striped cotton fabric in the waist.

The waistcoat is lined with a cotton fabric of grey color, and both sleeve and collar cuts have gold-grey colour binding tape (Fig. 2.4, b).

On each side of jacket has breast pocket, which is made of linen of natural color. Fig. 2.12, a shows the inside-out of the jacket. It coud be seen that the body part was lined with a cotton cloth of dark grey colour, the sleeves was lined with a striped cotton cloth. There is a linen base in the bottom of the sleeve between the top fabric and the lining of the sleeves, and many parallel stitches on the collar as shown in Fig. 2.12, b.

a b

Figure 2.12 – Slovenia young men's jacket: a – inside-out; b – stitches on half collar

European men's frock coat

To study the methods of frock coat shaping under influence of pattern block drafting and sewing technique, the real history men's coat which were made in 1900s from Garment Design Department (IVGPU) collection has been borrowed to obtain the knowledge about the technique. It should be noticed that the coat has shoulder pads, sleeve head and the 2~3 layers of interlining to adapt the shape of frock coat to male body in a good look.

Combining with the previous investigated in subchapter 1.2.4., method of shaping for each garment of European men's suit could be get.

Conclusion after Chapter 2

1. Using body scanning technology, an anthropometric database was created for converting solid-state avatars into soft-body digital mannequins. The database includes sections of the chest, waist and hip, their diameters, and the size of changes in the position of the body for typical bodies under the compression influence of corsets.

2. The historical database of selected HCC has been developed, including information on clothing design, historical textile materials, and their modern counterparts.

CHAPTER 3. METHODS OF IDENTIFICATION THE DIMENSIONAL ACCESSORIES, HIDDEN PROJECTED DESIGN AND TECHNOLOGICAL TECHNIQUES IN HISTORICAL PATTERN

The results obtained in this Chapter was published in two papers [162-163].

3.1. Material of research

3.1.1. Software

Software used in this research:

- ET CAD (BUYI Technology, China) for drafting historical men's coat pattern block.
- CLO 3D and Marvelous Design the visualization of HCC.
- Rhinoceros for measuring the thickness of clothes textile fabrics and anthropometrical data of the avatar.

3.1.2. Objects of reseaech

The objects of the research were taken as:

- preserved HCC in the form of coat in the late XIX - early XX centuries;
- 47 patterns of real HCC based on man's coat;
- digital twins of textile fabrics from 3D CAD library;
- five patterns of the historical men's coat for working out the technology of calculating ease allowance to body measurement;
- pattern of man's coat of the 1740s for checking the technology of dimensional identification.

3.2. Method of pattern reconstruction of partly saving HCC

In this subsection, method for reconstructing pattern based on the preserved HCC (Figure 2.4, b) was developed. This method does not affect the integrity and safety of historical clothing, which is useful for reconstructing the history of clothing.

There are three method for reconstructing clothing pattern [143-145]:

1. The disassemble and iron method, disassemble the whole prototype clothing, spread each piece and iron it flat, the pattern could be duplicated completely. Although this method with high precision, but it is not applicable to precious historical clothing;

2. The rub-off method, with the help of tools such as calico, pin, wax flake, tailor’s chalk, etc., cover the calico on the prototype clothing and rub, to duplicate the pattern of each piece the clothing without taking it apart, and record clothing details. This method will not destroy the prototype clothing, but low level of precision.

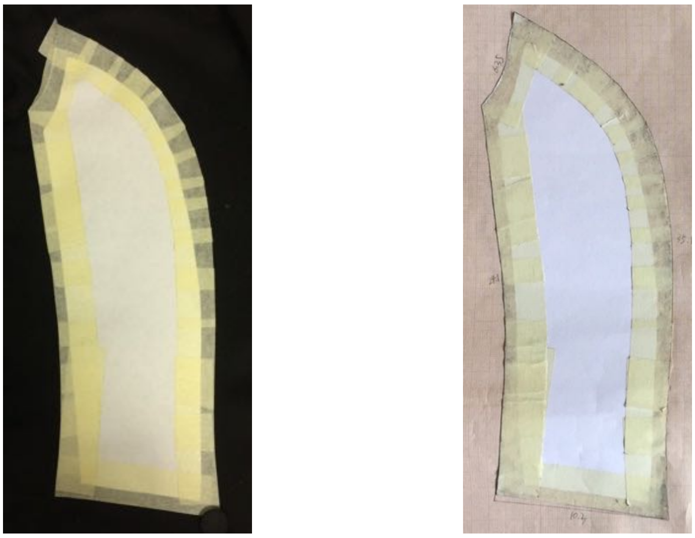
3. The plane measurement method, measure the size of each piece (width and length) of the prototype clothing, and then drafting the pattern based on them. However, this method has two problems. Firstly, the pattern drafting method of the original clothing should be known. Secondly, even if a similar or same size pattern could be drafted, it is still difficult to draft the exact shape and line of the prototype clothing as well as the shape and structure;

4. The masking tape method, put the prototype clothing on a flat desk, use masking tape and paper to paste each part of clothing. After that, remove them from the clothing, and place them on the paper with the adhesive side facing down, thus the pattern of each part could be obtained. This method takes a short time and simple to operate, can mark the exact seam line.

After comparing the above four methods, the fourth method was chosen for duplicating the pattern of real history men’s coat, and a new coordinate measurement method was developed for simultaneous work. To develop the method, a historical men's coat made in the late XIX - early XX centuries was taken from the collection of the Ivanovo State Polytechnic University (Fig. 2.4, b). Before starting the work, the original shape was carefully studied. This coat has a straight silhouette, does not have complex draperies, the direction of the warp thread and weft can be easily identified on the fabric, and its structure is easy to mark. The style is completely symmetrical, so the pattern can be reconstructed only one half, but to improve the accuracy of the reconstruction, the left and right parts were scanned. The masking tape with a width of 1.5 cm and 2.5 cm, A4 paper and millimeter paper were used.

The duplication algorithm was as follows. First sheet of paper slightly smaller impose on the item; then duct tape the correct width (in accordance with the portion size and the curvature of the edges) fixed it, just focusing on the seam line on the outer edge of this part. The edges of the adhesive tape should be superimposed on each other, so that it is easier to remove it later, without tearing it apart. When the paper is attached around the perimeter, the paper part is separated from the coat, laid with the sticky side down on the millimeter paper in a smooth state. Turn the paper over and use a polishing tool to remove all air pockets.

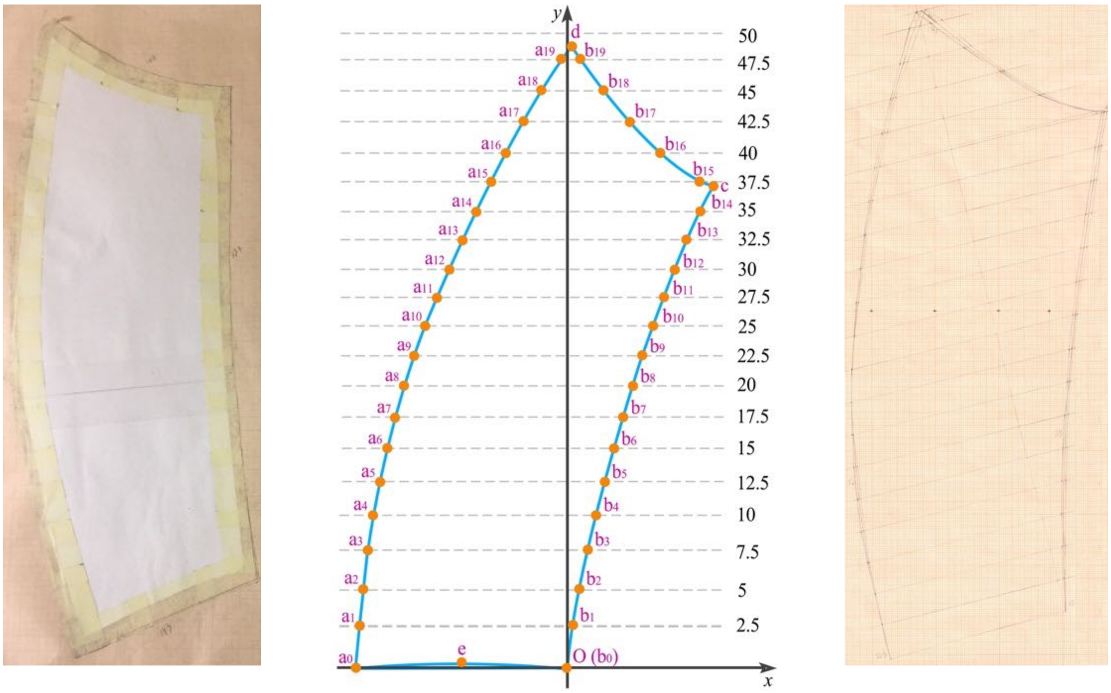
Fig. 3.1 shows, as an example, the positions of the side piece of coat and its paper counterpart, laid on the plane of the table.



a b

Figure 3.1 – The side piece of coat, duplicated with paper and masking tapes, during working and after laying the paper on the plane: a - tracing the coat; b-placing the twin on millimeter paper

According to the characteristics of the under sleeve pattern, the Cartesian coordinate system was established by defining the point b_0 as the starting point and two lines through it - the Y and X axes (Fig. 3. 2).



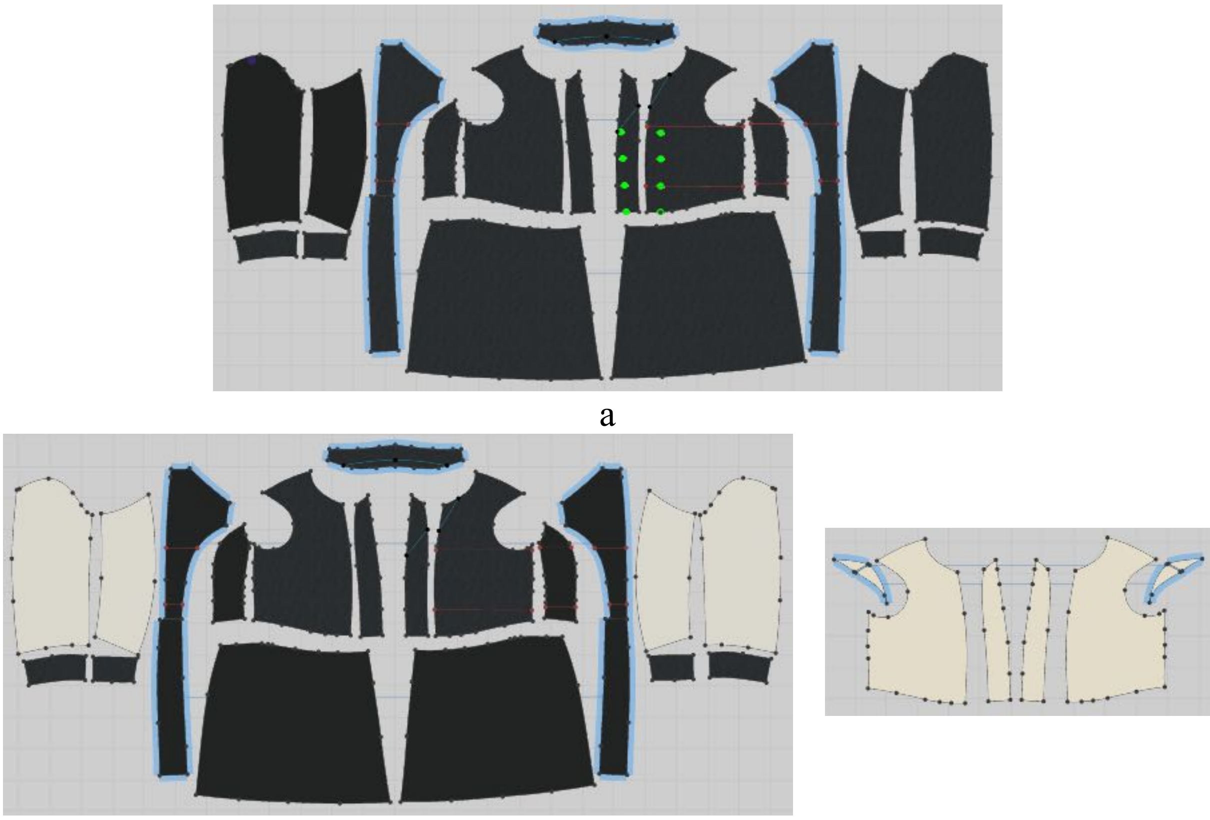
a b c

Figure 3.2 – Method of duplication: a – masking tape; b – coordinate measurement method; c – the final pattern after averaging the measurement results of left and right pieces

To accurately reconstruct the pattern of the piece of the HCC, parallel reference lines were plotted on the coordinate grid with an interval of 2.5 cm. The intersection of the left and right contours and the parallels were marked as reference points a_1, a_2..., a_{19}, b_1, b_2..., b_{19}, respectively. The four vertices were marked as a_0, b_0, c, d, respectively. In addition, the concave point of the hemline e was marked. The coordinates of each point were obtained by measuring the distance between the point and the X, Y axes. Therefore, the structure of the piece can be transferred to millimeter paper by connecting adjacent reference points with smooth curves, as shown in Fig. 3.2, b.

Thus, the two patterns - left and right, generated with masking tape (with the reference points indicated, Fig. 3.2, a) and coordinates-were superimposed in the same coordinate system by combining both lines of the bottom of the sleeves. The final pattern was reconstructed from the average coordinates of the reference points on each parallel of the two drawings, as shown in Fig. 3.2, b. Thus, the pattern of each part of the historical men's coat could be duplicated bt using this method with increased accuracy.

According to this scheme, scans of all the details of the coat were obtained. The resulting parts were digitized and Fig. 3.3 shows the complete set of men's coat pattern in CAD.



a

b c

Figure 3.3 – Screenshot of the complete set of pattern of the coat in CAD:
a - details of the top fabric; b - details of the lining; c - paddings

3.3. Method of non - contact measuring of the fabric thickness during virtual reconstruction

The aim of this research is to develop a method by using three-dimensional visualization programs to determining the thickness of the textile fabrics. The study used patterns of shirt, drawers, trousers, and waistcoat from the historical manual [93].

3.3.1. Generation of the avatar of historical male body

To determine the body measurements of avatar as the historical male body, the following experiment was conducted. From the historical pattern manual for clothing design, the most common typical male body was selected, for which the pattern drafting method was given, with the following measurements used in calculating the pattern: height 66 inches (167.64 cm), chest girth 36 inches (91.44 cm), waist girth 32 inches (81.28 cm).

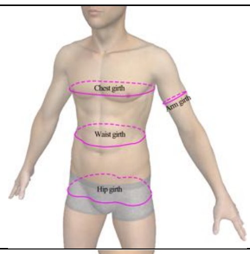
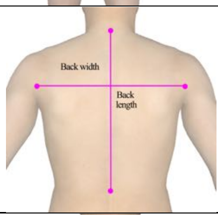
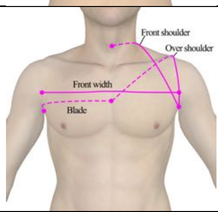
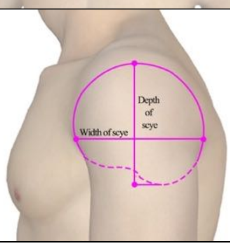
However, these measurements need to be adjusted for two reasons:

1) the influence of undergarments textile fabrics, since measurements of male body were took over waistcoat and trousers at that time, From these measurements, it is necessary to remove the increase in the thickness of the package of materials: at the level of the chest circumference -5.25 cm, waist circumference -7.06 cm

2) changing of male body due to wearing corset. Under the influence of the corset, according to previous research (see subsection 2.2), the average chest girth increases by 2.33 cm, and the waist girth decreases by 2.36 cm (data were obtained for body type A according to Chinese typology).

Thus, the avatar of historical male nude body with height 167.64cm, chest girth 88.52cm and waist girth 71.86 cm was finally generated, corresponding to the Y type. The avatar of historical male body was reconstructed according to the main body measurements, and the values of all measurements, including those used in historical manuals (No. 8-10, No.13, No.14) as shown in Table 3.1.

Table 3.1 – Body measurements of the avatar of historical male body

No.	Body measurements	Scheme	Symbol	Value, cm
1	Chest girth$_1$		CG_1	88.52
2	Waist girth$_1$		WG_1	71.86
3	Hip girth$_1$		HG_1	87.44
4	Arm girth$_1$		AG_1	28.32
5	Back width$_1$		BW_1	31.99
6	Back length$_1$		BL_1	36.41
7	Front width$_1$		FW_1	33.76
8	Front shoulder$_1$		FS_1	26.85
9	Over shoulder$_1$		OS_1	39.77
10	Blade$_1$		B_1	27.89
11	Neck diameter$_1$		ND_1	12.09
12	Shoulder length$_1$		SL_1	12.46
13	Depth of scye$_1$		DS_1	11.02
14	Width of scye$_1$		WS_1	12.04

Notes. 1. No.8 "Front shoulder$_1$" is the length from the back neck point to front armpit through side neck point; 2. No.9 "Over shoulder$_1$" is the length from the center of back chest to front armpit through shoulder; 3. No.10 "Blade$_1$" is the length from the center of back chest to front armpit through profile torso; 4. No.13 "Depth of scye$_1$" is the vertical distance between the shoulder point to the axilla; 5. No.14 "Width of scye$_1$" is the horizontal distance between front and back armpit.

3.3.2. Recalculation of the textile fabrics thickness

Since the XIX century, human body were measured with tape over clothes, the measurements included the sum thickness of the textile fabrics and air gaps which formed between types of clothes with different volumetric-spatial shapes. Therefore, the measuring results of the body girth took by tape contained three values at least: body measurements + sum thickness of the textile fabrics, including possible folds that occur when the body is measured with measuring tape, + air gaps, so the measurement results could be written as

$$BMo = BM + \sum T_{TF} + \sum AG, \quad (3.1)$$

where BMo is the result of girth measuring by tape around the body in underwear and some clothes such as waistcoat; BM is body measurement; $\sum T_{TF}$ is the sum of thicknesses of textile fabrics, cm; $\sum AG$ is the sum of air gaps which formed between body and undergarments, as well as between the layers of textile fabrics, cm.

In general, $\sum T_{TF}$ could be defined as follows:

1) summing the thickness of single textile fabric $\sum T_{TF1}$ measured separately according to subsection 2.4;

2) measuring the thickness of all textile fabrics $\sum T_{TF2}$ simultaneously.

Obviously, $\sum T_{TF1} < \sum T_{TF2}$ is due to the influence of the surface texture and air gaps, it was not equal to simple arithmetic sum. The both methods cannot be applied to obtain initial data and subsequent visualization of historical clothes, because the formation of four types of clothes with different spatial volume, and the thicknesses of clothes which worn simultaneously cannot be calculated by simple summation directly. Fig. 2.9 shows the scheme of forming the total thickness ($\sum T_{TF} + \sum AG$) about all types of clothes - shirt, drawers, trousers, waistcoat - dressed up in sequence.

To measure the thickness of textile fabrics, virtual environment was chosen, in which the procedure for measuring the male body with tape was simulated with slight compression of clothes. Four types of clothes were worn on the generated digital twin, and in this position, all fabrics were compulsorily compressed until it fit snugly against the surface of the avatar, pressed against with each other, and maximally removed air gaps from all layers. As analogues of historical fabrics, contemporary fabrics were taken from the library of the

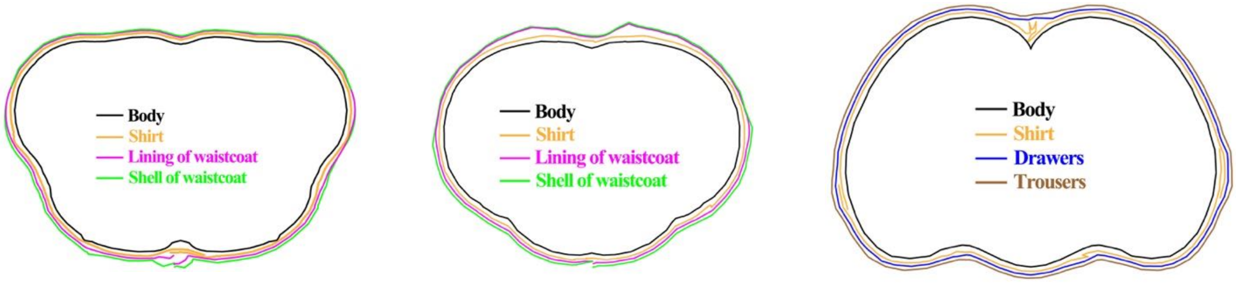
Marvelous Designer software. The procedure was performed using the "Pressure" function in the following modes: Thick Textured Surface and Transparent Surface.

Fig. 3.4 shows the stages of transformation for virtual twin, first to transparent fabrics, and then to the version with minimal air gaps ∑AG.


a b c d

Figure 3.4 – Stages of sequential transformation: a, b – basic virtual twin and transparent form with air gaps; c, d – systems without air gaps

As shown in Fig. 3.4, c, d all layers of clothes were tightly fit to the avatar due to the compression of textile fabrics. The last virtual twin (Fig. 3.4, d) can be considered as an analogue of a real historical body during its measurement by the tailor. The horizontal cross-section at the main anthropometric levels of this virtual twin were obtained. Fig. 3.5 shows the variants of the initial section which prepared for measuring the girth of each level.



a b c

Figure 3.5 – Cross-section of the "avatar + HCC" system after pressing the textile fabtics to the surface of avatar with minimal air gap: a – chest; b – waist; c – hip

The perimeters of the obtained sections were measured in Rhinoceros software, and the results were presented in Table 3.2.

Table 3.2 – Avatar's body measurements over waistcoat with minimal air gaps

No.	Measurement	Symbol	Value, см	Increment from original nude avatar CG_2 - CG_1
1	Chest girth$_2$	CG_2	95.05	6.53
2	Waist girth$_2$	WG_2	78.39	6.53
3	Hip girth$_2$	HG_2	93.93	6.49
4	Arm girth$_2$	AG_2	31.09	2.77
5	Back width$_2$	BW_2	34.49	2.5
6	Back length$_2$	BL_2	38.02	1.61
7	Front width$_2$	FW_2	35.24	1.48
8	Front shoulder$_2$	FS_2	30.02	3.17
9	Over shoulder$_2$	OS_2	43.08	3.31
10	Blade$_2$	B_2	30.25	2.36
11	Neck diameter$_2$	ND_2	14.01	1.92
12	Shoulder length$_2$	SL_2	12.79	0.33
13	Depth of scye$_2$	DS_2	12.58	1.56
14	Width of scye$_2$	WS_2	12.74	0.7

It is clearly to see that the biggest increment is the girth measurement. According to the data from Table 3.1 and 3.2 the sum thickness of the textile fabrics can be calculated by the formula

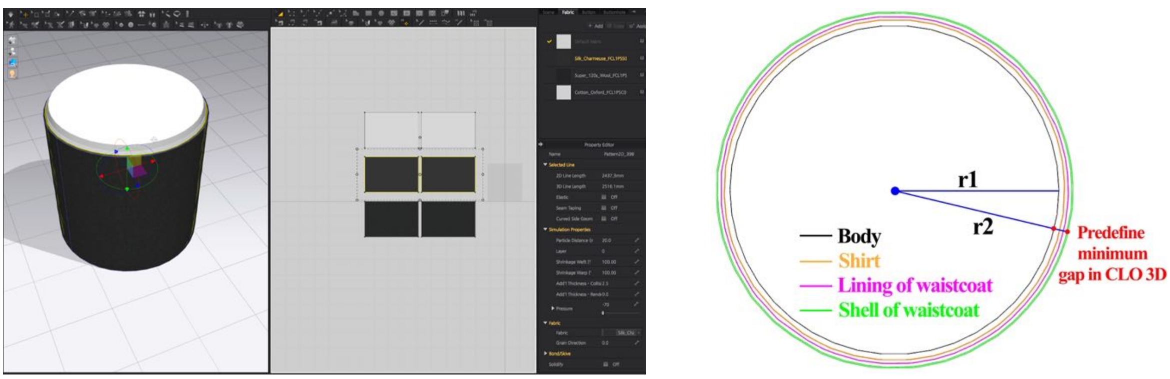
$$\sum T_{TF3} = (CG_2 - CG_1) / 2\pi \quad (3.2)$$

where CG_1 is the girth of nude avatar, CG_2 is the girth of the "avatar + tight-fitting clothes with minimal air gaps" system.

To get the sum thickness of the textile fabrics under other measurements - widths, arcs - instead of the angle value 2 π, the central angles could be use.

The sum thickness of the textile fabrics was measured using the Rhinoceros software at the same time. Sections of the avatar and the airless system with known girths and perimeters (Fig. 3.5) were converted into cylinders with the same perimeters in the CLO 3D software, for example, CG_2, WG_2, HG_2, and the selected textile fabrics were simulated around the cylinder. Saved files in the format .obj was exported to the Rhinoceros software, in which the sum thickness $\sum T_{TF2}$ was measured, equal to the difference between the radii r2-r1.

The cylinder in the Marvelous Designer software and the scheme for measuring the sum thickness of textile fabrics with predefine minimum air gap as shown in Fig. 3.6.



a b

Figure 3.6 – Method of measuring: a – a cylinder with the same textile fabrics at the waist level; b – measuring the the sum thickness of textile fabrics and minimum air gap in the program Rhinoceros

Table 3.3 shows the results of calculating the thickness of textile fabrics by different methods:

1) $\sum T_{TF1}$ by addition the thicknesses of flat samples of raw textile fabrics according to subsection 2.4;

2) $\sum T_{TF2}$ was measured in Rhinoceros software;

3) $\sum T_{TF3}$ was measured in Marvelous Designer, Rhinoceros software and calculating by the formula (2).

To simulate the thickness of multilayer textile fabrics with air gaps, which can be used to reconstruct historical costume complex, the coefficient of filling the textile fabrics with air gap K was proposed, which shows the increase in the thickness of multilayer textile fabrics due to the air gaps formed inside. It can be calculated by the formula

$$K_A = \sum T_{TF2} / \sum T_{TF1} \tag{3.3}$$

Table 3.3 – Thickness of textile fabrics measured by different methods, cm

<table>
<tr><th rowspan="3">Level</th><th rowspan="3">Structure and thickness of textile fabrics</th><th colspan="3">Thickness of textile fabrics for different calculation methods, cm</th><th rowspan="3">Thickness of the air gap, cm</th><th rowspan="3">Coefficient of filling the textile fabrics with air gap K_A, cm/cm</th></tr>
<tr><th rowspan="2">$\sum T_{TF1}$ excluding air gaps</th><th colspan="2">taking into account the air gaps</th></tr>
<tr><th>Rhinoceros program $\sum T_{TF2}$</th><th>$\sum T_{TF3}$ by equation (2)</th></tr>
<tr><td>Chest</td><td rowspan="2">Shirt (0.021) + lining of waistcoat (0.019) + shell of waistcoat (0.084))</td><td rowspan="2">0.124</td><td>0.911+ 0.124= 1.035</td><td>1.04</td><td rowspan="2">1.0375</td><td rowspan="2">8.37</td></tr>
<tr><td>Waist</td><td>0.911+ 0.124= 1.035</td><td>1.04</td></tr>
<tr><td>Hip</td><td>Shirt (0.021) + drawers (0.021) + trousers (0.084)</td><td>0.126</td><td>0.906+0.126=1.032</td><td>1.03</td><td>1.031</td><td>8.18</td></tr>
<tr><td>Thigh</td><td>drawers (0.021) + trousers (0.084)</td><td>0.105</td><td>0.631+0.105=0.736</td><td>0.74</td><td>0.738</td><td>7.03</td></tr>
</table>

From Table 3.3, it could be seen that the values of textile fabrics thicknesses calculated in the virtual environments $\sum T_{TF2}$ and $\sum T_{TF3}$ are very close to each other, therefore these value could be averaged. However, they have significantly different from the sum thicknesses of $\sum T_{TF1}$ from the publications, which does not contain air gaps.

Table 3.3 shows the values of the coefficient K_A were 7.03 for two-layers fabrics, and 8.18 ... 8.37 for three-layers fabrics.

The obtained results were extremely important for virtual reconstruction of realistic digital twins. Only use the thickness of textile fabrics in the software library as the source data for the reconstruction of multi-layered historical clothes, the sum thickness will not contain air gaps and less than the real one. It will lead to distortion of the three-dimensional shape of the virtual twin of the costume complex and discrepancy with the shape of the historical prototype.

To evaluate the effectiveness of this approach, a virtual twin was previously reconstruted from the same textile fabrics, and using the K_A coefficients from Table 3.3 to form air gaps between them. Both virtual twin are shown in Fig. 3.7.

a b c

Figure 3.7 – Virtual twins of the historical costume complex obtained by forming all textile fabrics: a – simply summing the thicknesses of the original fabrics; b – adding air gaps between each layer; c – Overlapped two contours, the twin is highlighted in red of (b)

Obviously, the second virtual twin (Fig. 3.7, b) looks more realistic due to the increased proportionality of the clothes and the reduction of air gaps. Thus, calculated the thickness of textile fabrics by using the K_A coefficient could increase in the degree of realism of virtual twin as shown in Fig. 3.7, b.

Combining the silhouettes of both twins, quantitative differences could be established, which due to the increasement of the all types of clothes volume. It could be found that there was increase in the seat depth of the trousers by a = 1.5 cm and smoothing of the side contour by b = 0.7 cm. After making detail adjustments to the silhouette in several places, the identity between the virtual twin and its historical prototype could be achieved.

Consequently, the thickness of the textile fabrics and air gaps should be considered when the multilayer clothes was reconstructed in virtual environment, which can be calculated by using the coefficient of filling the textile fabrics with air gap K_A.

3.4. Methods of graphic-analytical reconstruction of constructive methods of shaping, designing in historical pattern

An ease allowances and an indicators of the textile fabric property is the main type of digital information for parameterization and simulation of the three-dimensional shape of historical clothes. Ease allowance is indicator of artistic and design features of individual sections of the three-dimensional form of clothes, its construction and, as shown above, the content of the textile fabrics. Therefore, according to the thickness of textile fabrics, increments in the patterns are most important initial data for reconstruction and verification of its validity.

To illustrate the effect of ease allowance in the variability of the historical clothes shape, the selected patterns of coat were overlapped as follows: detail of the back - at the top of the middle line, coinciding with the spinous process of the seventh cervical vertebra (BNP), and detail of the forepart and skirt - along the front middle line at the point corresponding to the cervical point in front (FNP). Fig. 3.8 shows the overlap of back and front parts of the historical men's coat pattern.

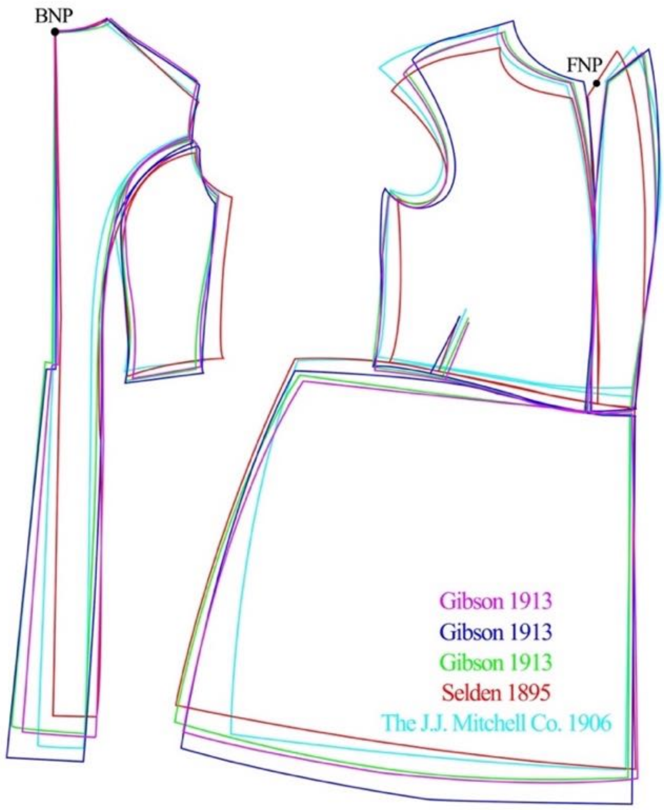


Figure 3.8 – Schemes of patterns of men's coat (the time of drafting was indicated on the skirt)

As shown in Fig. 3.8, the patterns which were drafted almost at the same time but have significant differences in silhouette and internal lines: shoulder, armholes of the forepart, neck, connections of the forepart and skirt. The different arrangement of five coat patterns relative to the anthropometric points of the male body is associated with the sewing technics, especially the method of shaping during heat-moisture treatment. Feature of the lines can be described by the relationship with anthropometric points - shoulder, back neck, front neck, armpit front, and others - with the help of ease allowance. It is clear to see that in Fig. 3.8, in additions to the slope of shoulder lines, the neck width of the forepart, the width of the chest and the depth of scye was also different.

3.4.1. Ease allowance for shaping historical men's coat in the late XIX - early XX centuries

To calculate the ease allowance, the method of anthropometric net (AN) was used to analyze the [146]. The surface of the avatar's torso was marked with anthropometric points and the lines of the chest, waist and hip, on the basis of Flatten function in Marvelous Designer software to obtained AN. Fig. 3.9 shows the screenshot of avatar and generated scan of its torso in Marvelous Designer software.

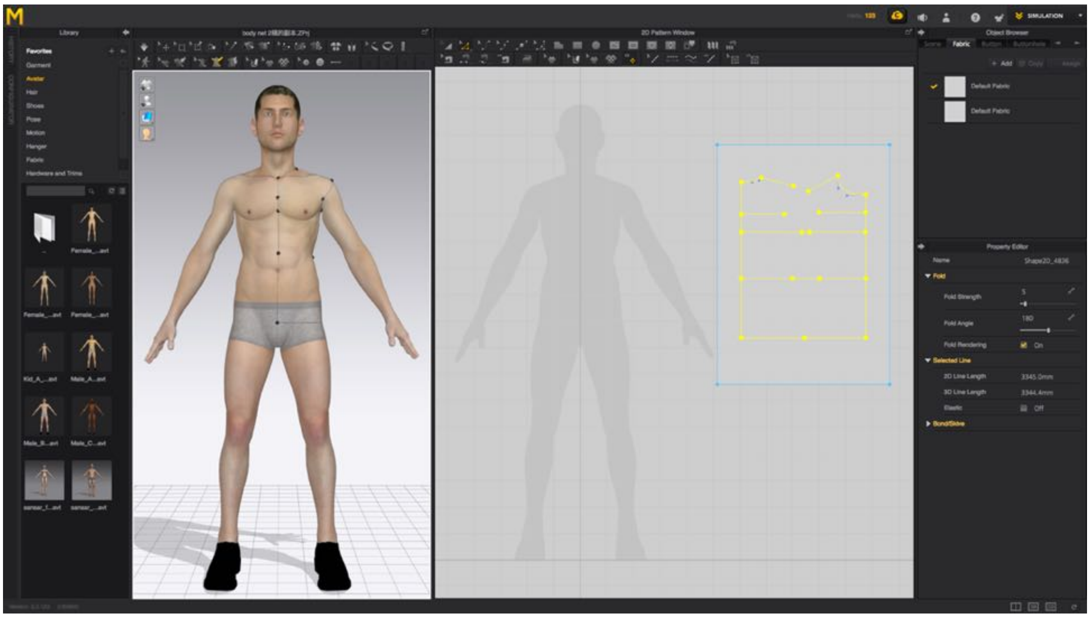


Figure 3.9 – The screenshot of the avatar and flat scan of its torso - AN

The selected patterns were drafted in scale 1: 1. The location of anthropometric points and lines of the AN and corresponding ease allowance as shown in Fig. 3.10.

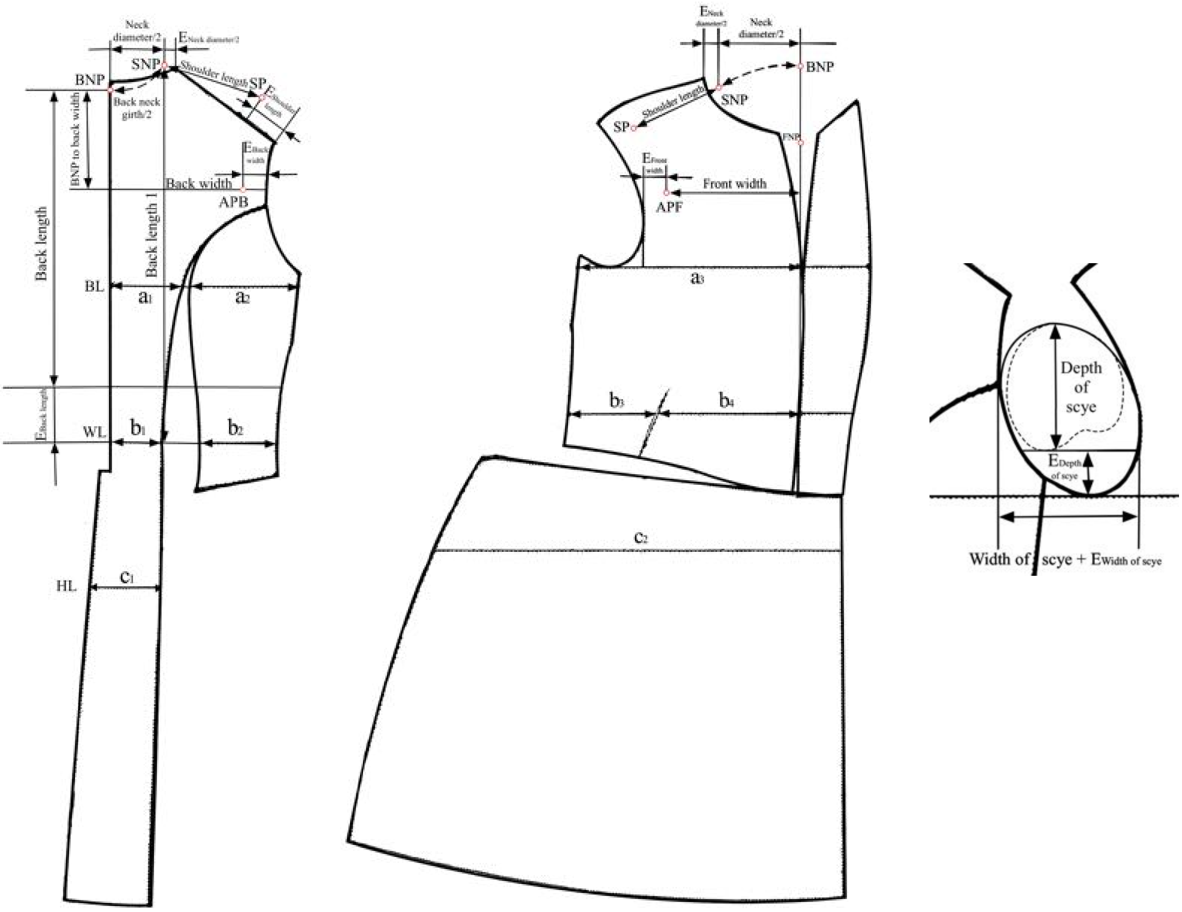


Figure 3.10 – The location of anthropometric points and lines: a – back; b – front; c – armhole

Table 3.4 presents the marking points, lines which were used in Fig. 3.10.

Table 3.4 – Symbols of AN in Fig. 3.10

Groupe of symbols	Symbol	Definition
Anthropometric points	BNP	Back neck point
	SNP	Side neck point
	FNP	Front neck point
	APB	Armpit back
	APF	Armpit front
	SP	Shoulder point
Body measurements	a1, a2, a3	Width along the chest level
	b1, b2, b3, b4	Width along the waist level
	c1, c2	Width along the hip level
	Back length	Distance between BNP to waist level
	Back length1	Distance between SNP to waist level
	Back width	Distance between APB to the central of back
	Shoulder length	Distance between SNP to SP
	Front width	Distance between APF to the central of front
	Back neck girth/2	Girth between SNP to BNP
	Depth of scye	Distance between SP to axilla
	Width of scye	Width between APF to APB
Patterns measurement	Neck diameter	Width between left and right sides SNP
Ease allowances	$E_{Back\ length}$	To the distance between BNP to waist level
	$E_{Back\ width}$	To the distance between APB to the central of back
	$E_{Shoulder\ length}$	To the distance between SNP to SP
	$E_{Neck\ diameter}$	To the width between left and right SNP
	$E_{Front\ width}$	To the distance between APF to the central of front
	$E_{Depth\ of\ scye}$	To the distance between SP to axilla
	$E_{Width\ of\ scye}$	To the width between APF to APB

The patterns which were drafted from the end of the XIX - beginning of the XX century and measured by applying historical and contemporary body measurements. The wearer’s body measurements as shown in Table 3.1. Table 3.5 shows the measurement results of the coat patterns.

Table 3.5 – Results of measurements of men's coat patterns

No.	Position of measurements	Symbol	Dimension of pattern, cm				
			PB1	PB2	PB3	PB4	PB5
1	Width along the chest level	PB_{CG}	103.88	106.32	101.78	109.87	103.80
2	Width along the waist level	PB_{WG}	93.02	96.99	91.81	99.56	92.43
3	Width along the hip level	PB_{HG}	123.74	128.10	117.50	118.64	113.01
4	Back width	PB_{BW}	38.73	40.43	38.04	39.74	39.23
5	Front width	PB_{FW}	43.95	42.55	42.46	45.67	43.31
6	Back length	PB_{BL}	42.67	45.03	42.75	42.87	41.43
7	Neck diameter	PB_{ND}	16.03	15.10	15.65	15.26	14.06
8	Shoulder length	PB_{SL}	15.23	16.16	15.03	18.34	17.80
9	Depth of scye	PB_{DS}	16.69	18.19	16.17	15.48	15.93
10	Width of scye	PB_{WS}	12.85	13.37	13.07	11.96	12.76
11	Armhole length	PB_{AL}	44.92	49.39	43.79	41.19	42.70
12	Front shoulder (AR+VK)	PB_{FS}	34.32	36.18	33.38	32.73	32.62
13	Over shoulder (BW+ZK)	PB_{OS}	47.20	51.04	46.24	44.01	45.29
14	Blade (BK)	PB_{B}	30.91	32.85	30.51	32.37	30.79

Among these measurements, No.9 cannot be measured directly on the pattern, it needs to imported the digital twin of “avatar - costume” system into Rhinoceros to measure the vertical distance between the shoulder point to the axilla of coat. As for historical measures, No.12 front shoulder is arc through the shoulder ramp in front (AR+VK), No.13 over shoulder is arc through the shoulder ramp in the back (BW+ZK), No. 14 blade is BK as shown in Fig. 3.11.

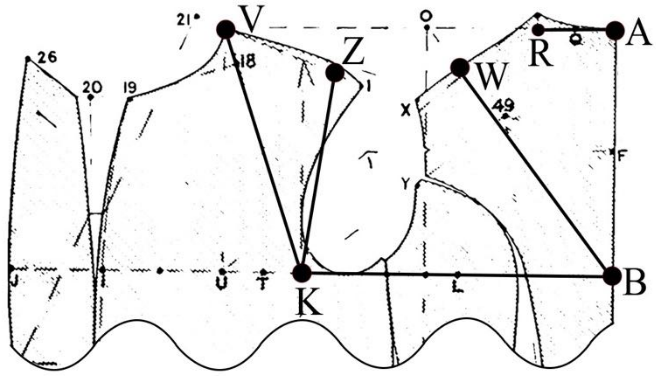


Figure 3.11 – Measurements used in the end of the XIX - beginning of the XX century

The total value of ease allowance, which contains all types of increases - for the sum thickness of textile fabrics, air gaps, fashionable - can be calculated by the formula, for example for the ease to the chest girth:

$$E_{CG} = PB_{CG} - CG_1 \tag{3.4}$$

where E_{CG} is the total ease allowance to the chest girth, PB_{CG} is double width of the pattern along the chest line, and CG_1 is the body measurement "chest girth" measured by the nude avatar's body. Such scheme of ease calculation is using in modern design and it can be used for the purpose of reconstruction.

The historical ease allowance which was used by the tailors to draft the patterns and it can be calculated by the formula, for example for the ease to chest girth:

$$E_{CGh} = PB_{CG} - CG_2 \tag{3.5}$$

where E_{CGh} is the historical ease allowance to chest girth, PB_{CG} is the doubled width of the pattern along the chest line, and CG_2 is the "Chest girth", measured over clothes that worn under the coat.

According to formulas (3.4, 3.5), the ease allowance of both type and calculated for all body measurements. The detail values of ease allowance of E_{CG} and E_{CGh} was shown in Appendix B.

Table 3.6 – Values of ease allowance

No.	Position	Average value of ease		Ratio between ease allowance E_{CG} / E_{CGh}	Difference Δ	Related to 1 cm length Δ/BM_h
		historical, which was used by the tailors E_{CGh}	total amount which can be used for historical reconstruction E_{CG}			
1	To chest girth	10.08	16.6	1.65	6.52	0.074
2	To waist girth	16.37	22.9	1.40	6.53	0.091
3	To hip girth	26.27	32.8	1.23	6.53	0.075
4	To arm girth	13.31	16.1	1.21	2.79	0.099
5	To back width	4.74	7.2	1.52	2.46	0.077
6	To back length	4.93	6.5	1.32	1.57	0.077
7	To front width	8.35	9.8	1.17	1.45	0.043
8	To front shoulder	3.83	7.0	1.83	3.17	0.118
9	To over shoulder	3.68	7.0	1.9	3.32	0.083
10	To blade	1.24	3.6	2.9	2.36	0.083
11	To neck diameter	1.21	3.13	2.59	2.9	
12	To shoulder length	3.72	4.1	1.1	0.38	
13	To depth of scye	3.91	5.5	1.41		
14	To width of scye	0.06	0.8			

Table 3.6 shows that the average difference between the ease allowances is quite significant.

To check the accuracy of the influence of the obtained results, based on the historical pattern drafting method of PB1 [93], reconstruction of the men's avatar coat with dimensional features from the Marvelous Designer program was performed. Images of virtual coat doubles and their combined outlines are shown in Fig. 3. 12.

a b c

Figure 3.12 – Digital twins of the coat generated based on PB1: a – ease allowance by formula (3.5) used by historical tailors from manuals; b – ease allowance by formula (3.4) used to reconstructed for contemporary body; c – overlapping contours of two types of ease allowance

E_{CG} calculated by equation (3.4) is bigger than E_{CGh} calculated by equation (3.5), so the coat with E_{CGh} (Fig. 3.12, a) is tight and the coat with E_{CG} (Fig. 3.12, b) is loose.

Thanks to the use of transparent materials in Fig. 3.12. it was possible to find that due to different values of increments, air gaps of different sizes were formed between the avatar and the coat. Obviously, for a nude avatar, using formula (3.4) for reconstruction will provide better conditions for proportionality and a balanced fit. This digital twin has broad shoulders, narrow waist, and accentuated longer and more muscular torso (Fig. 3.12, a). From the superimposed contours, it was possible to see the differences between the side contours and the inner lines, especially in the configuration of the lapels and collar, which arise under the influence of the thickness of the textile fabrics and air gaps.

3.4.2. Algorithm for recalculating the main ease allowance in historical pattern, taking into account the typology of modern body

In general, historical reconstruction is performed on contemporary body of different sizes, and not only on the pattern which from historical manuals directly. Therefore, the gradation of ease allowance is very important, which increase or decrease were depended on the body size.

The method of adjusting historical ease allowance for men's shoulder clothes (overcoat, tailcoat, frock coat) design, which based on the recalculation for a new body dimensions was proposed. For calculation, the size variants of historical and modern body, the recommend design ease allowance from historical manuals, and a coefficient that takes into account differences between the same body measurements should be known. The coefficient can be calculated by the formula

$$k = \Delta / BM_h, \tag{3.6}$$

where k is the coefficient of quantitative differences between the same body measurement in different anthropometric software; Δ - the difference between the body measurements measured by historical and modern anthropometric software, for example, $\Delta = E_{CG} - E_{CGh}$; BMh - the body measurement of the historical body, cm.

The values of the coefficients k as shown in Table 3.6.

The coefficients k can be used to develop new patterns which were needed for reconstruction of historical clothes. For contemporary male body with different body measurements from the historical analogue, the new ease allowance can be calculated by the formula

$$E_m = E_h \pm BM_m (\Delta / BM_h), \quad (3.7)$$

where Em is ease allowance to body measurements of contemporary male body, m - measurements, cm; E_h - ease allowance to body measurements of the historical body, BM_h from the historical manuals for design clothes, cm; BM_m - body measurements of contemporary male body, cm.

For example, a contemporary male body with chest girth of 100 cm. The historical pattern was designed for body with chest girth of 88.52 cm. It can be found that the coefficient k, which quantitative differences in chest girth is 0.074 Substituting values in (3.7), the value of the ease allowance of 10.08 + 100 · 0.074 = 17.48 cm could be calculated. Thus, the basic net width of the coat pattern for reconstructing should be (100 + 17.48)/2 = 58.74 cm (in the historical initial pattern, the width along the chest line was (PB1 + PB2 + PB3 + PB4 + PB5) : 2= 52.57 cm). Thus, for modern body, the width of the base grid of the historical pattern must be increased by 58.74 - 52.57 = 6.17 cm.

The formula (3.7) can be used to calculate and check all structural sections and, first of all, those for which outdated body measurements were used. In formula (3.7), sign "+" should be used when the body measurements of the contemporary male body bigger than the historical analogue, and sign "-" if less.

3.5. Identification of the body measurements in historical pattern

In the pattern manuals which published before the 19th century, which lack of many relevant information for pattern drafting. Although the patterns and its concrete indexes are accessible, the anthropometric features of the corresponding historical wearer are not mentioned. To optimize the virtual reconstruction of historical costume, most researchers investigated only the clothing itself without considering the vital impact of body in the virtual environment [10][18]. Thus, to precisely reconstruct the historical clothing and improve the efficiency of construction, the primary factor is the establishment of identical avatar which is consistent with the historical male body. Namely, in the virtual system "historical costume-body", the appearance, morphology, and anthropometric indicators of the reconstructed virtual avatar should be the same as the ones of the cotemporaneous European body [13].

Fig. 3.13 show the algorithm for calculating the body measurements hidden in the historical pattern.

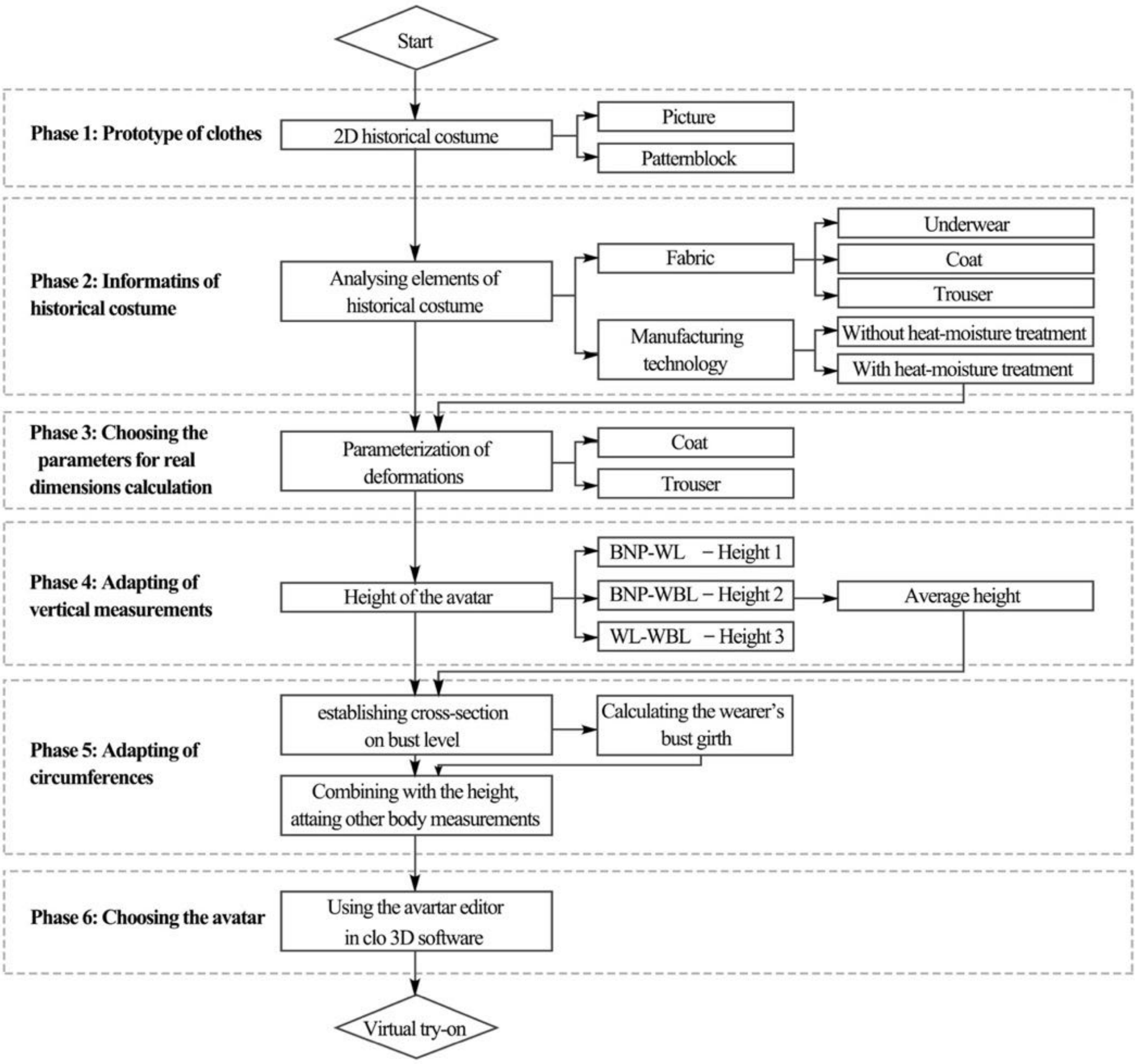
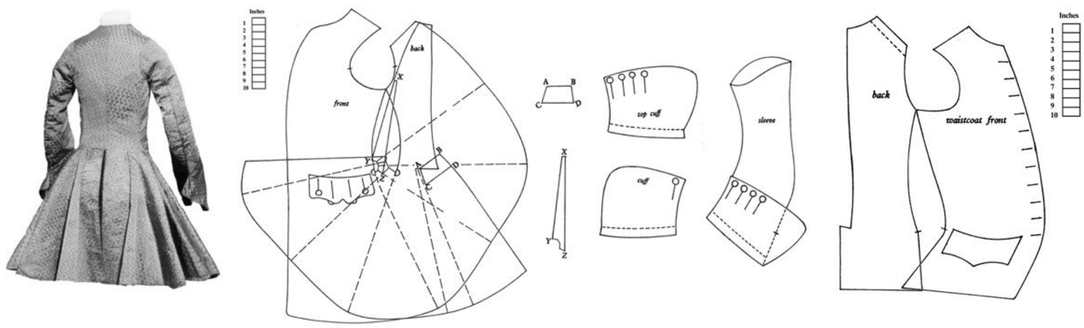


Figure 3.13 – Flowchart of the calculating the body measurements hidden in the historical pattern block

3.5.1. Object of research

In this subsection, the virtual male body of the 1740s was reconstructed by identifying the height of the body corresponding to the historical pattern. Fig. 3.14 shows caftan with a wide skirt with pleats. The folds fanned out below the waist [24]. Since the middle of the century, camisoles (vests) could be worn directly without a shirt [78]. This caftan was made of silk, brocade and damask.



a b c

Figure 3.14 – Men's caftan with a wide skirt: a – prototype of the 1740s; b – drawing of the caftan; c – drawing of the camisole (vest) [24]

3.5.2. Adapting the height of avatar in CLO 3D

Taking the 1740s' clothing as an example, algorithm for computing growth of the historical body were as follows (Fig. 3.15):

1. Mark the landmarks of BNP (back neck point), bust line (BL) and waist line (WL) on the back pattern.

2. Measure the distances from BNP to WL, from BNP to BL and from BL to WL on the pattern, respectively recorded as L1, L2 and L3.

3. Performed virtual fitting of the kaftan on the avatar in CLO 3D.

4. Measured along the surface of the kaftan distance from BNP to WL, from BNP to BL to BL and WL, respectively, written as L1', L2 ' and L3'.

5. These adjustments Rostov avatar, which are equality

$$L1 = L1', L2 = L2' \text{ and } L3 = L3'. \quad (3.8)$$

6. Calculated the average value, which would have been initially applied in the construction of the historical pattern. In this example, Hmean = 181.5 cm.

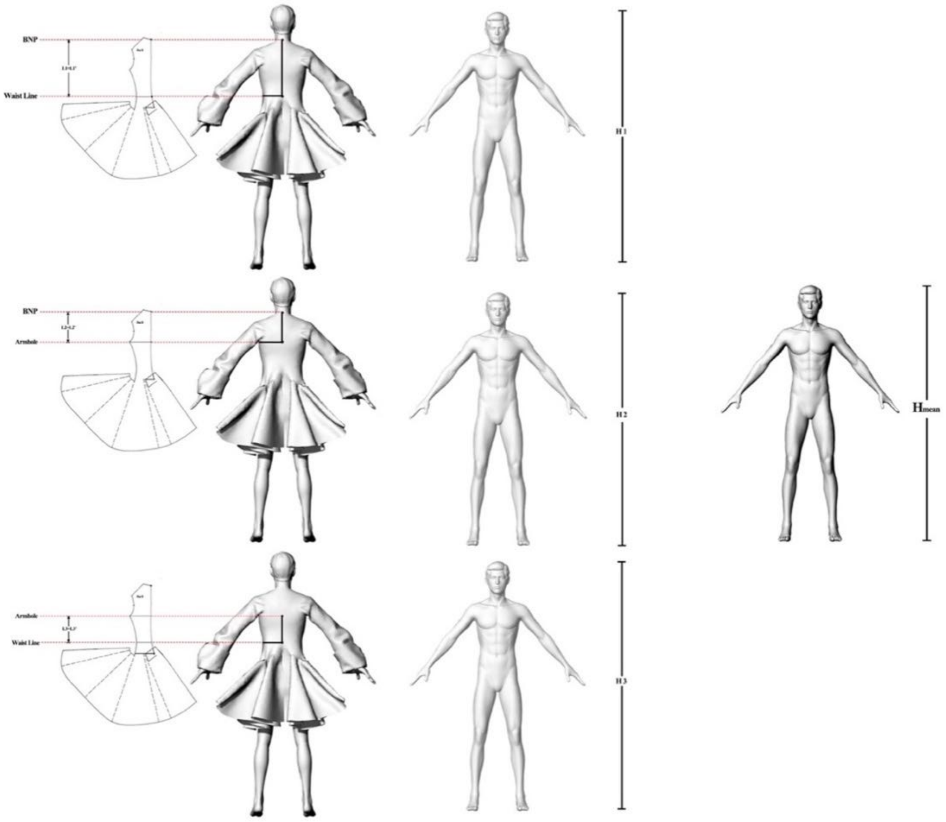


Figure 3.15 – Variants of virtual systems of a digital male body with different anthropometric data: H_1 – 180.5cm, H_2 – 183.5cm, H_3 – 180.5cm

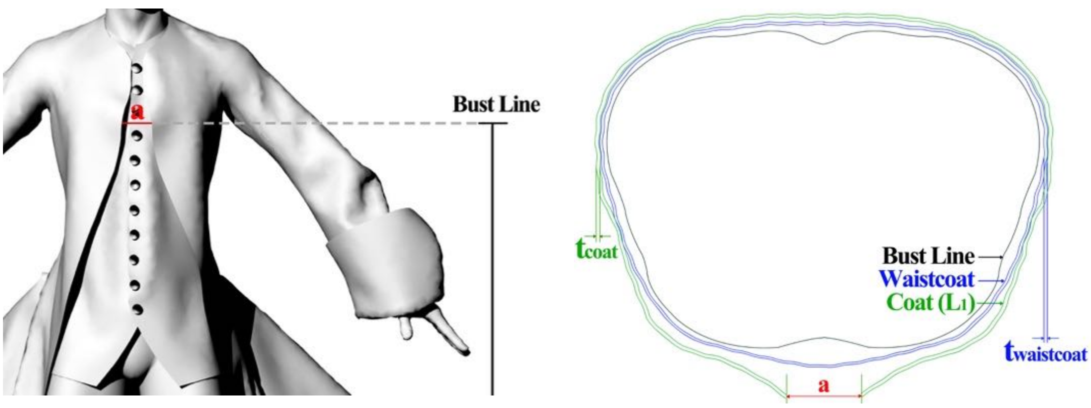
Thus, the reconstruction of the DT of the historical body was calculated based on the photograph of the HCC and pattern block of man's caftan in the 1740s (Fig. 3.16).

Figure 3.16 – DT of the male body and caftan in the 1740s

The algorithm considered on the example of this HCC was adopted as the basic one for identifying the growth of body from historical pattern.

3.5.3. Calculating the bust and waist girth of avatar

The male caftan of 1740s was reconstruted in CLO 3D with the height 181.5cm of European male avatar, was used further to identify the remaining body measurements. Fig. 3.17, a shows the upper part of its 3D image.



a b

Figure 3.17 – The scheme for calculating the bust and waist girth of the avatar: a – the image of the DT of the kaftan;
b – cross-sections at bust level

The cross-sections of the avatar and kaftan shown in Fig. 3.17, b were obtained at the chest and waist level. The historical owner's chest and waist girths were calculated using equations (3.9) and (3.10), respectively:

$$L1 = (CG - a) + 2\pi t_{(waistcoat + coat)} \quad (3.9)$$
$$L2 = (WG - b) + 2\pi t_{(waistcoat + coat)} \quad (3.10)$$

where L1 is the circumference of the caftan at bust level (indicated in green in Fig. 3.17, b); a is the distance between the edges of the sides of the caftan at bust level (indicated by the red line in Fig. 3.17); t is the thickness of the package of materials of the caftan and camisole (vest).

The measurement results in the CLO 3D software were: L1 = 97.61 cm, a = 3.78 cm, t = 0.5 cm separately. Thus, the bust girth is 98.25 cm, and the waist girth is 74.35 cm.

Thus, using the above algorithm, the values of the bust and waist girths of the DT of the historical body could be calculated based on its height.

3.5.4. Evaluation of avatar's body measurements

The avatar with the main body measurements (height 181.5 cm, bust girth 98.25 cm and waist girth 74.35 cm), reconstructed in CLO 3D, was imported into Rhinoceros. 49 body measurements were measured according to the typology of male figures accepted in Russia, as the most complete in comparison with the Chinese typology [147]. Fig. 3.18 shows the measurement schemes of the shapes in this system.

Using formulas (3.9) and (3.10), the bust and waist girths of the avatar were calculated. It can be confirmed that the morphological characteristics of this avatar correspond to the 4th full group of the typical male bodt, that is, the bust girth is between 88...104 cm.

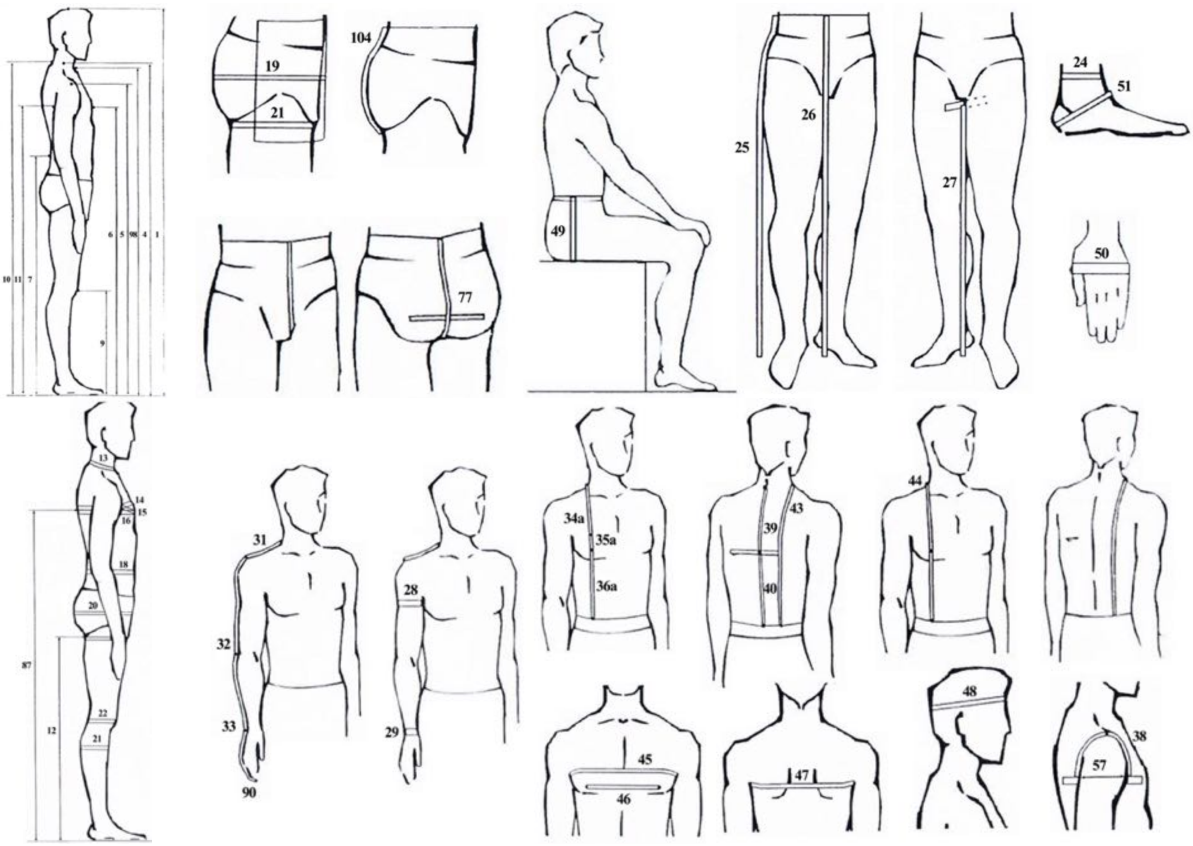


Figure 3.18 – The scheme of measuring the body measurements of male body [147]

Table 3.7 contains the results of comparison of 49 body measurements, (the designations of body measurements are shown in Fig. 3.18).

Table 3.7 – The difference between body measurements of the generated avatar in CLO 3D and typical male body, cm

No.	Measurement	Difference	No.	Measurement	Difference
1	Height	0.50	27	Crotch height	0.20
98	Neck height front	0.93	104	Waist to lower hip	-0.39
4	Neck height side	0.20	77	Crotch length	-0.70
5	Shoulder point height	-0.06	49	Distance crotch to waist	-0.10
6	Nipple point height	-3.54	28	Upper arm girth	1.12
7	Waist height	0	29	Wrist girth	0.33
9	Knee height	0	30	Hand girth	0.10
10	Neck height back	0.2	31	Shoulder width	0.35
11	Armpit height back	-0.58	32	Upper arm length to neck	5.40
87	Breast height	0	33	Arm length to neck	4.56
12	Thigh height	0.1	90	Hand length to neck	5.77
13	Neck girth	0.58	34a	Upper bust level to neck	-0.30
14	Upper bust girth	2.18	35a	Bust point to neck	-0.39
15	Bust girth (horizontal)	2.55	36a	Waist to neck front	0.50
16	Under bust girth	0.40	38	Armhole girth	0.38
18	Waist girth	-0.35	39	Neck to back width	0.04
19	Hip girth (with abdomen)	0.60	40	Neck to waist center back	0.19
20	Hip girth	0.56	43	Neck to waist back	0.08
21	Thigh girth	0.80	44	36a + 43	0.58
22	Knee girth	0.74	45	Width armpits	0.80
23	Calf girth	0.80	46	Bust points width	0.60
24	Ankle girth	0.06	47	Back width (armpit level)	0.06
51	Foot girth	0.20	57	Arm diameter (armpit level)	0.37
25	Side seam 3D waistband	0	48	Head circumference	0.23
26	Waistband front height	0			

As shown in Table 3.7, the large variation for only five measurements, and were mainly related to the upper extremities. It was also found that five traits are identical, with minor differences for 39 traits, but they do not exceed half of the indifference interval for these traits in modern Russian typology. It is shown that it is possible to accurately generate an avatar with the main measurements of historical body and additional features of typical body, which is necessary for further parametric analysis of historical pattern.

3.6. Graphic reconstruction of technological methods of shaping, projected in historical pattern

In this section, the method of transformation of technological techniques for shaping clothing sections when performing heat - moisture treatment of clothing parts and assemblies, developed by A. Yu. Moskvin [149].

3.6.1. Pattern preparation

In parallel with the selection of patterns, the main coat styles were studied for the subsequent grouping and selection of typical pattern of each style. Fig. 3.19 shows five variants of the coat style solutions.

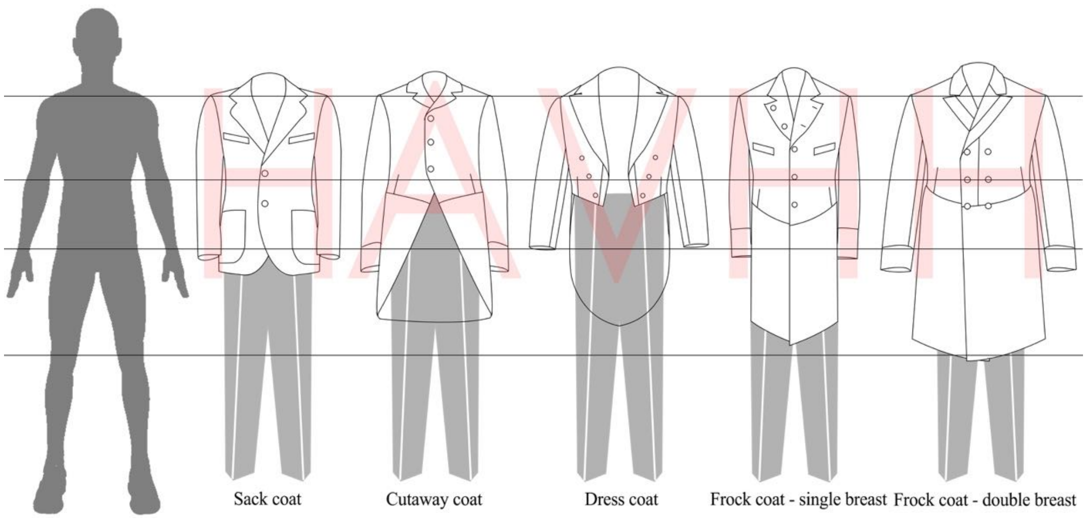


Figure 3.19 – Technical drawings of coat options

Sack coat also named lounge jacket, H type, which was an informal garment. Notched collar with lapels, with or without pocket flaps, length was reached above the thigh. This type of coat has become the dominant style of menswear in nowadays.

Cutaway frock also named morning coat or riding coat, A type, less formal than frock coat because it used the sloping front edges replace the straight front cut. Cutaway frock has narrow sleeves with cuffs.

Dress coat, V type, which was the prior garment for evening. It was cropped horizontally along the waist level in the front and tails to the back of knee. The front was always open to display the shirt, cravats and waistcoat.

Frock coat - single breast, H slim silhouette, had a suitable body extending to the bottom of skirt that generally above the knee. The special features were stand or revers collars and small dart seamed at waist level called "fish".

Frock coat - double breast, H type, retained stiffened and high waist, the body part looks similar with the military coats and the skirt was long and slight loose fitting [24, 25].

For Simulating of historical clothing, digitized patterns that can be edited in CAD environmen was needed [3].

Since the mid-nineteenth century, tailors have created a huge number of patterns, including various measurement methods, body measurements, pattern drafting based on scaling, proportionation, and the use of special techniques. Based on the pattern cutting methods published from 1891 to 1913 [43, 82, 83, 87, 88, 93, 94, 100], 47 objects were selected for parameterization (17 cutaway, 11 tailcoats and 19 frock coats) has been drawn for parameterization in total. According to the explanation of pattern cutting methods, the following original information has been collected:

- cut system (sizing system, method of measuring, content and condition of measuring, body measurements);

- pattern blocks;

- complete pattern drafting algorithm;

- methods of clothing shaping during pattern block drafting and its manufacturing.

3.6.2. Parameterization of pattern block

After drafting the patterns in 1:1 scale in CAD, three groups of parameters were chosen for measuring:

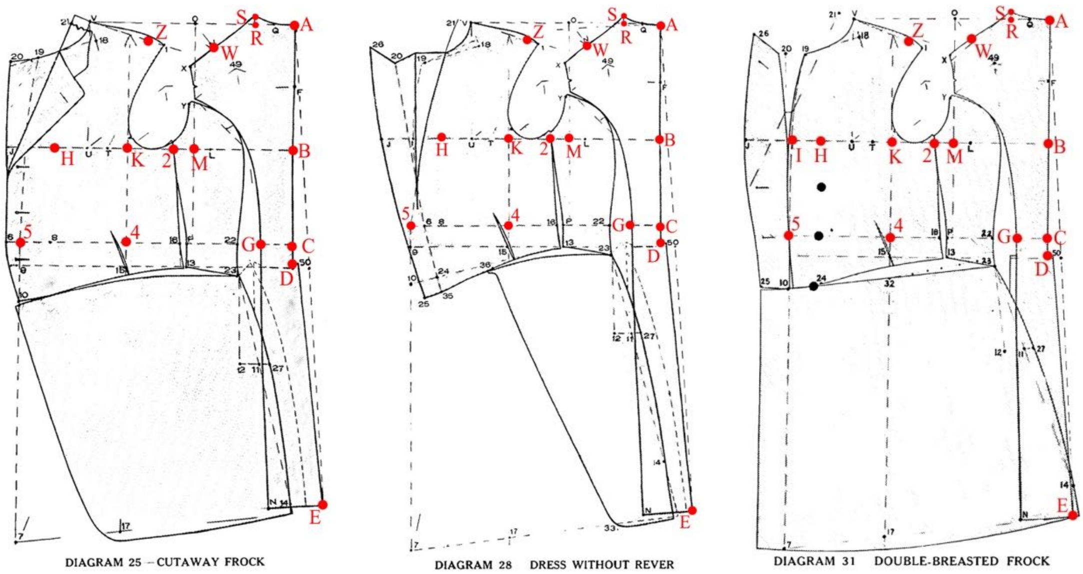
1. For finding out the relationship between pattern block parameters, body measurements and ease allowance in accordance with the full algorithm of pattern block drafting: depth of arm scye /A-B/, back length /A-C/, back width /B-M/, and position of fashion waist /A-D/, etc. should be measured (Fig. 3.20);

2. For determine the body measurements (chest girth and waist girth) of the wearer: /B1+B1+B3/, /W1+W2+W3/ (Fig. 3.21);

3. For calculating the deformation of sewing edge under heat-moisture treatment: the length of each pair of seam lines (a & b, c & e1, r1 & r2, etc.) should be measured (Fig. 3.21).

Exploration for 1st groups of parameters

Based on the original database, the body measurements were measured and full algorithm of pattern block drafting have been collected. The relations that existed between the parameters of the historical pattern, the ease allowance and the body measurements of the real owner were calculated. Fig. 3.20 shows examples of three patterns of different styles (cutaway coat, tailcoat, frock coat) with the same size characteristics, respectively. The patterns were selected from manuals published by L. Gibson, E. L. Streiff, S. S. Gordon, J. J. Mitchell. Co., and N. Holmes [93, 94, 100, 83, 88, 2].



a b c

Figure 3.20 – Diagrams of patterns of men's coat:
a – cutaway coat; b – dress coat; c – frock coat

Table 3.8 shows the equations relating to the three style coats.

Table 3.8 – Relationship between pattern block parameters, body measurements and ease allowance, cm

Item	Measurement	Relations	Item	Measurement	Relations
AB	Depth of scye + ease	CG/6 + 8.89	BK	Blade + ease	Blade + 3.18
AC	Position of natural waist (back length)	H/4 + 0.64	BM	(Blade width + ease)/2 + ease	(Blade width + 3.18)/2 + 3.18
AD	Position of fashion waist	H/4 + 3.81	B~2	-	CG/4
AE	Full length	-	BH	-	CG/2
AR	-	CG/24 + 3.81	HI	Ease	5.72
SR	Depth of neckline	CG/16 – 1.63	GC	CG/32 + ease	CG/32 + 3.18
BW +K	Over shoulder distance + ease	Over shoulder + 2.54	4~5	-	WG/4

Note. CG-chest girth, WG-waist girth, H-height, natural waist - the length of the back neck point to the waist, the fashionable waist is usually lower than the natural waist by 3.17 cm.

Due to the difference between the styles of men's clothing, the increases in chest width and waist were different in several patterns. The difference in chest width ranged from 0.64 to 2.54 cm [43, 87].

Exploration for 2nd groups of parameters

Fig. 3.21 shows the scheme of parameterization of the patterns (cutaway coat, dress coat, frock coat and sleeve).

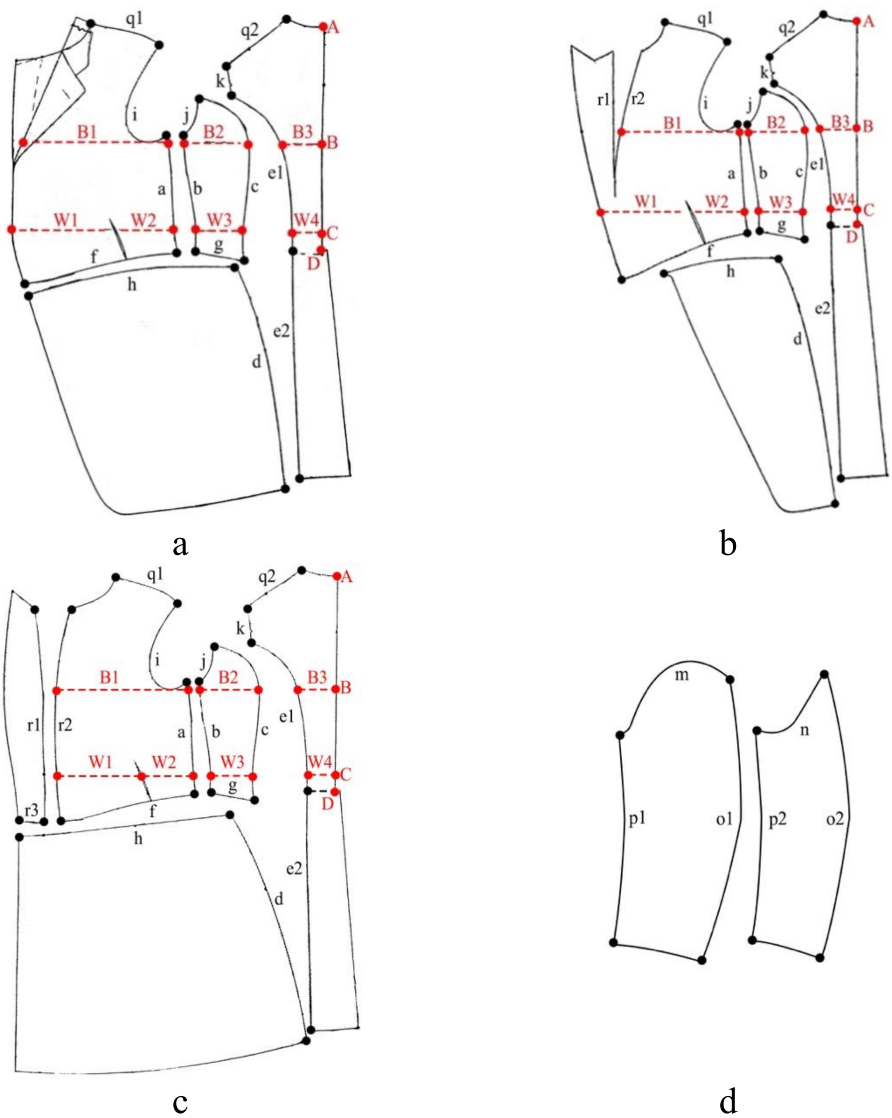


Figure 3.21 – Scheme of pattern blocks measurements of men’s coat:
a – cutaway coat; b – dress coat; c – frock coat; d – sleeve

(/B1+B1+B3/, /W1+W2+W3/) were measured in CAD. These data help to find the appropriate wearer’s body measurements for the XIX century patterns or real prototypes without sufficient initial information in next way:

1. Determine the coat style of pattern or real prototype;

2. Measure the length of natural waist and fashion waist of the pattern or real prototype, calculate the wearer's height according to the relations in Table 3.8;

3. Generate avatar according to according to subsection 3.5.3;

4. Determine the chest and waist girth of the potential owner according to the width of the patterns along the chest and waist of the patterns

The results was shown in Table 3.9 to Table 3.11.

Table 3.9 – The ease between the chest and waist girths of the reconstructed avatars and the width of the patterns along the chest and waist lines for 17 cutaway coats

<table>
<tr><th rowspan="2">No. of pattern</th><th colspan="2">Body measurements, cm</th><th colspan="2">Pattern parameters, cm</th><th colspan="2">Average value of the ease in girth</th></tr>
<tr><th>Chest girth</th><th>Waist girth</th><th>Chest width 2/B1+B1+B3/</th><th>Waist width 2/W1+W2+W3/</th><th>Chest</th><th>Waist</th></tr>
<tr><td>46</td><td rowspan="2">86.36</td><td rowspan="2">76.2</td><td>98.16</td><td>86.24</td><td rowspan="2">11.12</td><td rowspan="2">9.8</td></tr>
<tr><td>47</td><td>96.8</td><td>85.76</td></tr>
<tr><td>1</td><td rowspan="6">91.44</td><td rowspan="6">81.28</td><td>101.04</td><td>91.62</td><td rowspan="6">13.37</td><td rowspan="6">13.73</td></tr>
<tr><td>19</td><td>101.44</td><td>91.38</td></tr>
<tr><td>26</td><td>112.88</td><td>101.26</td></tr>
<tr><td>35</td><td>105.22</td><td>94.5</td></tr>
<tr><td>44</td><td>104.5</td><td>97.52</td></tr>
<tr><td>45</td><td>103.8</td><td>93.76</td></tr>
<tr><td>28</td><td rowspan="2">99.06</td><td rowspan="2">88.9</td><td>102.68</td><td>96.32</td><td rowspan="2">7.39</td><td rowspan="2">7.32</td></tr>
<tr><td>36</td><td>110.22</td><td>96.12</td></tr>
<tr><td>14</td><td rowspan="4">101.6</td><td rowspan="4">88.9</td><td>111.4</td><td>103.52</td><td rowspan="4">13.16</td><td rowspan="4">18.19</td></tr>
<tr><td>16</td><td>115.08</td><td>105.74</td></tr>
<tr><td>23</td><td>119.06</td><td>119.56</td></tr>
<tr><td>41</td><td>113.48</td><td>99.52</td></tr>
<tr><td>2</td><td>106.68</td><td>102.87</td><td>127.38</td><td>119.82</td><td>20.7</td><td>16.95</td></tr>
<tr><td>3</td><td>114.3</td><td>115.57</td><td>127.32</td><td>122.72</td><td>13.02</td><td>7.15</td></tr>
<tr><td>33</td><td>111.76</td><td>101.6</td><td>123.56</td><td>105</td><td>11.80</td><td>3.4</td></tr>
<tr><td colspan="5">Average eases</td><td>12.94</td><td>10.93</td></tr>
</table>

Table 3.10 – The ease between the chest and waist girths of the reconstructed avatars and the width of the patterns along the chest and waist lines for 11 dress coats, cm

No. of pattern	Body measurements, cm		Pattern parameters, cm		Average value of the ease in girth	
	Chest girth	Waist girth	Chest width 2/B1+B1+B3/	Waist width 2/W1+W2+W3/	Chest	Waist
4	91.44	81.28	101.4	91.62	12.06	9.06
5			98.66	84.14		
22			109.88	99.22		
25			107.68	92.68		
34			99.86	84.04		
30	99.06	91.44	110.14	98.82	11.4	9.01
31		83.82	111.44	98.88		
40		91.44	109.8	96.04		
15	101.6	88.9	112.28	98.9	11.35	10.46
18			113.62	99.82		
6	106.68	102.87	113.16	109.18	6.48	6.31
Average eases					10.32	8.71

Table 3.11 – The ease between the chest and waist girths of the reconstructed avatars and the width of the patterns along the chest and waist lines for 19 frock coats, cm

No. of pattern	Body measurements, cm		Pattern parameters, cm		Average value of the ease in girth	
	Chest girth	Waist girth	Chest width 2/B1+B1+B3/	Waist width 2/W1+W2+W3/	Chest	Waist
7	91.44	81.28	103.88	92.44	12.81	11.8
8			102.52	92.1		
10			99.32	84.46		
11			102.38	91.52		
12			106.32	96.24		
13			101.78	91.12		
20			104.46	95.44		
21			109.88	99.22		
24			108.2	96.54		
38			103.8	91.72		
29	93.98	86.36	106.18	95.38	10.49	10.38
32		81.28	102.76	93.02		
42	96.52	81.28	110.34	91.14	13.82	9.86
27	99.06	88.9	103.64	101.46	6.62	11.04
39		81.28	107.72	90.8		
17	101.6	88.9	116.6	106.52	12.49	12.56
37		99.06	113.3	110		
43		91.44	112.38	100.56		
9	106.68	102.87	112.48	107.46	5.8	4.59
Average eases					10.34	10.04

Exploration for 3rd groups of parameters

The differences between each pair of sewing seam lines (a & b, c & e1, r1 & r2, etc.) for the selected coat styles were calculated to determine the projected deformations. The results are shown in Table 3.12 to Table 3.14. Detail information in Appendix C.

Table 3.12 – Differences between each pair of sewing seam line for 17 cutaway coats

No. of pattern	The difference between the lengths of each pair, cm, for shaping							
	Under the armhole on the bulge of the chest	On the back in the area of the shoulder blades	On the skirt in the buttock area	On the front along the waist seam	On the sleeve edge	Along the front sections	Along the elbow sections	Along the shoulder sections
	a-b	c-e1	d-e2	h-(f+g)	(m+n)-(i+j+k)	p1-p2	o2-o1	q2-q1
1	0.73	2.1	-0.05	0.76	3.16	0.01	0.32	-2.43
2	0.44	2.48	0.28	-1.81	1.74	0.11	0.35	0.78
3	1.19	2.64	0.09	-1.38	2.13	0.11	0.35	1.04
14	0.12	2.48	0.97	-1.24	2.06	0.01	0.32	-0.11
16	-0.29	2.42	0.52	-1.26	1.52	0.05	0.37	0.27
19	0.67	1.54	-0.04	0.46	2.13	0.11	0.37	1.23
23	0.52	2.18	0.36	-0.56	1.57	0.05	0.34	0.44
26	-0.08	0.55	0.57	1.68	1.73	0.05	0.37	-0.14
28	0.35	1.2	0.09	-0.48	1.83	0.1	0.35	0.93
33	1.85	1.85	0.16	3.81	1.59	0.05	0.37	1.49
35	-0.09	1.78	0.48	0	1.82	0.05	0.34	-0.22
36	-0.1	2.24	-0.03	0.02	1.61	0.04	0.37	-0.03
41	0	2.26	0.1	-3.42	1.59	0.01	0.32	-0.27
44	-0.14	1.97	0.4	-2.2	2.17	0.05	0.34	-0.43
45	0.02	1.12	-0.2	-0.32	2.64	0.01	0.32	-0.13
46	0.01	1.62	0.55	2.11	2.13	0.11	0.35	-0.22
47	1.5	1.65	1.38	0.14	3.07	0.1	0.37	0.11
Average deformations	0.39	1.89	0.33	-0.22	2.02	0.06	0.35	0.14

Table 3.13 – Differences between each pair of sewing seam line for 11 dress coats

No. of pattern	The difference between the lengths of each pair, cm, for shaping								
	Under the armhole on the bulge of the chest	Under the armhole on the bulge of the chest	Under the armhole on the bulge of the chest	Under the armhole on the bulge of the chest	Under the armhole on the bulge of the chest	Under the armhole on the bulge of the chest	Under the armhole on the bulge of the chest	Under the armhole on the bulge of the chest	On the edge of the board
	a-b	c-e1	d-e2	h-(f+g)	(m+n)-(i+j+k)	p1-p2	o2-o1	q2-q1	r2-r1
4	0.95	2.16	0.57	-	2.35	0.01	0.32	0.7	-
5	0.89	2.19	0.58	0.48	2.79	0.01	0.32	0.7	1.59
6	0.63	1.56	0.51	-	2.6	0.05	0.37	0.95	-
15	0.63	2.68	0.71	0.13	1.62	0.01	0.32	-0.3	-
18	-0.19	2.08	1.24	-0.79	1.74	0.05	0.37	0.79	
22	0.33	1.68	0.56	-0.32	1.63	0.11	0.35	0.95	-0.36
25	0.07	0.32	0.34	1.02	2.16	0.05	0.37	0.94	0.91
30	-0.08	0.8	0.06	0	1.63	0.11	0.35	0	0.59
31	0.05	0.79	0	0.51	2.02	0.05	0.37	-0.14	-
34	0.57	0.64	0.37	0.09	2.34	0.1	0.37	0.33	1.45
40	-0.09	1.55	0.08	0.38	1.62	0.01	0.32	-0.16	0.36
Average deformations	0.34	1.50	0.46	0.17	2.05	0.05	0.35	0.43	0.76

Table 3.14 – Differences between each pair of sewing seam line for 19 frock coats

No. of pattern	The difference between the lengths of each pair, cm, for shaping								
	Under the armhole on the bulge of the chest	Under the armhole on the bulge of the chest	Under the armhole on the bulge of the chest	Under the armhole on the bulge of the chest	Under the armhole on the bulge of the chest	Under the armhole on the bulge of the chest	Under the armhole on the bulge of the chest	Under the armhole on the bulge of the chest	Under the armhole on the bulge of the chest
	a-b	c-e1	d-e2	h-(f+g)	(m+n)-(i+j+k)	p1-p2	o2-o1	q2-q1	r2-r1
7	0.54	2.62	0.35	0.72	1.59	0.01	0.32	-0.17	0.03
8	0.53	2.07	0.59	-0.05	1.73	0.01	0.32	-0.25	-
9	0.92	1.71	0.47	-0.42	1.82	0.05	0.37	1.29	-0.02
10	0.99	1.9	0.7	1.24	1.9	0.05	0.34	0.23	0.41
11	0.6	2.49	-0.06	0.3	2	0.01	0.32	0.08	-
12	1.12	1.58	0.78	1.22	1.61	0.11	0.25	0.65	0.1
13	0.73	2.51	0.14	0.77	2.71	0.01	0.32	-0.07	0.06
17	-0.21	2.61	0.78	0	1.74	0.11	0.25	0.6	0.04
20	0.15	-0.33	0.66	0.39	1.83	0.11	0.35	0.94	-
21	0.37	0.04	0.8	-0.33	2	0.01	0.32	0.73	-0.09
24	0.04	0.37	0.91	1.71	2.01	0.05	0.37	-0.1	0.34
27	0.43	1.19	0.76	2.58	1.61	0.05	0.34	0.73	1.38
29	-0.12	1.19	1.82	-0.15	2.01	0.01	0.32	0.03	-
32	1.37	1.41	0.25	0.11	2.3	0.05	0.34	0.84	1.72
37	0.04	1.55	0.64	0.18	1.61	0.05	0.34	-0.29	-
38	-0.09	1.28	0.15	0	1.94	0.05	0.34	-0.29	-0.17
39	-0.13	2.46	1.04	-0.04	1.71	0.01	0.32	-0.19	-0.33
42	-0.14	1.77	1.3	1.05	2.28	0.01	0.32	-0.22	-0.16
43	0.01	1.67	0.77	-0.39	2.03	0.04	0.34	0	0.16
Average deformations	0.38	1.58	0.68	0.47	1.92	0.04	0.33	0.24	0.25

These results will be useful for analyzing and correcting patterns, equalizing the length of each paired seam line by making darts. For example, a seam line that is longer should be deformed, using dart to shorten it during virtual reconstruction.

3.6.3. An example of using the databases

The pattern block of frock coat was selected for virtual reconstruction in software CLO 3D 6.0 as an example of results application. Men's suit with modified frock coat which was adjusting the suture lines by making darts was simulated. Fig. 3.22 shows the original and modified screenshot of the pattern, as well as DT of the coats generated from different patterns.

Figure 3.22 – Get DT of men's coat: a – original image [148]; b – original pattern; c – modified pattern for virtual try-on; d – DT of original coat without adjusting the suture lines; e – DT of coat, generated according to the modified pattern; f – combined the contours of DT

To prove the higher accuracy of the modified coat, the silhouettes of the coats were compared, which were reconstructed in two ways (Fig. 3. 22, f).

The selected photo of real man's coat of the XIX century, has the same style as the reconstructed DT, as shown in Fig. 3.22, a. To check the correspondence between real and virtual DT, the avatar was generated in the same pose as in the photo. Compared to the DT of the coat generated from the original patterns (Fig. 3.22, b, d), the modified DT (Fig. 3.22, c, e) has a better structure: the collar fits more tightly to the neck, the seam between the upper front part and the skirt of the coat is smoother, it fits more tightly to the figure. Thus, the new approach turned out to be quite effective.

Examples of the application of the developed methods and databases are also used in the reconstruction of European men's suits in subsection 5.5 and Appendix B.

Conclusion after Chapter 3

1. A new method for reconstructing the patterns of the details of the historical men's clothing has been developed. This method does not damage the HCC.

2. Algorithms for generating DT of a historical male body and finding the thickness of a package of textile materials for wearable clothing have been developed.

3. Databases of ease allowances to the body measurements used for the construction of 47 patterns of coats are developed, and an algorithm for their recalculation in the reconstruction of coats to modern body of other dimensional variants is proposed.

4. A method and algorithm for identifying the initial body measurements of the male body according to the historical pattern, taking into account the pattern parameters, the thickness of materials, and air gaps were developed.

5. In the future, the avatar will be formed in other software like Optitex, MakeHuman, etc. and make comparisons. The changeable morphology of virtual avatar will be considered when the corset is worn. This research proposed and validated the method of obtaining body measurements from pattern blocks and picture of historical costumes and virtual try-on technologies.

6. A method for obtaining DT of men's coat was developed, based on measurements of historical body, pattern systems, design and shaping of clothing in the production process.

CHAPTER 4. TECHNOLOGY OF GENERATING DIGITAL TWINS OF HISTORICAL CLOTHING WITH THE HELP OF REVERSING ENGINEERING

Historical costume in the form of preserved rarities, drawings, photographs, and diagrams of drawings is an inexhaustible source for finding new and adapting time-tested artistic and design-technological solutions to the possibilities of modern design [149]. The new form of historical costume is a symbiosis and synergy of several factors: the morphology of human body - original or changed to a fashionable standard; the design of the costume; a special configuration of drawings parts; the textile materials used, including the completeness of the underlying layers of clothing; manufacturing methods; the manner of wearing [150]. When reconstructing historical costume, according to the goal setting and expected results, information about all or part of the factors are used. The source database of historical data may include existing systems of dimensional features [151], drawings or diagrams of structures [152], realistic images or photographs [153].

In order to generate high-precision DT of the HCC, at least three kinds of information about the following components are required: the body, textile fabrics, and the structural arrangement of the suit. Such information can be obtained based on 3D real HCC, 2D image of the HCC, or pattern. However, for different research objects, the amount of information which could be get is completely different. The amount of information obtained after analyzing the 3D real HCC is the most, followed by 2D image of HCC, pattern at the least. In addition, three objects also different themselves. For example, few 3D real HCC which saved completely, not only can show real costume, but also dummy which is same as history human body; some 2D image of HCC was black-white, some was colorful; some pattern do not cotain information about the technology of sewing.

In this chapter, the concept of the technology for generating digital twins of components and HCC as a whole is formulated using the previously obtained results:

- graphic structure of men's clothing worn simultaneously in the late XIX - first half of the XX centuries for HCC of various purposes (subsection. 2.3);

- database of ease allowance for shaping men's historical coat in the late XIX - early XX centuries. (subsection. 3.4.1),

- database of anthropometric data on the historical fashionable male body deformed by a corset (subsection. 2.2);

- method of identification of the size accessories, the hidden projected design and technological techniques in the historical pattern of men's coat (subsection. 3.4.2 and 3.6);

- method of generating avatars by using the body measurements which calculated from the pattern (subsection. 3.5);

- method of non-contact measuring in virtual environment of the textile materials thickness belonging to several types of clothing worn simultaneously, taking into account the air layers between each other (subsection. 3.3);

- algorithm for recalculating the ease allowance in historical pattern into similar ease for constructing pattern on modern body (subsection. 3.42).

The technology for generating DT of HCC by using reverse engineering includes four algorithms:

1) getting DT of historical body;

2) obtaining DT of the textile material;

3) obtaining DT of HCC;

4) assessing the accuracy and complexity of obtaining DT of HCC.

The results obtained in this Chapter was published in three papers [164-165].

4.1. Algorithm for obtaining digital twin of historical body

Fig. 4.1 shows the flowchart of the developed method for reconstructing the historical male figure.

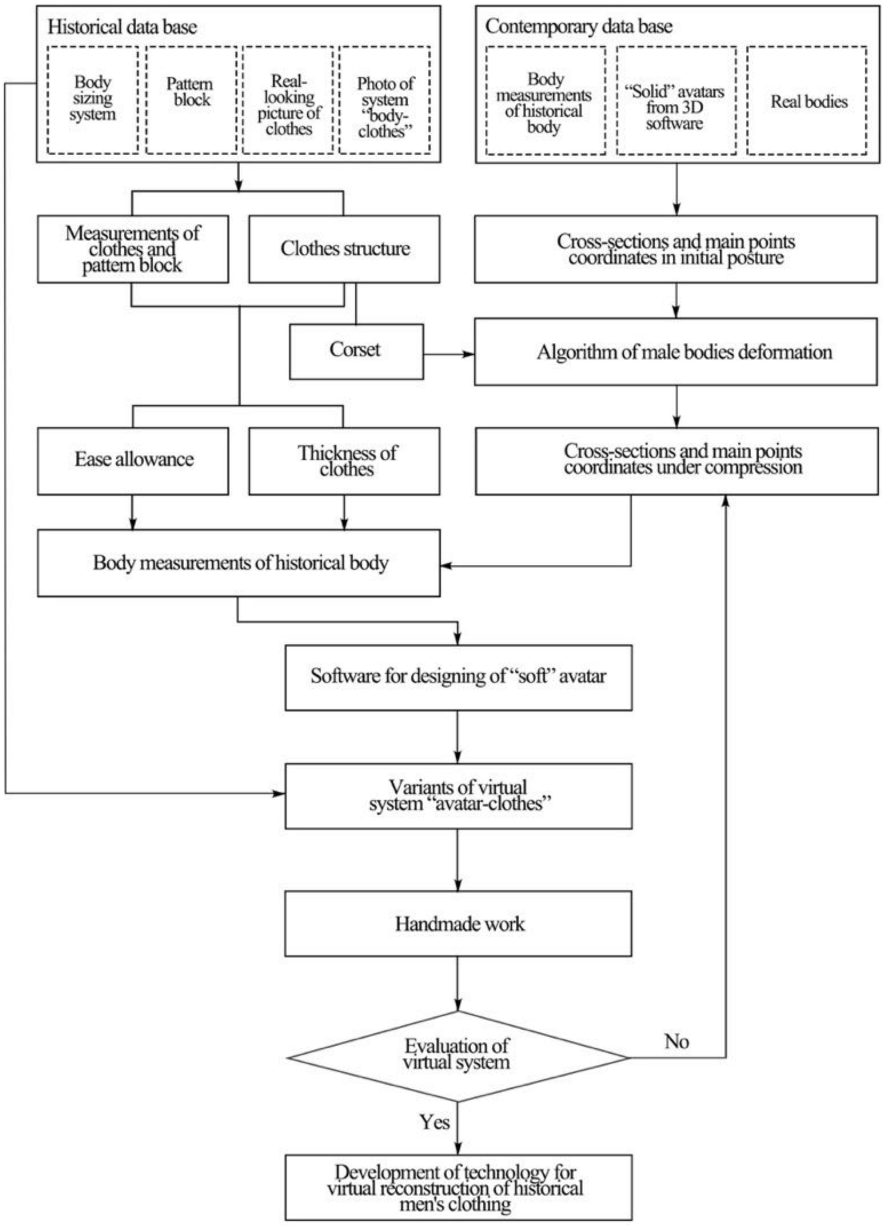


Figure 4.1 – Algorithm for generating digital twin of historical male body

Fig. 4.1 shows the steps for generating digital twin of historical body, the relationship between all sources of information, and the technological means of research for the detailed collection of data about the historical body.

One of the main factors for building DT are the results of anthropometry male body influenced by the historic corset for change in the plasticity of the body. For the virtual visualization of historical clothing, the modern solid-state digital counterparts of the real body can not be use derectly. Digital twin of the historical body should be soft, as in different historical periods, men corrected the plastic of their torso with corsets. As shown in subsection 2.2, to study the compression effect of the corset on the plastic of the male body, an adequate number of young men were measured using a Human Solutions Scanner (Germany) and an anthropometric database was created to convert solid-state avatars into soft digital models. A method of sequential approximation to the true height based on the dimensional characteristics of "back to waist length" and its derivatives is proposed and developed.

The collection of information about historical body includes the analysis of three possible situations, depending on the type of initial information about the HCC - the material fully or partially preserved, its visual image and patterns of the structures of the parts (usually from the main material). Fig. 4.2 shows the results - the proportions of the body, the maximum possible set of body measurements, the values of the deformation of the body by the dummy, available after analyzing the options presented by the HCC.

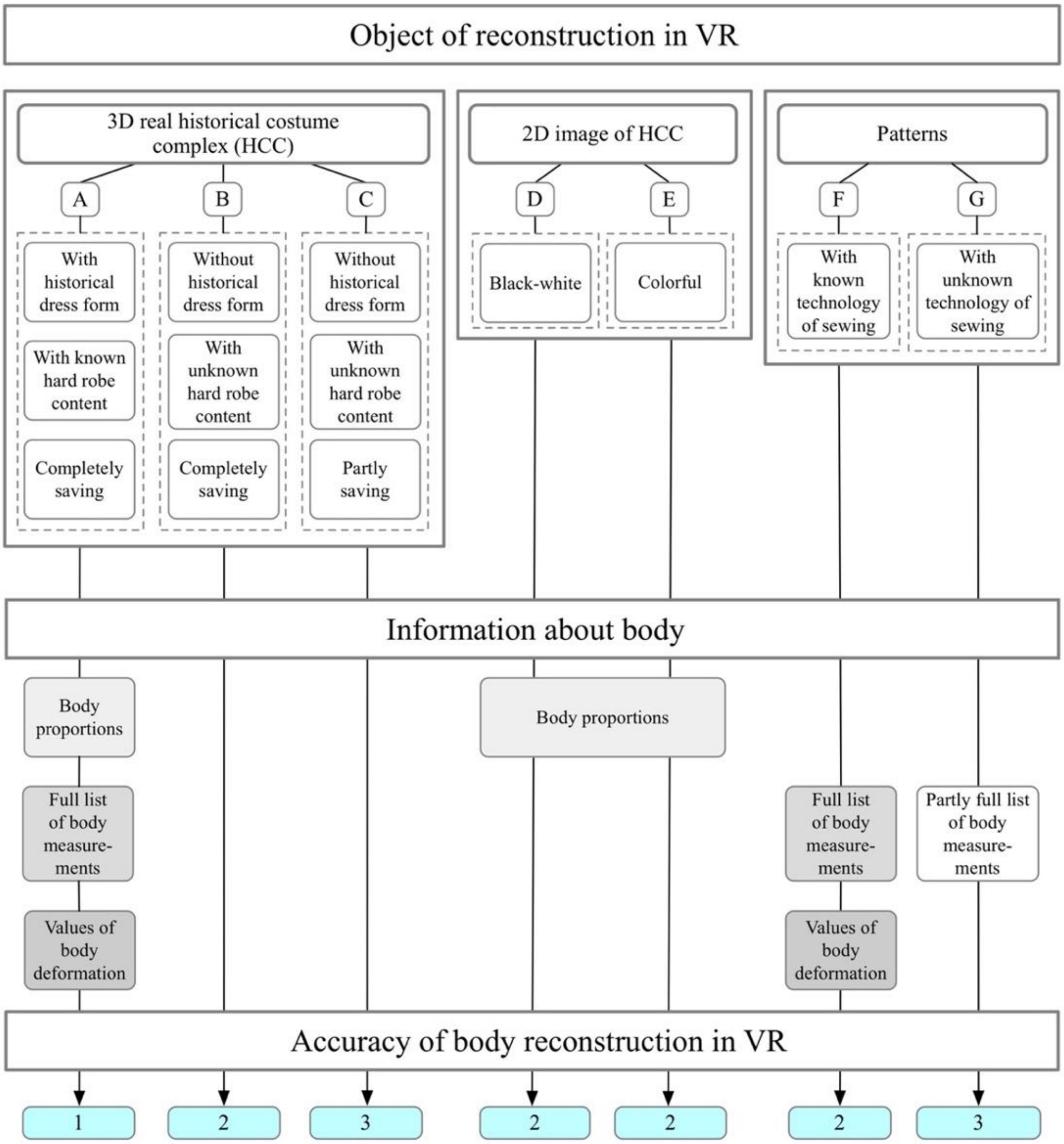


Figure 4.2 – Information for body reconstruction and DT generation

In the lower part of Fig. 4.2, a three-level point scale is formulated, which can be used to evaluate the three levels of accuracy of the virtual reconstruction of the BODY in which: 1 - best, 2 - normal, 3 - worst. The assessment can be obtained by objective and subjective methods, in particular, using the neuropsychological method of eye tracking.

4.2. Algorithm for obtaining digital twin of textile fabrics

The textile fabrics database includes information about historical textile fabrics from published works. In order to reconstruct the texture of historical material in a virtual environment with maximum realism, it is necessary to provide detailed information about their characteristics, since in 3D CAD, quantitative information about physical and chemical properties, such as stiffness, bending ability, linear density, etc., is needed to generate digital twin. To obtain DT, a new approach which can be implemented to select modern analogues of historical fabric that are closest to historical ones, and parallel selection of analogues from the CLO 3D library.

Fig. 4.3 shows the algorithm for obtaining information from different sources to generate the data center of textile fabrics.

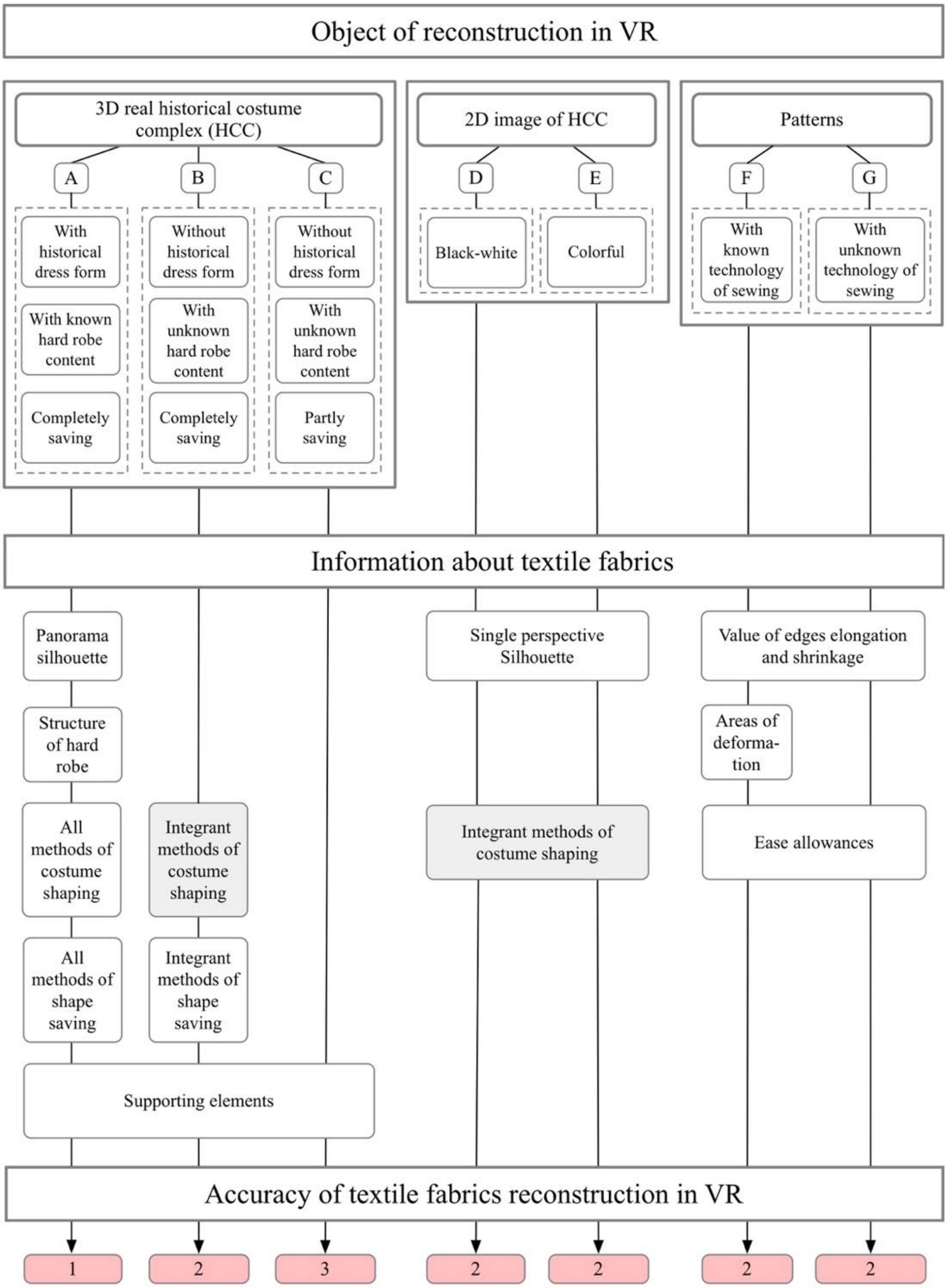


Figure 4.3 – Information for textile fabrics reconstruction and DT generation

4.3. Algorithm for obtaining the digital twin of the HCC

The algorithm is shown in Fig. 4.4.

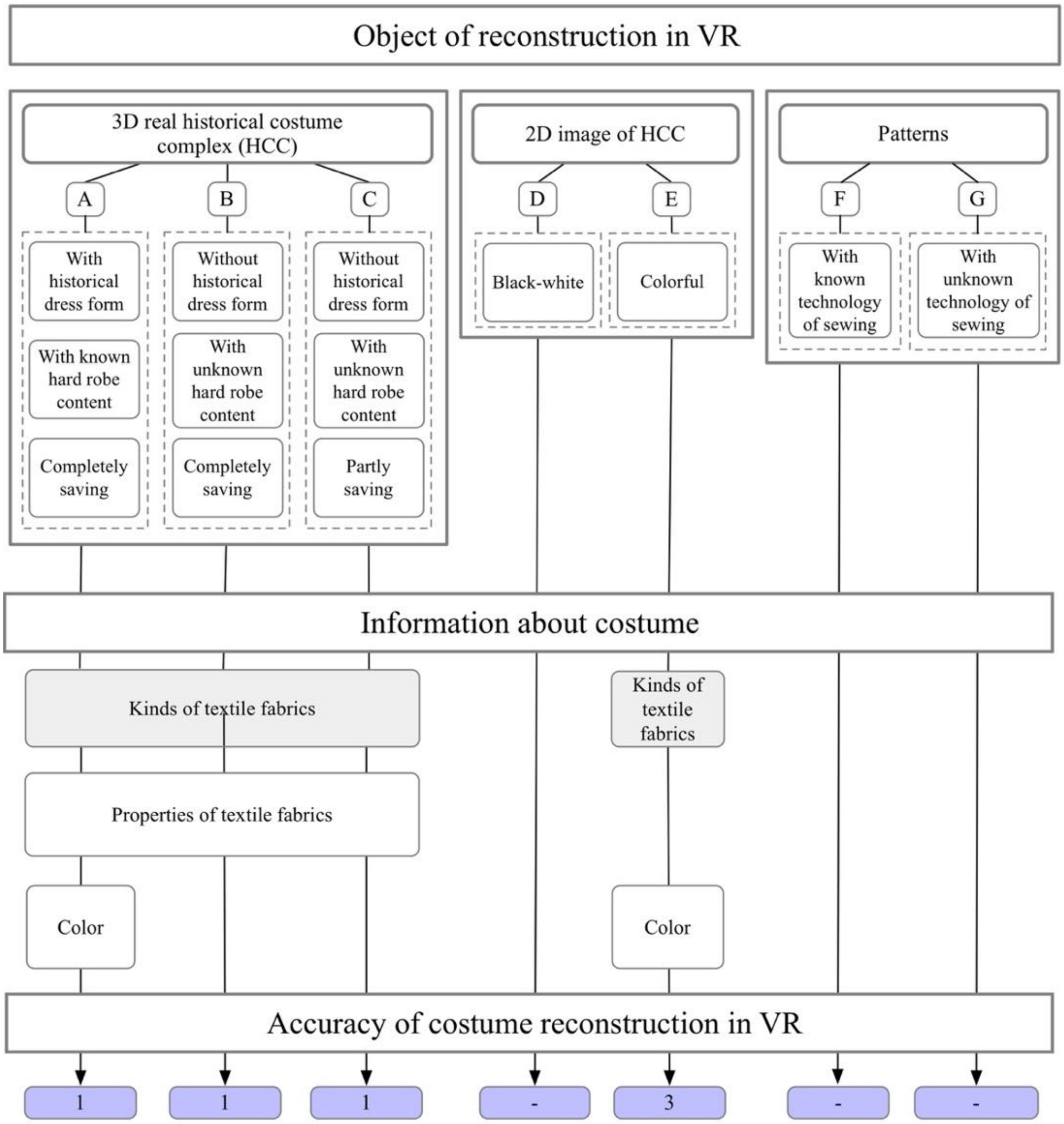


Figure 4.4 – Information for costume reconstruction and DT generation

When reconstructing historical clothing in accordance with the goal setting and expected results, the above information about all components should be used (Fig.4.1 – 4.3).

4.4. Algorithm for estimating the accuracy and complexity of obtaining the DT of the ICC

Fig. 4.5 shows the scheme for evaluating the accuracy of the generated DT of the HCC and the necessary technological support.

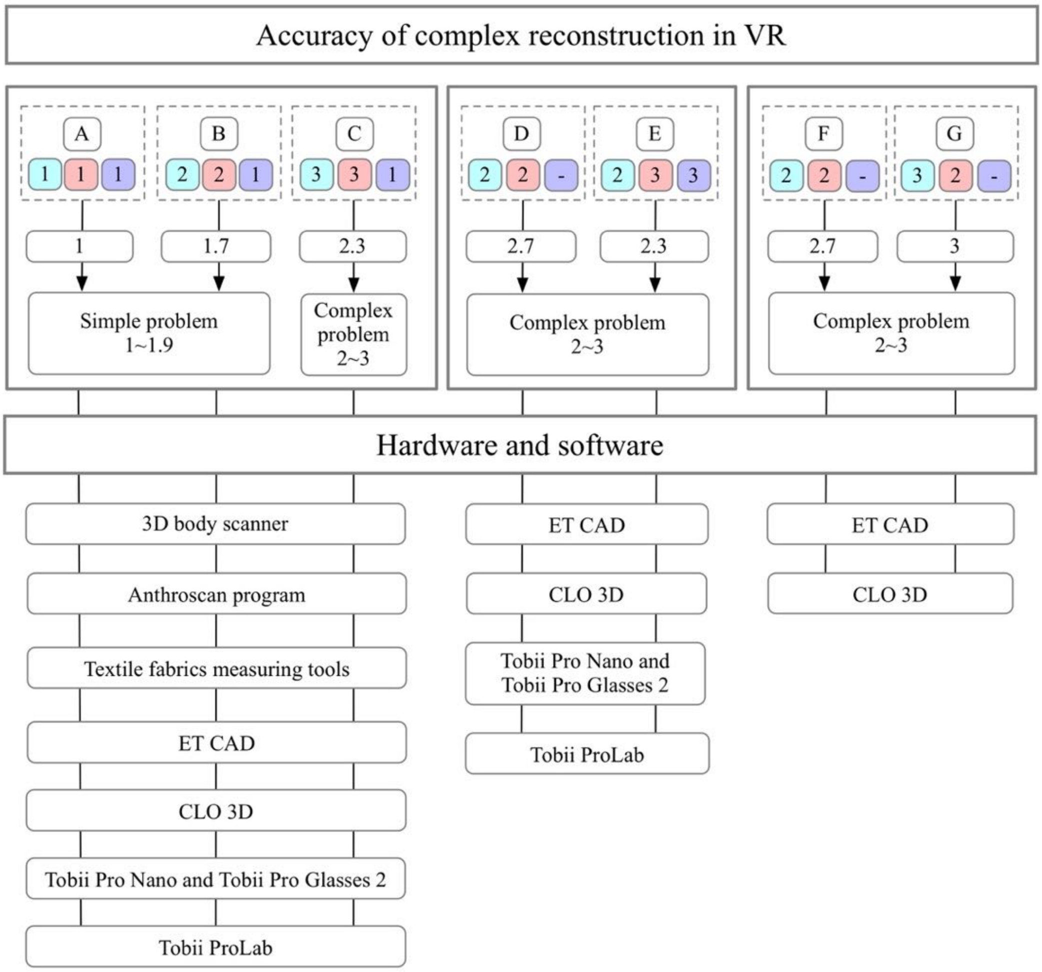


Figure 4.5 – Hardware and software for evaluating the accuracy of HCC reconstruction

The A, B, C, D, E, F, G denote the same types of HCC or visual images that can serve as sources of information. After generating the DT of the body and textile fabrics and their synthesis in the DT of the HCC, the level of complexity of the solved problem can be expressed quantitatively, as shown in Table 4.1.

Table 4.1 – Different reconstruct conditions and difficulty levels based on different object

Option	Source of information	Conditions for reconstruction	Level of complexity for generating DT HCC	Example of HCC, selected to check the developed technology
A	Real HCC, completely saving, with known hand robe content, on historical mannequin	1 - best	1-1.9 - simple problem	
B	Real HCC, completely saving	1.7 - best, normal	1-1.9 - simple problem	1. Slovenian youth uniform of the “Falcons” movement, 1937s; 2. Russian folk shirt of the XIX century; 3. European coat of the late XIX - early XX centuries
C	Real HCC, partly saving	2.3 - normal, worst	2-3 - complex problem	
D	HCC image, black and white	2.7 - normal, worst	2.7 - complex problem	
E	HCC image, colorful	2.3 - normal, worst	2.3 - complex problem	Professorial formal coat of the XIX century
F	Pattern with known sewing technology of HCC	2.7 - worst	2.3 - complex problem	
G	Pattern with unknown sewing technology of HCC	3 - worst	3 - complex problem	

Conclusions after Chapter 4

1. Algorithms have been developed for generating digital twins of the body, textile fabrics, and HCC, depending on the selected prototype: material, its 2D image, and patterns of parts. The necessary database and the factors influencing the content of the source database were investigated.

2. A scale has been developed to assess the content of the source database and the difficulty of obtaining a realistic-looking DT. Software and technological support for generating DT and verifying their compliance with historical prototypes are proposed.

CHAPTER 5. EXPERIMENTAL VERIFICATION OF THE DEVELOPED TECHNOLOGY FOR OBTAINING DIGITAL DOUBLES OF HISTORICAL COSTUME COMPLEXES

The study of prototypes and their photos, illustrations, descriptions HCC from published books, internet and museum materials, it was concluded that historical clothing should be evaluated only on the body with similar morphology as historical bodies and compatible characteristics of the image. In addition, for an accurate reconstruction of the HCC, it is necessary to take into account the synergistic effect of body sizes, textile materials, drafting methods, clothing shaping, etc..

In accordance with the databases developed in Chapter 2, the diagrams from Chapter 1, and the results from Chapter 4, virtual reconstruction of four men's clothing HCC was carried out. Photos and preserved HCC were selected as objects, and their selection was carried out according to the following principle: single-layer clothing (without taking into account the underlying layers of clothing and materials), double-layer clothing (from the main and lining fabrics), multi-layer clothing (taking into account several types of clothing worn simultaneously).

The results obtained were published in two papers [166-168].

5.1. Material of research

5.1.1. Software

The following softwares were used in this research:

ET CAD (BUYI Technology, China) for darfting the historical pattern blocks.

Computer program CLO 3D, version 6.0, (CLO Virtual Fashion, Republic of Korea) for generating static and dynamic virtual objects. This software not only presents a realistic 3D view of historical clothing, but also a 3D virtual effect of the historical clothing dynamic fashion show.

iMovie is a video editing software written by Apple computers, it not only can edit, add titles, and music, but also can add effects such as fade-in, fade-out and slideshow and so on to the 3D fashion show.

5.1.2. Object of research

Four male HCC were selected for virtual reconstruction:

1) professorial formal coat of the XIX century,

2) Slovenian youth uniform of the 1937s;

3) Russian folk shirt of the XIX century;

4) European coat of the late XIX - early XX centuries.

5.2. Visualization of the Russian professorial uniform from preserved images

The purpose of this experiment is to analyze the features of historical professor's formal coat and reconstruct both in virtual and real system in the modern version.

A search of the official websites of the Top 3 universities in 15 countries (Russia, Ukraine, Belarus, Uzbekistan, etc.) during the Soviet period showed that it was impossible to tell exactly when the professor's formal suit appeared. The earliest photo shows that professor's formal suit who wore at the Moscow State University of in 1771. Fig. 5.1 shows three examples of historical images of professor's formal suit from the mid of XVIII century to the end of XIX century.

a b c

Figure 5.1 – Historical images from official websites of Moscow State University: a – Prof. Melissino Ivan Ivanovich, 1771-1795; b – President Kachenovsky Mikhail Trofimovich, 1837-1842; c – Prof. Tsvetaev Ivan Vladimirovich, 1898 [154]

According to the collected images, features of historical professor's formal coat could be analyzed:

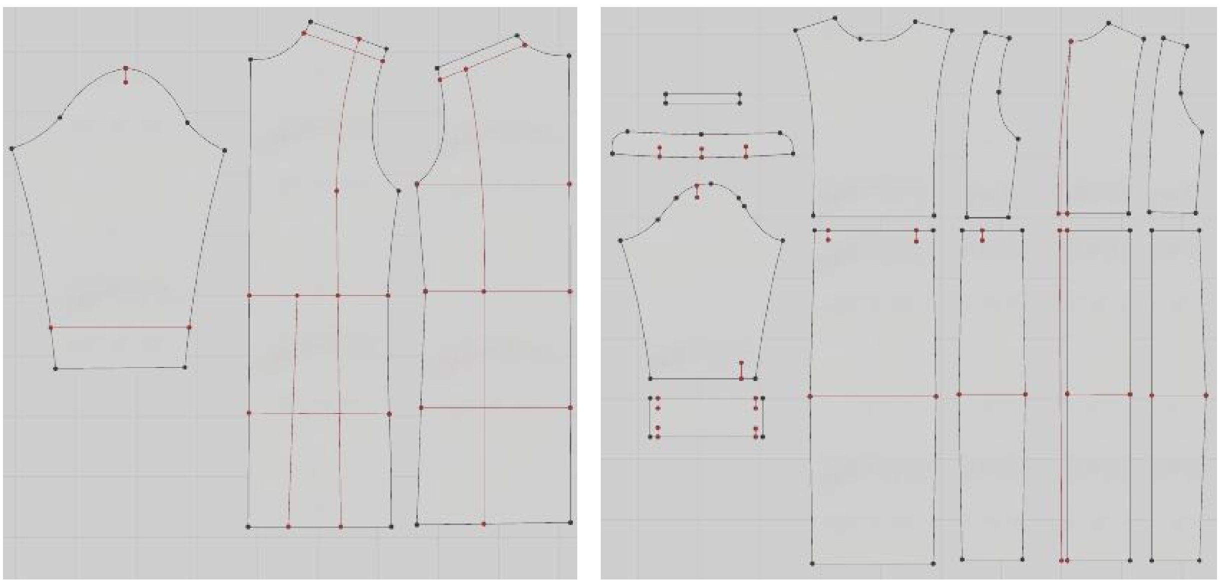
- The color of coat are mostly in dark blue, with stand-up collar and cuffs, the button with special emblem on its surface.

- The color of the stand-up collar, cuffs, embroidery pattern on the cuff and pocket flap, and the special emblem on the button surface all could be used as signs for distinguish different universities. Take the collar and cuffs as an example, they are crimson in Moscow State University, black velvet in Kharkov State University, and navy blue in Kazan Federal University. As for embroidery patterns on the cuffs and pocket flap, they are golden in Moscow State University, silver in Kharkov and Kazan. What's more, Moscow State University used smooth yellow buttons, Kharkov and Kazan – smooth white plain surface, without emblem.

- Different embroidery pattern represents the level of status of the wearer. The uniform for teachers and students of Moscow State University and its subordinate academy was changed. On crimson collar, cuffs, as well as on pocket flap, decorated gold embroidery with the following description: "The edges of these are covered with embroidery which representing bay leaves. Along... an oak branch extends on flap. On the front part of the collar are the same branches, and on the cuffs these branches are surrounded by button loops." Full sewing on the collar, cuffs, and pocket flap was required for those with VII and higher classes; the ranks of grades VIII class were deprived of sewing on the pockets, and IX and X classes-also sewing "branches on the cuffs"; the ranks of the lower classes had only "embroidery of bay leaves" on the collar and cuffs. Uniforms of employees who did not have ranks, and students of the University did not have sewing [155].

In accordance with these historical features, five variants of men's uniforms designed for special occasions were redesigned on the basis of the uniform of I. V. Tsvetaev (Fig. 5. 1, c).

The uniform is suitable for men of youth and middle age groups with different body type. The main material for making men's coat is plain knitted fabric in navy blue and black, yellow and red embroidery and lace for collar, cuffs and front side, yellow and red cloth for collar and cuffs, yellow button. When drafting the pattern block, the characteristics of this fabric should be take into account. Thus the pattern block could be drafted in CLO 3D, as shown in Fig. 5.2.



a b

Figure 5.2 – Basic patterns of two variants of the men's formal uniform:
a – basic design; b – after improving

As an analog of historical textile fabrics, their digital counterparts were taken from the CLO 3D library, as shown in Table 5.1.

Table 5.1 – Digital twin of textile materials from the CLO 3D library – professorial formal coat

No.	Position	Fabric ID	Type of DT	Characteristic		
				Title	Surface density (g/m^2)	Thickness (mm)
1	Main fabric	K001	Knit	Ponte Knit Jersey	330.889	0.86
2	Collar and cuff	W002	Шерсть	Coatweight Twill	345	0,84
3	Embroidery	H001	Linen	Linen	173.39	0.36

Based on the historical database developed, including the structure, digital textile material in CLO 3D, and the shaping method from Chapter 2, the 3D design rendering was completed, as shown in Fig. 5.3, a - d. The video of the 3D catwalk is shown in Fig. 5.3, e.

a

b

c

d

e

f

Figure 5.3 – 3D renconstructions: a-e – images of 5 men's formal coat;
f – screenshot of its 3D catwalk video [168]

Fig. 5.4 shows photos of ready-made men's formal uniforms made from the knitted fabric of the company "Mirtex" (Furmanov, Ivanovo region).

Figure 5.4 – Photos of men’s formal coat for special occasion in the modern version

Thus, the modern design of the men's formal coat with elements of the HCC was reconstructed and generated.

The material professorial formal coat and its digital counterpart were shown at the exhibition at the Ministry of Science and Higher Education of the Russian Federation (APPENDIX D).

5.3. Visualization of the Slovenian uniform according to the preserved HCC

The Slovenia young men's suit was existing in the "Falcons" movement in 1937. However, with modern museum’s technology it is difficult to preserve these historical clothing. It can also be degraded by factors, such as humidity, pressure, etc..

The aim of this experiment is to develop a DT of the historical form of the young men of Slovenia for online museum exhibits. This costume was taken from the Slovenian National Liberation Museum in Maribor as shown in Fig. 5.5.

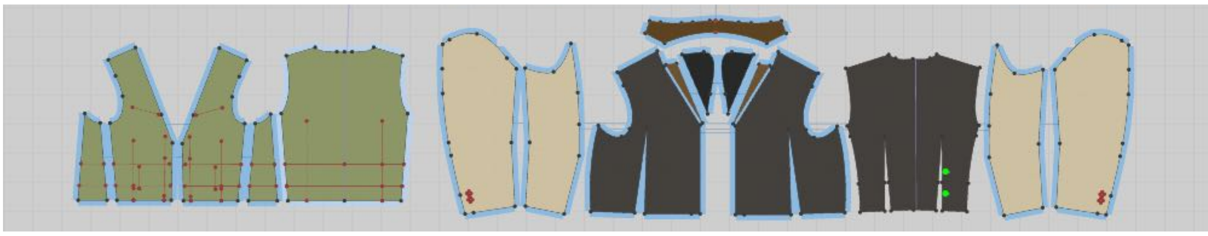
a b

c d e f

Figure 5.5 – HCC of young man of the Slovenian movement "Falcons" and its components: a – HCC from the museum's collections; b – technical drawing; c – shirt; d – waistcoat; e – jacket; f – trousers;

After measuring the detailed length, width and other parameters of real HCC, and obtained the necessary data for drafting according to the Slovenia historical pattern manuals of same style of each garment, pattern block could be drafted in CAD software, as shown in Fig.5.6.

a



b

Figure 5.6 – Pattern block of four garments of the uniform: a – shell of shirt, trousers, waistcoat and jacket; b – lining of waistcoat and jacket

Combining with the Body Sizing System produced by Engineering College of University of Maribor, the main body measurements of suitable avatar corresponding to a typical body of the 1930s, cm: height 176, bust 94, waist 72.

As the DT of the fabrics for reconstruction were selected, as shown in Table 5.2 and Table 5.3:

Table 5.2 – Digital twin of textile materials from the CLO 3D library - Slovenian youth uniform – Part 1

No.	Garment	Top fabric				
		Fabric ID	Type of DT	Characteristic		
				Title	Surface density (g/m^2)	Thickness (mm)
1	Shirt	C011	Cotton	Cotton Oxford	165	0.37
2	Waistcoat	W002	Wool	Super 120s Wool	157.5	1.9
3	Trousers					
4	Jacket					

Table 5.3 – Digital twin of textile materials from the CLO 3D library - Slovenian youth uniform – Part 2

No.	Garment		Lining				
			Fabric ID	Type of DT	Characteristic		
					Title	Surface density (g/m^2)	Thickness (mm)
1	Shirt		-				
2	Waistcoat		C007	Cotton	Cotton Twill	190.778	0.41
3	Trousers		-				
4	Jacket	Sleeve	C013	Cotton	40s Stretch Poplin	122.5	0.23
		Bodypart	C007	Cotton	Cotton Twill	190.778	0.41

According to the historical database including structure, textile materials, method of shaping developed in Chapter 2, the DT of Slovenia young men's suit could be simulated layer by layer, the garment positioning and 3D simulation were shown in Fig.5.7.

a

b

Figure 5.7 – DT of Slovenia young men's uniform: a – undergarments consist of shirt, trousers and waistcoat; b – full uniform

5.4. Visualization of the Russian folk shirt

Gavrilovo - Posad Museum of Local Lore was founded in the 1960s. The textile stock is quite exciting and diverse. It was with the collection of folk and urban women’s costume that the museum began. The most interesting are: a collection of the folk costumes of the eighteenth and twentieth centuries. These are sundresses of various cuts, women’s and men’s shirts, aprons, “couple” dresses, headscarves, shawls, tablecloths, fabrics, weaving patterns, including linen, bast shoes [156].

The purpose of this experiment is to obtain a digital double of the historical Russian folk shirt of the late 19th century. Fig. 5.8, a, b show photos of the front and back of the shirt. It can be seen the shirt is made of the main dense fabric "pestryad" and the lining of elastic cotton fabric.

a b

c d e

Figure 5.8 – Photos of the real shirt (a, b) and reconstructed diagrams of the patterns: c – pattern of main fabric; b – pattern of lining; c – dermatoglyphic pattern of top fabric after retouched

To parametrize a unique geometric structure, a special algorithm was developed and two types of parameters were measured: length and angle. Drawings of the details of the historical shirt were built in 3D CAD. In Fig. 5.8, c, d shows the diagrams of the patterns from the main fabric and lining. Figure 5.8, c shows the appearance of the main fabric after editing the photo using Photoshop.

As the DT of the fabrics for reconstruction were selected, as shown in Table 5.4:

Table 5.4 – Digital twin of textile materials from the CLO 3D library – Russian folk shirt

Main fabric	Fabric ID	Type of DT	Characteristic		
			Title	Surface density (g/m^2)	Thickness (mm)
Top fabric	C008	Cotton	Cotton Canvas	238.944	0.46
Lining	C004	Cotton	40s Chambray	103.111	0.23

This historical shirt should be generated on an avatar with a morphology similar to the historical one. According to the patterns, the body measurements of the avatar were determined according to the previously developed algorithm [13, 77]. According to the historical database, including the structure, textile materials, the method of shaping developed in Chapter 2, and the studied sewing technology and the scheme of assembling the shirt, the DT of the Russian men's folk shirt was generated, the location of the clothing and the simulation were shown in Fig. 5.9.

a b

Figure 5.9 – DT of Russian folk shirt : a – 3D arrangement; b – three views of virtual shirt

To evaluate the accuracy of the method developed in this dissertation, the silhouettes of men's shirts was compared, which were reconstructed in two ways. In the first method, cut details were used only from the main fabric (which is typical for most of the practiced approaches to virtual reconstruction, discussed in Chapter 1). In the second method took into account the presence of a lining (lining on the front and back, padded sleeves, body measurements and methods of their connection).

Fig. 5.10 shows two variants of the DT. The DT in Fig. 5.10, a was simulated directly without taking into account the methods of shaping the shirt, the presence of lining, and did not take into account the characteristics of historical fabrics. The DT in Figure 5.10, b was simulated based on all the databases collected after the analysis of the people's shirt.

a

b

Figure 5.10 – Virtual reconstruction of folk shirt in two ways: a – without consideration method of shaping and textile material; b – after combining all database

It is clearly seen that the DT in Fig. 5.10, b has the same silhouette and design features as the historical prototype, which indicates the high accuracy of the reconstruction according to the developed algorithm.

5.5. Visualization of the coat according to the preserved HCC

The purpose of this experiment is to obtain the DT of a historical men's coat based on a real HCC. A set consisting of a shirt, trousers, waistcoat and frock coat was chosen for the reconstruction. Taking into account the structural arrangement of the components, a method was developed for forming the shoulder of the coat by adding shoulder pads, the sleeve head by adding a podokatnik and non-woven parts, and adjusting the seam lines by making darts instead of cutting in relation to the other.

47 men's coat were reconstructed using this method, three examples of DT of three style men's coat as shown in Appendix D.

As an example, consider the algorithm for reconstructing the selected coat of the late 19th century to prove the level of accuracy of the DT.

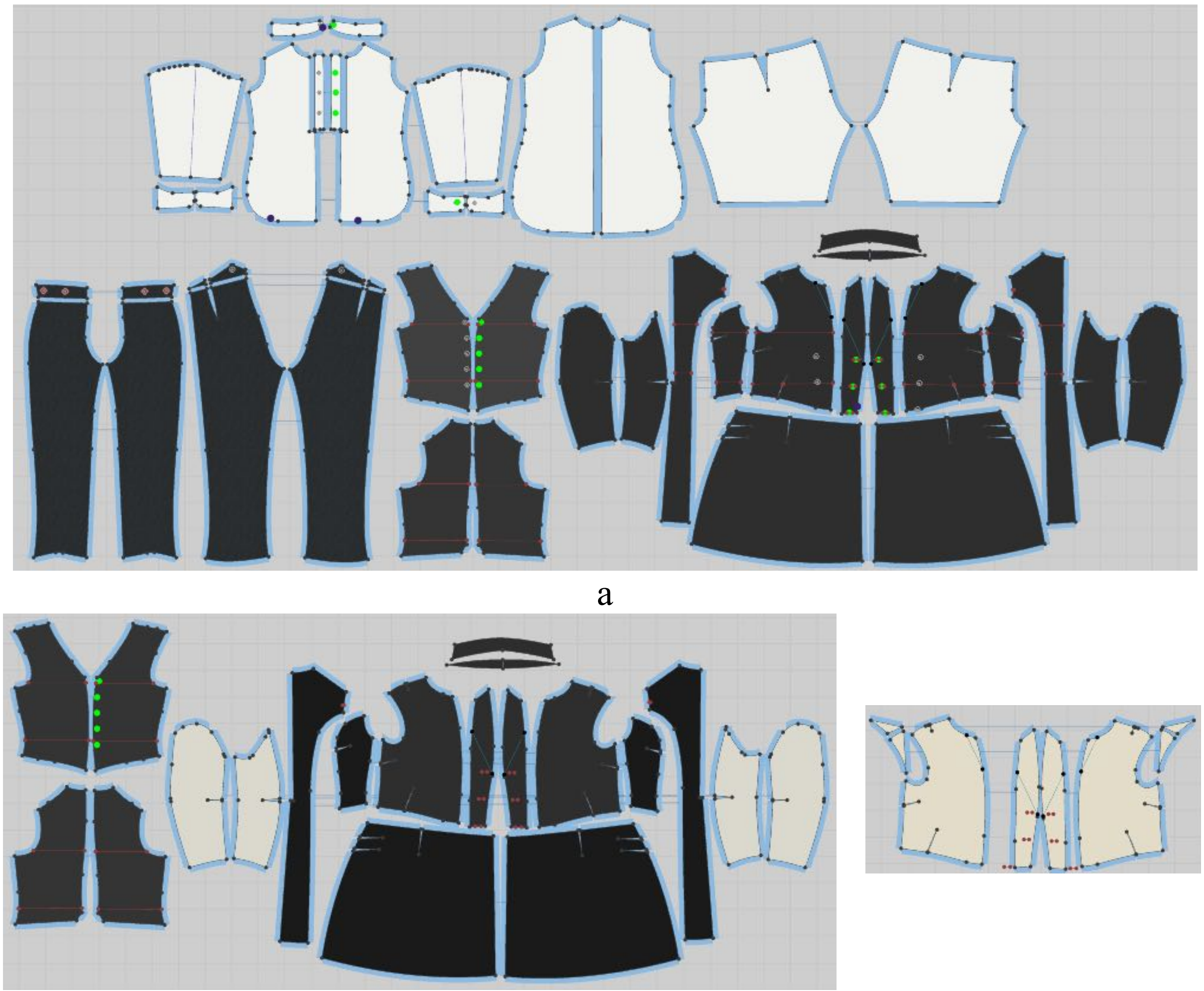
Fig. 5.11 shows the appearance of the HCC being reconstructed in a virtual environment.

Figure 5.11 – Appearance of the male HCC being reconstructed in a virtual environment

According to the database of body measurements and methods of pattern block drafting from published books, chosen the male suit that combined shirt [77], drawers [157], trouser [93], waistcoat [93] and coat (No.7 pattern block in subchapter 3.4.2.) which were all in same size: height 167.6, chest 91.4cm, waist girth 81.3cm, hip girth 94cm.

To calculate body maeasurements from historical pattern manuals and reconstruct digital twin of historical body in CLO 3D, the sizing system, the content and conditions for measuring dimensional features, and collecting the dimensions of the body that were used to pattern drafting need to be known. As noted above, at that time bodies were usually measured by shirt, trousers, and waistcoat, with the tendency to include the size of the naked body, the thickness of the fabric, and the air gap. Thus, the fabric thickness and air gap were first investigated in order to calculate the size of the nude figure to build the avatar in CLO 3D.

After detailed measurement of all types of clothing, their CAD patterns were obtained. Fig. 5.12 shows the patterns of each item of clothing that was combined by the DT HCC.



a

b c

Figure 5.12 – Pattern block of five garments of the suit: a – top fabric of shirt, drawers, trousers, waistcoat and coat; b – lining of waistcoat and coat; c – paddings of coat

The following are taken as digital counterparts of historical materials, as shown in Table 5.5 and Table 5.6:

Table 5.5 – Digital twin of textile materials from the CLO 3D library – European men's suit – Part 1

<table>
<tr><th rowspan="3">No.</th><th rowspan="3" colspan="2">Garment</th><th colspan="5">Top fabric</th></tr>
<tr><th rowspan="2">Fabric ID</th><th rowspan="2">Type of DT</th><th colspan="3">Characteristic</th></tr>
<tr><th>Title</th><th>Surface density (g/m^2)</th><th>Thickness (mm)</th></tr>
<tr><td>1</td><td colspan="2">Shirt</td><td rowspan="2">C003</td><td rowspan="2">Cotton</td><td rowspan="2">50s Cotton Poplin</td><td rowspan="2">105</td><td rowspan="2">0.21</td></tr>
<tr><td>2</td><td colspan="2">Drawers</td></tr>
<tr><td rowspan="2">3</td><td rowspan="2">Waistcoat</td><td>Back</td><td>S002</td><td>Silk</td><td>Silk Charmeuse</td><td>81.1</td><td>0.19</td></tr>
<tr><td>Front</td><td rowspan="3">W002</td><td rowspan="3">Wool</td><td rowspan="3">Coatweight Twill</td><td rowspan="3">345</td><td rowspan="3">0.84</td></tr>
<tr><td>4</td><td colspan="2">Trousers</td></tr>
<tr><td>5</td><td colspan="2">Coat</td></tr>
</table>

Table 5.6 – Digital twin of textile materials from the CLO 3D library – European men's suit – Part 2

<table>
<tr><th rowspan="3">No.</th><th rowspan="3" colspan="2">Garment</th><th colspan="5">Lining</th></tr>
<tr><th rowspan="2">Fabric ID</th><th rowspan="2">Type of DT</th><th colspan="3">Characteristic</th></tr>
<tr><th>Title</th><th>Surface density (g/m^2)</th><th>Thickness (mm)</th></tr>
<tr><td>1</td><td colspan="2">Shirt</td><td rowspan="2" colspan="5">-</td></tr>
<tr><td>2</td><td colspan="2">Drawers</td></tr>
<tr><td>3</td><td colspan="2">Waistcoat</td><td>S002</td><td>Silk</td><td>Silk Charmeuse</td><td>81.1</td><td>0.19</td></tr>
<tr><td>4</td><td colspan="2">Trousers</td><td colspan="5">-</td></tr>
<tr><td rowspan="4">5</td><td rowspan="4">Coat</td><td>Forepart</td><td>W002</td><td>Wool</td><td>Coatweight Twill</td><td>345</td><td>0.84</td></tr>
<tr><td>Paddings</td><td>H001</td><td>Linen</td><td>Linen</td><td>173.39</td><td>0.36</td></tr>
<tr><td>Side, skirt and tail</td><td>C001</td><td>Cotton</td><td>Cotton Gabardine</td><td>189</td><td>0.35</td></tr>
<tr><td>Sleeve</td><td>C003</td><td>Cotton</td><td>50s Cotton Poplin</td><td>105.03</td><td>0.21</td></tr>
</table>

After simulated in first attempt, it could be found that the shape of coat in this virtual system was not very fitted to the avatar and the skirts didn't give a straight line. So if copy the historical pattern block and sew the clothing in CLO

3D directly, the result couldn't be successful without special knowledge related to craftsman skills which have been lost in the past.

Then measured the length of each paired suture lines in CLO 3D and found that there are differences between each other, as Table 3.14 showns in subchapter 3.6.2.. Fig. 5.13 shows, a is 5.4mm bigger than b, c + d is 29.7 mm bigger than e, h is 7.2 mm bigger than r4 + f + g. The differences between other suture lines were less than 5 mm so can ignore.

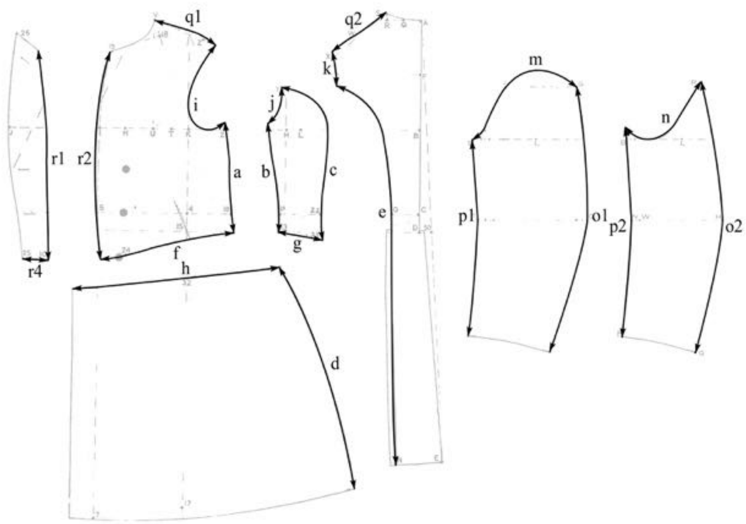
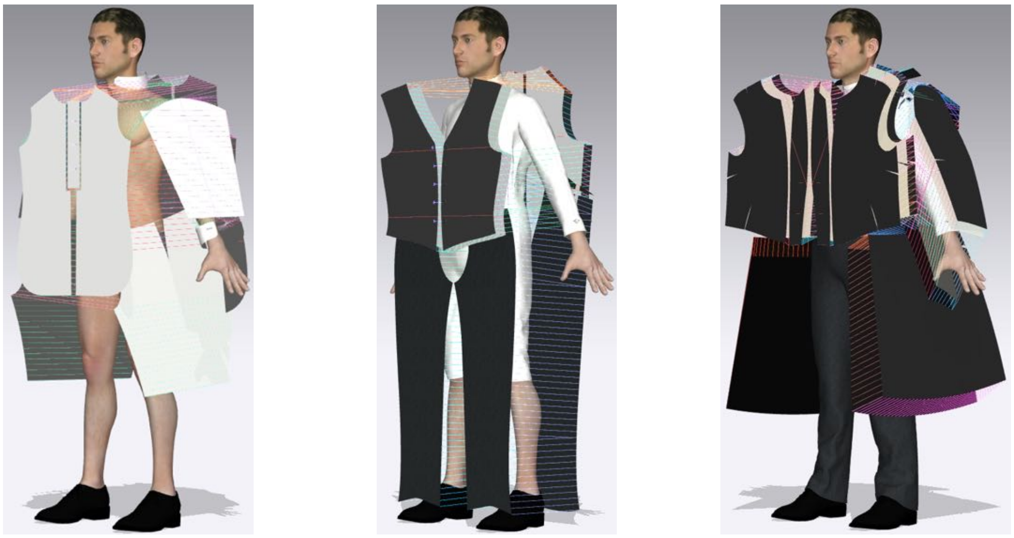


Figure 5.13 – The suture lines which need to be analyzed

After comparing the length of the sections of the same name, the established difference between them was projected into darts according to the method of A. Y. Moskvin along each section [13]. Thus, the length of the seam line, which is longer, should be shortened by darts.

The DT HCC with corrected seam lines, inserted darts, shoulder pads, filled sleeve head, reinforced with non-woven fabric was generated again, as shown in Fig. 5.14.



a b c

d

Figure 5.14 – Virtual reconstruction of Full men's suit: a – shirt + drawers; b – shirt + drawers + waistcoat + trousers; c – shirt + drawers + waistcoat + trousers + coat; d – full suit

To evaluate the new method, the silhouette of men's coats which have been reconstructed in two ways was compared and overlapped these two contours in same scale from the front view. To observe more clearly, the coat was changed in grey color. Fig. 5.15 shows the combined silhouettes of the DT, the dotted line of which is the patterns drafted from published book directly and solid line is the patterns from our method.

a b c d

Figure 5.15 – Silhouette of frock coat in two ways: a – without consideration method of shaping; b – modified coat; c – overlapping two contours of the original and modified coat; d – the cross-sections of the original and modified coat at the same level of bottom

The vertical distance between the silhouettes of the original and modified coat have been measured: shoulder point is 11 mm, waist level is 12 mm, front bottom level is 10 mm, back bottom level is 16 mm.

As shown in Fig. 5.15, b, the DT obtained taking into account the shaping, in the neck, shoulder girdle, chest, waist, hips and bottom, more precisely corresponds to the shape of the avatar, which was characteristic of the sartorial art of the late 19th century. The lines of the shoulder point, waist and bottom are raised, the left and right edges of the board are pulled up to each other. DT HCC, obtained by the developed algorithm, has a fitted and muscular appearance, soft shoulders and a narrower waist, favorably emphasizes the plastic figure.

Conclusions after Chapter 5

1. The wide possibilities of the developed technology in obtaining digital twins of HCC based on different source information: photographic images and preserved artifacts with different structural devices are shown.

2. Based on the analysis of visual information about the historical uniforms of Russian professors of the 19th century, material uniform and its digital counterparts in five versions were developed.

3. Based on the historical database and the preserved Russian folk shirt of the XIX century, consisting of the main and lining fabrics, its digital twin was generated, taking into account the techniques of shaping and framing the influence of the linen lining.

4. DT of the preserved multi-layers uniform of the Slovenian youths of the "falcons" movement of the 1930s was obtained.

5. DT of the multicomponent HCC, including the coat and the underlying types of clothing, was obtained. When it was generated, the shaping techniques were reproduced due to the choice of ease allowance, the introduction of framing elements and cushioning materials.

CONCLUSIONS

FINAL RESULTS OF RESEARCH

1. The technology of virtual reconstruction of HCC based on reverse engineering, including the choice of material object or its image, the collection of initial information about the features of artistic and constructive and technological solutions, the reconstruction of missing data, the generation of avatar of body, DT of textile materials, DT of the HCC, etc. assessment of their similarity has been developed.

2. The method of identification of the size accessories, the hidden projected design and technological techniques in historical pattern of men's coat was developed, which allows to determine the body measurements of the body and control the indicators of the three-dimensional shape.

3. The regularities of the formation of fashionable male historical body under the influence of corset have been established.

4. Developed a method for selecting textile materials for historical men's clothing based on published materials and prototype of clothing and achieving similarity between generated digital twins and their material prototypes.

5. Method of non-contact measuring in virtual environment of the thickness of textile materials belonging to several types of clothing worn simultaneously, taking into account the air layers between each other, has been developed.

6. The ease allowance to the body measurements used to draft patterns of coat was developed, and an algorithm for the recalculation in the reconstruction of coat to contemporary male body of other body measurements was proposed.

7. A virtual reconstruction method of historical men's clothing system based on reverse engineering has been developed, including the selection of a material object, the collection of initial information about the features of artistic,

constructive and technological solutions, the reconstruction of missing data and the generation of a digital twin.

8. The following types of men's historical clothing of the XIX and XX centuries were reconstructed: Russian professorial formal coat, European coat, a Slovenian uniform of the youth movement "Falcons", Russian folk shirt, which confirmed the correctness of the results obtained, algorithms of methods and databases.

RECOMMENDATIONS, PERSPECTIVES OF FUTURE RESEARCH

1. The results obtained in the dissertation can be used as follows:

- in educational process of higher and secondary educational institutions in studying the historical costume and design of men's clothing;
- as resource and source of designing historical costume for theatrical productions and films;
- as resource for sociologists, anthropologists and historians;
- in the concepts of online museums;
- in the preservation of intangible cultural heritage.

2. In further research, it is necessary to use other HCC to form more complete base for generating DT.

REFERENCES

1. Glassie, H. Material Culture / H. Glassie. - Indiana University Press, 1999. - 41p.

2. Martin, K. Virtual historic costume across cultures and disciplines / K.Martin, H.Ko // Proceedings of the 15th International Conference on Virtual Systems and Multimedia, 9-12 September 2009, Vienna, Austria, pp. 104-108.

3. Kuzmichev, V. Computer reconstruction of 19th century trousers / V. Kuzmichev, A. Moskvin, E. Surzhenko, M. Moskvina // International Journal of Clothing Science and Technology 2017.

4. Kang, Y. A Study on Men's Wear Production Using Digital Clothing Program / Y. Kang, S. Wu, Y. Ko, A. Kim, N. Kim, J. Kim, ... & H. Ko // Journal of Korea Multimedia Society 17.2, 2014, pp. 266-275.

5. The Official Ralph Lauren 4D Experience - New York. [Электронный ресурс] // URL: https://www.youtube.com/watch?v=c3n8j2uWA8o (дата обращения: 30.03.2018).

6. Burberry's Beijing Digital Fashion Show. [Электронный ресурс] // URL: https://www.youtube.com/watch?v=7PI19s-wy08 (дата обращения: 30.03.2018).

7. Volino, P. From early virtual garment simulation to interactive fashion design / P. Volino, C. Frederic, M. T. Nadia // Computer-aided design, 37 (6), 2005, pp.593-608.

8. Juanfen, J. Generating 3D virtual garment based on 2D sketches / J. Juanfen // Doctoral dissertation of Donghua University, China, 2012.

9. Martin, K. Standards in the visual and linguistic language of an onlinehistoric costume collection / K. Martin // Research Journal of Textile and Apparel, 10 (3), 2006, pp. 59-66.

10. Kang, Y. Digital production of traditional costumes / Y.Kang, S. Wu, Y. A, K. Martin, H. Ko // Digital Heritage International Congress (Digital Heritage), Vol. 1. IEEE, 2013, pp. 329-335.

11. Kang, Z. Historical costume simulation / T. Cassidy, T. Cassidy // In: 2014 International Textiles and Costume Culture Congress, 2014
12. Kang, Z. Historic costume simulation and its application / Z. Kang, T. Cassidy, T. Cassidy, D. Li // In: Proceedings of the 15th Autex World Textile Conference, 2015.
13. Kuzmichev, V. Virtual reconstruction of historical men's sui / V. Kuzmichev, A. Moskvin, M. Moskvina // Autex Research Journal, 18 (3), 2018, pp. 281-294.
14. Moskvin, A. Digital replicas of historical skirts / A. Moskvin, V. Kuzmichev, M. Moskvina // The Journal of The Textile Institute, 110 (12) 2019, pp. 1810-1826.
15. Ryu, K. A Study of the Historical Reconstruction of the Western Man's Coat in the Early of the 19th Century / K. Ryu, K. Yang-Hee // Journal of the Korean Society of Costume, 65(1), 2015, pp. 136-149.
16. Magnenat-Thalmann, N. Modeling of bodies and clothes for virtual environments / N. Magnenat-Thalmann, F. Cordier, H. Seo, G. Papagianakis // International Conference on Cyberworlds, IEEE, 2004.
17. Martin, K. 3D simulation: a new embodiment for historic fashion / K. Martin, M. Dave // International Conference on Culture and Computing, IEEE, 2013.
18. Martin, K. Virtual historic costume across cultures and disciplines / K. Martin, K. Hyeong-Seok // 15th International Conference on Virtual Systems and Multimedia, IEEE, 2009.
19. Steel, P. A historical of fashion and costume / P. Steel // vol. 7 The nineteenth century, Bailey Publishing Associates Ltd. Vancouver, Canada, 2005.
20. Victoria and Albert Museum. [Электронный ресурс] // URL: https://www.pinterest.com/pin/177610779024009618/ (дата обращения: 10.03.2018).

21. Frock coat and trouser. [Электронный ресурс] // URL: https://www.pinterest.com/pin/383580093246644084/ (дата обращения: 10.03.2018).
22. The Metropolitan Museum of Art. [Электронный ресурс] // URL: https://www.pinterest.com/pin/369928556873397463/ (дата обращения: 10.03.2018).
23. The perfume baby. 1900s fashion. [Электронный ресурс] // URL: https://www.pinterest.com/pin/122441683592660108/ (дата обращения: 10.03.2018).
24. Waugh, N. The cut of mens clothes 1600–1900 / N. Waugh. – New York: Theatre arts books, 1964. -187p.
25. Daniel, J. The History of Modern Fashion From 1850 / J. Daniel, D. Nancy. – London: Laurence King Publishing Ltd. 2015. -481p.
26. Zhang, L. English-Chinese introduction to fashion / L. Zhang. – Beijing: China Textile Press, 2005. -225p
27. Nilson, T. Cultural Heritage Preservation: The Past, the Present and the Future / T. Nilson, K. Thorell // 2018
28. An, M. Study on the Conservation and Restoration of excavated costume / M. An // Journal of the Korean society of Costume, 57 (3), 2007, pp.14-22.
29. Welters, L. Historic textile and costume collections in the academic setting / Linda M, Welters // 2011.
30. Cybulska, M. Archaeological textiles–A need for new methods of analysis and reconstruction / M. Cybulska, M. Jerzy // Fibres & Textiles in Eastern Europe, 15.5 (6), 2007, pp. 100-105.
31. Cybulska, M. To see the unseen-Computer graphics in visualisation and reconstruction of archaeological and historical textiles / M. Cybulska // Computer Graphics, InTech (Rijeka), 2012, pp. 213-228.
32. Magnenat, T. From early draping to haute couture models: 20 years of research / T. Magnenat, Nadia, V. Pascal // The Visual Computer 21.8-10, 2005, pp. 506-519.

33. Emanuel, A. Handbooks of the textile industry / A. Emanuel. – Philadelphia: vol 4 Fabrics Analysis Textile Publish Company, 1920.
34. Grace, G. D. Fabrics / G. D. Grace. – Chicago: J. B. Lippincott Company, 1923.
35. Dyer, E. Textile fabrics / E. Dyer. – Boston: Houghton Mifflin Company, 1923.
36. Scott, A. A treatise on cutting garments to fit the human form / A. Scott, M. Wilson. – New York: Published by authors, 1841. - 201p.
37. Vincent, W.D.F. The cutters practical guide frock and dress coats, livery clerical, naval military police and other special garments / W.D.F. Vincent. – London: The J. Williamson company limited, 1898. - 112p.
38. Antebellum tailcoats. [Электронный ресурс] // URL: https://www.pinterest.com/pin/556194622726939264/ (дата обращения: 10.05.2018).
39. Man’s coat. [Электронный ресурс] // URL: https://www.pinterest.com/pin/293578469460201559/?nic=1 (дата обращения: 10.05.2018).
40. Aldrich, W. History of sizing systems and ready-to-wear garments. Sizing in Clothing: Developing Effective Sizing Systems for Ready-to-wear Clothing / W. Aldrich. – Cambridge: Woodhead Publishing Limited, 2007. - 56P.
41. Scott, A. J. The tailor's master-piece / A. Scott, J. Wilson. – New York: Published by the author, 1840. - 22p.
42. Acton, R. Acton`s improved system of actual measurement / R. Acton. – New York: William R. Acton & Co, 1867. - 29p.
43. Arvidson, P. The Arvidson coat and vest system / P. Arvidson. – Kalamazoo: Published by the author, 1892. - 24p.
44. William, R. The tailor`s transfer, or a new improved system of measurement and garment cutting / R. William. – Printed by James young, Lithography of E. Weber & Co, 1846. - 24p.

45. The keystone systems. Coat, vest and trousers. Practical methods of cutting by proportions and by measures / New York: The Tailors' Review Co, 1903. - 200p.
46. The new dress maker / New York: The butterick publishing company, 1921. - 176p.
47. James, Q. The taylor`s instructor, or a comprehensive analisis of the elements of cutting garments of every kind / Q. James, L. William. – Philadelphia: Published by the authors, 1809. - 157p.
48. Gove, J. Rules and direction for cutting men's clothes by the square rule / J. Gove. – Published by Amanda Jones. J. W. Copeland, Printer, 1822. - 25p.
49. James, G. Report of the present fashions, with the square rules and variations to fit the human shape / G. James. – New York: 1827. - 28p.
50. Scott, W. The tailor's master-piece: being the tailors' complete guide / W. Scott. – New York: Published by the author, 1840. - 22p.
51. James, J. The Anatomical Standard / J. James. – Manchester: W. Shackleton and Son, printers, ducie place, 1841. - 45p.
52. Young. The Archetypal Consummation: a system of garment drafting / Young, Rathvon. – Columbia: Published by the author, 1845. - 52p.
53. William, S. The young crook`s guide, or self-varying system for cutting garments / S. William. – Gettysburg: Printed by H. C. Neinstedt, 1851. - 22p.
54. Dilday, E. Dilday's plain and concise method of garment cutting / E. Dilday. – Illinois: Published by the author, 1856. - 58p.
55. Brockway, W. The Great Balance-measure System / W. Brockway. – New York: Baker & Godwin, printers, 1864. - 16p.
56. Brundage, W. A Complete System of Cutting / W. Brundage. – New York: Printed by A. Marrer, 1867. - 38p.
57. Acton. Acton's improved system of actual measurement / Acton, R. William. – New York: Published by the author, 1867. - 29p.
58. Phyliky, L. New system of drafting / L. Phyliky. – New York: Thomas Holman, printer, 1867. - 32p.

59. Matheson, H. H. Matheson's scientific and practical guide for the tailor's cutting department / H. Matheson. – New York: Published by the author, 1871. - 90p.
60. Linthicum, W. O. Divisional and exact measurement systems for garment cutting / W. O. Linthicum. – New York: Lawrence & Allen, stationers and printers, 1876. - 60p.
61. Glencross, W. A scientific guide to practical cutting / W. Glencross. – New York: William Glencross, 1873. - 102p.
62. William, S. A treatise on the measurement of the human body and the art of cutting materials for gentlemen's clothes / S. William. – Chicago: C. F. Lichtner, Book and job printer, 1873. - 32p.
63. Koch, A. The cutters' centennial guide / A. Koch. – Poughkeepsie, New York: Printed at the office of the Poughkeepsie telegraph and daily press, 1876. - 68p.
64. Madison, J. O. Elements of garment cutting / J. O. Madison. – Hartford, Conn.: The case, lockwood & Brainard company, printers, 1878. - 180p.
65. Pecori, E. Perfect cutting system by actual measurement / E. Pecori. – Philadelphia: Wolf Bros., Economy print, 1878. - 26p.
66. Thomas, N. Practical essays on shirt cutting together with exhaustive lessons in shirt making / N. Thomas. – Canada: Published by the author, 1881. - 28p.
67. Charles, H. Proportionate system of coat cutting / H. Charles – New York: Printed by F. H. Adams, 1883. - 54p.
68. Augustus, K. The cutter and guide / K. Augustus. – Poughkeepsie, N.Y. Washington, D. C., 1883. - 77p.
69. Charles, H. Vest cutting, a manual for the practical tailor and cutter / H. Charles. – New York: 1883. - 46p.
70. Madison, J. O. Madison's shoulder measure coat and vest systems improved, and elements of garment cutting / J. O. Madison. – New York: J. J. Mitchell co, 1885. - 172p.

71. Stone, C. J. Stone's paramount-cutter; a system for cutting garments, based upon scientific principles, including the self-varying shoulder, in connection / C. J. Stone. – Chicago: Meyer & brother, 1887. - 72p.
72. Martin, J. A. Martin's shirt system / J. A. Martin. – Peoria: E. Hine & co., printers, 1890. - 18p.
73. Van, A. Key line system of garment cutting / A. Van, A. Frank. – Toledo, Ohio. 1892. - 168p.
74. Henry, G. K. The science of coat and vest cutting / G. K. Henry. – Chicago: Published by the authors, 1892. - 52p.
75. Vincent, W. D. F. The cutter`s practical guide to cutting and making all kinds of clerical dress / W. D. F. Vincent, A. J. Tonkin. – London: The J. Williamson company limited, 1899.
76. Vincent, W. D. F. The Cutters Practical Guide to Making Every Kind of Garment: Part One / W. D. F. Vincent, A. J. Tonkin. – London: The J. Williamson company limited, 1890.
77. Vincent, W.D.F. The Cutter's practical guide to cutting and making shirts, undergarments, collars, and specialite clothing for various occupations / W. D. F. Vincent. – London: The J. Williamson company limited, 1898. - 45p.
78. Vincent, W.D.F. The Cutter's practical guide to the cutting and making all kinds of waistcoats / W. D. F. Vincent. – London: The J. Williamson company limited, 1898. - 48p.
79. Vincent, W.D.F. The Cutter's practical guide to the cutting and making all kinds of trousers, breeches & knickers / W. D. F. Vincent. – London: The J. Williamson company limited, 1898. - 108p.
80. Vincent, W.D.F. A magnificent plate illustrating all kind of British liveries and civil uniforms / W. D. F. Vincent. – London: The J. Williamson company limited, 1898. - 84p.
81. Gunther, F. H. Garment cutting in the twentieth century / F. H. Gunther. – Toledo: The B. F. Waude co., printers, 1894. - 158p.

82. Holmes, N. The Holmes cutter. A practical system for garment cutting that is based on selfvarying principles for block patterns / N. Holmes. – Chicago: Published by the author, 1894. - 64p.
83. Selden, S. G. The American coat, vest and trousers system / S. G. Selden. – New York: JNO.J. Mitchell, Co, 1895. - 114p.
84. Joseph, D. The geometric - A system of cutting garments for ladies and gentlemen on geometric lines and principles / D. Joseph. – Chicago: Published by the author, 1900. - 15p.
85. Hutcheson, J. H. Dr. Wampen's world renowned system of anthropometry as simplified and Americanized / J. H. Hutcheson. – Chicago: Published by the author, 1903. - 115p.
86. Regal, S. The American garment cutter / S. Regal. – New York: American fashion company, 1904. - 174p.
87. Schulman, L. Schulman's system of garment cutting, coat and vest measure and adjustable trouser system / L. Schulman. – New York: Published by the author, 1904. - 100p.
88. Jno, J. M. Co. The new standard coat system / J. M. Co. Jno. – New York: The J.J. Mitchell Co, 1906. - 310p.
89. Croonborg, F. T. Grand edition of Supreme system for producing men's garments / F. T. Croonborg. – New York, Chicago: Croonborg Sartorial Co, 1907. - 252p.
90. Gordon, S.S. Gordon's work on cutting men's garments / S.S. Gordon. – Huntington: The S.S.Gordon Company, 1910. - 182p.
91. Short methods: a treatise on cutting, designing and manufacturing men’s clothing / – Charlottw, N.C.: The Charles publishing co, 1911. - 132p.
92. Stone, C. J. Stone's scientific system of grading patterns for men's garments / C. J. Stone. – Chicago: The Chas. J. Stone co, 1912. - 45p.
93. Gibson, L. International Cutting System / L. Gibson. – Washington, D. C.: Published by the author, 1913. - 62p.

94. Streiff, E. L. Streiff's system of garment cutting / E. L. Streiff. – Detroit: Printed by A. W. Brookes, 1913. - 40p.
95. Wendorf, W. Wendorf’s practical cutting method / W. Wendorf. – Chicago: Printed by J. B. Porter company, 1913. - 24p.
96. Croonborg, F. T. New supreme system for production of men's garments / F. T. Croonborg. – New York, Chicago: Croonborg Publication Fund, 1917. - 264p.
97. Popular gentle man system for cutting and designing of men's garments / – Philadelphia: Popular gentleman service company, 1917. - 84p.
98. Regal, S. The American pattern grader / S. Regal. – New York, Chicago: American Fashion Company, 1917. - 186p.
99. Simons, H. Drafting cotton garments and mackinaws / H. Simons. – New York: The Clothing designer company, 1918. - 54p.
100. Streiff, E. L. Streiff's ideal system of garment cutting / E. L. Streiff. – Detroit, Michigan: Published by the author, 1920. - 28p.
101. Kidwell, C. B. Cutting a fashionable fit : dressmakers' drafting systems in the United States / C. B. Kidwell. – Washington: Smithsonian Institution Press, 1979. - 173p.
102. Полный Академическій курс кройки мужского платья Перваго Вспомогательнаго Общества С. Петербургскихъ Закройщиковъ.-СПб.: Типо-литография Р. Голике, 1906г.
103. ВКОЛА КРОЙКИ мужского и дамекаго платья. Руководство для самообученія и самостоятельной кройкиСоставиль. Карлъ Беррисъ, Антеерпенъ 1906 г.
104. McCall, J. Instruction book for the French and English systems of cutting, fitting and basting / J. McCall. – New York: Published by the author, 1881. - 106p.
105. Sipe, T. E. Mrs. Self-instructor to the independent tailor system / T. E. Sipe. – Washington: Published by the author, 1887. - 18p.

106. Evan, H. P., co. Instruction book for the standard tailor system / – Chicago: H. P. Evan co., 1896. - 122p.
107. Blair, M. J. Margaret Blair system of garment drafting / M. J. Blair. – Minneapolis: H. L. Collins Company, 1897. - 100p.
108. Glicksten, P. Practical methods of designing according to proportions / P. Glicksten. – New York: The reich printing co., 1909.
109. Aldrich, W. Metric pattern cutting for menswear / W. Aldrich. – Oxford: Black well publishing, 2011. - 173p.
110. Surzhenko E. Y. Comparative analysis of the late 19th century and modern population size typologies / E. Y. Surzhenko, A. Moskvin, M. Mariia // Online magazine "Science Studies". The Institute of Public administration, law and innovative technologies (HOPIT). Issue 3, May-June. 2014.
111. Yan, J. Q. Exploration about Parameterization of Shape and Fit of Women / J. Q. Yan // Master dissertation of Wuhan Textile University, China, 2017. - 130p.
112. Daanen, H. M. Whole body scanners / H. M. Daanen, G. Jeroen // Displays, 1998, 19(3), pp. 111-120.
113. Robinette, K. M. Precision of the CAESAR scan-extracted measurements / K. M. Robinette, A. D. Hein // Applied Ergonomics, 2006, 37(3), pp. 259-265.
114. Lu, J. M. The evaluation of scan-derived anthropometric measurements / J. M. Lu, J. J. Mao // IEEE Transactions on instrumentation and measurement, 2010, 59(8), pp. 2048-2054.
115. Treleaven, P. Sizing us up / P. Treleaven // IEEE Spectrum, 2004, 41(4), pp. 28- 31.
116. Frank S. M. Development of a positioning aid to reduce postural variability and errors in 3D whole body scan measurements / S. M. Frank, M. Russell, S. Steve // Applied ergonomics, 2018, 68, pp.90-100.
117. 3–D Scanning Methodologies for Internationally Compatible Anthropometric Databases EN ISO-2010-20685 / Geneva Int. Stand. Organ.

118. Nicola, D. 3D body scanning technology for fashion and apparel industry / D. Nicola // International Society for Optics and Photonics, Videometrics IX. Vol. 6491, 2007.
119. Han, H. Comparative analysis of 3D body scan measurements and manual measurements of size Korea adult females / H. Han, N. Yunja, C. Kyungmi // International Journal of Industrial Ergonomics, 2010, 40(5), pp. 530-540.
120. Mckinnon, L. Body scanning / L. Mckinnon, L. I. Cynthia // Journal of Fashion Marketing and Management: An International Journal, 2002.
121. CAD [Электронный ресурс] //URL: https://baike.baidu.com/item/CAD/990 (дата обращения: 10.04.2018).
122. Fashion Silicon Valley Apparel Manufacturing Industry 4.0. The development process of clothing CAD software [Электронный ресурс] //URL: https://baike.baidu.com/item/CAD/990 (дата обращения: 10.04.2018).
123. Huang, H. Q. Block pattern generation: From parameterizing human bodies to fit feature-aligned and flattenable 3D garments / H. Q. Huang, P. Y. Mok, Y. L. Kwok, J. S. Au // Computers in Industry, 2012, 63(7), pp. 680-691.
124. Xu, J. A study on impact factors of the distance eases between body and garment / J. Xu, Z. Wenbin, X. Ping // 9th International Conference on Computer-Aided Industrial Design and Conceptual Design, IEEE, 2008.
125. Kim, S. H. Development of similarity evaluation method between virtual and actual clothing / S. H. Kim, K. Sungmin, K. P. Chang // International Journal of Clothing Science and Technology, 2017.
126. Oancea, G. Computer aided reverse engineering system used for customized products / G. Oancea, N. V. Ivan, R. Pescaru // Academic Journal of Manufacturing Engineering, 2013, 11(4), pp. 30-35.
127. Bradley, C. Advances in the field of reverse engineering / C. Bradley, C. Bernadette // Computer-Aided Design and Applications, 2005, 2(5), pp. 697-706.

128. Motavalli, S. Object-oriented modelling of a feature-based reverse engineering system / S. Motavalli // International Journal of Computer Integrated Manufacturing, 1996, 9(5), pp. 354-368.
129. Abella, R. J. Reverse engineering industrial applications / R. J. Abella, M. D. James, J. M. Roger // Computers & industrial engineering, 1994, 26(2), pp. 381-385.
130. Yau, H. T. Reverse engineering in the design of engine intake and exhaust ports / H. T. Yau, S. Haque, C. H. Meng // ASME PROD ENG DIV PUBL PED, New York, USA, 1993, 64, pp. 139-148.
131. Raja, V. Reverse engineering: an industrial perspective / V. Raja, J. F Kiran // Springer Science & Business Media, 2007.
132. Otto, K. A reverse engineering and redesign methodology for product evolution / K. Otto, K. Wood // Proceedings of the 1996 ASME Design Theory and Methodology Conference, 1996, Vol. 96.
133.Schröder, K. Image-based reverse engineering and visual prototyping of woven cloth / K. Schröder, Z. Arno, K. Reinhard // IEEE transactions on visualization and computer graphics, 2014, 21(2), pp. 188-200.
134.Bernardini, F. Building a digital model of Michelangelo's Florentine Pieta / F. Bernardini, H. Rushmeier, I. M. Martin, J. Mittleman, G. Taubin // IEEE Computer Graphics and Applications, 2002, 22 (1), pp. 59-67.
135. Pescaru, R. Parameteric modeling of shoe lasts using reverse engineering thchnique / R. Pescaru, O. Gheorghe, B. Iulian // Academic Journal of Manufacturing Engineering, 2012, 10(3).
136. Kuzmichev, V. Research on 3D reconstruction of late Victorian riding skirts / V. Kuzmichev, A. Moskvin, M. Moskvina, J. Pryor // International Journal of Clothing Science and Technology, 2018.
137. First auxiliary society of Saint-Petersburg cutters. Full Academic class of men’s dress cutting of the first Auxiliary Society of Saint-Petersburg cutters (in Russian). - Saint Petersburg, Golike printing house, 1906.

138. Красавец-мужчина. Русский модник середины - начала века / Авт.-сост. Н. М. Виноградова. - М.: Исторический музей, 2017. - 252 с.
139. General Administration of Quality Supervision, Inspection and Quarantine of the People’s Republic of China 2008 National Standards of People’s Republic of China: Standards sizing systems for garments-Men (China: Standards Press of China) 1-36.
140. Кузьмичев, В. Е. Основы теории системного проектирования костюма : учебное пособие для академического бакалавриата / В. Е. Кузьмичев, Н. И. Ахмедулова, Л. П. Юдина ; под науч. ред. В. Е. Кузьмичева. — 3-е изд., испр. и доп. — М. : Издательство Юрайт, 2018. — 392 с.
141. Кузьмичев, В.Е. Бодисканеры и одежда: новые технологии проектирования одежды. - Саарбрюкен, LAMBERT Academic Publishing (Германия), 2012. - 546 с.
142. Yao, M. Textile Materials / M. Yao. – Beijing: Chine Textile Press, 2015. -287p.
143. Duplicating pattern [Электронный ресурс] //URL: http://www.cdbbbw.com/svg4ux3/926.html (дата обращения: 08.06.2019).
144. Duplicating pattern [Электронный ресурс] //URL: http://news.ef360.com/Articlesinfo/2014-4-30/253672.html (дата обращения: 08.06.2019).
145. Instructables craft [Электронный ресурс] //URL: https://www.instructables.com/id/How-to-Copy-a-Garment-that-Fits-Perfectly-Without-/ (дата обращения: 08.06.2019).
146. Anthropometry, Apparel Sizing and Design (Second Edition), Edited by Norsaadah Zakaria and Deepti Gupta. The Textile Institute Book Series. - Duxford, United Kingdom, Cambridge, United States, Kidlington, United Kingdom, Woodhead Publishing, 2020,415 p. - Chapter 9 Evaluation of pattern block for fit testing (Контроль качества чертежей для оценки качества

посадки одежды), p. 217-251, https://doi.org/10.1016/B978-0-08-102604-5.00009-3
147. Типовые фигуры мужчин. Размерные признаки для проектирования одежды / ОАО «ЦНИИШП». – Москва: ОАО «ЦНИИШП», 2005. – 93 с.
148. The Metropolitan Museum of Art Suit [Электронный ресурс] //URL: https://www.pinterest.com/pin/369928556873397463/ (дата обращения: 10.02.2020)
149. Москвин, А.Ю. Проектирование мужской одежды на основе ретроспективного системного анализа конструктивных решений: диссер. ... канд. техн. наук; 17.00.06 Техническая эстетика и дизайн; Санкт-Петербургский гос. ун-т промышленных технологий и дизайна. - СПб, 2015, 239 с.
150. Васильев, А. Европейская мода. Три века. - М., СЛОВО/SLOVO, 2006.
151. Sizing in clothing. Developing effective sizing systems for ready-to-wear clothing. Edited by S.P. Ashdown. - Cambridge, England, Woodhead Publishing Textiles, 2008. - 378 p.
152. Свидетельство о гос. регистрации базы дан- ных РФ № 2014620287 База данных кроя мужской одежды 19 века / А. Ю. Москвин; заявитель и право- обладатель СПГУТД. - Заявл. № 2013621712 от 17.12.13; опубл. 20.03.14, официальный бюллетень "Программы для ЭВМ. Базы данных. Топологии ин- тегральных микросхем". - № 3(89), 2014.
153. Васильев, А. Русская мода: 150 лет в фотографиях. - М., СЛОВО/SLOVO, 2012.
154. Official websites of the Moscow State University [Электронный ресурс] //URL: https://www.msu.ru/ (дата обращения: 12.08.2017).
155. ГОСТ 22977-89. Детали швейных изделий. Термины и определения.
156. Гаврилово-Посадский краеведческий музей [Электронный ресурс] //URL: http://www.museum.ru/M521 (дата обращения: 26.02.2020).
157. Half of drawers drawing piece: gentleman's drawers, 1907 – The ladies treasury of clothing and fashion [Электронный ресурс] //URL:

https://www.pinterest.com/pin/553028029212603540/ (дата обращения: 08.08.2019).
158. Zhang, S. C. Virtual Scenario of Men Historical Clothes Adaption / S. C. Zhang, V. E. Kuzmichev, A. Moskvin // Information environment of the University: materials of the XXIV edition. scientific-technical Conf. IVGPU, Ivanovo, 22-23 Nov. 2017, p.160-164.
159. Zhang, S. C. Retrospective Analysis of European Men's Suit from 1850s to 1920s for Virtual Reconstruction / S. C. Zhang, V. E. Kuzmichev // DEStech Transactions on Social Science, Education and Human Science aems, 2019.
160. Чжан, Шичао. Получение цифровых двойников мужских фигур по изображениям и чертежам конструкций исторической одежды / Шичао. Ч, В.Е.Кузьмичев // Известия высших учебных заведений. Технология текстильной промышленности 2 (2019): 106-113.
161. Zhang, S. C. A method of selection the textile materials for virtual reconstruction / S. C. Zhang, V. E. Kuzmichev // 6th International Conference on Advanced Engineering and Technology: IOP Conf. Series: Mater. Sci. Eng. 2019.
162. Zhang, S. C. Calculation of the body measurements after analyzing the historical drawing / S. C. Zhang, V. E. Kuzmichev // Aegean International Textile and Advanced Engineering Conference: IOP Conf. Series: Mater. Sci. Eng, Vol. 459, No. 012087, 2019.
163. Zhang, S. C. Method of historical patterns analyzing / S. C. Zhang, V. E. Kuzmichev // International Conference on Technics, Technologies and Education: IOP Conf. Series: Mater. Sci. Eng. 2020.
164. Кузьмичев,В.Е. Проблемы генерирования цифровых двойников исторических костюмов с помощью технологии реверсивного инжиниринга / В.Е.Кузьмичев, А.Ю.Москвин, Д.С.Адольф, Ч. Шичао // Физика волокнистых материалов: структура, свойства, наукоемкие технологии и материалы: сборник материалов XXII межд. науч.-практ. форума. - Иваново, ИВГПУ, 2020, с.59-65.

165. Кузьмичев,В.Е. Проектирование цифровых двойников исторических систем "фигура - костюм" / В.Е.Кузьмичев, Н.А.Сахарова, А.В.Корнилович, ЧЖАН ШИЧАО, М.А.Москвина, А.Ю.Москвин, Д.Л.Орлов, Г.А.Карева, Д.С.Адольф // Известия вузов. Технология текстильной промышленности, 2019.
166. Шичао, Ч. Виртуальная реплика мужской народной рубашки конца XIX века (из фондов Гаврилово-Посадского музея) / Ч. Шичао, В.Е.Кузьмичев // Молодые ученые – развитию Национальной технологической инициативы (ПОИСК–2020):сб.материаловНациональноймолодёжнойнаучно-техническойконференции. – Иваново:ИВГПУ, 2020, с.714-716.
167. Шичао, Ч. Новый подход к симуляции исторического мужского пальто / Ч. Шичао, В.Е.Кузьмичев // Молодые ученые-развитию Национальной технологической инициативы (ПОИСК) 1-1 (2019): 137-140.
168. Мундир для торжественных случаев: пат. 123089 Российская Федерация / Е.В.Румянцев, В.Е.Кузьмичев, Т.Н.Грищенко, Ч.Шичао ; заявитель и патентообладатель ФГБОУ ВО Ивановск. гос. политех ун-т. — № 2019505136 ; заявл. 18.11.2019 ; – опубл. 17.12.2020.

APPENDIX A.

Results of men's body measurements without corset and in corset (for Chapter 2)

Table A.1 – Results of male body measurements at chest level, cm

Body Type	Sample ID	Height	Chest girth		Diameters without corset		Difference between $d_{tra.B}$ and $d_{an.B}$	Diameters with corset		Difference between $d_{tra.B}$ and $d_{an.B}$
			without corset	with corset	$d_{tra.B}$	$d_{an.B}$	Λ	$d_{tra.B}$	$d_{an.B}$	Δ
Y	Soldier1	183.50	97.50	97.20	34.73	23.15	11.58	35.92	22.98	12.94
Y	Soldier2	177.70	99.70	101.80	35.36	24.24	11.12	35.57	24.71	10.85
Y	Soldier3	187.40	104.60	105.60	37.46	25.28	12.18	37.84	25.92	11.92
Y	Soldier4	186.70	100.80	104.50	34.46	25.24	9.21	36.74	25.75	10.99
Y	Soldier7	177.70	101.10	103.10	36.18	24.47	11.70	36.34	25.07	11.27
Y	Soldier8	177.70	108.30	109.90	38.98	26.54	12.44	37.17	25.62	11.55
Y	Soldier9	171.50	105.60	106.10	37.40	26.96	10.44	35.52	27.40	8.12
Y	Soldier10	176.90	109.50	112.90	37.70	26.90	10.80	40.41	26.79	13.62
Y	Soldier13	184.20	104.50	106.20	34.82	26.83	8.00	37.50	27.43	10.07
Y	Soldier14	174.80	102.60	105.10	35.79	25.15	10.64	37.25	25.81	11.44
Y	Soldier17	180.20	92.00	90.80	32.22	21.73	10.49	32.64	21.13	11.51
Y	Soldier18	176.20	97.50	101.10	33.73	24.42	9.31	36.59	23.83	12.75
Y	Soldier20	180.20	102.10	109.10	36.57	24.31	12.26	38.54	25.31	13.23
Y	Athlete23	184.90	111.30	110.60	37.48	28.15	9.32	36.76	28.48	8.28
Y	Athlete24	187.40	115.90	117.30	39.67	29.22	10.46	39.65	30.26	9.39
Y	Athlete25	170.40	116.00	117.00	40.29	29.27	11.02	39.88	29.23	10.65
Y	Athlete26	169.70	104.00	106.00	36.42	25.35	11.07	37.31	25.88	11.43
Y	Athlete27	168.30	94.60	97.30	32.42	24.44	7.99	33.06	25.16	7.90
Y	Athlete28	179.50	104.30	106.00	36.90	26.18	10.72	37.33	26.50	10.82
Y	Athlete29	165.00	107.60	107.40	36.76	26.45	10.31	37.46	26.29	11.17
Y	Athlete30	174.80	116.00	116.70	38.22	31.03	7.19	38.32	31.16	7.16
Y	Athlete31	181.60	123.00	126.40	40.17	31.62	8.55	40.97	32.67	8.30
Y	Student1	173.00	92.20	95.70	31.62	22.71	8.91	32.31	23.99	8.32
Y	Student2	176.20	98.60	98.40	35.65	24.79	10.86	34.78	25.30	9.48
Y	Student4	188.10	93.40	97.50	34.90	21.59	13.32	37.39	21.75	15.65
Y	Student5	184.90	89.60	90.00	31.38	21.15	10.24	31.30	21.84	9.46
Y	Student13	173.80	94.40	97.10	33.68	22.45	11.23	34.07	23.96	10.11
Y	Student14	181.60	95.80	95.30	34.03	21.94	12.09	33.43	22.10	11.33
Y	Student15	177.70	97.90	99.30	34.14	25.34	8.80	30.98	24.16	6.82
A	Soldier5	180.20	99.30	101.40	35.00	24.13	10.88	35.75	24.27	11.48
A	Soldier6	180.90	117.10	121.90	41.65	30.79	10.86	42.88	31.52	11.36
A	Soldier11	183.50	91.60	94.60	33.53	20.81	12.72	34.27	21.61	12.66
A	Soldier12	178.80	93.10	95.30	32.09	23.31	8.78	32.73	25.13	7.60
A	Soldier15	177.70	93.50	95.90	32.49	22.83	9.66	33.75	23.29	10.47
A	Soldier16	184.20	91.20	93.40	33.16	21.20	11.97	34.17	21.88	12.29
A	Soldier19	179.50	109.70	110.00	39.72	25.89	13.83	39.27	26.74	12.54
A	Athlete22	179.50	115.10	116.40	38.14	29.90	8.24	37.43	30.56	6.87
A	Student3	175.50	91.70	94.80	31.08	23.13	7.95	31.95	24.24	7.71
A	Student12	175.50	94.60	96.50	33.32	24.14	9.18	34.27	24.37	9.91
B	Soldier21	177.00	91.80	95.30	31.61	23.04	8.57	32.61	24.66	31.61
B	Student11	188.90	83.50	86.40	29.06	22.54	6.52	30.79	22.95	29.06

Table A.2 – Results of male body measurements at waist level, cm

Body Type	Sample ID	Height	Waist girth		Diameters without corset		Difference between $d_{tra.B}$ and $d_{an.B}$	Diameters with corset		Difference between $d_{tra.B}$ and $d_{an.B}$
			without corset	with corset	$d_{tra.B}$	$d_{an.B}$	Λ	$d_{tra.B}$	$d_{an.B}$	Δ
Y	Soldier1	183.50	78.70	78.20	28.56	20.61	7.95	28.65	22.29	6.35
Y	Soldier2	177.70	79.60	77.40	29.28	20.42	8.86	28.93	21.01	7.92
Y	Soldier3	187.40	85.20	83.40	32.03	21.54	10.49	30.89	20.80	10.09
Y	Soldier4	186.70	79.00	80.60	28.10	21.50	6.60	28.30	22.16	6.14
Y	Soldier7	177.70	80.60	78.60	29.30	21.39	7.91	28.09	21.47	6.62
Y	Soldier8	177.70	86.50	87.70	32.29	21.39	10.90	30.51	24.28	6.23
Y	Soldier9	171.50	86.60	85.50	30.16	23.57	6.59	29.20	24.25	4.95
Y	Soldier10	176.90	90.10	88.30	31.75	25.06	6.70	31.80	23.84	7.96
Y	Soldier13	184.20	82.40	85.20	29.06	22.89	6.17	29.55	24.17	5.37
Y	Soldier14	174.80	79.50	78.00	28.28	21.38	6.89	28.06	21.06	7.00
Y	Soldier17	180.20	74.30	77.10	27.32	19.25	8.07	27.47	21.24	6.24
Y	Soldier18	176.20	77.30	79.30	27.28	21.16	6.12	28.25	21.10	7.15
Y	Soldier20	180.20	79.80	80.70	28.35	21.13	7.23	29.09	21.92	7.17
Y	Athlete23	184.90	85.60	83.60	29.74	23.42	6.33	29.10	23.69	5.41
Y	Athlete24	187.40	91.90	89.00	32.74	24.57	8.17	31.93	23.44	8.50
Y	Athlete25	170.40	93.50	90.40	33.23	24.69	8.54	31.88	24.92	6.97
Y	Athlete26	169.70	87.70	85.10	31.59	22.20	9.39	30.37	21.98	8.39
Y	Athlete27	168.30	75.70	75.40	27.38	20.11	7.27	26.41	20.71	5.70
Y	Athlete28	179.50	85.10	84.70	29.31	23.66	5.65	29.66	23.19	6.47
Y	Athlete29	165.00	87.60	86.60	30.21	24.73	5.48	29.44	24.95	4.49
Y	Athlete30	174.80	92.10	90.40	31.58	25.03	6.55	30.89	25.60	5.29
Y	Athlete31	181.60	98.10	92.10	32.80	28.25	4.55	32.38	26.57	5.81
Y	Student1	173.00	72.90	76.60	25.74	19.48	6.26	26.36	20.73	5.62
Y	Student2	176.20	82.10	81.70	29.09	22.30	6.79	28.14	23.23	4.90
Y	Student4	188.10	71.00	74.10	26.40	17.33	9.07	26.73	18.41	8.32
Y	Student5	184.90	68.50	70.10	26.15	17.19	8.96	26.24	17.74	8.51
Y	Student13	173.80	75.50	76.40	26.55	21.02	5.53	27.48	20.61	6.87
Y	Student14	181.60	75.30	75.70	27.98	19.22	8.76	27.16	19.84	7.32
Y	Student15	177.70	76.30	78.40	29.02	19.14	9.89	28.46	20.59	7.87
A	Soldier5	180.20	84.00	82.30	31.01	21.80	9.21	29.22	21.95	7.27
A	Soldier6	180.90	101.20	100.70	35.62	27.47	8.15	34.82	28.29	6.53
A	Soldier11	183.50	79.50	81.00	29.80	19.81	9.99	29.92	20.04	9.88
A	Soldier12	178.80	78.30	76.00	27.74	21.77	5.96	26.49	21.13	5.36
A	Soldier15	177.70	80.30	80.30	28.57	21.73	6.84	28.71	21.74	6.97
A	Soldier16	184.20	75.70	76.90	27.56	20.35	7.21	27.51	20.71	6.80
A	Soldier19	179.50	94.50	91.50	32.66	26.42	6.25	31.89	25.16	6.73
A	Athlete22	179.50	99.50	91.40	34.97	27.67	7.31	32.12	25.44	6.68
A	Student3	175.50	78.20	76.30	28.28	19.99	8.29	29.11	21.09	8.02
A	Student12	175.50	80.30	81.60	28.18	22.30	5.88	28.67	22.47	6.20
B	Soldier21	177.00	83.10	86.20	28.92	22.63	6.29	29.32	24.78	4.53
B	Student11	188.90	74.50	75.90	27.61	18.89	8.72	27.84	20.28	7.56

Table A.3 – Results of male body measurements at hip level, cm

Body Type	Sample ID	Height	Hip girth		Diameters without corset		Difference between $d_{tra.B}$ and $d_{an.B}$	Diameters with corset		Difference between $d_{tra.B}$ and $d_{an.B}$
			without corset	with corset	$d_{tra.B}$	$d_{an.B}$	Λ	$d_{tra.B}$	$d_{an.B}$	Δ
Y	Soldier1	183.50	97.10	94.40	36.82	22.82	14.00	35.70	23.24	12.46
Y	Soldier2	177.70	96.70	96.20	35.16	24.91	10.25	36.06	25.56	10.50
Y	Soldier3	187.40	103.60	101.60	38.07	25.81	12.26	37.04	25.84	11.20
Y	Soldier4	186.70	97.20	97.10	35.59	24.96	10.63	35.50	25.70	9.80
Y	Soldier7	177.70	97.20	96.20	36.11	23.72	12.39	35.82	24.33	11.49
Y	Soldier8	177.70	100.30	99.70	36.18	24.49	11.69	34.52	25.55	8.97
Y	Soldier9	171.50	100.40	100.10	36.20	24.73	11.48	35.50	25.53	9.97
Y	Soldier10	176.90	100.90	98.80	35.57	27.14	8.43	36.01	26.58	9.43
Y	Soldier13	184.20	96.90	95.90	33.68	25.44	8.24	36.06	24.08	11.98
Y	Soldier14	174.80	96.60	99.00	28.28	21.37	6.90	35.51	24.96	10.55
Y	Soldier17	180.20	87.60	87.70	32.90	21.71	11.20	32.41	22.65	9.76
Y	Soldier18	176.20	94.00	93.60	34.76	22.99	11.77	34.07	23.56	10.51
Y	Soldier20	180.20	93.00	93.60	33.35	24.38	8.96	33.47	24.50	8.98
Y	Athlete23	184.90	103.70	101.70	37.33	26.05	11.28	36.46	27.66	8.80
Y	Athlete24	187.40	114.80	111.30	40.86	28.64	12.22	40.17	29.00	11.17
Y	Athlete25	170.40	106.10	103.90	37.41	28.01	9.39	36.47	28.39	8.08
Y	Athlete26	169.70	105.40	94.00	38.00	24.10	13.91	33.31	25.32	7.99
Y	Athlete27	168.30	94.80	90.10	33.61	22.70	10.92	33.44	21.71	11.73
Y	Athlete28	179.50	99.80	100.60	36.28	25.12	11.16	35.84	26.80	9.04
Y	Athlete29	165.00	95.50	91.40	24.56	24.91	(0.35)	32.47	25.40	7.07
Y	Athlete30	174.80	105.30	104.50	35.68	28.88	6.79	37.82	27.29	10.53
Y	Athlete31	181.60	111.50	107.20	37.30	29.73	7.57	36.67	30.26	6.41
Y	Student1	173.00	95.90	95.40	35.46	23.16	12.30	35.60	22.43	13.17
Y	Student2	176.20	100.10	101.00	35.56	26.65	8.91	37.15	27.33	9.82
Y	Student4	188.10	89.50	90.20	32.56	22.71	9.86	33.06	21.74	11.32
Y	Student5	184.90	90.90	89.60	34.58	20.55	14.03	34.39	20.83	13.56
Y	Student13	173.80	94.60	92.50	34.51	23.50	11.01	33.69	23.64	10.05
Y	Student14	181.60	96.80	92.90	34.88	25.96	8.93	33.87	23.53	10.33
Y	Student15	177.70	93.60	91.20	34.62	21.85	12.78	33.70	21.47	12.23
A	Soldier5	180.20	99.70	98.70	35.75	24.87	10.88	37.28	29.39	7.89
A	Soldier6	180.90	107.70	106.80	38.35	29.13	9.22	37.66	29.37	8.30
A	Soldier11	183.50	95.40	96.20	36.42	22.96	13.46	36.67	23.95	12.72
A	Soldier12	178.80	96.30	96.44	34.77	24.21	10.56	34.41	25.40	9.01
A	Soldier15	177.70	98.50	99.00	36.57	23.85	12.72	35.27	24.47	10.80
A	Soldier16	184.20	94.80	93.20	35.19	22.66	12.53	35.56	21.58	13.98
A	Soldier19	179.50	100.50	102.30	35.68	26.51	9.17	35.97	27.87	8.10
A	Athlete22	179.50	108.00	106.40	37.71	29.01	8.70	36.75	29.83	6.92
A	Student3	175.50	98.80	99.60	35.71	24.98	10.73	36.23	24.93	11.30
A	Student12	175.50	96.40	96.00	34.76	25.50	9.25	34.53	24.34	10.19
B	Soldier21	177.00	97.80	98.28	35.09	26.34	8.75	34.84	26.90	7.95
B	Student11	188.90	95.40	95.40	34.99	23.80	11.19	34.60	24.35	10.25

Table A. 4 – Projection dimensions of body, cm

Body Type	Sample ID	Results of the measurements						
		Height	Without corset		Λ	With corset		Δ
			Distance back neck point to vertical	Distance scapula to vertical		Distance back neck point to vertical	Distance scapula to vertical	
Y	Soldier1	183.50	29.00	20.00	9.00	28.30	21.60	6.70
Y	Soldier2	177.70	32.20	23.20	9.00	30.30	22.80	7.50
Y	Soldier3	187.40	29.70	20.40	9.30	31.40	21.20	10.20
Y	Soldier4	186.70	28.20	20.00	8.20	25.80	20.00	5.80
Y	Soldier7	177.70	29.70	20.80	8.90	29.20	21.20	8.00
Y	Soldier8	177.70	26.80	20.80	6.00	28.50	21.20	7.30
Y	Soldier9	171.50	29.00	21.20	7.80	27.60	20.40	7.20
Y	Soldier10	176.90	28.80	20.00	8.80	29.10	20.00	9.10
Y	Soldier13	184.20	26.20	20.00	6.20	29.10	20.80	8.30
Y	Soldier14	174.80	28.60	20.00	8.60	28.10	20.00	8.10
Y	Soldier17	180.20	29.00	20.80	8.20	29.10	21.60	7.50
Y	Soldier18	176.20	26.50	20.00	6.50	25.30	21.20	4.10
Y	Soldier20	180.20	28.10	20.40	7.70	28.20	20.60	7.60
Y	Athlete23	184.90	29.60	20.00	9.60	30.20	20.40	9.80
Y	Athlete24	187.40	33.10	22.40	10.70	33.30	24.40	8.90
Y	Athlete25	170.40	29.50	20.00	9.50	29.60	21.60	8.00
Y	Athlete26	169.70	30.90	23.60	7.30	30.70	23.60	7.10
Y	Athlete27	168.30	30.20	20.00	10.20	31.10	21.60	9.50
Y	Athlete28	179.50	27.10	20.00	7.10	28.00	20.00	8.00
Y	Athlete29	165.00	30.70	22.00	8.70	31.10	21.20	9.90
Y	Athlete30	174.80	30.50	20.00	10.50	29.50	20.20	9.30
Y	Athlete31	181.60	30.60	20.40	10.20	28.90	20.80	8.10
Y	Student1	173.00	27.70	20.40	7.30	26.60	20.00	6.60
Y	Student2	176.20	28.70	23.60	5.10	29.00	24.00	5.00
Y	Student4	188.10	26.90	20.00	6.90	26.70	21.20	5.50
Y	Student5	184.90	29.30	20.00	9.30	27.50	20.00	7.50
Y	Student13	173.80	27.30	20.00	7.30	27.80	20.80	7.00
Y	Student14	181.60	29.30	23.20	6.10	24.10	22.00	2.10
Y	Student15	177.70	29.50	20.00	9.50	30.70	20.80	9.90
A	Soldier5	180.20	29.00	22.00	7.00	31.30	23.60	7.70
A	Soldier6	180.90	28.60	20.00	8.60	27.80	22.00	5.80
A	Soldier11	183.50	29.10	20.00	9.10	31.60	21.60	10.00
A	Soldier12	178.80	29.60	20.00	9.60	30.10	20.00	10.10
A	Soldier15	177.70	26.70	20.40	6.30	24.90	20.00	4.90
A	Soldier16	184.20	31.50	23.30	8.20	31.70	24.80	6.90
A	Soldier19	179.50	28.40	20.00	8.40	28.50	20.00	8.50
A	Athlete22	179.50	31.40	20.40	11.00	30.90	20.80	10.10
A	Student3	175.50	30.70	22.80	7.90	28.80	22.40	6.40
A	Student12	175.50	29.50	21.60	7.90	29.40	22.00	7.40
B	Soldier21	177.00	31.90	24.00	7.90	29.30	21.20	8.10
B	Student11	188.90	32.30	22.80	9.50	32.60	23.80	8.80

APPENDIX B.

Value of ease allowance for the shaping of historical men's coat (for Chapter 3)

Table B.1 – Value of ease allowance which can be used to reconstruct clothes for contemporary men, cm

No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Dimension of pattern														
Symbol	PB_{CG}	PB_{WG}	PB_{HG}	PB_{AL}	PB_{BW}	PB_{BL}	PB_{FW}	PB_{FS}	PB_{OS}	PB_{B}	PB_{ND}	PB_{SL}	PB_{DS}	PB_{WS}
PB1	103.88	93.02	123.74	44.92	38.73	42.67	43.95	34.32	47.2	30.91	16.03	15.23	16.69	12.85
PB2	106.32	96.99	128.1	49.39	40.43	45.03	42.55	36.18	51.04	32.85	15.1	16.16	18.19	13.37
PB3	101.78	91.81	117.5	43.79	38.04	42.75	42.46	33.38	46.24	30.51	15.65	15.03	16.17	13.07
PB4	109.87	99.56	118.64	41.19	39.74	42.87	45.67	32.73	44.01	32.37	15.26	18.34	15.48	11.96
PB5	103.8	92.43	113.01	42.7	39.23	41.43	43.31	32.62	45.29	30.79	14.06	17.8	15.93	12.76
Dimension of body measurements														
Symbol	CG_1	WG_1	HG_1	AG_1	BW_1	BL_1	FW_1	FS_1	OS_1	B_1	ND_1	SL_1	DS_1	WS_1
Nude body	88.52	71.86	87.44	28.32	31.99	36.41	33.76	26.85	39.77	27.89	12.09	12.46	11.02	12.04
Value of ease by formulas (4), $E_{CG} = PB_{CG} – CG_1$														
Position	To chest girth	To waist girth	To hip girth	To arm girth	To back width	To back length	To front width	To front shoulder	To over shoulder	To blade	To neck diameter	To shoulder length	To depth of scye	To width of scye
PB1	15.36	21.16	36.3	16.6	6.74	6.26	10.19	7.47	7.43	3.02	3.94	2.77	5.67	0.81
PB2	17.8	25.13	40.66	21.07	8.44	8.62	8.79	9.33	11.27	4.96	3.01	3.70	7.17	1.33
PB3	13.26	19.95	30.06	15.47	6.05	6.34	8.7	6.53	6.47	2.62	3.56	2.57	5.15	1.03
PB4	21.35	27.7	31.2	12.87	7.75	6.46	11.91	5.88	4.24	4.48	3.17	5.88	4.46	-0.08
PB5	15.28	20.57	25.57	14.38	7.24	5.02	9.55	5.77	5.52	2.90	1.97	5.34	4.91	0.72
Average	16.61	22.9	32.76	16.08	7.24	6.54	9.83	7.00	6.99	3.60	3.13	4.05	5.47	0.76

Table B.2 – Value of ease allowance which were used by tailors in history, cm

No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Dimension of pattern														
Symbol	PB_{CG}	PB_{WG}	PB_{HG}	PB_{AL}	PB_{BW}	PB_{BL}	PB_{FW}	PB_{FS}	PB_{OS}	PB_{B}	PB_{ND}	PB_{SL}	PB_{DS}	PB_{WS}
PB1	103.88	93.02	123.74	44.92	38.73	42.67	43.95	34.32	47.2	30.91	16.03	15.23	16.69	12.85
PB2	106.32	96.99	128.1	49.39	40.43	45.03	42.55	36.18	51.04	32.85	15.1	16.16	18.19	13.37
PB3	101.78	91.81	117.5	43.79	38.04	42.75	42.46	33.38	46.24	30.51	15.65	15.03	16.17	13.07
PB4	109.87	99.56	118.64	41.19	39.74	42.87	45.67	32.73	44.01	32.37	15.26	18.34	15.48	11.96
PB5	103.8	92.43	113.01	42.7	39.23	41.43	43.31	32.62	45.29	30.79	14.06	17.8	15.93	12.76
Dimension of body measurements														
Symbol	CG_2	WG_2	HG_2	AG_2	BW_2	BL_2	FW_2	FS_2	OS_2	B_2	ND_2	SL_2	DS_2	WS_2
Body over vest with minimal air gap	95.05	78.39	93.93	31.09	34.49	38.02	35.24	30.02	43.08	30.25	14.01	12.79	12.58	12.74
Value of ease by formulas (5), $E_{CGh} = PB_{CG} - CG_2$														
Position	To chest girth	To waist girth	To hip girth	To arm girth	To back width	To back length	To front width	To front shoulder	To over shoulder	To blade	To neck diameter	To shoulder length	To depth of scye	To width of scye
PB1	8.83	14.63	29.81	13.83	4.24	4.65	8.71	4.3	4.12	0.66	2.02	2.44	4.11	0.11
PB2	11.27	18.6	34.17	18.3	5.94	7.01	7.31	6.16	7.96	2.6	1.09	3.37	5.61	0.63
PB3	6.73	13.42	23.57	12.7	3.55	4.73	7.22	3.36	3.16	0.26	1.64	2.24	3.59	0.33
PB4	14.82	21.17	24.71	10.1	5.25	4.85	10.43	2.71	0.93	2.12	1.25	5.55	2.9	-0.78
PB5	8.75	14.04	19.08	11.61	4.74	3.41	8.07	2.6	2.21	0.54	0.05	5.01	3.35	0.02
Average	10.08	16.37	26.27	13.31	4.74	4.93	8.35	3.83	3.68	1.24	1.21	3.72	3.91	0.06

APPENDIX C.

Length of each suture line (for Chapter 3)

Table C. 1 – Length of each suture line for 17 Cutaway coats, cm

No.	1	2	3	14	16	19	23	26	28	33	35	36	41	44	45	46	47
a	24.66	28.16	26.4	24.74	22.48	23.48	23.31	23.23	24.79	23.29	25.6	26.37	23.62	25.67	26.94	25.02	24.74
b	23.93	27.72	25.21	24.62	22.77	22.81	22.79	23.31	24.44	21.44	25.69	26.47	23.62	25.81	26.92	25.01	23.24
c	38.67	45.3	42.55	38.49	39.1	36.06	37.44	37.49	37.3	38.21	41.17	43.39	40.15	41.24	41.17	41.1	36.43
e1	36.57	42.82	39.91	36.01	36.68	34.52	35.26	36.94	36.1	36.36	39.39	41.15	37.89	39.27	40.05	39.48	34.78
d	46.56	56.51	53.49	57.19	48.7	40.96	53.58	38.8	37.84	48.57	44.71	34.23	40.02	44.95	44.95	44.95	46.4
e2	46.61	56.23	53.4	56.22	48.18	41	53.22	38.23	37.75	48.41	44.23	34.26	39.92	44.55	45.15	44.4	45.02
f	32.28	43.19	42.9	36.29	36.02	29.51	39.78	35.73	33.48	33.79	30.04	31.38	33.43	32.38	30.66	28.96	27.51
g	10.32	13.09	13.4	11.95	12.73	13.43	15.53	11.33	9.75	13.38	11.28	11.37	12.1	11.46	11.23	10.5	10.16
r4	-	-	-	5.8	-	-	-	-	-	-	-	-	-	-	-	-	-
h	43.36	54.47	54.92	52.81	47.49	43.4	54.75	48.74	42.75	50.98	41.32	42.77	42.11	41.57	41.57	41.57	37.81
i	28.17	33.35	32.34	28.1	29.42	23.6	27.45	31.99	29.24	29.24	27.81	29.87	31.44	26.93	29.61	26.46	25.39
j	8.91	10.49	11.27	8.48	11.33	8.06	8.34	9.59	7.54	12.46	9.73	10.55	9.57	9.94	9.42	7.14	8.62
k	6.26	8.75	8.59	7.87	7.28	6.72	7.28	6.24	4.58	6.36	5.28	6.26	3.91	5.6	4.84	4.78	6.11
m	32.37	36.86	36.86	32.37	34.41	29.57	31.7	34.41	30.99	34.41	31.7	33.53	32.37	31.7	32.37	29.57	30.99
n	14.14	17.47	17.47	14.14	15.14	10.94	12.94	15.14	12.2	15.14	12.94	14.46	14.14	12.94	14.14	10.94	12.2
p1	46.56	48.32	48.32	46.56	47.31	45.48	46.37	47.31	46.1	47.31	46.37	46.95	46.56	46.37	46.56	45.48	46.1
p2	46.51	48.21	48.21	46.55	47.26	45.3	46.32	47.26	46	47.26	46.32	46.91	46.55	46.32	46.55	45.3	46
o1	59.92	63.55	63.55	59.92	61.13	56.09	58.61	61.13	57.74	61.13	58.61	60.24	59.92	58.61	59.92	56.09	57.74
o2	60.24	63.9	63.9	60.24	61.5	56.49	58.95	61.5	58.34	61.5	58.95	60.69	60.24	58.95	60.24	56.49	58.34
q1	18.2	17.38	16.52	14.79	16.09	16.55	17.07	18.4	16.56	15.45	17.61	18.01	15.9	18.27	17.66	18.74	14.47
q2	15.77	18.16	17.56	14.68	16.36	17.78	17.51	18.26	17.49	16.94	17.39	17.98	15.63	17.84	17.53	18.52	14.58
r1	-	-	-	43.63	-	-	-	-	-	-	-	-	-	-	-	-	-
r2	-	-	-	44.95	-	-	-	-	-	-	-	-	-	-	-	-	-

Table C. 2 – Length of each suture line for 11 dress coats, cm

No.	4	5	6	15	18	22	25	30	31	34	40
a	25.54	24.42	24.89	25.14	22.22	21.83	23.41	24.19	24.24	25.6	25.37
b	24.59	23.53	24.26	24.51	22.41	21.5	23.34	24.27	24.19	25.03	25.46
c	39.74	38.44	39.64	38.57	38.33	34.92	37.61	39.52	39.99	37.98	41.55
e1	37.58	36.25	38.08	35.89	36.25	33.24	37.29	38.72	39.2	37.34	40
d	57.69	56.36	57.76	54.26	53.77	53.4	46.05	44.66	49.82	52.69	54.94
e2	57.12	55.78	57.25	53.55	52.53	52.84	45.71	44.6	49.83	52.32	54.86
f	-	25.02	-	18.51	17.3	26.4	30.98	32.43	32.95	24.56	31.68
g	-	10.39	-	11.89	12.55	13.19	11.16	12.23	11.38	11.18	12.32
h	-	35.89	-	30.53	29.06	39.27	43.16	44.66	44.84	35.83	44.38
i	29.06	28.11	31.08	28.37	29.69	23.9	31.6	29.95	30.44	24.91	29.97
j	8.87	8.57	9.33	8.71	11.08	8.5	9.48	10.91	11.31	9.59	9.95
k	6.23	6.04	6.54	7.81	7.04	6.88	6.31	5.8	5.78	6.35	5.11
m	32.37	32.37	34.41	32.37	34.41	29.57	34.41	33.53	34.41	30.99	32.37
n	14.14	14.14	15.14	14.14	15.14	10.94	15.14	14.46	15.14	12.2	14.14
p1	46.56	46.37	47.31	46.56	47.31	45.48	47.31	46.95	47.31	46.1	46.56
p2	46.55	46.32	47.26	46.55	47.26	45.3	47.26	46.91	47.26	46	46.55
o1	59.92	59.92	61.13	59.92	61.13	56.09	61.13	60.24	61.13	57.74	59.92
o2	60.24	60.24	61.5	60.24	61.5	56.49	61.5	60.69	61.5	58.34	60.24
q1	15.15	15.15	15.56	15.02	15.47	16.04	17.24	18.55	17.3	15.34	19
q2	15.85	15.85	16.51	14.72	16.26	16.99	18.18	18.55	17.16	15.67	18.84
r1	-	47.63	-	-	-	46.8	46.7	51.47	-	48.34	50
r2	-	44.73	-	-	-	41.7	44.99	47.57	-	45.66	46.61
r3	-	4.49	-	-	-	4.74	2.62	4.49	-	4.13	3.75

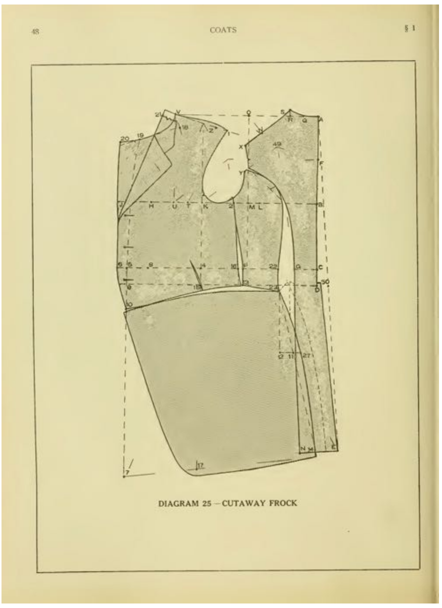
Table C. 3 – Length of each suture line for 19 frock coats, cm

No.	7	8	9	10	11	12	13	17	20	21	24	27	29	32	37	38	39	42	43
a	25.41	25.42	25.41	23.09	25.29	25.99	25.14	22.89	22.95	24.5	23.41	23.11	25.46	26.59	25.49	24.48	26.83	24.82	24.15
b	24.87	24.89	24.49	22.1	24.69	24.87	24.41	23.1	22.8	24.13	23.37	22.68	25.58	25.22	25.45	24.57	26.96	24.96	24.14
c	40.77	40.61	40.57	36.87	40.36	40.39	39.83	40.14	34.15	36.57	37.81	36.37	40.35	39.09	41.79	39.93	44.3	40.94	40.76
e1	38.15	38.54	38.86	34.97	37.87	38.81	37.32	37.53	34.48	36.53	37.44	35.18	39.16	37.68	40.24	38.65	41.84	39.17	39.09
d	53.88	53.07	51.74	42.75	52.92	57.81	52.49	60.54	51.49	54.85	47.17	50.31	52.41	54.25	55.51	54.56	57.1	43.97	56.42
e2	53.53	52.48	51.27	42.05	52.98	57.03	52.35	59.76	50.83	54.05	46.26	49.55	50.59	54	54.87	54.41	56.06	42.67	55.65
f	30.81	35.22	35.64	27.02	34.97	31.33	30.38	35.4	32.61	31.8	32.1	32.18	34.49	32.27	39.07	30.19	30.21	31.37	33.44
g	10.24	10.17	11.84	10.73	9.96	11.31	9.96	12.96	13.18	14.4	11.91	9.01	11.3	11.04	13.41	11.27	11.22	11.17	12.25
r4	5.9		6.14	8.67	-	6.33	5.78	5.74	-	5.47	3.63	5.54	-	6.9	-	6.11	5.82	7.72	7.1
h	47.67		53.2	47.66	45.23	50.19	46.89	54.1	46.18	51.34	49.35	49.31	45.64	50.32	52.66	47.57	47.21	51.31	52.4
i	27.62	45.34	30.38	26.75	27.61	32.31	27.23	29.96	23.7	25	32.41	27.84	29.13	27.28	30.79	27.39	28.38	29.09	30.64
j	9.35	27.69	9.23	8	9.2	8.73	8.91	11.85	8.33	9.1	9.13	9.42	10.03	9.04	10.15	9.77	10.42	9.85	9.87
k	7.95	9.18	8.12	7.99	7.7	8.36	7.66	7.46	6.65	7.09	6	5.77	5.34	6.02	5.65	5.54	6	5.29	5.45
m	32.37	7.91	34.41	31.7	32.37	35.13	32.37	35.13	29.57	30.99	34.41	31.7	32.37	31.7	33.53	31.7	32.37	32.37	33.53
n	14.14	32.37	15.14	12.94	14.14	15.88	14.14	15.88	10.94	12.2	15.14	12.94	14.14	12.94	14.46	12.94	14.14	14.14	14.46
p1	46.56	14.14	47.31	46.37	46.56	47.68	46.56	47.68	45.48	46.1	47.31	46.37	46.56	46.37	46.95	46.37	46.56	46.56	46.95
p2	46.55	46.56	47.26	46.32	46.55	47.57	46.55	47.57	45.3	46	47.26	46.32	46.55	46.32	46.91	46.32	46.55	46.55	46.91
o1	59.92	46.55	61.13	58.61	59.92	61.94	59.92	61.94	56.09	57.74	61.13	58.61	59.92	58.61	60.24	58.61	59.92	59.92	60.24
o2	60.24	59.92	61.5	58.95	60.24	62.19	60.24	62.19	56.49	58.34	61.5	58.95	60.24	58.95	60.69	58.95	60.24	60.24	60.69
q1	15.31	60.24	15.29	15	15.2	15.83	15.06	16.14	16.87	17.82	18.44	15.94	17.99	14.73	19.06	17.95	18.03	17.95	19.55
q2	15.14	15.36	16.58	15.23	15.28	16.48	14.99	16.74	17.81	18.55	18.34	16.67	18.02	15.57	18.77	17.66	17.84	17.73	19.55
r1	47.87	15.11	40.39	43.16	-	48.11	46.85	46.05	-	46.16	43.79	43.49	-	44.2	-	44.39	50.91	47.19	47.41
r2	47.9		40.37	43.57	-	48.21	46.91	46.09	-	46.07	44.13	44.87	-	45.92	-	44.22	50.58	47.03	47.57

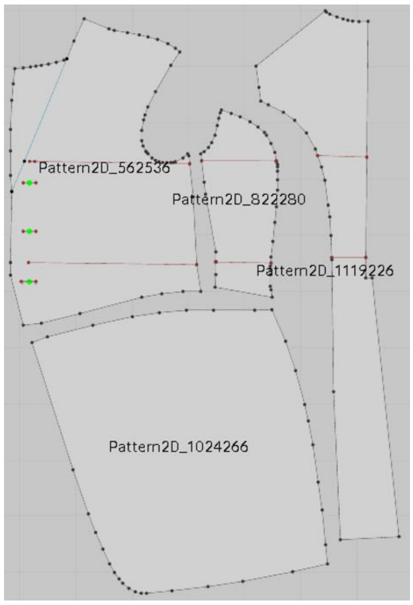
APPENDIX D.

Examples of DT of three style men's coat

Men’s cutaway coat



a

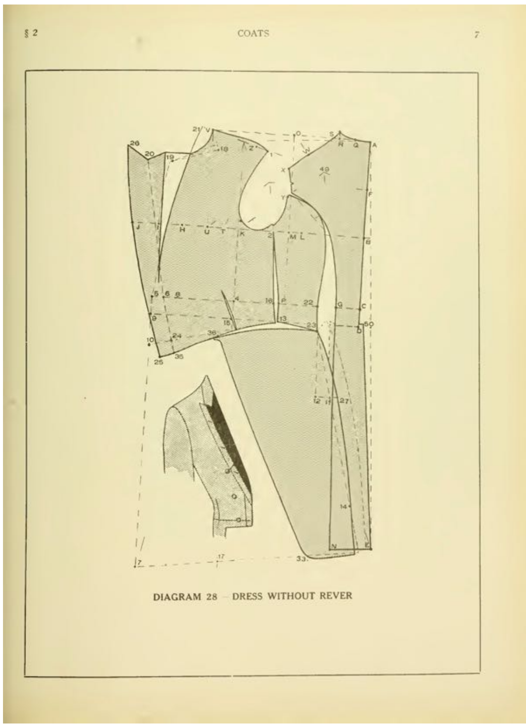


b

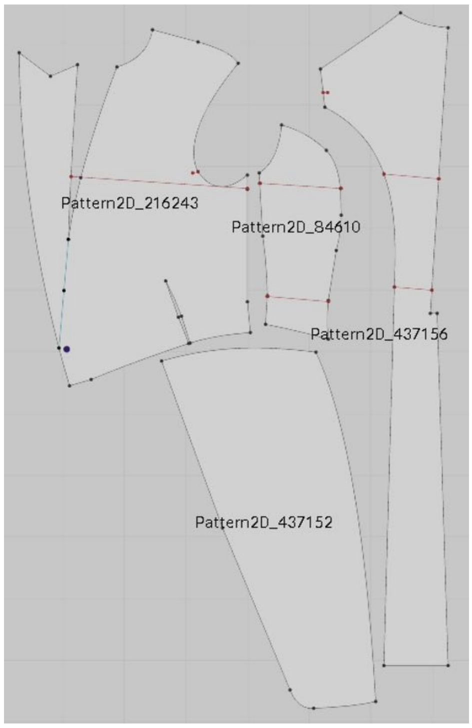
c

Figure C. 1 – Simulation of men’s cutaway coat: a – historical pattern; b – 2D pattern in CAD; c – virtual system

Men’s dress coat



a

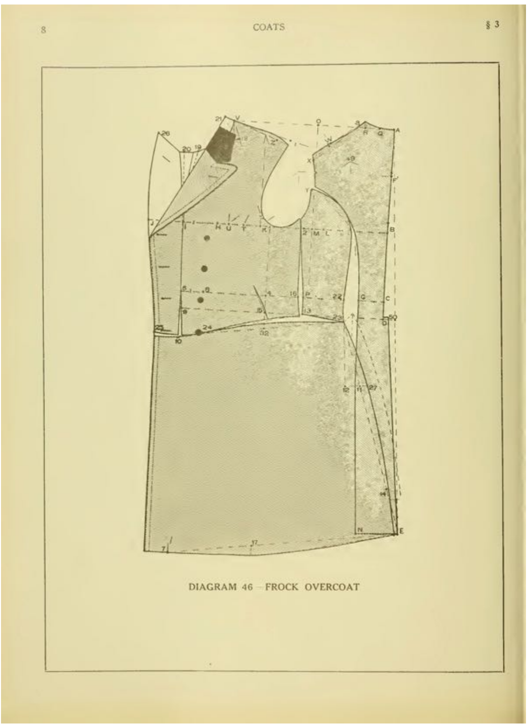


b

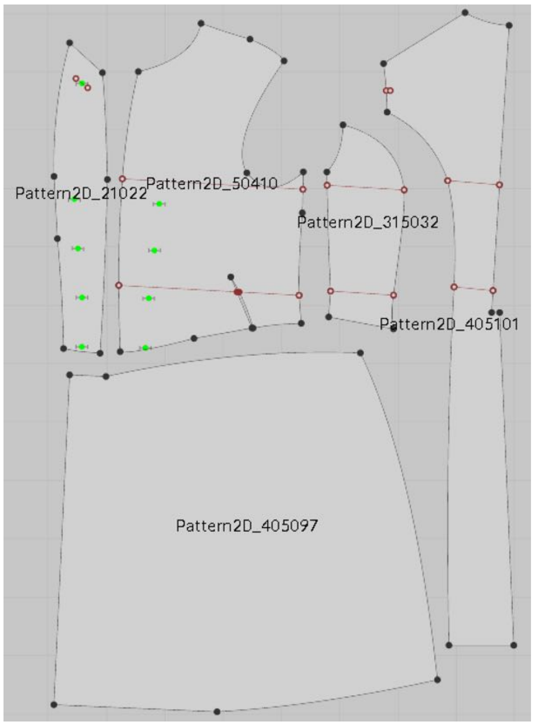
c

Figure C. 2 – Simulation of men’s dress coat: a – historical pattern; b – 2D pattern in CAD; c – virtual system

Men’s frock coat



a



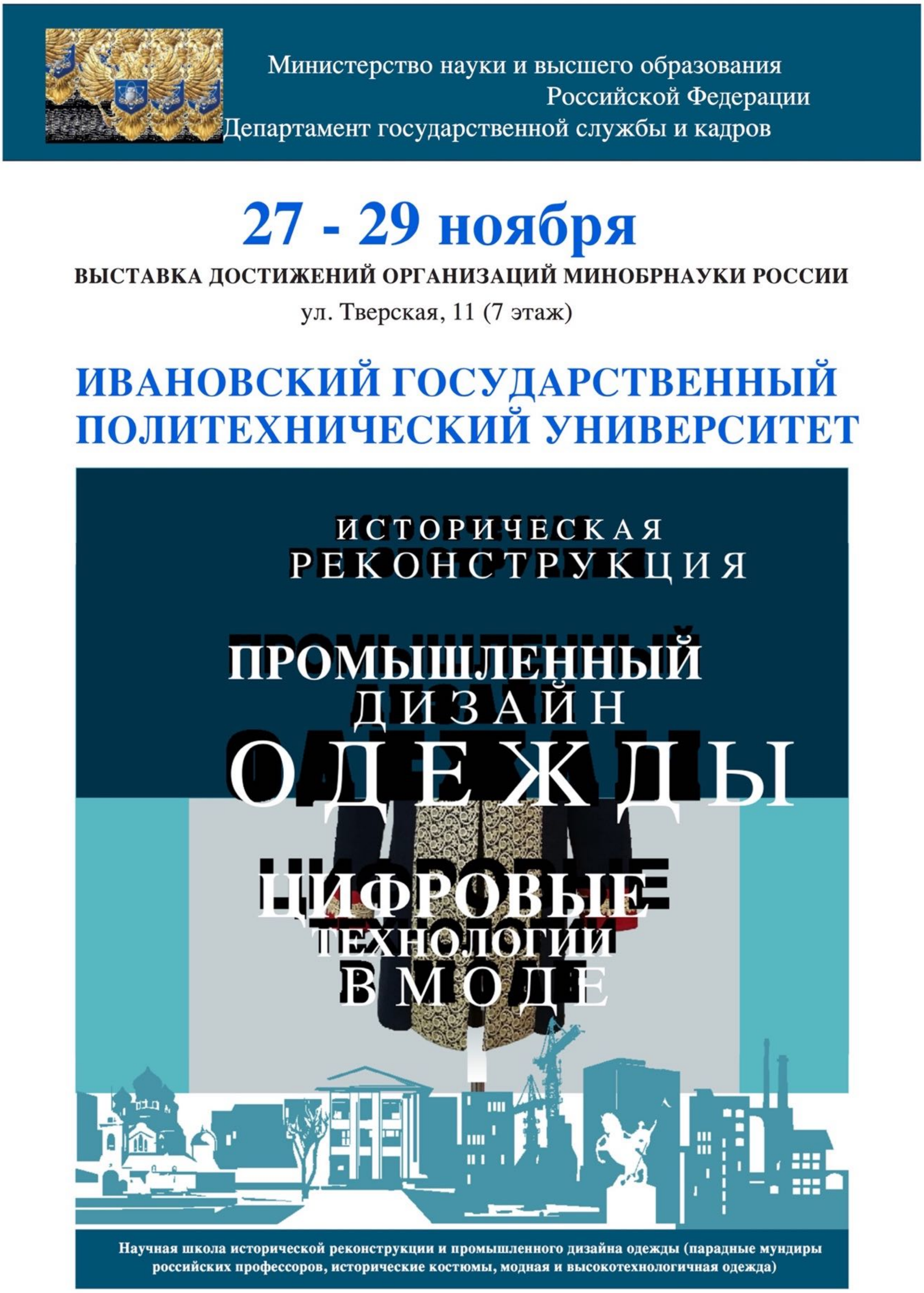
b

c

Figure C. 3 – Simulation of men’s frock coat: a – historical pattern; b – 2D pattern in CAD; c – virtual system

APPENDIX E.

Notice of exposition in Russian Ministery of High Education



APPENDIX F.

Copy of patent for industial design

РОССИЙСКАЯ ФЕДЕРАЦИЯ

ПАТЕНТ

НА ПРОМЫШЛЕННЫЙ ОБРАЗЕЦ

№ 123089

МУНДИР ДЛЯ ТОРЖЕСТВЕННЫХ СЛУЧАЕВ

Патентообладатель(ли): *Федеральное государственное бюджетное образовательное учреждение высшего образования "Ивановский государственный политехнический университет" (RU)*

Автор(ы): *см. на обороте*

Заявка № **2019505136**

Приоритет(ы) промышленного образца **18 ноября 2019 г.**

Дата государственной регистрации в Государственном реестре промышленных образцов Российской Федерации **17 декабря 2020 г.**

Срок действия исключительного права на промышленный образец истекает **18 ноября 2024 г.**

Руководитель Федеральной службы по интеллектуальной собственности

Г.П. Ивлиев

APPENDIX G.

Certificate of contest award #УзнайРоссию

Второй Международный Конгресс волонтёров познавательного туризма, культуры и медиа «Живое наследие малой Родины»

Литературный фестиваль #Узнай Россию. Донское слово

"The Living Heritage of the Motherland»

The Second International Congress of Volunteers for Media, Culture and Cultural Tourism

Literature Festival #Discover Russia. Don word

Реализуется при поддержке

ФОНДА ПРЕЗИДЕНТСКИХ ГРАНТОВ

МИНИСТЕРСТВО КУЛЬТУРЫ РОССИЙСКОЙ ФЕДЕРАЦИИ

Правительства и Общественной палаты Ростовской области

членов Общественной палаты Российской Федерации

ДИПЛОМ ПОБЕДИТЕЛЯ

международного дистанционного конкурса просветительского проекта # УЗНАЙ РОССИЮ

награждается

Чжан Шичао,

Китайская Народная Республика,
за победу в конкурсе на лучший костюм
героя литературного произведения
выдающихся писателей и поэтов Дона и Приазовья,
направленного на изучение и популяризацию их творчества

Л.А. Шафиров
член Общественной палаты Российской Федерации

З. П. Болотова
вице-президент
ОМОО «Ассоциация почётных граждан, наставников и талантливой молодёжи»

2020 г.