TALLINNA TEHNIKAÜLIKOOL
DOKTORITÖÖ
22/2018

Integration of Automated Data Collection, Enrichment and Transfer to CAD Systems in Digital Tailoring

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TTÜ PRESS

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This dissertation was accepted for the defence of the degree of Philosophy in Computer Science on May 9, 2018.

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Defence of the thesis: June 12, 2018, Tallinn

Declaration:
Hereby I declare that this doctoral thesis, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology has not been submitted for any academic degree.

European Union
European Social Fund

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ISSN 2585-6898 (publication)
ISBN 978-9949-83-255-2 (publication)
ISSN 2585-6901 (PDF)
ISBN 978-9949-83-256-9 (PDF)

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Informatsiooni automaatse kogumise, rikastamise ja CAD-süsteemile sisestamise meetod digitaalses rätsepakunstis

PIRJO ELBRECHT

TTÜ KIRJASTUS

CONTENTS

ACKNOWLEDGEMENTS

I am utmost grateful to my supervisor Docent Jaak Henno who accepted me as his supervisee in the Summer of 2010 with no prior contact and relatively close to the formal application deadline. He always found time to discuss with me the questions I had and encouraged and supported me through the writing of the thesis.

I would like to thank David Bruner, who gave me the chance to use their software (SizeStream).

I would like to thank my friend Eveli Kuuse for the moral help and support.

I want to thank you my co-researcher industrial designer Mr. Knut-Joosep Palm for the research and all the academic discussions and work we have had during those years with my dissertation.

I would like to thank Incognito Ballistic LLC., who has been my biggest financial supporter and business partner with this thesis.

Thank you for Prof Rein Kuusik who had given me the opportunity to step into the science world.

I would like to thank my family and friends for their continuous direct and indirect support, patience, understanding and encouragement at different stages of the present work.

LIST OF PUBLICATIONS

The following publications are presented at the end of the thesis and referred to in the text by their Roman numerals I-V:

Paper I

Elbrecht, Pirjo; Palm, Knut-Joosep (2016). Information Processing For Mass Customized Clothing Production. *2016 IEEE Tenth International Conference on Semantic Computing (ICSC).* IEEE, pp 362−365 (1).

Paper II

Elbrecht, Pirjo; Palm, Knut-Joosep (2014). The precision of 3D Body scanners. *18th International Conference on Intelligent Engineering Systems, Tihany, Hungary. July 3-5 2014.* IEEE, 127−132 (2).

Paper III

Elbrecht, Pirjo; Henno, Jaak; Palm, Knut-Joosep (2013). Body Measurements Extraction from 3D Scanner Data*. In: Wen J. (Ed.). Mechatronics and Control Engineering (372−377).* Trans Tech Publications Ltd. (Applied Mechanics and Materials; 339) (3).

Paper IV

Elbrecht, Pirjo; Henno, Jaak; Palm, Knut-Joosep (2013). The Data Integration Tool for Digitized Tailoring. The Digital Tailoring system for digitized tailoring. *17th IEEE International Conference on Intelligent Engineering Systems.* IEEE, pp 193-196 (4).

Paper V

Elbrecht, Pirjo; Henno, Jaak; Palm, Knut-Joosep (2013). Waist circumference measurement extraction from 3D scanner data. *In: Advanced Materials Research (725−731). Switzerland:* Trans Tech Publications Ltd (5).

OTHER RELATED PUBLICATIONS

Paper VI

Elbrecht, Pirjo; Henno, Jaak; Palm, Knut-Joosep. (2013). Body Measurements Extraction from 3D Scanner Data. In: Wen J. (Ed.). Mechatronics and Control Engineering (372−377). Trans Tech Publications Ltd. (Applied Mechanics and Materials; 339).

Paper VII

Elbrecht, Pirjo; Henno, Jaak; Palm, Knut-Joosep (2010). Implementational anthropometric studies. Info- ja kommunikatsioonitehnoloogia doktorikooli IKTDK neljanda aastakonverentsi artiklite kogumik: Info- ja kommunikatsioonitehnoloogia doktorikooli IKTDK neljas aastakonverents, 26-27 November, Essu Parish, Estonia. Infotrükk OÜ, 121−123.

Paper VIII

Elbrecht, Pirjo; Henno, Jaak; Palm, Knut-Joosep (2016). Information Processing For Mass-Customized Clothing Production. 2016 IEEE Tenth International Conference on Semantic Computing (ICSC). IEEE, 362−365.

AUTHOR'S CONTRIBUTION TO THE PUBLICATIONS

I. Research about information processing for Mass Customized clothing production resulting in a (newly proposed) method for automated digitalized measurement taking using 3D scanners and a new tool for automatic enrichment of measurements data with data from other custom-designed databases and automatic communication of this enriched data to CAD-based system of the CIM system, which allowed to design a new method for Mass Customized clothing production. The research design followed the methods of design science. The author carried out the research, wrote the manuscript and presented the results at the international conference. The results are presented in this thesis chapter 4 and 5.

II. Research of problems with the proposed earlier automatic customer measurements taking system - usability of commonly used 3D body scanners; collecting 3D body scanning measuring results from most common NX16 and KX16 3D body scanners and analyzing the results. The author found that the two scanners produce significantly different measuring results which need correction in order to create platform-agnostic data. The author presented the results at the international conference. The results are presented in this thesis chapter 4.

III. Research about different apparel basic blocks and measurements used for trousers. Based on the previous results, it was suggested to introduce a new measurement technology for trousers' basic block construction. The technology was tested in industrial production and the obtained results were better than with previous technology. The author collected the data, analysed it and wrote the manuscript. The author presented the results at the international conference. The results are presented in this thesis chapter 5.

IV. Presentation of the design of a central subsystem for automating information collection from 3D-scanners, enrichment with data from other custom-design databases (material properties, Tailor Knowledge, requirements of a particular CIM-system), and presenting the enriched data to the CAD-subsystem. The work involved designing and performing the research, data analysis, and writing the manuscript. The research design followed the methods of design science. The author presented the results at the international conference. The results are presented in this thesis chapter 3.

V. Experimental work, testing several algorithms in measurement extraction program to create better algorithms for waist measurement extraction from 3D body scanning for different waistlines. The new algorithm presented for waist measurement extraction was tested in commercial production. The author carried out the research, wrote the manuscript and presented the results at the international conference. The results are presented in this thesis chapter 4.

LIST OF ABBREVIATIONS AND SYMBOLS

CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
CIM	Computer Integrated Manufacturing
CRM	Customer Relationship Management
MTM	Made-To-Measure
PLM	Product Lifecycle Management
PDM	Product Data Management
CAPP	Computer Aided Process planning
CAE	Computer Aided Engineering
CAQA	Computer Aided Quality Assurance
PPC	Production Planning and Control
ERP	Enterprise Resource Planning
API	Application Programming Interface

Chapter 1

1. INTRODUCTION AND AIM OF THE RESEARCH

“We are getting closer to the computerized factory, but we need more than electronics here and there. We need a totally integrated system of hardware and software.”

Robert J. Potter (6)

The three basic human needs are nutrition, shelter, and clothing (7). This explains why the textile industry is as old as human civilization. From ancient times to present day, textile has been a necessity for our daily life. Besides the basic functions of textile, the use of fashion textiles enables to reshape the spiritual outlook of humans, and most important of all, it provide an intuitive way for us to interact in daily life (8).

The apparel-manufacturing process evolved as an art and underwent several technical changes. The technological advancements in the apparel industry include the use of computerized equipment, especially in design, pattern-making and cutting, 3D scanning technology, automation and robotics, integration of wearable technology and advanced material transport systems (9).

The fashion apparel industry is one of the most influential industries in the word. Value of the global fashion industry: 3,000 billion dollars, 2 percent of the world’s Gross Domestic Product (10). About 60 million to 75 million people are employed in the textile, clothing and footwear sector worldwide (2014) (11). Nowadays, to support fashion business operations, computerized information systems are essential. Recent developments in social media, big data analytics, RFID technology, artificial intelligent methods, and the commonly used enterprise resource planning systems are all driving innovative business measures in the fashion apparel industry (12).

In a following section is described research motivation. After that, the research methodology of the thesis is explained, namely design-science research, accompanied by a list of research guidelines that are obeyed. Different parts of the overall research goal are underpinned with detailed research questions. The listed research steps that adhere to the research-methodology guidelines, address the research questions.

The structure of the thesis shows in which chapters what research steps are carried out. Contributions of the thesis are formulated as result of the research.

1.1 Motivation

Mass Customization in the clothing industry is the new edge to competitive advantage in the 21st century. This approach is marketing orientated as it offers the customized product corresponding to exact individual measurements to the increasingly demanding consumers (13). In Figure 1.1 is shown level of interest for personalized products and services by categories and age groups (14).

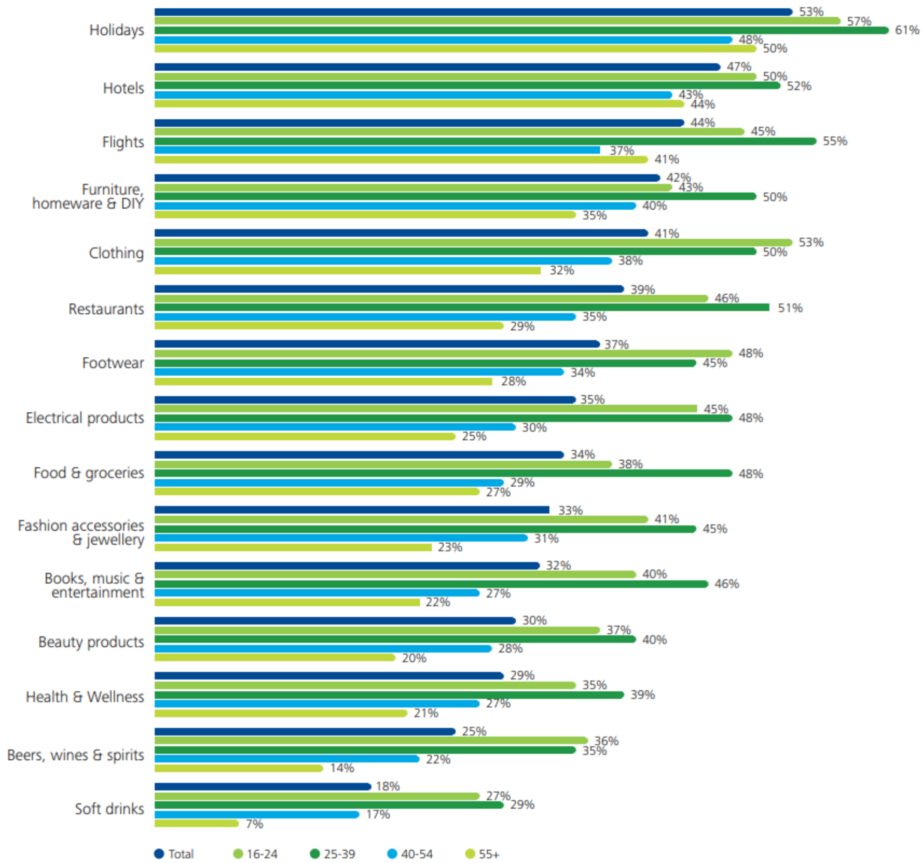

Figure 1.1 Level of interest for personalized products and services by categories and age groups

Manufacturing is undergoing tremendous transformation process. Build to order, speed and engagement with consumer are most important competitive factors. Garment manufacturing is entering the mass customization era: producing with mass production methods garments which are fitting for every customer, corresponding to customer individual measures. The challenge for manufacturing companies is to lower cost of products (15). At the same time, customers' demand is mass customization, what is potentially increasing the production cost.

The ultimate target is to organize production of customized garments as automatically as possible, i.e. to minimalize human interference. In ideal humans have to make only one click to start the process, all the following decisions are made by the system. The speed of one-click manufacturing process will change value chain economics and change the way companies organize their manufacturing processes (16).

All clothing manufacturers are currently pursuing two goals:

- to produce customized garments according to individual needs/tastes/wishes of each customer (customized garments)
- to apply mass-production methods for Mass Customized cloth to reduce production costs (Mass Customization)

These two goals are contradictory, individual needs/taste of a customer means a lot of custom information per each customer, which is difficult to take into account in mass production. The very contradiction is under scrutiny in this thesis. To solve the problem, a two-fold approach is proposed:

- to introduce methods and technology which maximally allow considering individuality and individual needs/taste of each customer in the first phase (model selection and measuring),
- in the second phase (production) - introduce methods for customized mass production

In the past, consumers were treated as individuals. With the development of mass-production, these values have been lost. The biggest problem for the consumer when buying ready-made clothes is to find well-fitting clothing. Between vanity sizing[1], inaccurate measuring charts, and the fact that no two bodies are the same, figuring out the well-fitting size of the mass-produced garment is not an easy task. It is even harder for plus-size customers because most brands stop producing apparel beyond size 46 (in the EU sizing system). Women in size 38 can have four different sizes in their closets because of different size ranges offered by different companies.

The fact that people are all different presents a big problem to apparel companies. Figure 1.2 presents a scatter diagram with a regression line for 2000 women between their waist and seat measurements – two important parameters for trousers. The data is collected by the author in years 2011-2014 (in Finland). The regression line (red) can represent production size range for the target market. As seen from the diagram, most people fallout from the regression line. They have to tolerate the apparel squeeze or ease in some places. They do not get a well-fitting product.

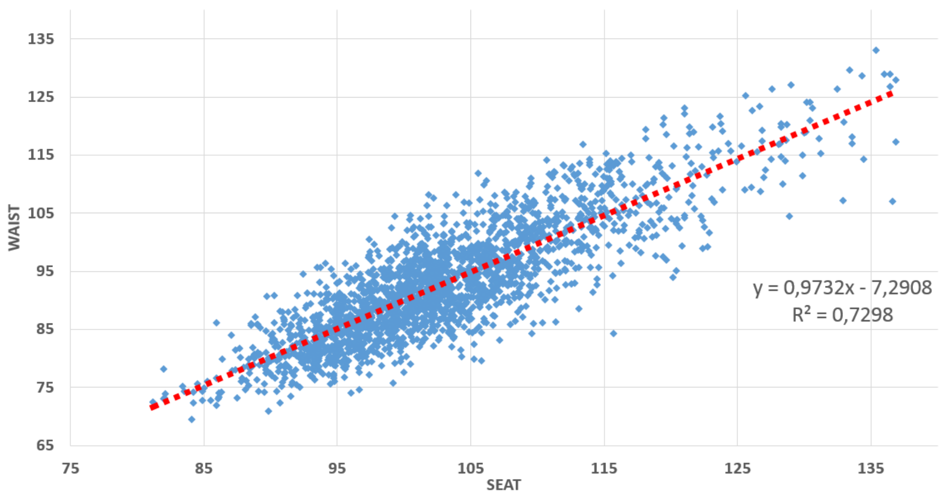

Figure 1.2 Scatter diagram for 2000 women of two important parameters for trousers - the waist and the seat measurements.

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[1] Vanity sizing, or size inflation, is the phenomenon of ready-to-wear clothing of the same nominal size becoming bigger in physical size over time (103), . Size inconsistency has existed since at least 1937. In Sears's 1937 catalog, a size 14 dress had a bust size of 32 inches (81 cm). In 1967, the same bust size was a size 8. In 2011, it was a size 0 (104)

1.2 Research Problem

This dissertation aims to answer the question,

How to organize production for Made-to-Measure (MTM) garments seamlessly by designing a system that combines 3D body scanning measurements, customer order and Tailor Knowledge and translates the information into a format readable by Computer Aided Design (CAD) systems, so that the customer can co-design[2] the garment and it would fit the customer (Figure 1.3)?

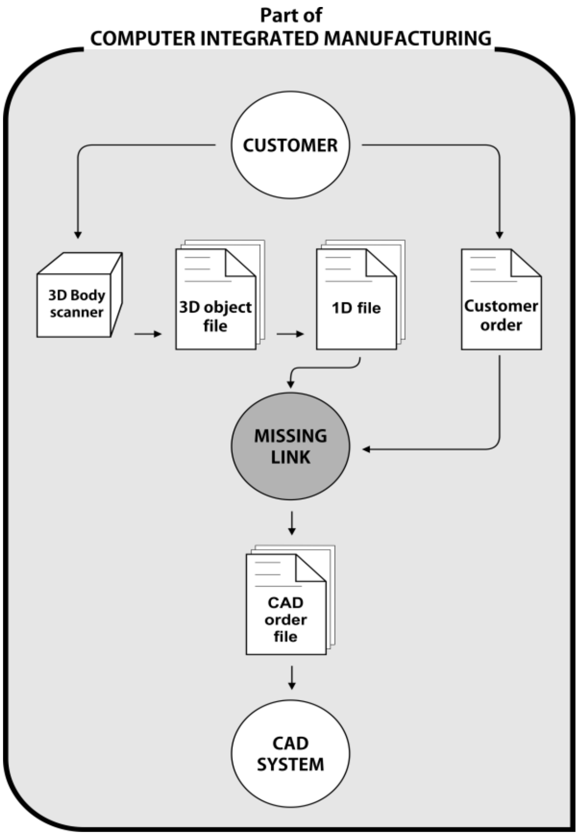

Figure 1.3 Context diagram of the research problem

The focus point of this research is mass customization – the technologies and systems to deliver goods and services that meet individual customers' needs with near mass production efficiency (17). This definition implies that the goal is to detect customers' needs and then to fulfil these needs with efficiency that is almost equals that of mass production (18) (19) (20) (21) (22).

In this research production of well-fitting garments, corresponding to personal measures and wishes of every customer is based on customer measuring using 3D

[2] Customer Co-Design describes a development process in which the customer and provider collectively ideate, elaborate and create a design specification for a product, which is purchased by the customer (102).

scanner. The production process gets as input the customer's measurements, co-design options and material.

The research problem of this thesis is to automate customer data manipulation in mass customized production process to order to make it one-click process (23), i.e. human operator only starts the process and all the following operations are made automatically by the system.

There is a 'missing link' between 3D body scanner output, customer order and CAD pattern-matching subsystem. The system input format is largely determined by Application Programming Interface (API) of the used 3D scanner, its output format by the API of the used CAD system (24). Since these formats are different for different 3D scanners and CAD systems is in the following considered semantics of data transformation realized in The Digital Tailoring system (25) and not presented detailed syntax, i.e. formats.

1.3 Research Method

The research method used in this study is "Design Science" (26), (27), (28), (29), (30), (31), (32). Especially in the context of information systems, the purpose of design science is to create innovations that define ideas, practices, technical capabilities and products, which help to analyze, design, implement, manage, and use the systems more effectively and efficiently (26). The result of design science research is an artifact, which provides a solution for the formulated problem, and its research should provide new data on the research topic itself (27). The artifact is constructed for a specific function, and the construction shows that the design problems have been resolved (28). The resolution of the problems is, in essence, the process of application, testing, modification, and extension of existing kernel theories through experience, creativity, and intuition (28), (30), (31). In this thesis, the artifact of the design science is the proposed generic architecture, and this thesis describes the design process and the existing technologies utilized in its construction (section 2.15).

In addition to the design process, an important factor in the creation of the artifact is the validation process, which is typically based on case-specific performance metrics (28). To validate the generic architectural design, the crucial metrics – or quality attributes– of the system need to be considered and the overall design should be validated to conform to the requirements. The advantage of executing multiple projects while designing the architecture lies in the feedback achieved from a wide audience – from internationally peer-reviewed conferences and publications as well as from people involved in the research projects.

The relevancy of the research must be clearly presented with respect to the target community (28). In the scope of this thesis, the community consists both of various industrial and educational partners participating in the research projects as well as potential developers of systems that utilize complex content analysis systems. Additionally, as the research has been carried out over multiple research projects, discussions with industrial and educational project partners have indicated the importance of the content analysis research, and of the design of a practical solution.

For the purpose of systematically validating the research approach of this thesis, the seven guidelines created by Hevner (28) for assisting researchers, reviewers, editors, and readers to understand the requirements for effective design-science research have been followed throughout the research process. The guidelines and their meanings, in relation to the context of this thesis, are summarized below:

1. Design as an Artifact. The primary outputs of design science in information systems research are purposeful artifacts created to address important organizational problems. The artifacts must be described effectively, enabling the implementation and application of the artifacts in appropriate domains.
    a. The overall problem of this thesis was to improve quality of mass produced garments and make their quality (first of all, fitting, but also speed of production) comparable to custom, tailor-produced garments, while at the same time not losing advantages of mass-production - lower price of production.
2. Problem Relevance. The objective of research in information systems is to acquire knowledge and understanding that enable the development and implementation of technology-based solutions to previously unsolved and important business problems.
    a. There does not exist technology, which would allow producing Mass Customized clothing according to customer measurements seamlessly.
3. Design Evaluation. The design is an iterative and incremental activity, and the design artifact is complete and effective when the pre-defined requirements have been fulfilled. The utility, quality, and efficacy of a design artifact must be demonstrated through the design process.
    a. Proof of concept case study for Digitally tailored jeans (section 6.4). Papers I (1) and IV [4].
    b. Test of the implementation as an industrial method and deployment.
4. Research Contributions. Often, the contribution of the design-science research is the artifact itself (for example, a prototype system), which may create new knowledge or apply existing knowledge in new and innovative ways. The new value can also be created through the innovative use of evaluation methods or by extending existing methodology.
    a. The author's publications [1 and 5] and this thesis provide guidelines for the design of the tool for digital Mass Customization.
5. Research Rigor. An important aspect is the effective use of existing theoretical foundations and research methodologies, and appropriate metrics should be applied to validate the created function.
    a. The development of The Digital Tailoring system has been driven mainly by needs from the customers, CAD Made-To-Measure system and factories.
6. Design as a Search Process. The design is essentially an iterative search process to discover an effective solution to a problem by utilizing the available means.
    a. The research described in the thesis can be taken as an evolutionary path to the ultimate goal.
7. Communication of Research. The artifact, how it can be applied, and how it is to be constructed (implemented), must be presented to the appropriate (technology-oriented and management-oriented) audiences.
    a. Design-science research must be presented both to technology-oriented as well as management-oriented audiences. Therefore, the author of the thesis has taken part in various events and presented the below publications, in addition to others mentioned in this thesis, as follows:

- Elbrecht, Pirjo (2012). Made-to-measure jeans. Proceedings of the Asian Workshop on 3D Body Scanning Technologies: 1st Asian Workshop on 3D Body Scanning Technologies, Japan, Tokyo, 17-18 April 2012. Hometrica Consulting - Dr. Nicola D´Apuzzo, 134−138
- Elbrecht, P. (2013). Use of 3D Body Scanner Data in The Digital Tailoring. 4th International Conference on 3D Body Scanning Technologies: 4th International Conference on 3D Body Scanning Technologies, Long Beach CA, USA, 19-20 November 2013. Ed. N. D'Apuzzo. Switzerland: Hometrica Consulting - Dr. Nicola D'Apuzzo

b. The author has published V publications [1, 2, 3 4, 5], which have been indexed in Scopus Publications database.

All the publications by the author prove (directly or indirectly) the validity of the method explained in this thesis. Most of the presented publications use case studies, user trials, or prototype applications that were used to test a part or describe a proof-of-concept implementation based on the architecture. Thus, being performed by pilot users or other researchers, these test cases can possibly prove the validity of the approach even better than the tests executed by the author of this thesis – or at the very least complement the author's own observations.

The most important part of any design science research is the design process (33). Thus, this thesis describes the evolution of the system as well as presents the proof-of-concept implementations to better illustrate the path taken to achieve the final version of the architecture.

Furthermore, the study has followed the six steps of the mental model proposed by Peffers et al. (33), which provides a nominal process for the conduct of design science research.

The model does not require the research to follow the steps in order. The case is referred to by Peffers (33) as the design and development approach with the logical starting point being the third step of the model. In other words, the overall research can be considered to have started from step three, although the process of realizing this thesis started from step one after the goals and the research domain (content analysis) had been chosen. Additionally, the last step (communication) was performed continuously during the progression of the research in the form of publications of the research work.

1.4 Specific Research Questions

This dissertation aims to answer the question,

> How to organize production for Made-to-Measure (MTM) garments seamlessly by designing a system that combines 3D body scanning measurements, customer order and Tailor Knowledge and translates the information into a format readable by Computer Aided Design (CAD) systems, so that the customer can co-design the garment and it would fit the customer?

Guided by Design Science guidelines (28), the following specific research questions were stated;

Q1. How to set up a CAD system for industrial 3D body scanner and customer order-based Mass Customized production (combined Made-To-Measurei3 and On-Demand4 production).
An important part of seamless data flow is MTM CAD program. It has to be programmable and allow quick custom data import from a server. The content of The Digital Tailoring CAD import file is defined by the MTM CAD knowledge base. It will define the CAD system API which is taken into consideration in the development of The Digital Tailoring system.

Q2. How to automate data transfer from 3D body scanner and sales system for the readable format for CAD Made-To-Measure system so that no data needs to be entered manually?
To produce MTM garments seamlessly, it is necessary to combine 3D body scanning measurements and customer order, and translate the information into a format readable by CAD system, so that the customer can co-design the garment.

Q3. How to make the artifact take into consideration personal characteristics?
To ensure that the garment is fitting for every body type, it is necessary that The Digital Tailoring system would take into account Tailor Knowledge.

1.5 Thesis organization

The second chapter gives an overview of the terms used in this thesis and how previous work relates to the author's research. It starts with an overview of garment terminology, describes problems in Mass Customization and approaches to Mass Customization in clothing production.

In chapter three, a CAD system for MTM garments is introduced. It gives an overview of what is the content of a The Digital Tailoring import file needed for automated data collection from CRM and 3D body scanner. It defines CAD system API which should be taken into consideration when developing The Digital Tailoring system.

The fourth chapter gives an overview of how to automate data transfer from 3D body scanner and sales system for the readable format for CAD Made-To-Measure system, so that no data needs to be entered manually.

The fifth chapter introduces how to make the artifact take into consideration personal characteristics. There are introduced rules (Tailor Knowledge) which are implemented to the author's solution for Mass Customized clothing production. It starts with a body curve descriptor and how the alteration rules based on the body curve descriptor are designed. It also describes how the visual appearance of the garment changes when the customers are starting to be the common standard. Measurement based changes and fabric-based changes are described.

The sixth chapter contains the proof of concept case study for Digitally Tailored jeans. Additionally, it points out the benefits of The Digital Tailoring compared with traditional tailoring and mass-production. It gives an overview of how Digital Mass Customization helps to prevent and eliminate waste, thus increase the value of the product.

In chapter seven, the conclusion of the thesis is presented.

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[3] Made-To-Measure (MTM) typically refers to clothing that is sewn by modifying a standardized base pattern to fit each customer individually.

[4] On-Demand production is a term for production which starts when the order has been placed by the customer.

1.6 Contribution of the thesis

The author improved the traditional **Computer Integrated Manufacturing (CIM) model for Digitally Mass Customized garments** by establishing interfaces between 3D body scanning, Customer Relationship Management system (CRM), CAD system (patterns, alterations, Made-To-Measure (MTM)) and manufacturing (communication between factories), as well as automating pattern creation from orders and 3D body scanner measurements, and testing and improving the scalability of the processes. The preliminary version of the technology was tested in industrial production in Incognito Ballistic Company.

For enrichment 3D data produced by the 3D scanner into information suitable as input for the CAD system have been developed by the author:

- pattern knowledge base
- lay limits/annotation knowledge base
- alteration knowledge base
- MTM knowledge base
- knowledge base for men's and women's measurements' extraction
- knowledge base for different body types (for different countries)

The author has integrated Tailor Knowledge into a set of computer rules that allow producing mass- customized patterns with tailor precision.

The author created a preliminary system enabling Integration of Automated Data Collection, Enrichments and Transfer to CAD system.

The results have been presented at eight (8) different peer-reviewed international conferences on four (4) different continents. The author has published eight (8) international scientific papers directly associated with the research, all of them as the first author. Papers I-V are indexed in the Scopus Publications database, papers I, II and IV in the IEEE Xplore Digital Library.

1.7 Timeline of the Research

The research schedule is presented in the Figure 1.4.

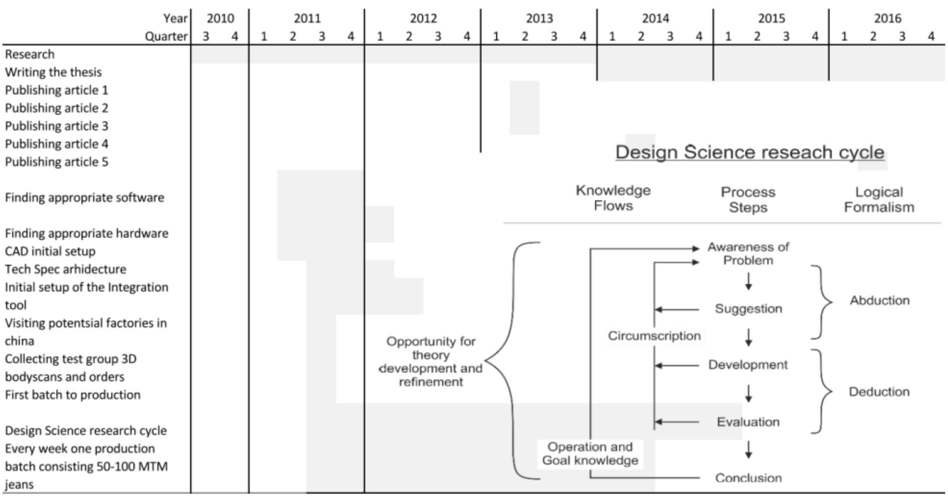

Figure 1.4 Research schedule

1.8 The Result of Research

This research analyses Information Processing in Mass Customized clothing production. The outcome is an integrated method, automating taking client measurements, identifying redundant data in this 3D data cloud and enriching this data in a specifically developed The Digital Tailoring system with information based on client wishes and data from several custom-designed databases (cloth properties, Tailor Knowledge, used CIM system specific properties), and automatically communicating this enriched digital data to the CAD subsystem of the CIM system in order to improve resource use, production and management efficiency as well as increase competitiveness.

The automatic measurements taking system based on the use of 3D scanner and the collected information enrichment and automatic communication in CIM system by The Digital Tailoring system enables a seamless information flow between the customer measures taken with 3D body scanner and Computer Aided Design (CAD) system for creating design patterns, which maximally uses Tailor Knowledge and customer order information.

Chapter 2

2. GARMENT MANUFACTURING TECHNOLOGY

"No useful sewing machine was ever invented by one man; and all first attempts to do work by machinery, previously done by hand, have been failures. It is only after several able inventors have failed in an attempt that someone with the mental powers to combine the efforts of others with his own, at last produces a practicable sewing machine."

James Gibbs (34)

This chapter outlines the basic background for the thesis. First, it describes the essence of tailoring. It is followed by methods of garment industry for customized garment production. Thereafter computer aided manufacturing, mass production and Mass Customization are briefly introduced. From those emerges the research problem. At the end of this chapter, earlier approaches to the research problem are described; and in conclusion earlier The Digital Tailoring solutions are brought out.

2.1 Essence of Tailoring

Standard operating procedure in the apparel industry goes as following: make clothes, and then sell them. It can take weeks, if not months, to manufacture clothes, so that step has to come first. It can be a costly upfront investment, and items that do not sell get discounted, eating into margins (35).

The essence of tailoring is the process of producing aesthetic, well-fitting and practical garments for humans (36) with reasonable expenses.

The process consists of four steps:

- designing a garment
- taking measurements
- mapping measurements to design – pattern design
- sewing a garment (37)

All these steps are used in different manufacturing and marketing techniques for garment production:

- classical tailoring (hand-made)
- industrial Mass Production (Ready-To-Wear[5])
- industrial Mass Customization (Made-To-Order[6] and Made-To-Measure)

The emerging technologies (3D body scanning, measurement extraction, 3D visualization, e-commerce) have opened the door to a new approach to garment manufacturing and marketing, transforming clothing production into a demand-driven, knowledge-based, high tech industry:

- industrial 3D body scanner and customer order-based Mass Customized production (combined Made-To-Measure and On-Demand production)

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5 Ready-To-Wear is the term for factory-made clothing, sold in finished condition and in standardized sizes and it is cut and style determined by the designer.

6 Made-To-Order is the term for factory-made clothing, sold in standardized sizes. The customer can choose the fabric, style and standard size.

The input to the process is a set of human measurements. This set has great variability and all three technologies describe an individual human (the customer) with a different number of parameters (measures), e.g. for trousers:

- human tailor – 6 measurements (38)
- industrial mass-production – according to EN 13402-3 (39) men' s garment sizes cover from 84 cm to 144 cm in chest girth (14 sizes), women's garment sizes cover from 76cm to 152cm in chest girth (16sizes). Each size code is defined with one or three body measurements (40)
- 3D body scanner captures more than 300 000 three-dimensional surface data points from a human. The data points are linked and surfaced automatically in a fully digital 3D model that can be measured in multiple ways including linear, slice and surface area, and measurements for each scan (41)

The quality of the output (garment) is usually described by two parameters:

- customer satisfaction - how products and services supplied by a company meet or surpass customer expectation (42)
- production cost

The whole process for trousers can be described with the Table 2.1, depicting the flow of information in tailoring when different technologies are used:

Table 2.1 Information flow

	Tailor	**Mass-production**	**Customized industrial production with 3D scanner**
Measuring (output)	6 measures	14-16 pre-fixed sizes	300 000 three-dimensional surface data points
Mapping measures to patterns	Hand-made (Tailor Knowledge)	Pre-fixed by used size system	The Digital Tailoring system – filtering and factoring measurements and adjusting them according to data from database of Tailor Knowledge (the 'memory' of the system), technical data (properties of cloth, special features of used CIM system etc.)
The size of the input set of patterns:	60-100 pieces without grading	50-500 sets of patterns dependent on company	1000-6000 pieces with grading
Output: prize	100%	50%	60%
Complaints	0 (close to)	25-50%	10-20%

2.2 Novelty of the research problems

Background research for this thesis indicated that **currently there does not exist any system that would allow producing Mass Customized clothing seamlessly**. Never before has the apparel industry been able to produce Mass Customized clothing with mass production processes. This has become possible with the emergence/development of 1) low-cost 3D body scanners that allow taking precise measurements (43), 2) Made-To-Measure programs and 3) Product Lifecycle Management (PLM) programs.

First, 3D body scanners are 76% more accurate than measurements from the most skilled hand-measuring experts (44). The price of 3D body scanners has dropped four times since 2010 – from €40 000 to €10 000 (45). Google launched Tango — a depth sensor-based 3D environment mapping technology that is small enough to build into smartphones (46). It has opened a door for 3D body scanning app market. In the next five years, it might be possible to 3D body scan with phones and order Digitally Mass Customized cloths from home (47).

Second, Made-to-Measure programs allow combining and altering different patterns (48).

Third, PLM allows the enterprise to create, capture and share the product related requirements, expectations and preferences of targeted customers and markets and align these requirements with specific innovative content that customers want for a price they can afford at the time when it is needed, PLM concept gives new product ideas against quickly rising customer requirements and cost-effective manufacturability (49).

The significant positive consequence of this is that the sewing factories nowadays are taking orders for Mass Customized products. Previously the factories were accepting only batches of products (50). All of this has happened in the past few years.

Despite the three named factors, companies are missing the crucial link between the 3D body scanner and CAD system, and between the customer order and CAD system. Until now, it has always required human intervention (manual order input or manual measurement input or both to CAD system). This thesis proves that the missing link (i.e. The Digital Tailoring system) has been created by the author, tested *with real customers,* and the tool could be taken up by apparel industry / in Mass Customized Clothing Production.

Researching the history of my research problem and development of tailoring technology produced the timeline (Table 2.2) of different stages of an Industrial Revolution in the garment industry (51). As seen from this timeline, all developments in industrial production are based on improvements in information collection, processing, and use. 3D body scanner together with information technology applications (including the author-developed The Digital Tailoring system) is part of the fourth Industrial Revolution in the garment industry. The table is followed by Figure 2.1 describing the relations between the key elements of the Industrial Revolution in the garment industry and customer satisfaction correspondents to productivity, and price for technology (author's subjective evaluation on a 10-point scale).

Table 2.2.Timeline of Industrial Revolution in garment industry

	Time	Important events
First Industrial Revolution	1769-1784	The need to produce batches of similar garments arose from the clothing of the army and the navy (41). R. Lowe, a sole supplier to the marines, delivered 127 245 garments (52).
	1730	Patented flying shuttle (J. Kay) (53).
Second Industrial Revolution	1846	Patented sewing machine (Elias Howe) (53).
	1852	The Englishwoman´s Domestic Magazine launched with instructions and patterns for home dressmaking (53).
	1871	Half a million sewing machines sold (production of garments increased 500%) (53).
	1888	Eastman introduces first fabric cutting machine (54).
Third Industrial Revolution	19 the C.	Expansion of department stores (53).
	1914	Start of the First World War
	1932	Letty Lynton film - Macy's department store copied the dress, and it sold over 50,000 replicas nationwide (55).
	1938	DuPont launches Nylon (53).
	early 1960	H. Joseph Gerber introduced the first automated machines for drafting (U.S. Air Force C-5 Transport, the Boeing 747) (56).
	1969	H. Joseph Gerber invents the world's first automated cloth the cutting machine - has been widely cited as the most important technological advance of the century (56).
	1988	The first PC-based pattern making, grading, and marker system are launched to the apparel market (56).
	1999	Four 3D body measurement systems delivered (Levi Strauss & Co., San Francisco, CA, U.S. Navy, North Carolina State College of Textiles, and Clarity Fit Technologies of Minneapolis) (57)
Fourth Industrial Revolution	2006	Software for automatic generation of markers (56).
	2006	The start of the development of PLM solutions.
	2010	3D body scanner expansion for larger markets.
	2014	New technology enabling to combine 3D body scanner data and customer order for CAD system (1).

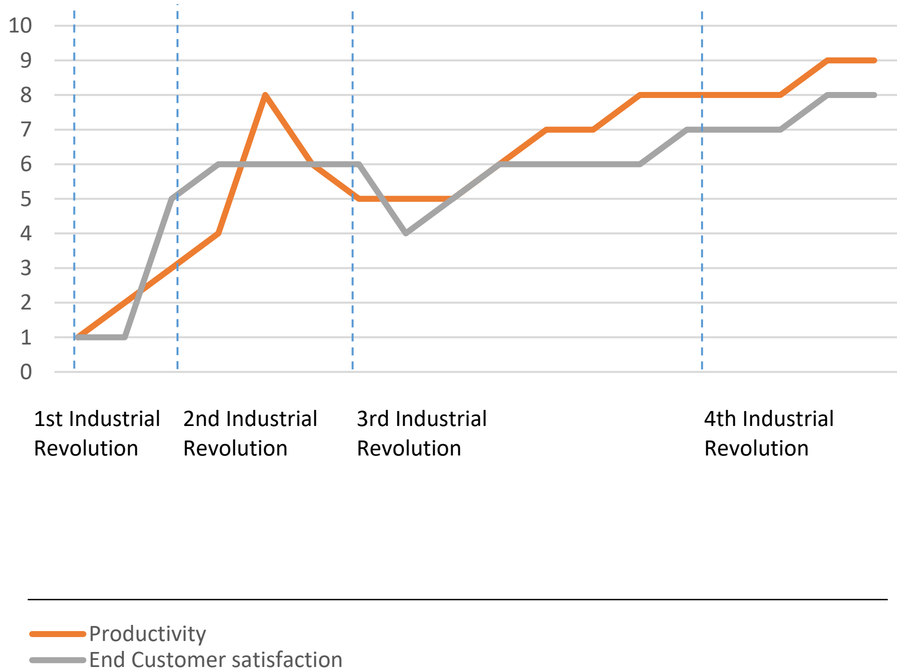


Figure 2.1 Customer satisfaction correspondence to productivity and price of technology

2.3 Methods of Garment Industry for Customized Production

A following section presents a short overview of different methods used in the garment industry for producing customized products with minimal production cost.

The garment industries were revolutionized by the invention of the sewing machine, patented in 1846 by the American inventor Elias Howe, and underwent a tremendous expansion during the 1860s. Spurred by the urgent demand for uniforms during the American Civil War, clothing manufacturers developed standardized sizes, a prerequisite for the mass production of ready-made garments (58).

Wholesale bespoke[7] tailoring is a term widely acknowledged and referred to as factory measure cutting. In the nineteenth century~~,~~ it has been a process by which retailer took the customer´s measurements and the suit was produced in the factory or outsourced to a workshop. However, the garments were not cut to individual sizes; they had been cut from model patterns in various styles. These were then drafted in various basic sizes or graded by using tables of proportionate measurements. To make up the customer´s bespoke order for a jacket, the nearest breast size pattern was selected and alterations made to the pattern where the customer´s measurements differed from standard measurements.

[7] In 1846, Henry Poole, credited as being the "Founder of Savile Row", opened an entrance to his tailoring premises into No. 32 Savile Row [45] Savile Row is a shopping street in the Mayfair section famous for its traditional men´s “bespoke”, or custom tailoring. The term "bespoke" is understood to have originated in Savile Row when cloth for a suit was said to "be spoken for" by individual customers [46].

In today’s clothing market, customers wish to personalize the design, fit and tone of the garments they purchase. This has driven the garment industry to Mass Customization, which is a hybrid of mass production and customization.

In the apparel industry, a number of new technologies have aided Mass Customization operations. Apparel businesses have invested in computer systems to control production, patterns, design, cutting, embroidery and sewing.

Traditional tailoring - the tailor is met on site and the garment is produced in-house. This approach allows the tailor to have direct contact with the customer to understand the customer needs, take necessary measurements by hand, evaluate posture and body proportions to make an individual state-of-the-art garment (Figure 2.2).

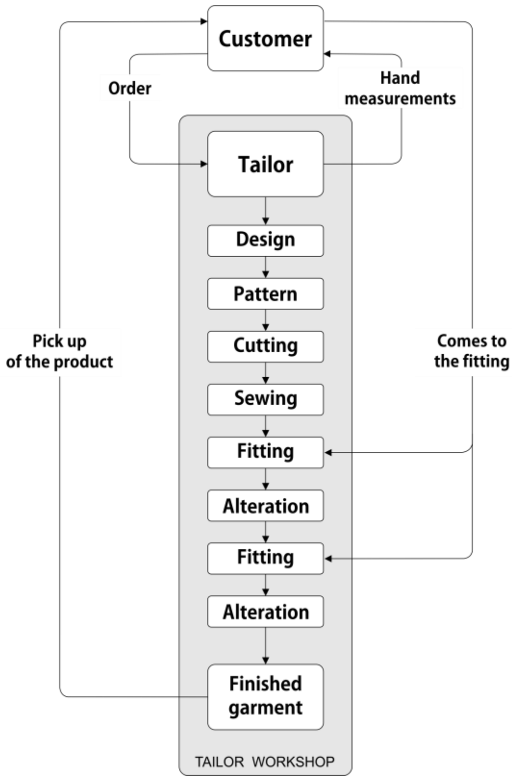


Figure 2.2 Traditional tailoring

Web tailoring - Web tailoring includes ordering a garment from e-commerce websites from all around the world. This enables to use the cheapest labor in every step of the process. The disadvantages of web tailoring are:

- Clients must measure themselves and enter the measurements to the Webstore.
- Fabric selection must be made from the screen.
- If additional alterations are essential the garment must be shipped back or altered by a local tailor.

Sometimes web tailors offer to pay or give a voucher for needed alterations at a local tailor. Web tailoring is a Mass Customization form for apparel business. The client is making design choices based on the co-design options offered on website (Figure 2.3).

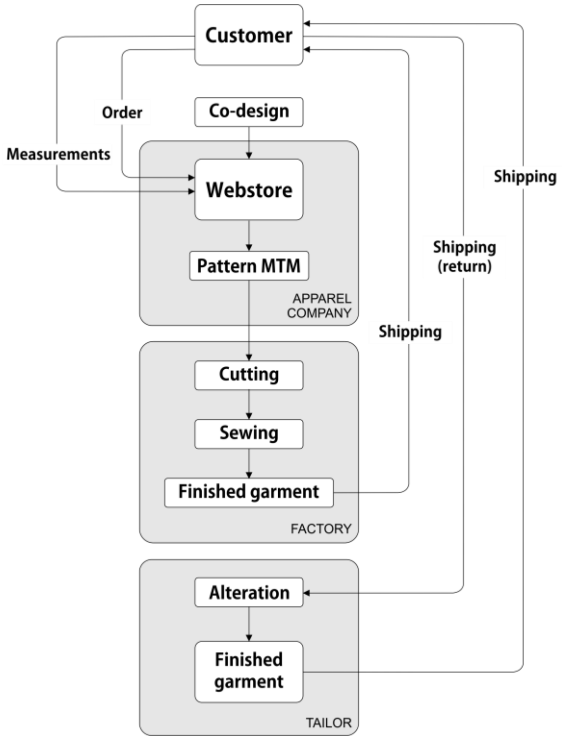


Figure 2.3 Web tailoring

Table 2.3 presents the basic differences between a tailor shop and a garment manufacturing unit.

Table 2.3 Tailor shop versus garment unit (59).

Tailor shop	**Garment unit**
One person to make the garment.	A group of people takes part in producing the garment.
No special machines or guides.	Special machines and work aids which ensure high quality.
Throughput time is very high.	Small trough put time.
Minimal productivity.	High productivity.
Individual measurements for individual.	Standard sizes (S, M, L, XL).
High labor cost.	Reduced labor cost.
Material consumption is big.	Material consumption is minimal.
Bad stitching quality compared with factories because factories owe special machinery, which enables better quality.	High-quality stitching.
Shrinkages not considered.	Shrinkages considered
Single garment is being cut at a time.	Bunch of garments is being cut in one shot.
No patterns. Only templates.	Patterns for each component of a garment.

2.4 Computer Integrated Manufacturing

Computer Integrated Manufacturing uses computers to control the entire production process that involves manufacturing planning and control, Manufacturing Engineering, manufacturing processes and indirect elements such as sales order processing, finance, and accounting. Manufacturing planning and control include shop floor control, inventory control, etc (59).

CIM improves production productivity by 40 to 70 percent, as well as enhances engineering productivity and quality. CIM can also decrease design costs by 15 to 30 percent, reduce overall lead time by 20 to 60 percent, and cut work-in-process inventory by 30 to 60 percent (60).

CIM has been widely used in textiles due to rapid changes in market demand and product modification, for better use of materials, personnel, reduction in inventory, better control of production and management of total manufacturing operation, manufacture of high-quality products at low cost, elimination of paper and the costs associated with its use, automation of communication within a factory and increase in speed, facilitate simultaneous engineering etc.

2.5 Mass Production Model

The objectives of mass production are to achieve economies by standardizing products and developing efficient processes thereby producing more of each product at one time and selling at a lower price (61).

The main disadvantage of mass production is the absence of product uniqueness. By definition, the fashion process is many people choosing the same style, and mass production accommodates fashion better than custom production. It makes it possible for more people to purchase a fashionable item, the style of the times, sooner. If long, black, cotton cardigans suddenly become fashionable, many of them can be mass-produced quickly to meet the demand (62).

To benefit from mass production, the trousers must be the same style and have the same fabric. This lowers the cost of efficient processes and quantity purchases of materials. All consumers are offered the same selection; individual modifications are not regularly available (62).

Another disadvantage of mass production is the inventory of products that builds up before the products are sold. This happens because many items are produced at one time. Inventory costs money till it is sold because of the investment in materials and labor. Manufacturers and retailers try to limit inventory by only making the number of products that are ordered and by forecasting exactly the number of items that will sell. Unsuccessful guesses result in retail markdowns and other tactics to sell the excess inventory. Manufacturers' outlet stores and discount retailers are strategies used to get rid of unsold inventory (62).

2.6 Mass Customization Model

"Today I define Mass Customization as the low-cost, high-volume, efficient production of individually customized offerings".

B. Joseph Pine (63)

The aim of Mass Customization is for the customers to get an exact product that they want, when they want it, and at a reasonable price. During the last 20 years, the choice has become a central ingredient of consumer purchasing selections.

Customization may cover one or more aspects of the product or service and this in varying degrees. Between pure standardization and customization is a full range of options:

- Pure standardization: the customer can only choose from a full pre-defined range.
- Segmented standardization: Products are customized for each segment. An example is the automobile industry where cars destined for the U.S. are standard equipped with an automatic transmission and cars destined for the European market with a manual gearbox.
- Customized standardization: the customer can choose from a number of predefined options. For a car, the customer can, for example, choose the body color, the color and composition of the upholstery and the type of the engine.
- Tailored customization: the customer can choose a number of parameters. An example is a men's shirt offering the possibility choose the type of collar and cuff, the number of breast pockets, the length of the sleeves, etc.
- Full customization applied to the above example would allow the customer to also design the style and the print or weave (64).

The concrete implementation of the paradigm "Mass Customization at mass production price" can, therefore, be very diverse (64).

It is crucial that to adopt Mass Customization, an apparel organization has to bring many changes in the operations. Roughly we can categorize these changes into three groups:

- first, technological development (CAD, the 3D body scanning, etc.)
- second, implementing flexible manufacturing systems, CIM tools, and techniques
- third, organizational changes in terms of flexible culture and empowering workers by assigning more responsibilities

Considering these business strategies as Mass Customization umbrella concept will shorten product life and development cycles as well as letting manufacturers respond more quickly and flexibly to changing customers' drives. Finally, customers will have access to a variety of high-quality, customized garment while manufacturers can reduce excess inventory and markdowns. Mass Customization is a paradigm shift from the Product-Centric approach (made-to-stock) to the Customer Centric Approach (made-to-order), where customers' involvement also shifts from purchase to the development of the product.

Mass Customization system must address a full range of problems related to sizing. These problems can be categorized into four main areas:

- body dimension data and conversion of these data into a sizing system
- fit issues including fit preferences
- design, manufacturing, and distribution issues
- size selection and communication issues (65)

Target market population measures have been categorized as the database developed using different methods and measurement categories provide different types of data that must be analyzed and applied appropriately to the problem of developing or perfecting sizing systems. The correct sizing system helps to develop correct base patterns for CAD system, which will be later modified according to a specific customer.

Design, production, and distribution issues are important as they encompass basic concepts as varied as whether a company makes tailored or less fitted clothing, how much control they have over manufacturing and quality issues, how garments are made and delivered, how many different materials needs to be in stock, and whether functionality or aesthetics are more important to their customers.

2.7 Earlier Approaches to The Digital Tailoring

Digital tailoring could be described as creating garments for a specific individual from 3D body scan measurements and customer co-design choices.

There have been several attempts to create The Digital Tailoring systems in the clothing industry.

2.7.1 Levi Strauss Co.

Levi Strauss Co. was a pioneer in creating a customization concept for jeans in 1994, but they ended the concept in 2003.
In the beginning, it was aimed at women but later also for men. Personal Pair jeans were customized mostly on fit, but also on look based on the five-pocket variety. In a store, four initial measurements were taken from the waist, hip, inseam and rise (Figure 2.4) by a trained fit specialist. The measurements were entered into a computer, which suggested a prototype pair of jeans. The customer tried on the prototype jeans and fit modifications could be made according to four initial measurements based on customer preference, such as tighter, looser fit, shorter, longer and so on. Fitting of two or three prototypes was usually sufficient to find the perfect fit for the customer. The order with final fit was sent via modem to Levi Strauss´ factory in Mountain City, Tennessee, where a dedicated team of sewing operators constructed the jeans (Figure 2.5). The customized

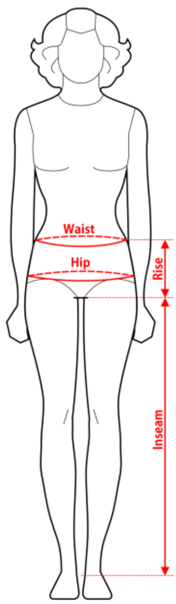


Figure 2.4. Body measurements

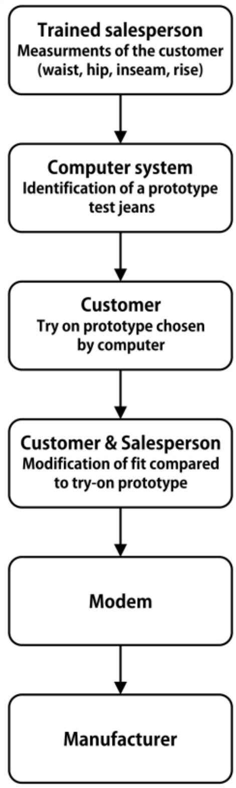


Figure 2.5. Levi Strauss process

jeans were ready in two or three weeks, and they cost about US$ 65 at the time, and this was around US$ 15 more expensive than buying directly from the shelf (66).

In 1997, from Levi´s “Personal Pair” emerged Original Spin. The Original Spin had much more options for customization in addition to the fit.

The process began at a kiosk, where the shopper registered and entered personal data. The measurements were still taken with a measuring tape, until the opening of the 15th Original Spin store, where in August 1998 was introduced the Tc2 body scanner to take measurements (67).

After the scan, the sales person utilized the information to offer a variety of appropriate styles to try according to personal preferences such as loose or close. The sales person entered the selection data into the customer´s profile, and the file was transferred to the remote manufacturing facility.

However, despite good reputation and feedback, at the end of 2003, Levi Strauss discontinued Spin program without further explanations. This was caused by the bad business situation of Levi Strauss. To cut costs the last US factory producing the customized jeans was finally closed (68).

Douglas Tarr has another opinion about the failure of the Levi Strauss. Douglas Tarr was Levi Strauss & Co Technical Lead. He had built the website and back-end system for Levi´s Original Spin. He says:

"I don't think it was the lack of technology to design the jeans. It was the lack of technology that could actually produce them to the measurements that were recorded. At the time, Levi's added some more measurements than just waist and inseam. In fact, I suspect that if you have some fancy Kinect enabled measurer, it would create lots of new measurements that apparel manufacturers would have a tough time producing, no matter where they were located.

Yes - Levi's "Personal Pair" program (before 1997) was about fit (not about color), which was very difficult to make successful. It attracted older women looking for hard to fit jeans, who were not the target market (which for Levi's was optimally 18-25-year-olds)

Levi's then pivoted and rebranded it to Original Spin. For this article to say that it failed because Levi's "didn't offer color" is an oversimplification. Levi's Original Spin offered many different colors, washes, and fits. There was a barcode embedded in the jeans, and a website where you could reorder the jeans online (yes even in 1998).

Even when they pivoted, buying jeans online was not an easy thing to do online (is it much better today??) So, this made for a very expensive program, requiring in-store fittings, new technology, high-touch retail, and lots of returns. Even worse, you had to wait a week or two for these jeans.

Then, because of manufacturing challenges - jeans shrink when you wash them within a certain tolerance - they didn't fit right a lot of the time when you finally received them. So, there were a lot of returns. And a customized product that is returned is worthless for resale (69)".

2.7.2 Bodymetrics

Bodymetrics was the next company to try Mass Customization of the jeans. The first Bodymetrics boutique opened in Selfridges (London) in 2004 which targeted a largely female clientele with private-label jeans and licenses with other denim brands. On 2006, a second boutique opened in Harrods, expanding the service to include women's tailoring for brands like Vivienne Westwood and Nick Holland**.**

Bodymetrics was using the 3D body scanner to provide three services: Made-To-Measure jeans, Body-shape jeans, and online virtual try-on.

With Made-To-Measure jeans, the scan is used to create a pattern for the jeans, which are hand-tailored to the exact lines and contours of the customer's body. The jeans are ready for three to six weeks, at which time the customer has a final fitting with a Bodymetrics tailor. The jeans were produced in the Far East or North America.

Based on its experience with Made-To-Measure jeans, Bodymetrics had identified three body shapes: straight, semi curvy, and curvy. Body-shape jeans were specifically designed to fit these different body shapes. After customers were scanned, a Bodymetrics jeans expert helps them determine their body shapes. Customers could then instantly purchase jeans matching their body shapes off the rack in the store.

The online virtual try-on allows customers who had been scanned to try on jeans virtually on their own bodies without physically trying on jeans in a dressing room. The service created an avatar (a three-dimensional graphical representation of the customer). Then, the customer could pick various styles of jeans and "virtually see" what the jeans look like on her or his avatar (70).

Today, this company does exist, but their concept has changed. They are using 3D body scan to determine the best jeans for customer shape, size and style from leading brands: 7 for all Mankind, J. Brand, AG, Citizens of Humanity, Hudson, Paige and more (71).

2.7.3 Left Foot Company

The Left Shoe Company is a made-to-measure men's shoe brand that combined traditional craftsmanship with state of the art 3D scanning technology. The company was founded in 1998 in Helsinki as The Left Foot Company. It was renamed and rebranded The Left Shoe Company in the fall of 2010 (72).

Measurements were taken using a 3D foot scanner analysing one's precise foot size. Once the 3D-scanning process was completed, the customer was able to individualize his choice of shoes in accordance with the made-to-measure term, both in the store and on the website, he could choose the sole, colour and leather to his liking. The prize started from £ 305 (73).

The custom shoes were then handcrafted in Europe, using the finest Italian leather and suede, and shipped to the preferred address within 6 weeks.

The Left Shoe Company unfortunately didn’t make it and filed for bankruptcy in 2016. Carter Clark from Essex in the UK is the curator. In the US the company filed for bankruptcy om May 10, 2016 (74). In the UK it's in the process of liquidation since July 18, 2016 (75).

2.8 Conclusion

The chapter outlines the basic background for the thesis. It describes the essence of tailoring. Most importantly, it describes the novelty of the research - three aspects (3D body scanner, MTM system and PLM system), which have opened the door to new technology.

The timeline of different stages of the Industrial Revolution in the garment industry is presented. The 3D body scanner together with information technology applications (including the author-developed The Digital Tailoring system) forms part of the fourth Industrial Revolution in the garment industry. As a result, customer satisfaction with garments has increased with the development of technology.

Finally, the chapter introduces earlier approaches to/for The Digital Tailoring.

Chapter 3

3. MASS CUSTOMIZATION TECHNOLOGY

The following chapter gives an overview of Mass Customization technology needed for building The Digital Tailoring system, foremost answers to the question of how to set up CAD system for MTM garments. The CAD system defines the structure for The Digital Tailoring system output file for CAD. The output from The Digital Tailoring system is an input to the CIM-technology subsystem – the CAD-based pattern-making system and has to follow the API of the CAD system.

The MTM CAD system is the foundation for the Mass Customization. The CAD system holds base pattern databases and alteration rule databases. Alteration rules are necessary to change base patterns according to the customer measurements. Each alteration rule is linked to the corresponding 3D body scanner 1D anthropometric measurement.

The chapter introduces CAD software chosen by the author. The workflow of pattern alteration in MTM CAD system is introduced. It states the steps to set up the MTM CAD system.

3.1 CAD Technology for Mass Customization

Apparel CAD system has different modules for various tasks: pattern design for drafting and grading, marker making for layouts of patterns, MTM for pattern alterations.

MTM apparel pattern systems are a vital part of Mass Customization because it can solve how to produce attractive and accurately fitting apparel according to customers' needs. These systems will enable the creation of garments, customized for fit, in a very quick and accurate manner and can be inserted into normal production lines as an additional size and produced like every other garment of the same style. They also allow styles to be customized, repeatedly, without time-consuming preparing activities. This means that successful companies with huge libraries of garment styles would be able to implement Mass Customization strategies with relatively little effort (76).

In mass production, the patterns for produced garments are created to fit company's sizing system, not for an individual customer. Most of the pattern makers do not know how to alter patterns for a particular client. Pattern makers have no idea how body measurements relate to the development or fit of the specific garment. MTM modules are not only complicated but require a significant level of knowledge and practical experience not easily obtained.

Automation of processes in the garment industry is a vital part of Mass Customization because they constitute the connection between the consumer´s desires and requests, and the ability of a manufacturer to create the products accordingly. A fundamental to the use of these enabling technologies is the ability of CAD systems to incorporate measurement information and make alterations to patterns, as necessary, without forever changing the basic, original garment pattern.

The basic strategies for an MTM clothing systems are:

- A consistent measuring method required to take measurements of customers (the 3D body scanner).
- A complete set of size charts with different size ranges for categorized figure types, which should provide measures for the standard sizes.

- Individual sets of garments patterns for the standard sizes, which should accurately reflect the characteristics of the categorized figure types and measurements of the corresponding size charts.

Before implementing computerized pattern alterations, a large database with reference to the standard graded patterns, the alteration movements, and relevant information, needs to be generated.

When making an alteration plan through the creation of a personal measurement alteration chart, the subject´s body curves should be categorized accurately and the standard graded blocks at the nearest size selected correctly. This scheme may enhance the efficiency and the quality of pattern alterations because it is not necessary to carry out the actual procedures of cutting, spreading and/or overlapping of pattern pieces. The new system, together with its developed pattern alteration strategies, allows pattern designers to generate the MTM patterns using commercial CAD system (77).

3.2 The Gerber Technology

The output from The Digital Tailoring system is an input to the CIM-technology subsystem – the CAD-based pattern-making system and has to follow the API of the CAD system. The API-s of different CAD-systems used in the garment industry are different; a following section focus on CAD software developed by the Gerber Technology Company, which basically is setting values for ca 500 attributes for the drawing system. The Gerber Technology system is chosen because it has the most advanced Made-to-measure module. On the figure below (Figure 3.1) is shown information flow inside of Gerber Technology CAD system.

AccuMark® Explorer is a file manager inside of Gerber Technology CAD system which enables to manage, create, and generate reports from the Explorer and Import/Export data.

Gerber Accumark Pattern Design software is for pattern design and grading.

Gerber Accumark Marker Making is used to place pattern pieces into the marker that represent the fabric of which it is to be cut. The process of marker making is to place the pieces for the best utilization of material to create the end product desired. The name of the marker corresponds to the Order ID number (section 4.4).

AccuMark® Made-To-Measure program automates order selection and decision making using knowledge-based rules.

3.2.1 Individual Pattern Alteration

Alteration of garment pattern is an essential step in producing attractive and accurately fitting clothing from patterns that already exist. Commercial CAD alteration systems are based on one of the following two approaches. One approach uses basic patterns and applies a mathematical formula to change them to fit specific body measurements. Another approach uses graded patterns in conjunction with sizing and measurements (78) (Figure 3.2). Both approaches have the common feature of reference to size charts for either standard size grading or calculation of the alterations to be applied (79).

CAD software used to develop patterns is limited by the information it holds about each pattern piece. When an object is created by pattern maker, it is merely a conglomerate of lines, curves, and points until the pattern maker identifies the parts that will make the whole piece or block. The pattern represents the two-dimensional building blocks of a garment. They are used as a guide for cutting the fabric, which when sewn together forms a three-dimensional garment. To assure the desired fit of a garment, the pattern maker must make a number of decisions about how much each pattern is modified and exactly where each pattern is changed.

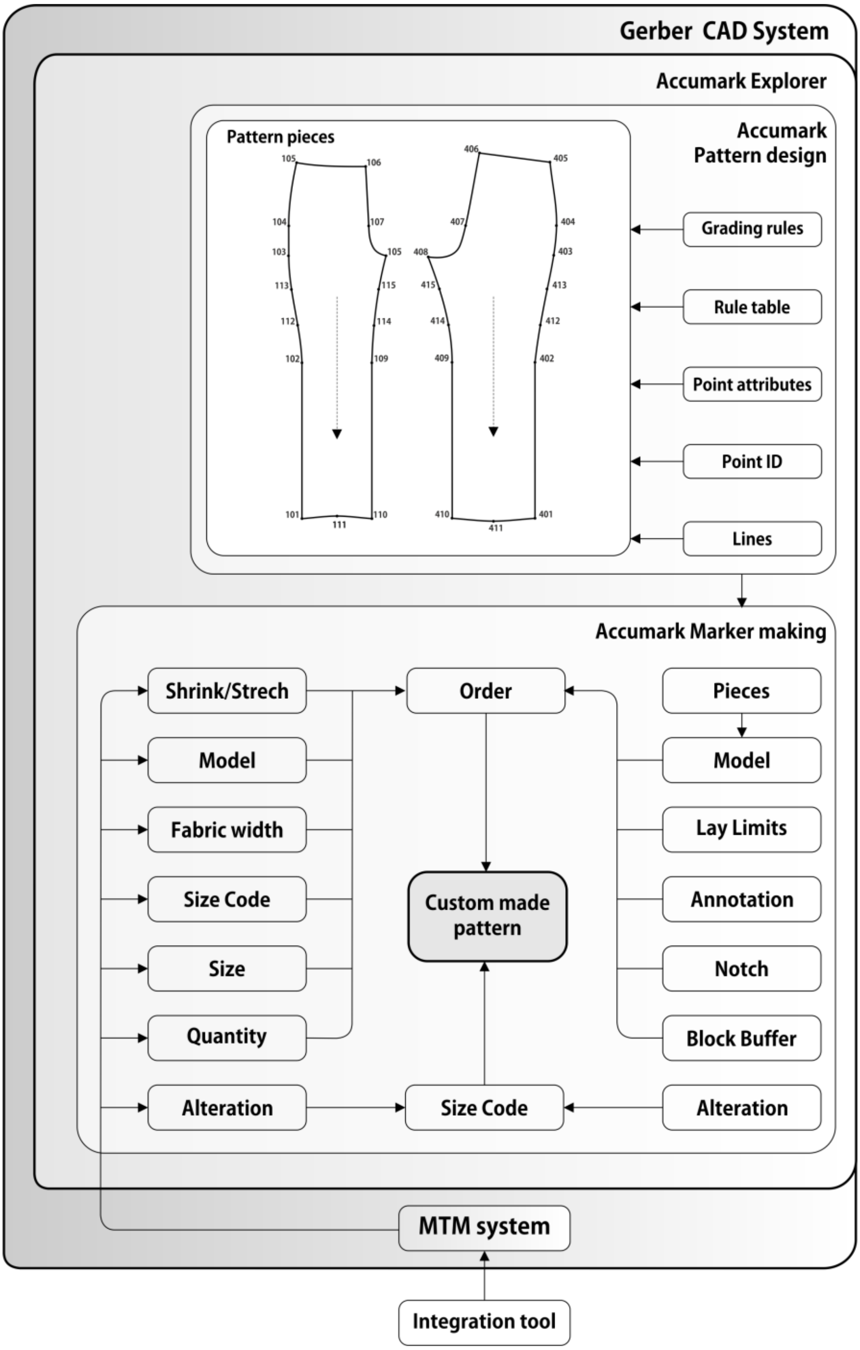


Figure 3.1. Information flow inside the CAD system.

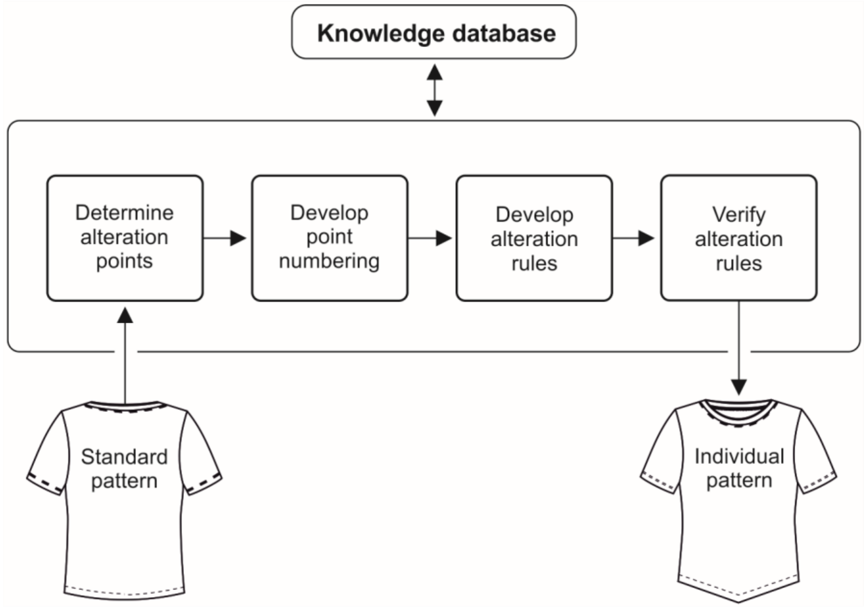


Figure 3.2. The workflow of pattern alteration in MTM CAD system (78)

The process starts with designer designing the collection.

Step 1. Knowledge base of Co-design options

The knowledge base of Co-design options is a collection of design elements composed by the head designer. Customers can choose design elements (pattern pieces) in order to combine with their MTM product. The designer can also limit or define elements, which can be used together with certain fabrics or options. Co-design options are divided into categories according to the options offered to the customers – different back pockets are making one category back pockets, different beltloop options are making one category of beltloops, etc.

For every Co-design category element, a naming conversion has to be created and added to CAD system (Figure 3.3).

Figure 3.3 Example of Co-design naming conversion for trousers back pockets

Step 2. Design patterns

Pattern makers construct according to the designer vision:

- pattern pieces
- model(s) - a model is a group of all pattern pieces that make a complete garment or item
- model options - Information that the designer specifies to order variations of a model (co-design options). This prevents a company from having to create a separate model to accommodate all style variations that are required for a particular garment or item

Step 3. Prepare pattern with grading

Pattern grading is the scaling of a pattern to a different size by implementing important points of the pattern using an algorithm in the clothing industry. The amount that the pattern increases or decreases, and the directions of these size changes, have to be determined. At the same time, the correct proportions of the garment have to be maintained without distorting the style features. In Figure 3.4 is presented pattern grading from size to size (it is called graded nest). The numbers in the figure represent “grade points” which are positioned at the cardinal points of a pattern where the measurements to another size take place. This movement is in an X and Y direction.

“Grade rules” record each movement of a point in both X and Y and are numbered relevant to the pattern grade point. The grade rules are listed in a grade rule table (Figure 3.5). Grade rules must be created and applied to pattern pieces, in order to tell the computer how to increase or decrease the size of each piece. The grading rule numbers identify the required action for CAD system.

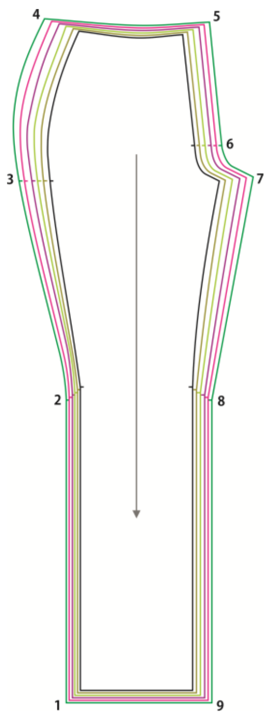
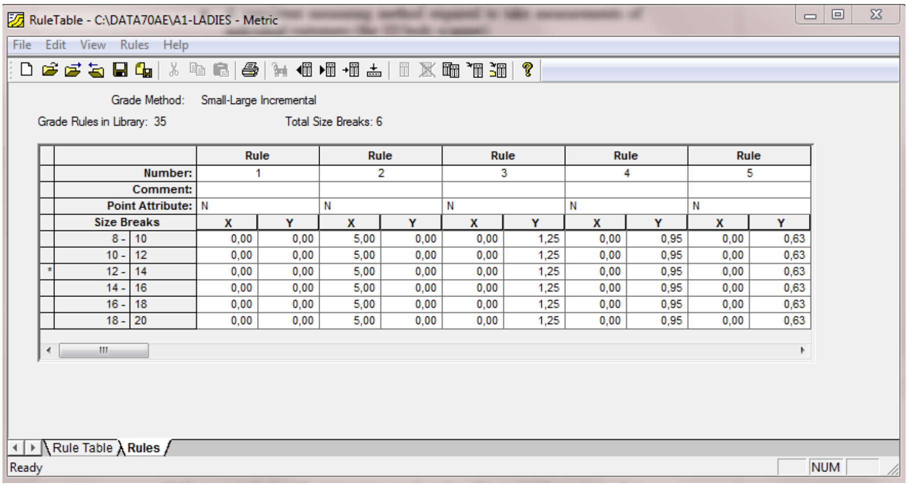


Figure 3.4. Grading nest



	Rule		Rule		Rule		Rule		Rule	
Number:	1		2		3		4		5	
Comment:										
Point Attribute:	N		N		N		N		N	
Size Breaks	X	Y	X	Y	X	Y	X	Y	X	Y
8 - 10	0,00	0,00	5,00	0,00	0,00	1,25	0,00	0,95	0,00	0,63
10 - 12	0,00	0,00	5,00	0,00	0,00	1,25	0,00	0,95	0,00	0,63
* 12 - 14	0,00	0,00	5,00	0,00	0,00	1,25	0,00	0,95	0,00	0,63
14 - 16	0,00	0,00	5,00	0,00	0,00	1,25	0,00	0,95	0,00	0,63
16 - 18	0,00	0,00	5,00	0,00	0,00	1,25	0,00	0,95	0,00	0,63
18 - 20	0,00	0,00	5,00	0,00	0,00	1,25	0,00	0,95	0,00	0,63

Figure 3.5. Grade Rule Table

Step 4. Define critical alteration locations on the pattern

To operate within the MTM program, specified alteration locations are allocated to points on the respective pattern pieces. Garments are altered at alteration points (Figure 3.6). Alteration point action is defined in alteration rule table. One alteration point can be part of one rule or several.

Step 5. Define alteration rules and create a rule table

Alteration rules are created for each body measurement considered "key" for the fit of a specific garment. Alteration rules are connected to the human:

- girth measurements – neck, chest/bust, waist, hips, biceps, thigh, knee, etc.
- length measurements - arms, height, hip height, etc.
- landmark positions

Each alteration rule needs to be linked to the corresponding 3D body scanner 1D anthropometric measurement, landmark position or Tailor Knowledge wisdom

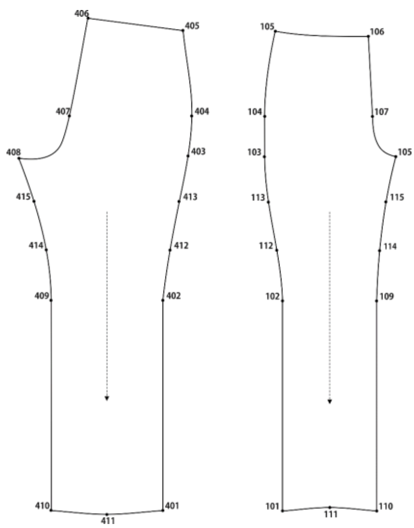
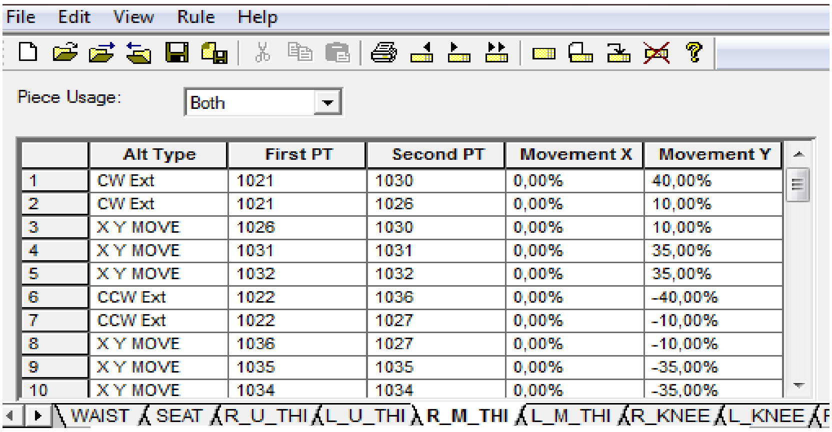


Figure 3.6 Alteration points

implemented to The Digital Tailoring system. Over one hundred alteration rules were created to the system. These configuration points are defined in the alteration library stored within CAD system.

Within each alteration rule, commands must be developed to control every point on a garment related to a specific location where an alteration should occur. Example of a rule in Figure 3.7.

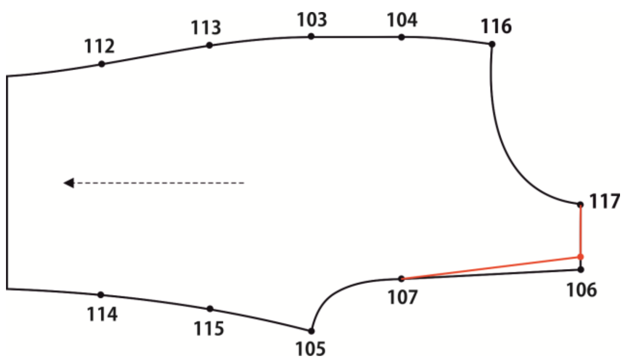


	Alt Type	First PT	Second PT	Movement X	Movement Y
1	CW Ext	1021	1030	0,00%	40,00%
2	CW Ext	1021	1026	0,00%	10,00%
3	X Y MOVE	1026	1030	0,00%	10,00%
4	X Y MOVE	1031	1031	0,00%	35,00%
5	X Y MOVE	1032	1032	0,00%	35,00%
6	CCW Ext	1022	1036	0,00%	-40,00%
7	CCW Ext	1022	1027	0,00%	-10,00%
8	X Y MOVE	1036	1027	0,00%	-10,00%
9	X Y MOVE	1035	1035	0,00%	-35,00%
10	X Y MOVE	1034	1034	0,00%	-35,00%

Figure 3.7. Rule table

Instructions for alteration rules are based on types of movements that can be used to generate an alteration. There are four basic movements available for alteration rule (78).

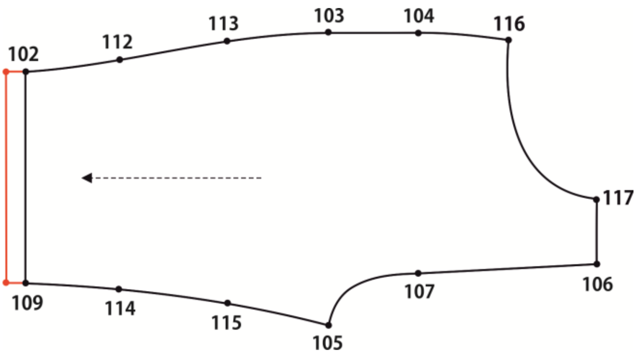
1. Moving a single point.
   Selecting X-Y MOVE in the alteration type field and defining the same alteration point number for both first point and the second point will allow the lines from the next alteration points to create the alteration according to the percentage set in the movement field in alteration table (Figure 3.8).



Alt Type	First PT	Second PT	Movement X	Movement Y
X Y MOVE	106	106	0,00%	100,00%

Figure 3.8. X Y MOVE

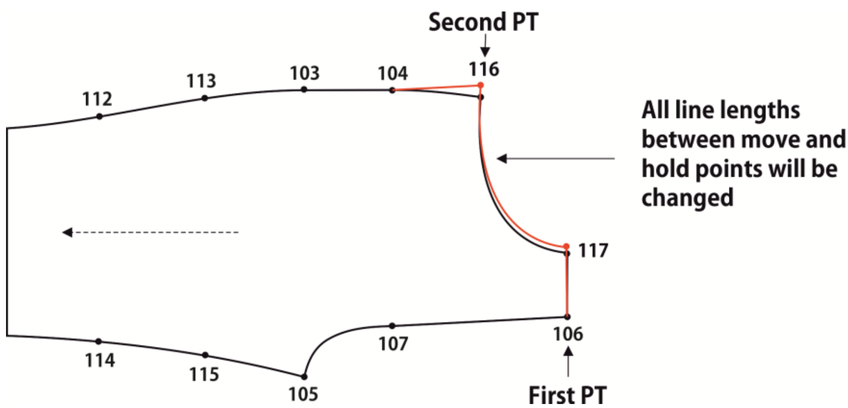
2. Moving a line parallel with offset.
Selecting X-Y MOVE in the alteration type field and defining different values for the first point and the second point, allows the lines from next alteration points to create the alteration according to the percentage set in the movement field in alteration table (Figure 3.9).



Alt Type	First PT	Second PT	Movement X	Movement Y
X Y MOVE	102	109	-100,00%	0,00%

Figure 3.9. Moving a line parallel with offset

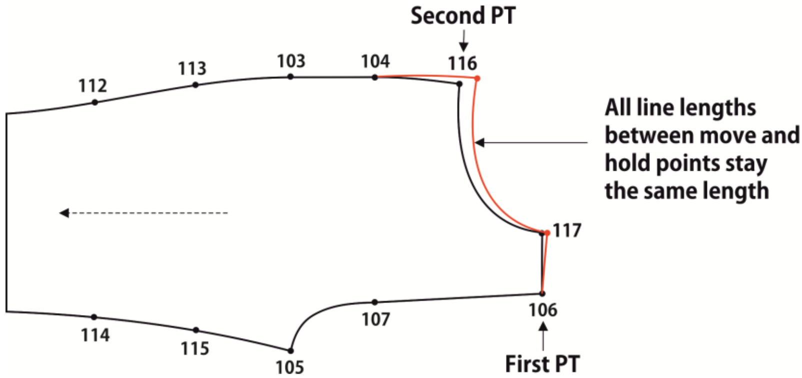
3. Pivoting a line with line-extension.
Selecting CW EXT move in the alteration type field and defining the first point and second point, will cause piece to pivot at the line of the first point up to the second point clockwise (CW) or counter-clockwise (CCW) around the piece, according to the percentage set in the movement field in alteration table. The line is pivoted at the specified point. The pivot line and the next line segment are extended to create a new segment (Figure 3.10).



Alt Type	First PT	Second PT	Movement X	Movement Y
CW Ext	106	116	0%	100,00%

Figure 3.10. Pivoting a line with line-extension

4. Pivoting the line without extension
   Selecting CW No Ext (clockwise, no extension) or CCW No Ext (counter-clockwise, no extension), indicates a clockwise or counterclockwise movement from the first point to the second point by the alteration rule value without a change in the existing pattern line.



Alt Type	First PT	Second PT	Movement X	Movement Y
CW No Ext	106	112	100,00%	0,00%

Figure 3.11. Pivoting the line without extension

To provide control of these alteration movements, hold points (First PT) and move points (Second PT) must be defined. Beginning with one alteration rule at a time, identify all points that should be adjusted and determine the kind of move that would be most appropriate for each. It is possible that more than one move operation could cause the same change in the pattern piece. Once all alteration rules have been determined and the descriptions defined by the point number, movement type, and percentage, an alteration rule table will be created in CAD system.

3.2.2 Configuration of Accumark® Made-To-Measure

MTM requires a one-time setup of company information in MTM knowledge base using forms accessed from the Setup Menu**.** The MTM utilizes information entered during this setup whenever an order is entered and processed**.** The base measurement entity–relationship model is shown in Figure 3.12 and table example in Figure 3.13.

AccuMark® Data - This form is to enter names for AccuMark data and options/sub options/measurements into the database.

Base measurements - This form is for entering measurements and limits for alterations for a particular style. Base Measurements are relative measurements that reference body or garment measurements; they must be consistent with the measurements taken at the point of sale. The base measurements table compares customer measurements in the Order Entry form to the base measurements of the customer's size and calculates the amounts needed to alter patterns to fit the customer. A Base Measurements table also contains alteration limits based on size.

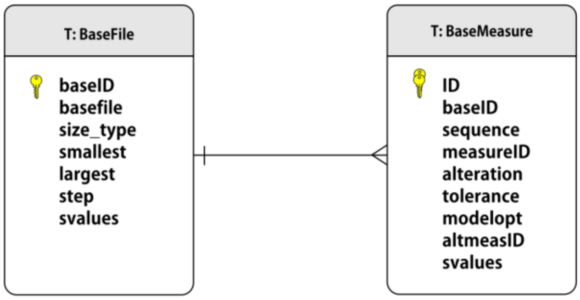
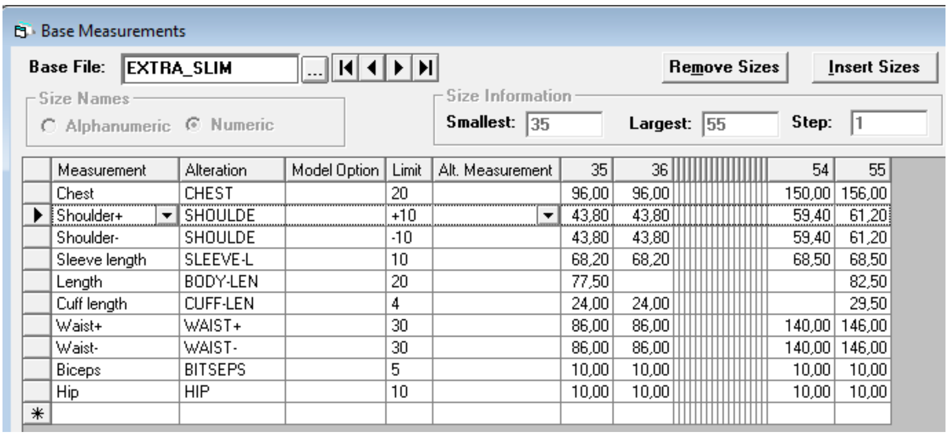


Figure 3.12. Entity–relationship model for Base measurements

Garment Definition - This form is to define a model, options/sub options, and measurements for each garment type.

Rules – This form is to set up if/then statements that determine how MTM orders will be processed. Rules allow MTM to automate order selection. A Rule is a single if/then statement, i.e. *if* the condition is met in the order, *then* MTM applies the specified action(s) during order processing. An If/then Statement gives the condition(s) to be met before an action is initiated.

Preferences - This form is to select default Batch Processing and AccuMark storage areas/parameter tables for processing orders.



Measurement	Alteration	Model Option	Limit	Alt. Measurement	35	36	54	55
Chest	CHEST		20		96,00	96,00	150,00	156,00
Shoulder+	SHOULDE		+10		43,80	43,80	59,40	61,20
Shoulder-	SHOULDE		-10		43,80	43,80	59,40	61,20
Sleeve length	SLEEVE-L		10		68,20	68,20	68,50	68,50
Length	BODY-LEN		20		77,50			82,50
Cuff length	CUFF-LEN		4		24,00	24,00		29,50
Waist+	WAIST+		30		86,00	86,00	140,00	146,00
Waist-	WAIST-		30		86,00	86,00	140,00	146,00
Biceps	BITSEPS		5		10,00	10,00	10,00	10,00
Hip	HIP		10		10,00	10,00	10,00	10,00

Figure 3.13. Base measurement table

3.2.3 Defining Categories

For MTM system, categories need to be defined according to the products which company produces.

- Garments — coat; pants; a vest. The general description.
- Options — Options refer to company options from spec sheet or order form for a made–to–measure garment, for example, buttons; front opening; back pocket; waistband; beltloops. They are also called customer Co-design options.
- Sub options — Sub options refer to company sub options from spec sheet or order form for a made–to–measure garment, for example, two or three

buttons; double or single breasted; wide or narrow; center, side or none; flap, patch, or besom; regular or vented.

- Measurements (AccuMark MTM) — Measurements refer to body measurements from a company spec sheet, for example, body length, half-back, shoulder width, sleeve length.
- Models — These are AccuMark style names listed for each garment type.
- Alterations (blue pencil) — Blue Pencil Alterations are extra alterations selected by an expert. These alterations are determined by considering body shape, tailor measurements/notes, and style/fabric characteristics, for example: erect; stooped; sloping shoulder; square shoulder.

The garment definition entity–relationship model is in Figure 3.14 and Sample Company setup in Figure 3.15

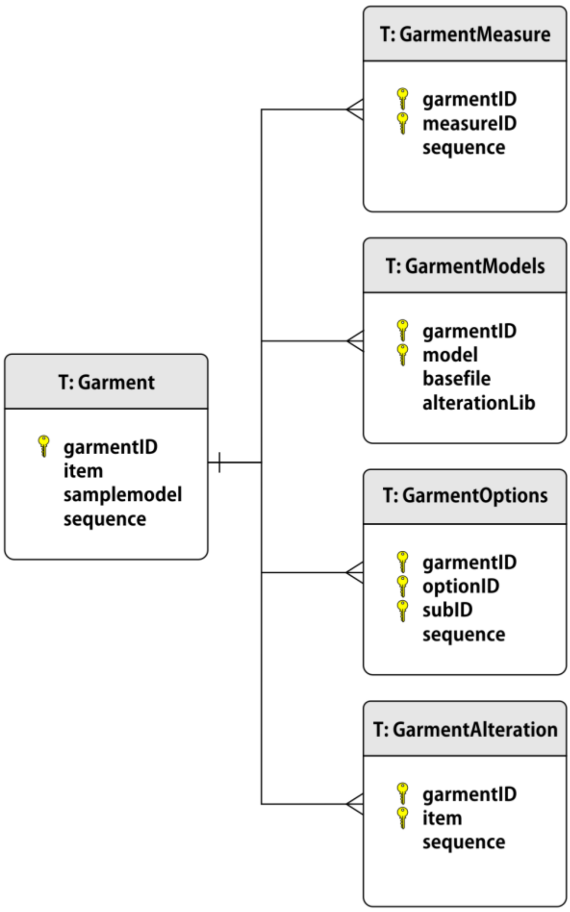


Figure 3.14. Entity–relationship model for garment definition.

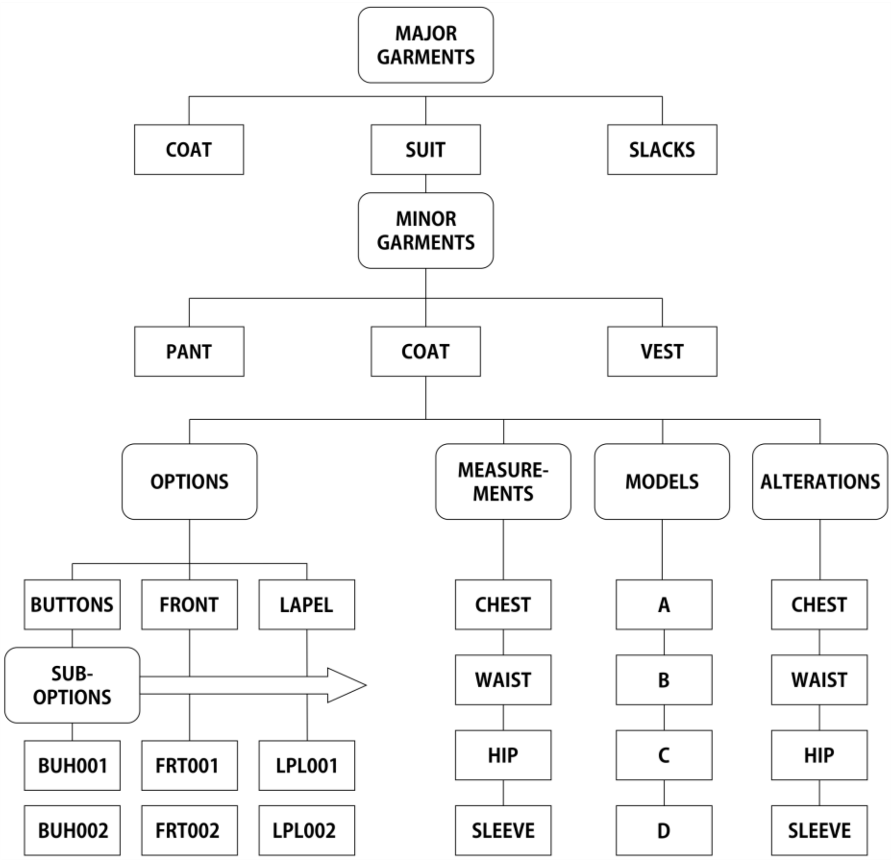


Figure 3.15. Sample Company's setup

3.2.4 MTM Order

The MTM Order Entry form displays default information and provides selections defined in Setup forms. The MTM order entity–relationship model is in Figure 3.16.

The standard MTM Order form is used to enter the following information for a customer order:

- sales Order Information
- fabric Details
- AccuMark Data
- garment type, model, size, quantity, fabric type
- options and Sub options
- measurements (full body)
- blue Pencil Alterations (Extra alterations)
- plot/Cut options
- cutdowns / Half pieces

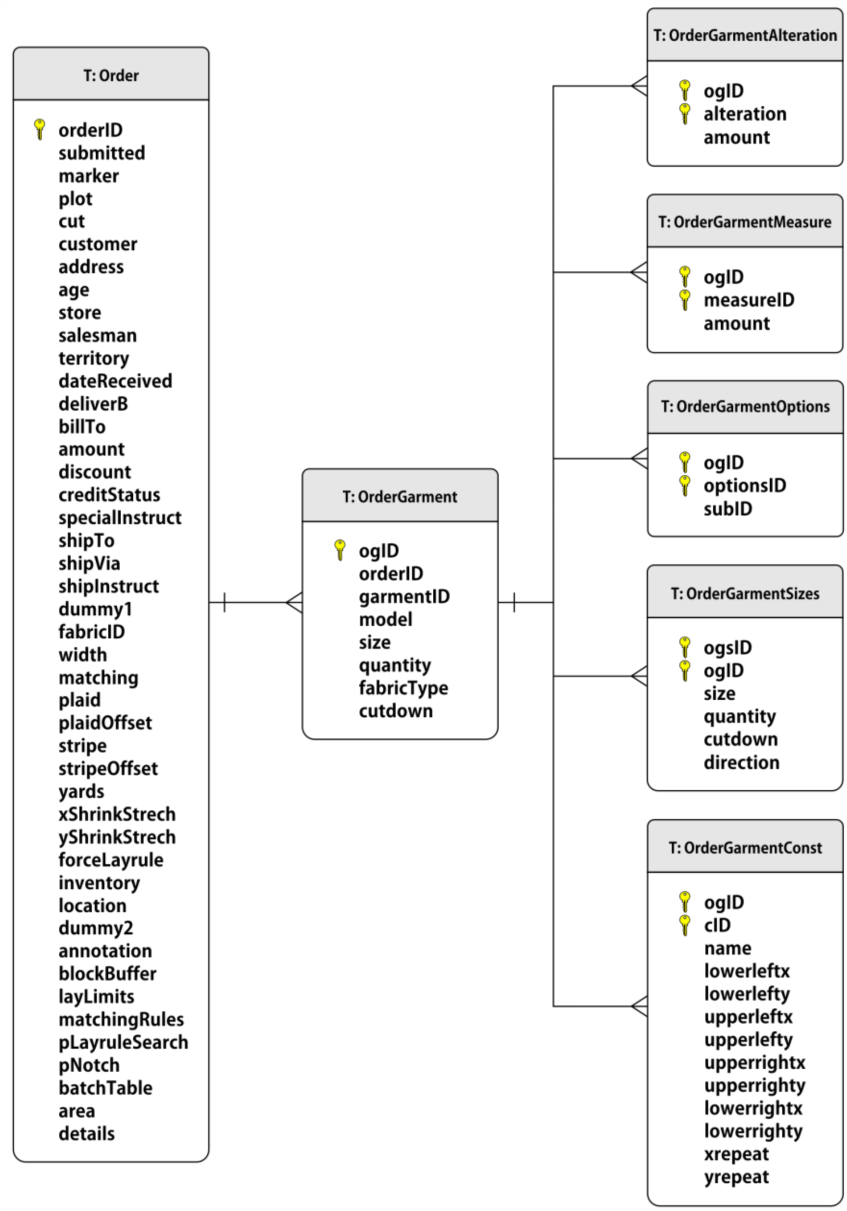


Figure 3.16. Entity–relationship model for MTM oder

MTM order file is the output of The Digital Tailoring system (Table 3.1). Orders can be imported from other systems, including a mainframe, as long as the orders are in the acceptable text format. Order file to be imported requires a specific text format.

MTM import system is capable of processing the orders without human intervention. Do to so, the MTM import directory needs to be set to a specific folder (import window kept open) where the import files are directed from The Digital Tailoring system (Figure 3.17).

Table 3.1. The order import file for the MTM.

ORDERID = 12345678901234567890 PLOT = 1 CUT = 1 Customer = Katy Berry Address = 168 Station Road, London Age = 30 Store = Macys Salesman = Mary Territory = London Date Received = 10.10.2014 Deliver By = 20.10.2014 Bill To = Client Amount = €369 Discount = 0,00 Credit Status = 0 Ship To = Store	Sales Order Information
Fabric Details = 0 Fabric ID = ALC 123 Width = 150 Matching = STANDARD xShrinkStretch = 10,00% yShrinkStretch = 4,00% Inventory = London Location = England	Fabric Details
AccuMark Data = 0 Annotation = Annotation Block Buffer = ver1 Lay Limits = L P-Layrule-Search = P-LAYRULE-SRCH P-Notch = P-NOTCH Batch Table = P-BATCH Storage Area = C:PRODUCTION	AccuMark Data
GARMENT = WOMAN MODEL = EXTRA SLIM SIZE = 36 QTY = 1 FABRIC TYPE = 1 CUTDOWN = 0	Garment type, model, size, quantity, fabric type
OPTION Front fastening = FFT101 OPTION Cuff = CFF102 OPTION Collar = COL101 OPTION Pocket = PCK101 OPTION Contrast cuff = CCU101 OPTION Factory = STOYAN	Options and Suboptions
MEASURE Length = 156,000 MEASURE Chest =100,000 MEASURE Waist = 85,000 MEASURE Hip = 106,000	Measurements (full body)
ALTER E_LEN = 1,000 ALTER L_SLE = 0,500	Blue Pencil Alterations (Extra alterations)

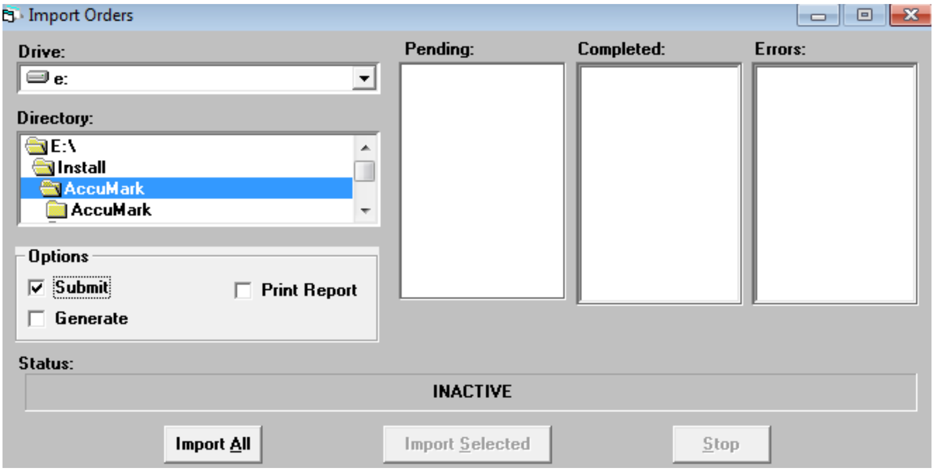


Figure 3.17. Import window

3.3 MTM evaluation

The MTM system was evaluated through hundreds of smaller and larger production runs containing 50-100 order per one production run. One order contained one real customer order, measurements and fabric data.

MTM compares a base measurement for the ordered size with a customer's measurement. The difference between these two measurements is the alteration amount.

Next, MTM compares the alteration amount with the alteration limit (Figure 3.18).

Specifying limits is *not* required. A Limit in a Base Measurements table is the maximum alteration amount allowed. Using limits allows for various courses of action when a limit is exceeded. These alternative actions can include:

- using alternative pieces
- aborting an order
- using alternative alterations
- performing a model option

If the amount is within the limit, the alteration will be performed.

If the amount exceeds the limit, and an alternate measurement is available, the alternate alteration is performed. An Alternate Measurement is a measurement that can be used when a limit is exceeded. If the amount exceeds the limit and *no* alternate measurement is available, MTM aborts the order.

During MTM system development, several MTM CAD software bugs were discovered. The biggest bug sets working hours for The Digital Tailoring system - the MTM CAD system stops working at midnight for one hour.

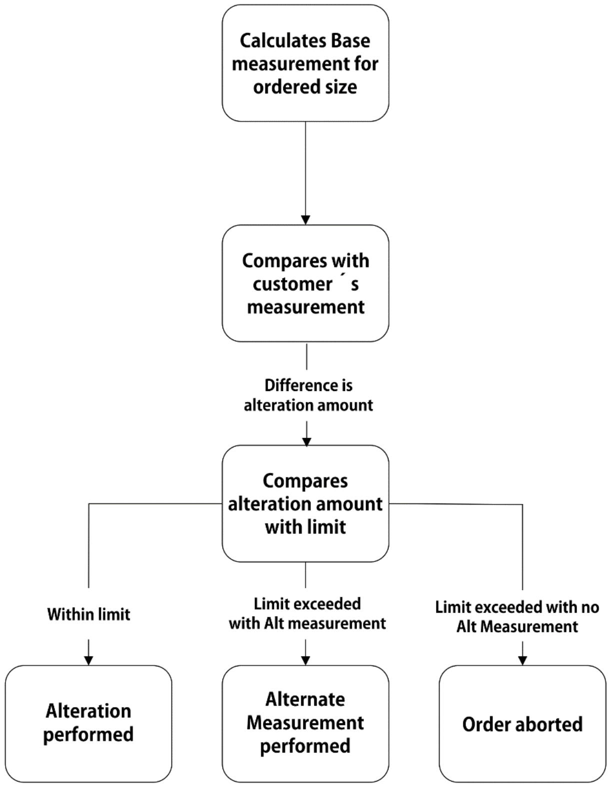


Figure 3.18. How MTM calculates alteration values

3.4 Conclusion

The chapter describes how to set up CAD system for MTM garments and CAD software chosen by the author. The MTM CAD foundation for The Digital Tailoring system is the Gerber Accumark® MTM because it is the most advanced and programmable MTM module.

According to the user defined MTM CAD knowledge base, the content of The Digital Tailoring CAD import file can be determined. The measurement extraction from 3D body scanner can be specified by the measurements needed for pattern alteration.

The author had set up MTM CAD system.

According to the system requirements, the author has created:

- pattern knowledge base
- lay limits/annotation knowledge base
- alteration knowledge base
- MTM knowledge base

The MTM system was evaluated through hundreds of smaller and larger production runs containing 50-100 order per one production run.

Chapter 4

4. INTEGRATION OF AUTOMATED DATA COLLECTION, ENRICHMENTS AND TRANSFER TO THE CAD SYSTEM

This chapter introduces Computer Integrated Manufacturing model for Digitally Mass Customized garments. It describes how to automate data collection from 3D body scanner and sales system for the readable format for CAD MTM system so that no data needs to be entered manually. The output of the system is Digitally Mass Customized cloth.

Proposed CIM model for Digital Mass Customization is introduced, it is followed by the detailed description of the solution which takes 3D body scanning measurements, customer order and Tailor Knowledge and translates the information into a readable format for CAD system.

The chapter answers the questions of what The Digital Tailoring system is; what the input and output of The Digital Tailoring system is; what the Order ID number is.

4.1 CIM Model for Digital Mass Customization

In a following section, an overview of the proposed and tested CIM model for Digital Mass Customization in the garment industry for producing customized products with minimal production cost is presented.

For producing products with high-quality with super-productivity and at minimal production cost requires the integration of an extremely complex system. This step can be accomplished only when all elements of the manufacturing process – design, fabrication and assembly, quality assurance, materials handling – are computer integrated, individually and collectively. Computer-aided process planning permits the selection, from the thousands of possible sequences and schedules, of optimized processes.

Computer integrated manufacturing model for Mass Customized cloth (Figure 4.1) starts with a customer willing to buy Mass Customized product. First, the customer designs the product from available co-design options. This information is entered into CRM system which is directing this information into operation management system (shop floor control, purchasing, cost accounting, production planning and control, order entry). Secondly, the customer will be the 3D body scanned (3 scans are taken in a row to ensure the quality of the scans) and 3D object file and the 1D anthropometric data file is created. The customer order information and 3D body scanner measurements are enriched and transferred to CAD system.

CAD system process order file (output from The Digital Tailoring system) and generates according to the file the customer 3D visualization. The customer can see the visualization after the 3D body scanning.

Simultaneously with the creation of the customer order to the CRM system the Webstore account is created for the customer. In the Webstore, the customer can see the 3D visualization and follow the status of the product and place new orders online.

At the same time with 3D visualization generation the pattern creation will be done (marker files) and fabric consumption calculated. All the data will be directed to the server.

Inventory system pulls consumption information (marker info, accessory list) from the server. An Inventory Management system enables to know what the company has, what it needs, and when they need. It helps to keep track of a number of fabrics, accessories, packaging, etc.

4.2 The Digital Tailoring system

The basic information handling tasks required during the life cycle of a product are steps that form the basic strategy for computer-aided-manufacturing. A significant phase in this process is capturing the information generated during the design process (6).

The key for Digital Mass Customization is the novel and unique The Digital Tailoring system developed by the author, which enables:

- to produce customized garments according to individual needs/taste/wishes of each customer (Mass Customized garments)
- to apply mass-production methods for Mass Customization products to reduce production costs

The Digital Tailoring system is an automatic order processing system. It takes two kinds of information as input:

1. Customer's order.
2. Customer's anthropometric data from the scanner(s).

With this information, The Digital Tailoring system can output different files and documentation needed for manufacturing:

1. Customer specific *Order file* for CAD 2D program
2. Customer specific *Order file* for CAD 3D program
3. Technical specifications for the Mass Customized product.
4. Documents requested in the manufacturing process.

The Digital Tailoring system integrates the data from different outputs and enriches the data with knowledge base collected from tailors, encodes for the CAD system and transfers to the CAD system.

The 3D body scanner measurement extraction program creates a 1D anthropometric data file. This file contains only information about 1D anthropometric data and landmark coordinates (chapter 2) – it does not describe body curves; neither does it take into account Tailor Knowledge. Customer order information (e.g. model, fabric, etc.) and preferences (e.g. additional length for high heels) are missing.

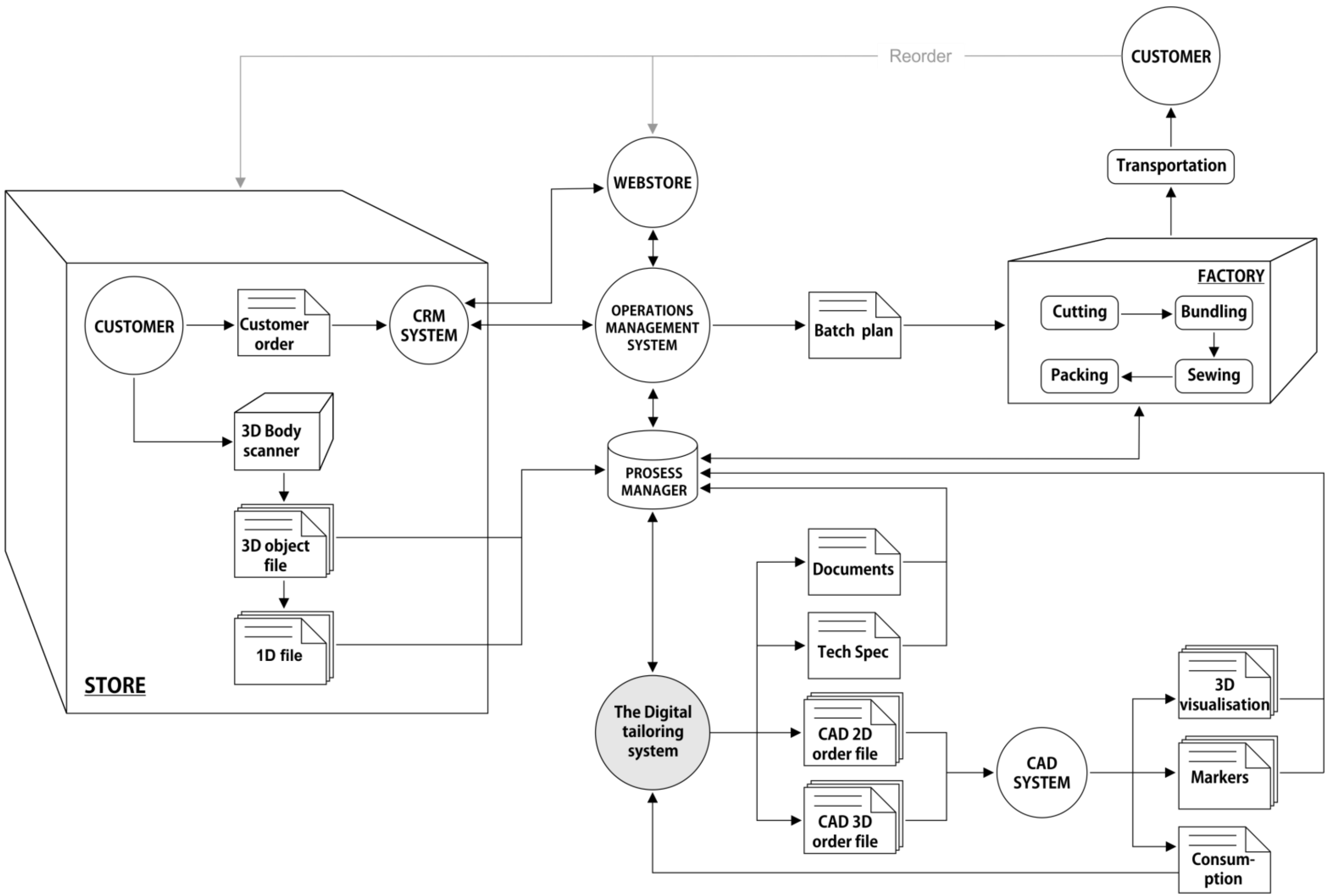


Figure 4.1 CIM Model for mass-customization technology

4.3 Functional Scheme of The Digital Tailoring system

The functional scheme of The Digital Tailoring system is divided into several parts (Figure 4.2):

1. *Automated data collection from CRM* – imports the CRM data into the program.
2. *Automated data collection from 3D body scanner* – imports three scanner anthropometric data files per customer into the program.
3. *Average anthropometric measurements* – averages customer three measurement sets to one measurement set per customer.
4. *Data integration* – combines data residing in different sources.
5. *Encoding* – encodes commercial names to readable format for CAD
6. *Data enrichment with Tailor Knowledge* – applies fabric specific ease, model specific alterations, body curve specific alterations and customer preferences.
7. *Updating CRM* – creates update info for CRM system.
8. *Creating technical specifications* – creates key documentation per customer for the factory.
9. Generating production data – creates batch info.
10. Data transfer to CAD 3D files – generates 3D CAD files.
11. Data transfer to CAD 2D files – generates 2D CAD files.

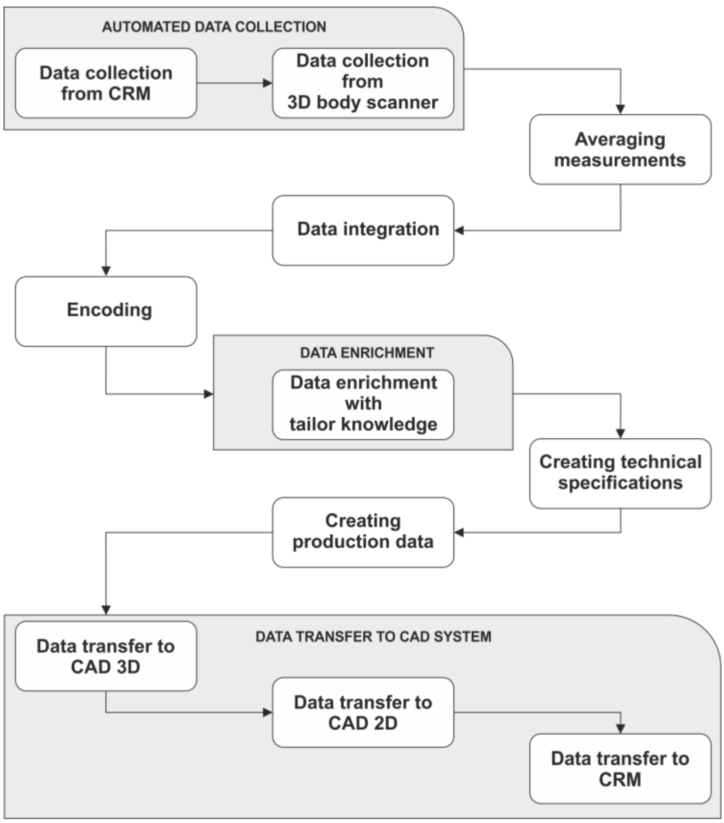


Figure 4.2. Functional scheme of the Digital Tailoring system

The preliminary version of The Digital Tailoring system has been developed using the Microsoft Excel spreadsheet program and has been programmed to perform tasks through Visual Basic (VB) interface forms for data input and output.

In the following is presented detailed explanations of these steps.

1. Automated Data Collection from CRM

The first task of The Digital Tailoring system is to import orders and store them.

The most important input for The Digital Tailoring system is **Customer order**, which consists all the data about the customer, design preferences, and special requests.

The customer order is a part of Customer Relationships Management (CRM) system that is consecutively part of Operation Management system. Customer relationship management is a system for managing a company's interactions with current and future customers. It often involves using technology to organize, automate, and synchronize sales, marketing, customer service, and technical support (80).

Table 4.1 presents an example of the CRM system data and role of the data items in The Digital Tailoring system.

Table 4.1. CRM system data

CRM data	Purpose in The Digital Tailoring system
Customer Name	Earlier purchase history is checked; if there have been returns, correct fit data will be added in The Digital Tailoring system. Customer name will be directed to the CAD system.
Gender	Gender is necessary for the correct list of co-design option choices separated by the gender. Gender is part of the order file naming convention.
Product Sequence No	A 5-digit number, the previous customer no + 1, zero padded from left, start from 00001 onwards. Part of file naming convention.
C_ORD	CRM identification code is used to fetch back data from The Digital Tailoring system.
Store	Store information will be directed to the CAD system.
Sales Associate	Sales associate name will be directed to the CAD system.
Created Date	Purchase day of the product will be directed to the CAD system
Model/Style	According to the co-design option, The Digital Tailoring system applies Tailor Knowledge to the measurements and correct Model name for the CAD system.
Waist height	Customer preference for waist position will come as a comment to the CAD system.
Modified leg length	According to the Extra length ordered by the customer, The Digital Tailoring system generates alteration.
Hem Style	According to the stitching type at the hem edge, The Digital Tailoring system generates alteration.
Fabric	According to the base material type and color The Digital Tailoring system applies Tailor Knowledge to the measurements.

CRM data	Purpose in The Digital Tailoring system
Lining fabric	Lining material will be directed to the CAD system as coded no.
Stitching color	Will be directed to the technical specification sheet.
Front pockets	According to the co-design option The Digital Tailoring system codes the option applies Tailor Knowledge and directs to the CAD system.
Back pockets	According to the co-design option The Digital Tailoring system codes the option applies Tailor Knowledge and directs to the CAD system.
Embroidery	According to the co-design option, The Digital Tailoring system codes the option and directs to the CAD system.
Front fastening	According to the co-design option The Digital Tailoring system codes, the option applies Tailor Knowledge and directs to the CAD.
Waistband	According to the co-design option The Digital Tailoring system codes, the option applies Tailor Knowledge and directs to the CAD.
Double stitching	Will be directed to the technical specification sheet.
Belt loops	According to the co-design option, The Digital Tailoring system codes the option and directs to the CAD system.
Contr. stitching	Will be directed to the technical specification sheet.
Wash	According to the co-design option The Digital Tailoring system codes the option applies Tailor Knowledge and directs to the CAD.
Effects	According to the co-design option The Digital Tailoring system codes the option applies Tailor Knowledge and directs to the CAD.
Back label	Will be directed to the technical specification sheet.

2. Automated Data Collection from 3D Body Scanner

The second most important input for The Digital Tailoring system is the 3D body scanner anthropometric data file. An example of SizeStream 3D body scanner anthropometric data file is in Appendix 1.

The anthropometric data is the result of measurement extraction from the 3D body scanner point data cloud. The point data cloud is used for the creation of critical landmarks and anthropometric data.

Once a scan is taken, the produced data is sent to a computer and visualized on the screen (point data cloud). In the next step, the software automatically locates body landmarks and generates measurements (Figure 4.3). Thereafter, the scan data is saved in a special format to be read by The Digital Tailoring system that allows the body measurements to be analyzed and directed into CAD system.

The information about body curves will be transferred to CAD program through The Digital Tailoring system, which would take the 3D body scanner anthropometric data and landmark information and convert this information into a suitable form of measurements, alterations, models or options required for CAD program.

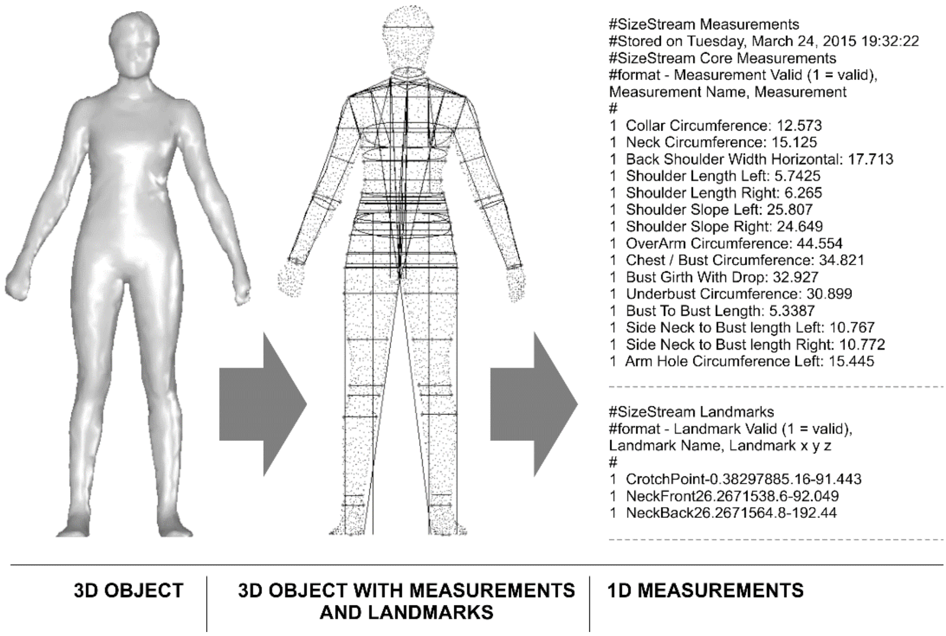


Figure 4.3. Formation of anthropometric data

From every customer is made three 3D body scans to ensure the accuracy of measurements. The body scanner names the files automatically as follows:

File name = <Customer name><Time Date><Scan_sequence_number>".obj"

Example:

Kate Middleton.0505PM Apr 05 2015.1.obj;

Kate Middleton.0505PM Apr 05 2015.2.obj;

Kate Middleton.0505PM Apr 05 2015.3.obj;

Data produced by body scanner is very precise, but protocols for locating body landmarks still need to be perfected. Traditional body measurements are based on landmarks on the body, which are often identified or located by palpitation while a computer must be programmed for every occasion. This affects the percentage accuracy of measurements of the body scanner since certain body landmarks are difficult to identify. This is one of the major reasons for incorrect locations of the waist, stomach, and crotch point measurements (81).

3. Data Integration

Data integration involves combining data from the customer order, which is imported from the Customer relationship management system and averaged measurements residing in different sources and providing users with a unified view of these data.

An example of data integration for jeans, Table 4.2.

Table 4.2. Current Batch sheet

Name	Gender	CRM code	Jeans ID	Store
John Smith	M	00001	0025684631	Il Salotto di

Salesman	Date Received	Model	Waist position	Extra Leg Length
Mary	DD.MM.YYYY	Slim fit	Low	M + 1

Hem	Fabric ID	Waist cross-	Pocket Fabric	Stitching
Normal Stitch	A 01234	2	White (thick)	Dark Blue

Front Pocket	Back Pockets	Embroidery	Fastening	Waistband
iPhone coin	Style 505	V-embroidery	Buttons	Classic

Seams	Beltloops	Contrast	Wash	Effects
Topstitch	Classic	No	Indigo	Stacks

Back Label	Buttons	MEP Used	Payment	Delivery
Black	Customer	AAA1	Debit	Pickup

Outseam_H	Outseam_R	Outseam_L	Waist_H	Waist_R
95,27	95,20	95,20	91,84	91,84

Waist_L	Seat	Knee_Left	Knee_Right	Knee_H_Left
91,84	101,77	37,80	37,80	26,87

Knee_H_Right	Calf_Left	Calf_Right	Calf_H_Left	Calf_H_Right
26,87	37,50	37,87	41,80	41,23

Flare_L_10%	Flare_R_10%	Crotch_Flare_L	Crotch_Flare_R	Inseam_Left
48,50	48,87	12,37	12,00	75,17

Inseam_R	Thigh_100_L	Thigh_100_R	CrotchLength_1	CrotchLength_1
74,93	59,23	59,23	21,40	37,87

CrotchLength_2	CrotchLength_2	CrotchLength_3	CrotchLength_3	Thigh_75_L
21,40	37,87	21,40	37,87	42,03

Thigh_75_R	Seat_Back_Angl	Waist Factor	A THI_S_L	A THI_S_R
42,03	13,65	0,96	0,00	0,00

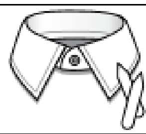
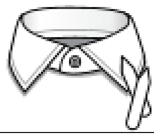
A KNEE+BOT_L	A KNEE+BOT_R	A CR_DEPT	Notes	Waist
0,00	0,00	0,00		

4. Encoding

All the customer options, Co-design choices are named in CRM system with their commercial names. The next step is to re-code all the commercial names to a readable format for CAD. Most names in CAD are limited with 6 letters.

In the following is an example for collar Co-design option renaming conventions (Table 4.3).

Table 4.3. Collar Co-design options

Option	Commercial name	Picture	CAD name
Collar	Business classic		COL001
	Business superior		COL002
	Cut-away classic		COL003
	Cut-away modern		COL004
	Cut-away superior		COL005
	Cut-away extreme		COL006
	Cut-away two buttons		COL007

5. Data Enrichment with Tailor Knowledge

Data Enrichment with Tailor Knowledge applies fabric specific ease, model specific alterations, body type specific alterations and customer preferences.

A detailed discussion of Tailor Knowledge and knowledge base introduced by authors for describing Tailor Knowledge is presented in chapter 3. Built-in Tailor Knowledge.

6. Updating CRM

The CRM system will be updated according to customer order, List of materials and Customer marker. According to the list of materials, the accessory inventory will be updated.

7. Technical Specification

The document used throughout the process of apparel development is the Technical Specification (TS). It is generated from customer order and TS template database.

The primary function of TS is communication between the company and manufacturing company. The TS provides the following information:

- identification of construction techniques
- specific fabrics, findings, and trim details
- quality assurance measurements
- labels, hangtags, and information about their attachment to the product
- packaging information

It is a document of the exact standards for the production of an item.

Quality assurance measurements are to assure the fit and size of the product by the factory. When the product is washed after sewing, then there is a need for two sets of measurements – before wash and after wash measurements of the garment.

The Digital Tailoring system calculates needed quantities of thread, labels, zippers, studs, buttons, etc (List of materials).

8. Generating Production data

Production documentation is created according to the customer order. Usually, they are a different list that allows the manufacturing unit to assemble the production batch in an effective way.

9. Data Transfer to CAD 3D

The CAD 3D Order file is created according to the customer order. It consists all the data needed for the visualization. The file is directed to the CAD software, where the visualization takes place, automatically.

10. Data Transfer to CAD 2D

The CAD 2D Order files (MTM order, section 3.2.4) are created according to the customer order.

From one customer order are created several 2D Order files:

- one per basic fabric
- one for the fusing, and
- one for the interlining

They contain all the data needed for Mass Customized pattern creation in CAD 2D software. The files are directed to the CAD software, where the pattern creation takes place, automatically.

The entire entity–relationship model of The Digital Tailoring system is presented in Appendix 2.

4.4 Order ID number

The order ID number is needed for customer identification. The customer pair of jeans will get unique Order ID number. The naming convention will create an identifier for different customer orders and for different materials used in one apparel product. For example; to make one pair of Mass Customized jeans we need three Order ID numbers for the CAD system (for the main material, lining and interlining).

All the customers and their orders are coded for the production. It helps to recognize the order details and materials used in an easy way in the middle of the manufacturing processes and gives privacy for the customers. In the example below is described naming convention for jeans production.

The order name is limited by a maximum number of characters allowed for the Order ID field in the CAD system. Order ID consists of 20 digits:

File Name = <Customer_ID><Order_Seq><Order_ID><Material_ID>".ORD"

Example of coding for Customer ID number, Order Sequential number, and Material ID number (Figure 4.4):

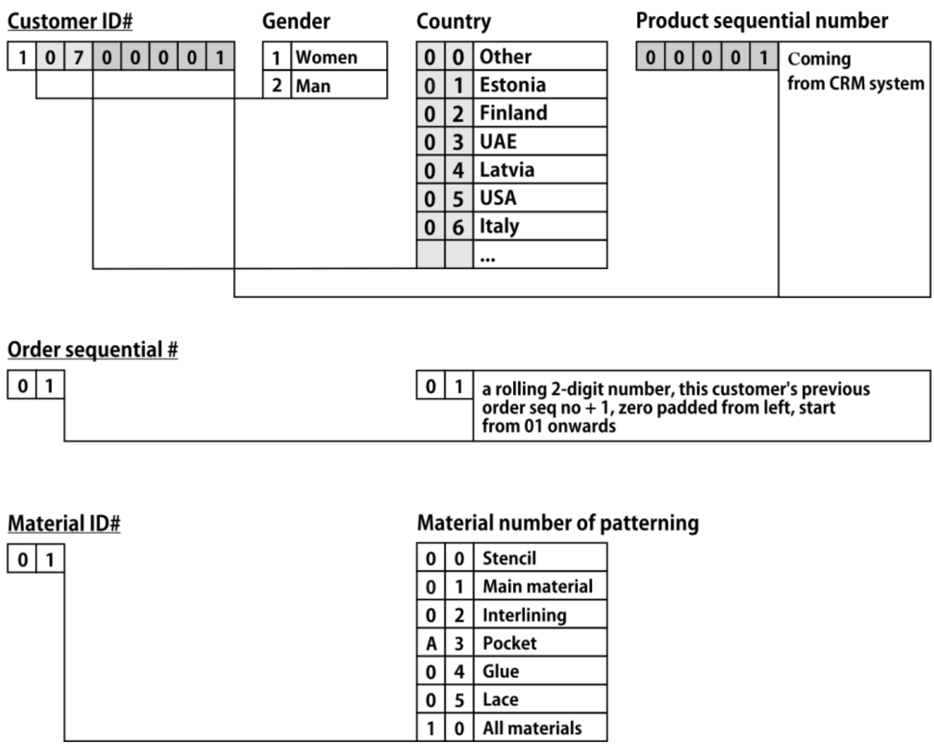


Figure 4.4. Customer ID number, Order Sequential number, and Material ID number

4.5 Evaluation

The Digital Tailoring system has been developed over four years’ time and over 200 production runs containing 50-100 customer orders has been tested. At first, the function of The Digital Tailoring system was only data collection and data integration, but after a while, it was understood that it needs to be more to produce fitting garments to customers. That´s why the Tailor Knowledge was added to the tool. The tool was evaluated every week by performing production run for previous week orders and the feedback of the changes came in 5-6 weeks’ time when the jeans were delivered to the customers. The feedback was valued by the number of jeans returned from the customers. With the time, new production facilities were taken into use. The system had to take this into account again – different factories have different technologies used which require modified patterns to fit the customers. The Digital Tailoring system is an artifact that develops with the time.

4.6 Conclusion

In this chapter is described how to automate data collection from 3D body scanner and sales system for the readable format for CAD MTM system so that no data needs to be entered manually.

It starts with automated data collection from CRM and the 3D body scanner. The 3D body scanner measurements are CRM data is integrated and encoded. The encoded data is enriched with Tailor Knowledge. Next, the system creates technical specifications, production data and import files to the CAD system for data transfer.

The author contribution is a new technology which makes Mass Customization seamless (The Digital Tailoring system),

- creating a link between the 3D body scanner, customer order and the CAD software (first end) and CIM production system (back end), which would allow to translate 3D measurements and customer orders into import files to MTM CAD system

The Digital Tailoring system creates unique Order ID number for every customer order. It helps to recognize the order details and materials used in an easy way in the middle of the manufacturing processes and gives privacy for the customers. The output file consists unique Order ID which enables to make pair personalized jeans.

Chapter 5

5. BUILT-IN TAILOR KNOWLEDGE

An important part of The Digital Tailoring system is built-in Tailor Knowledge. The Digital Tailoring system creates a link between the 3D body scanner, customer order and the CAD software, which would allow translating 3D measurements and customer orders into import files to MTM CAD system.

To produce fitting garments to the customers, it is necessary to enrich the CRM data and 3D body scanner measurements with Tailor Knowledge. The Digital Tailoring system transfers Tailor Knowledge into a readable file for CAD MTM which allows automating work processes and makes possible Mass Customization of the clothing business. This chapter answer to the question of how the artifact takes into consideration personal characteristics.

More closely it looks for answers to what is Body Curve Descriptor? What is the visual appearance of the garment? What are the fabric-specific changes?

5.1 Body Curve Descriptor

The most important part of The Digital Tailoring system is body curve descriptor which enables to choose suitable patterns and implement pattern alterations of a particular human.

The procedure starts with the 3D body scanning of the subject's figure shape, after that the computer program analyses:

- measurements and
- body landmarks; each landmark is characterized by its position coordinates. The XYZ values all are calculated in reference to a point on the floor directly below the crotch point (the 0-point). The x means movement to the front, the y means movement to the left and the z movement to the up (Figure 5.1).

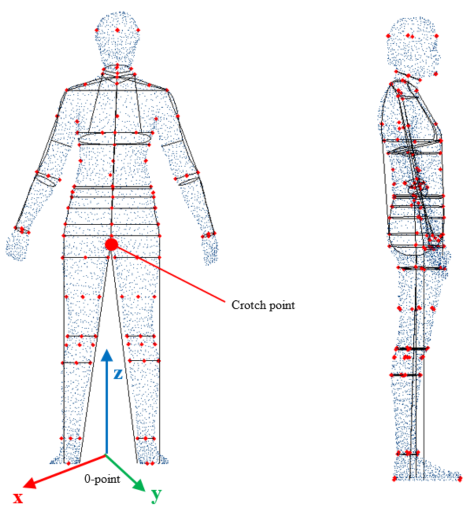


Figure 5.1 Landmarks and measurements

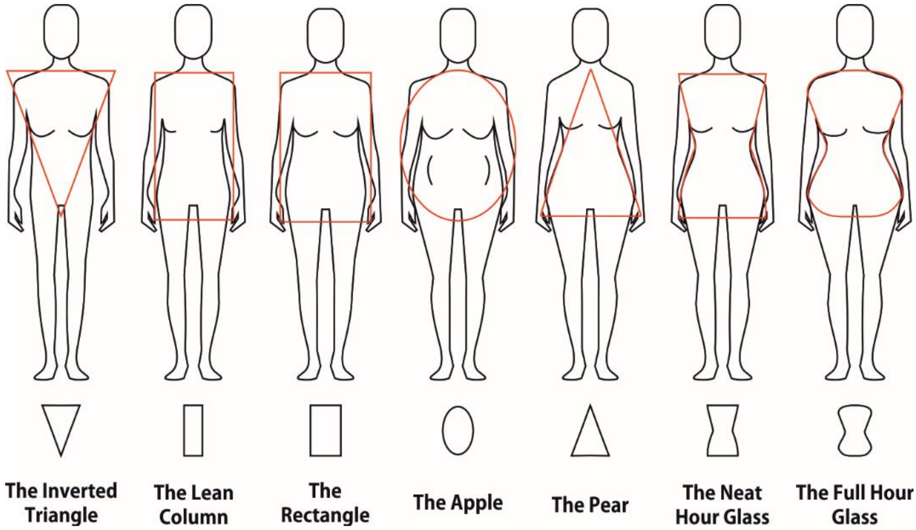


Figure 5.2 Body shape (65)

From pattern construction point of view, it is important to understand body curves, not body shape. Body shape describes human body from neck to toe in front view (Figure 5.2), does not describe any other view, neither in measurements or angles.

But body curve descriptor enables to characterize every specific curve in numbers and angles (Figure 5.3) needed for altering pattern according to the customer.

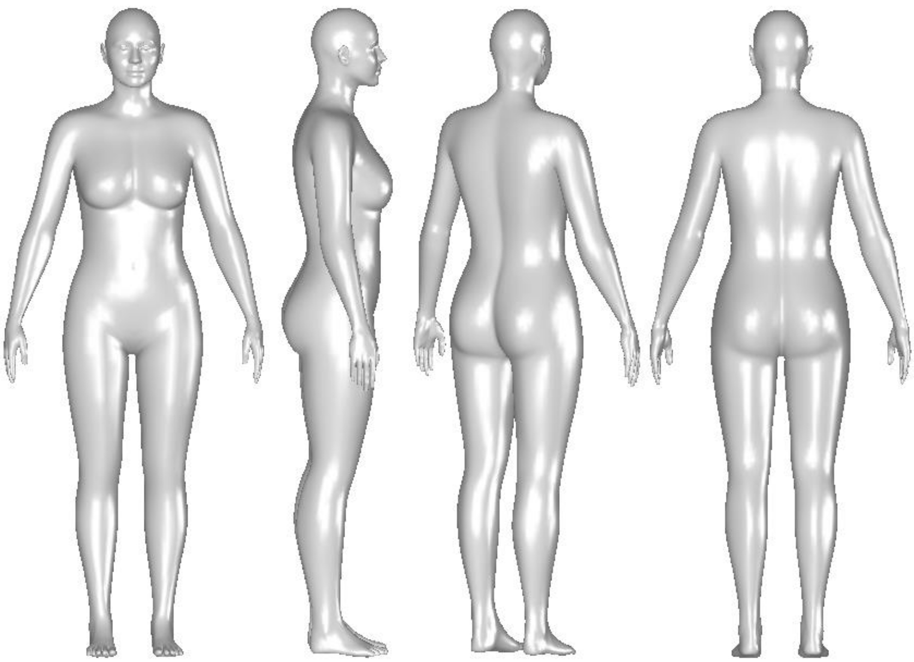


Figure 5.3. Body curves

According to the back-body curves we can define common five different back silhouettes (Figure 5.4), six stomach curves (Figure 5.5), seat stances (Figure 5.6), different leg stances (Figure 5.7) and thigh stances (Figure 5.8) for men (65).

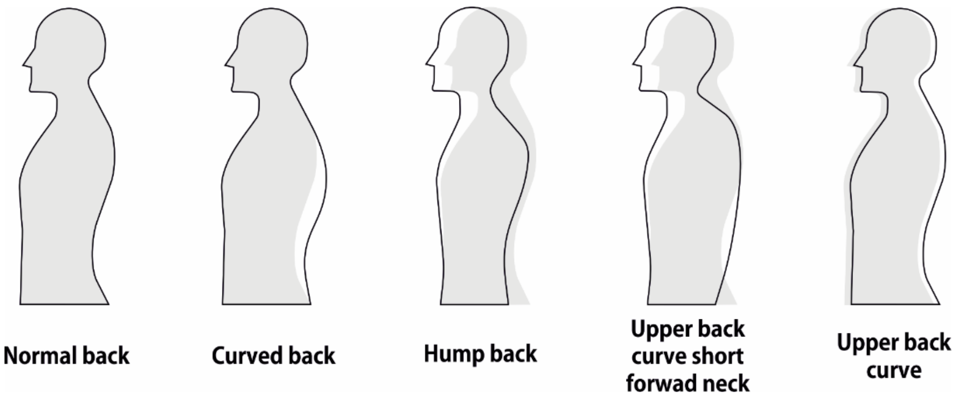


Figure 5.4 Back curves

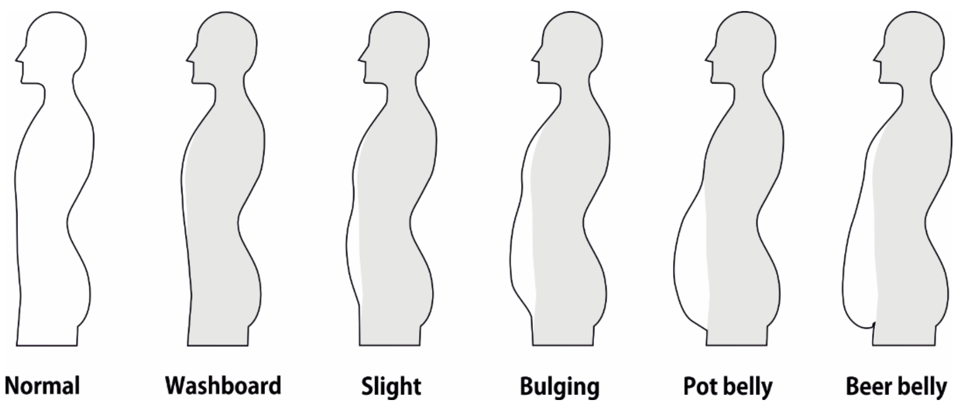


Figure 5.5 Stomach curves

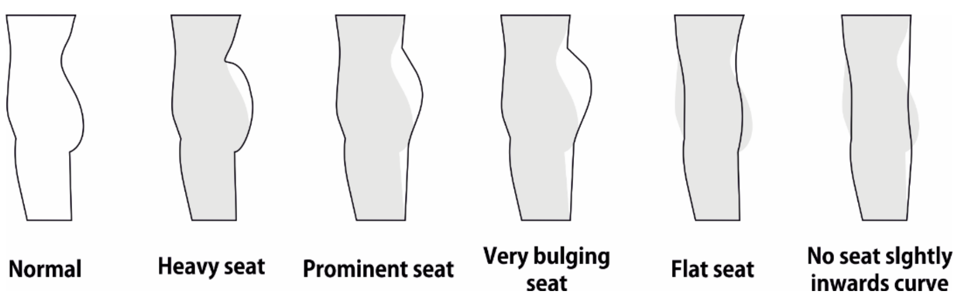


Figure 5.6 Seat stance

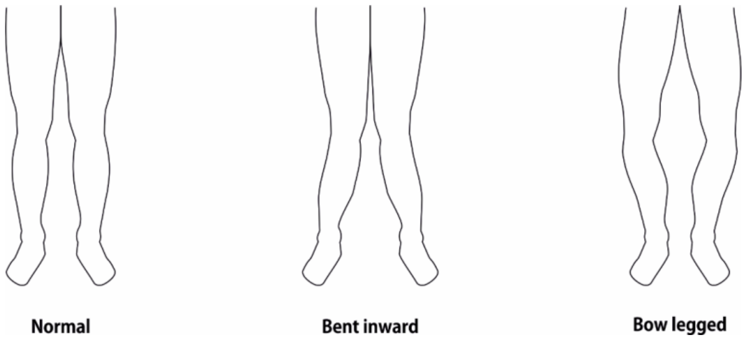


Figure 5.7 Leg stance

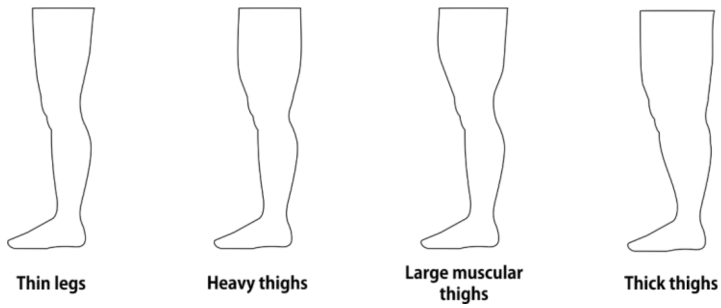


Figure 5.8 Thigh stance

5.2 Pattern Changes Based on Body Curve Descriptor

The section from center front to crotch needs to be adjusted if the customer has strong thighs (muscles or adipose tissue), otherwise, it would cause creases in the crotch and hip area (Figure 5.9). In the same time changes the knee/hem and grain line position (Figure 5.10).

Center front position on the waistline needs to be adjusted if the person has the big stomach (corpulence), the trousers do not have darts and also to regulate the level of ease in the waistline (Figure 5.11). The center front position on the waistline is also dependent on the outseam shape. If the outseam shape "comes" too curvy or straight, it needs to be adjusted accordingly from the center front.

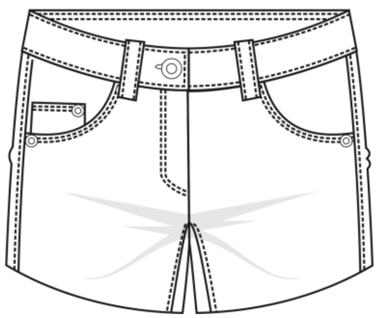


Figure 5.9 Too tight across hips

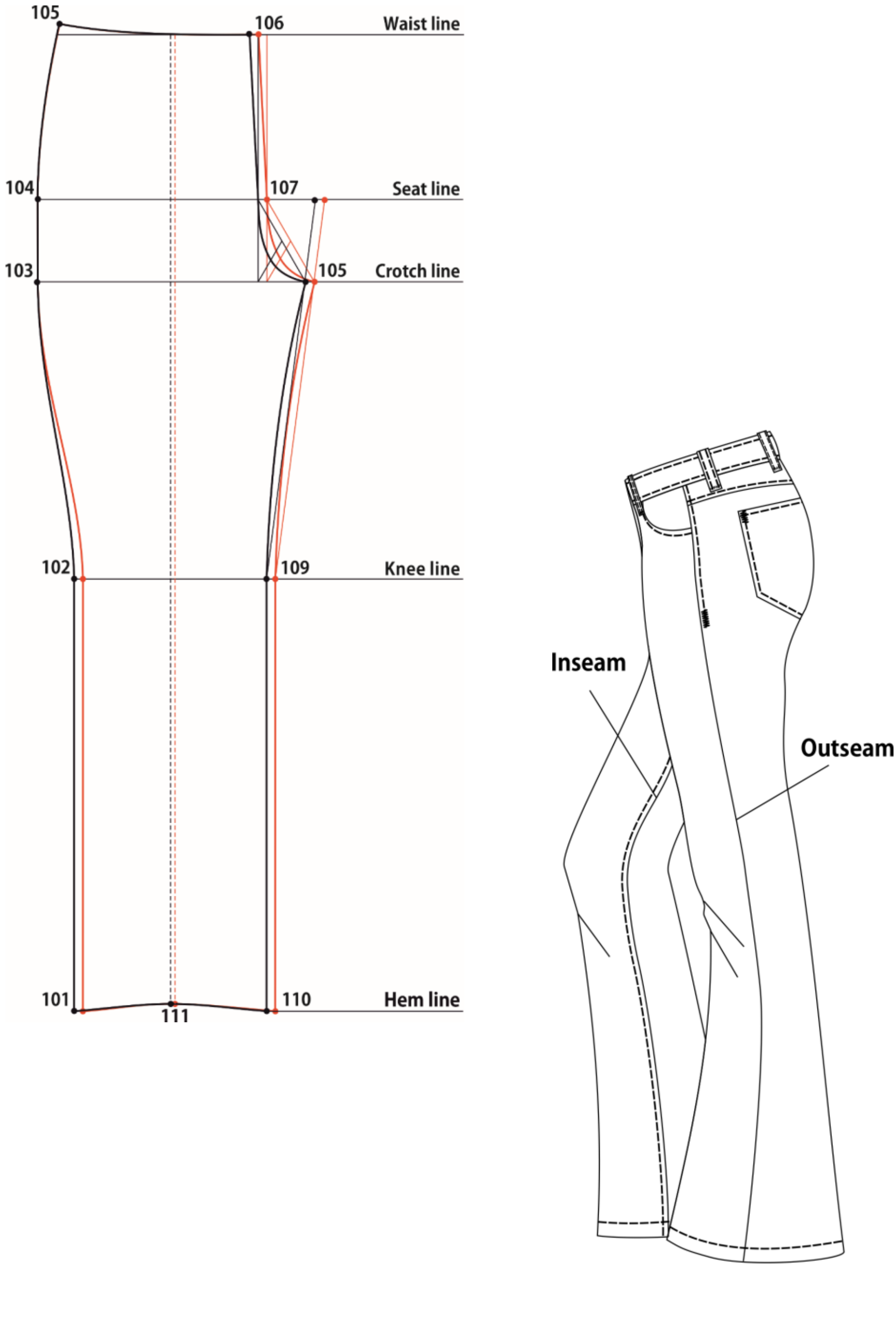


Figure 5.10. Centre front to extended inseam line

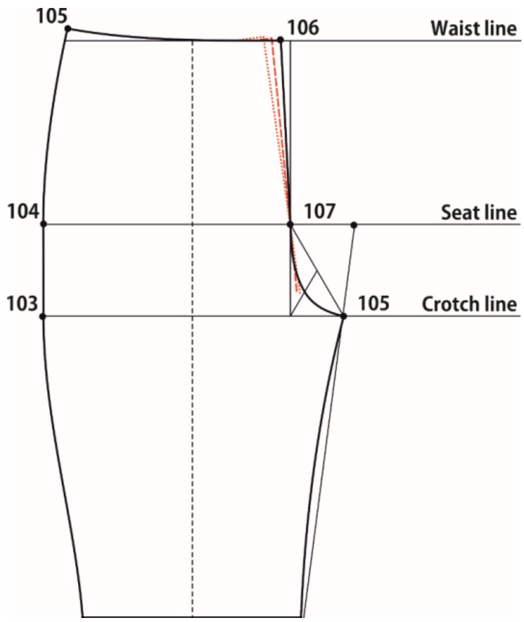


Figure 5.11. Center front position on the waistline

Centre back position and angle on the waistline need to be adjusted according to the seat back angle value. If the seat back angle exceeds a certain value, the center back needs to be tilted more to the side (Figure 5.12). From the center back angle depends on the appearance of the butt.

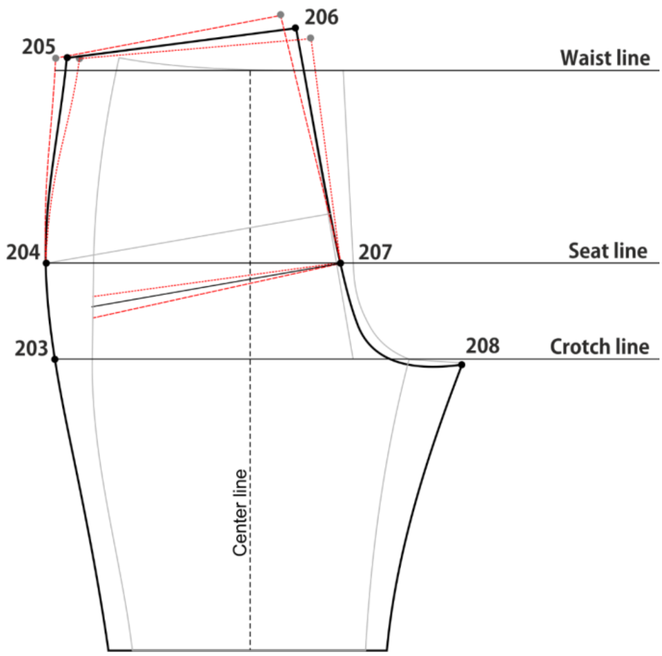


Figure 5.12. Centre back position on the waistline

Nowadays more and more people have X-shaped (bent inwards) or O-shaped (bow) legs. X-shaped curvature is a congenital bone deformation where the standing position shows the touching of only knees, and the ankles are apart; in this type of deformation, the closed legs look the letter X. O-shaped curvature is a congenital bone deformation where in the standing position - only ankles are touching, and the knees separate; both ankles in this deformation come off like the letter O (82).

If a person has X-shaped legs, pattern modifications have to be done from the knee down until bottom hem. The bottom hem is moved outside direction according to the level of X-legs (Figure 5.13).

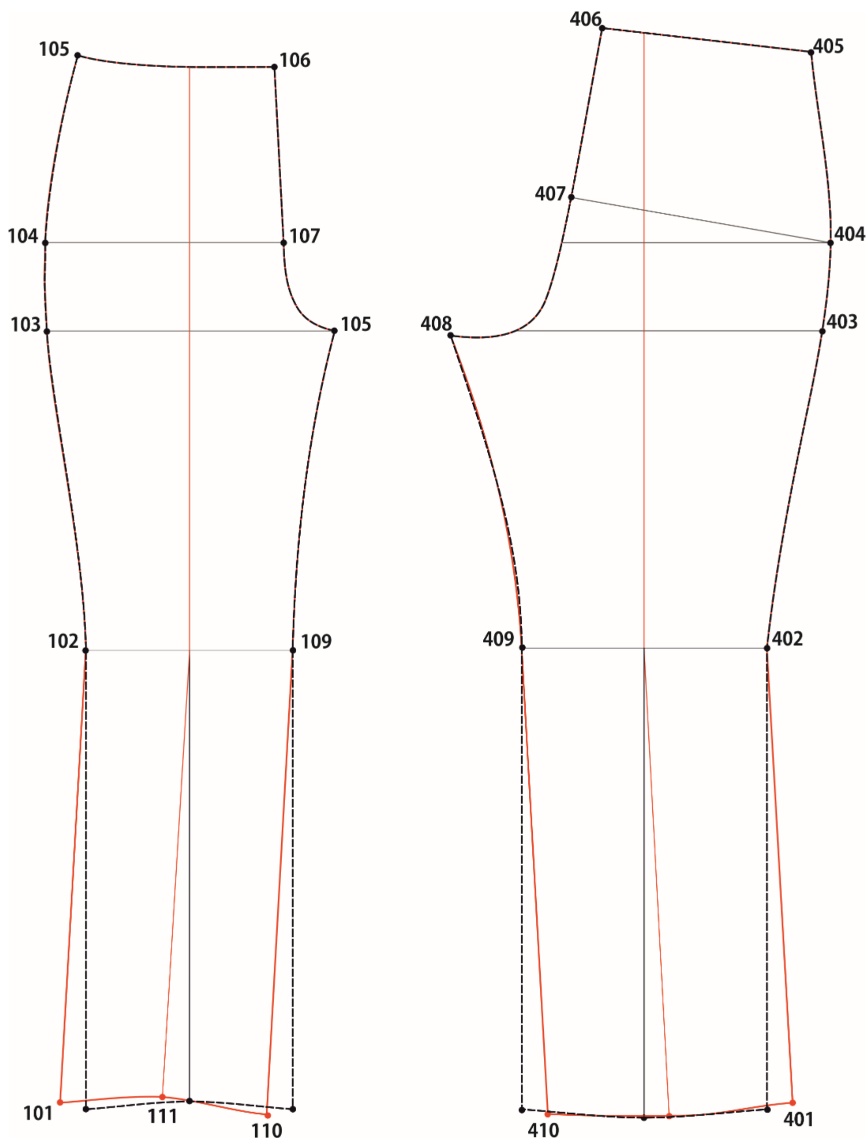


Figure 5.13. X-leg modified pattern

If a person has O-shaped legs pattern modifications has to be done from the knee down until bottom hem. The bottom hem is moved inside direction according to the level of O-legs (Figure 5.14. O-leg modified pattern).

Some people are strongly asymmetric and the pattern has to be modified accordingly if not, it will cause wrinkles, and the garment looks bad.

To detect asymmetric body (Figure 5.15) the body curve descriptor compares left and right outseam measurements, the pattern will be changed if they differ more than 1,5 cm.

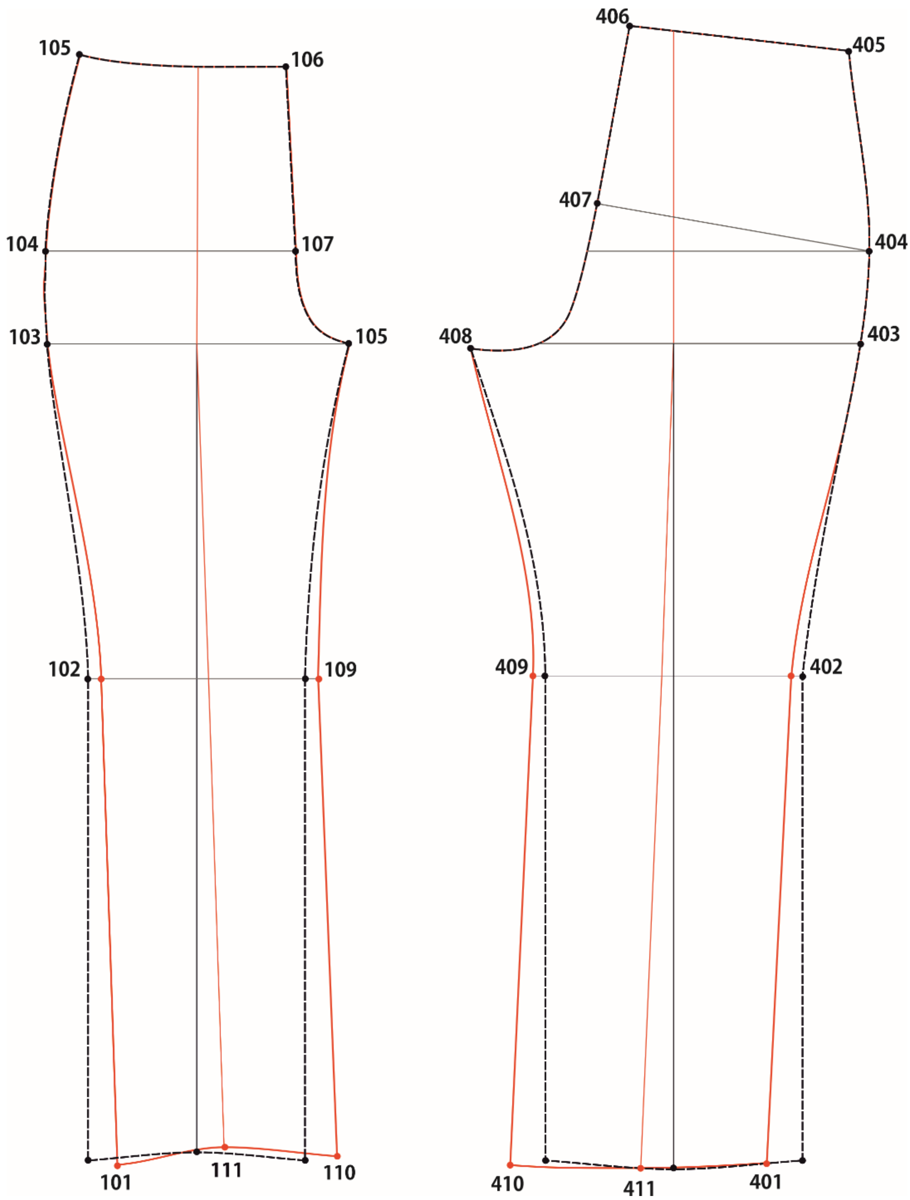


Figure 5.14. O-leg modified pattern

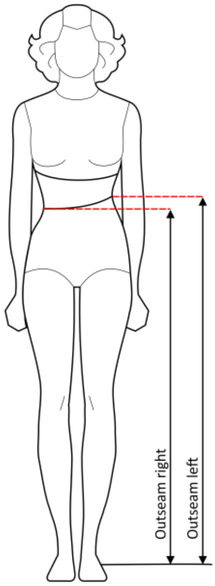


Figure 5.15. Asymmetrical body

One body side will be lowered and the other increased according to the asymmetry, resulting in different pattern pieces for the front left and right also for back right and left (Figure 5.16).

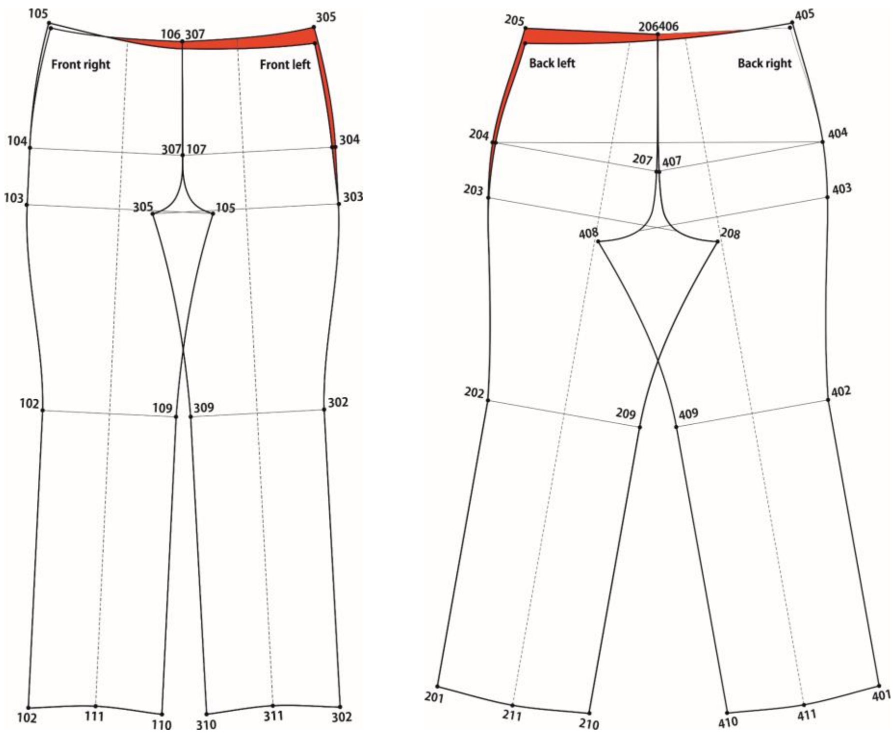


Figure 5.16. Asymmetric pattern

Many people develop heavy front thighs duo to sports activities (swimming, running, gym, etc.) which will cause the front pants legs to be too snug at the upper thighs. The pattern needs to be modified to avoid the tightness of the trousers and keep the side seam in the center of the side view. For this purpose, is added *n* unit extra space to the front piece (thigh area) and taken away the 1/3*n* unit from the back piece (Figure 5.17).

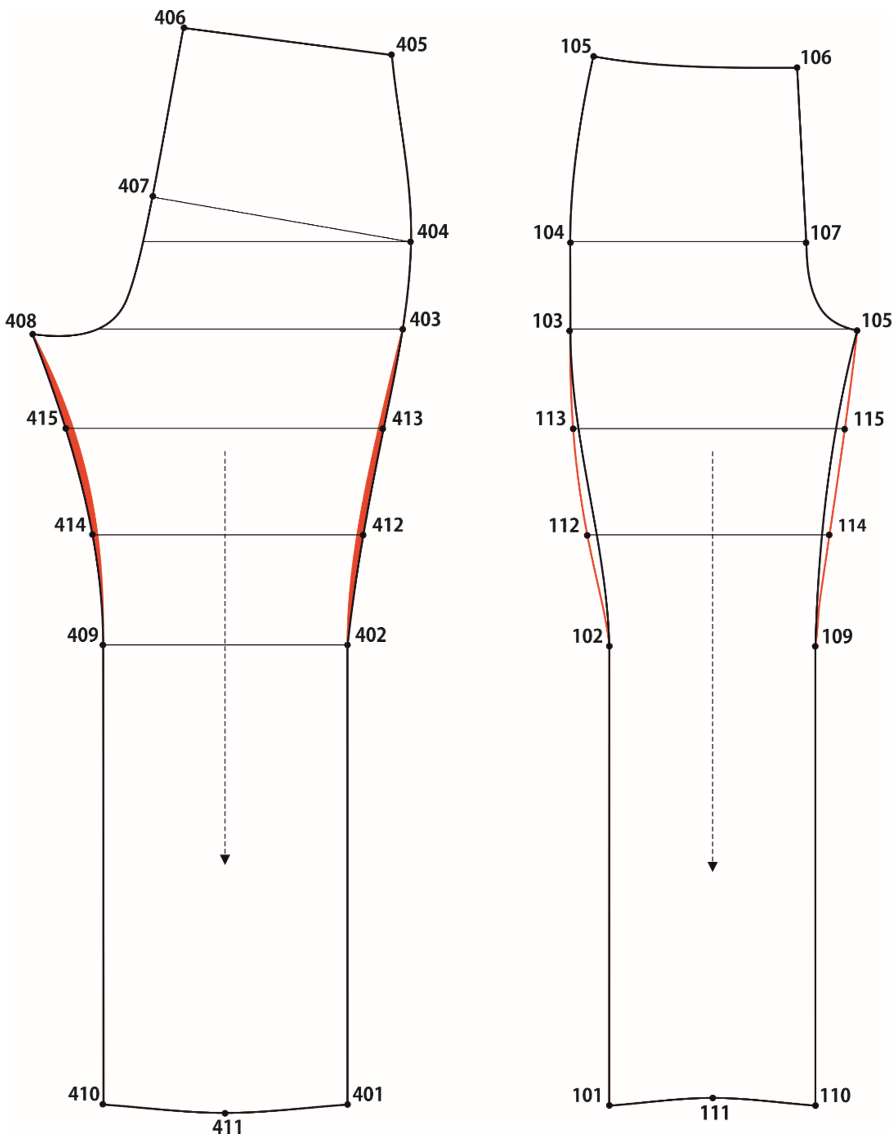


Figure 5.17. Pattern modification for heavy or muscular thighs.

5.3 Visual Appearance of Garment

Every model corresponds to the certain characteristics which define the look of the overall style. One of the most important components is the ease. Ease is the difference between actual body measurements and finished garment measurements at the same points (bust, waist, and hips). There exist two types of ease:

- Wearing ease is the minimum amount of extra room added to a pattern to allow for comfortable, non-restricted movement. All commercial patterns, as well as ready-made clothing, has wearing ease built in to allow to sit, move, raise arms, breathe easily, etc.
- Design ease is any amount of ease, beyond the basic wearing ease, that's added to a pattern to alter its silhouette or general shape. Design ease is the difference between a pencil skirt and a full circle skirt.

The Digital Tailoring system has a built-in knowledge base for different model eases for base circumference measurements. The Digital Tailoring system adds a certain percentage to the customer measurements according to the model (Figure 5.18) chosen by the customer. In this way, we can use one pattern for different models which use the same alteration points. Example; in Table 5.1 is presented model eases for different trouser models. We can use one pattern for styles 01 and 02 because they use the same anchor measurements. In the same way, we can combine 03 and 04.

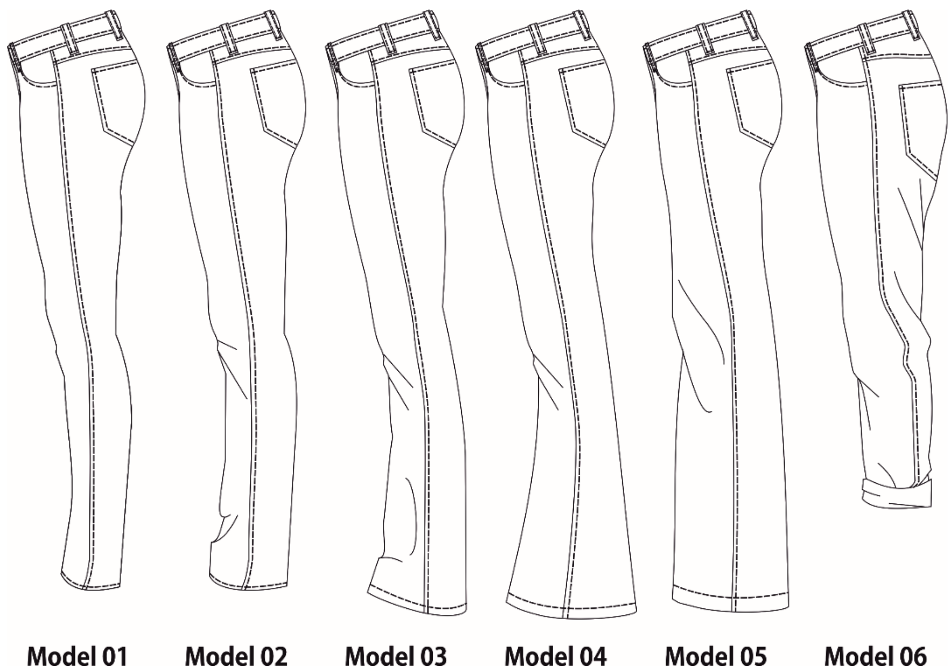


Figure 5.18. Trouser styles

Table 5.1. Example database of model ease inside of The Digital Tailoring system.

Body	Model name						
	01	**02**	**03**	**04**	**05**	**06**	**07**
Waist	0,0%	0,0%	0,0%	0,0%	0,0%	4,0%	2,0%
Seat	0,0%	0,0%	0,0%	0,0%	0,0%	4,0%	2,0%
Upper thigh	0,0%	0,0%	0,0%	0,0%	2,0%	6,0%	6,0%
Middle thigh	0,0%	2,0%	2,0%	2,0%	-	6,0%	6,0%
Lower thigh	0,0%	2,0%	-	-	-	-	-
Knee	0,0%	2,0%	10,0%	10%	-	10%	6,0%
Calf	0,0%	2,0%	-	-	-	-	-
Inseam	-	-	-	-	-	0,0%	-4,0%
Outseam	-	-	-	-	-	0,0%	-4,0%

If the customer base circumference measurement falls off from the range defined in database additional changes will be made to maintain the same visual look for different body types but still same models. The required/calculated change will be imported to CAD system as alteration value.

Example for straight fit trousers. The pattern definition for straight trousers is, that they should be with the same width on the knee and bottom hem circumference. In Figure 5.19 left side drawing, knee width equals to bottom hem (m = m). In reality, it is true for "regular" people, but not for larger people (with bigger knee circumference). In Figure 5.19 right side drawing, the knee is bigger than bottom hem (m > m-n). In straight fit styles, it is necessary to define knee and bottom hem relations to keep required fit (Table 5.2).

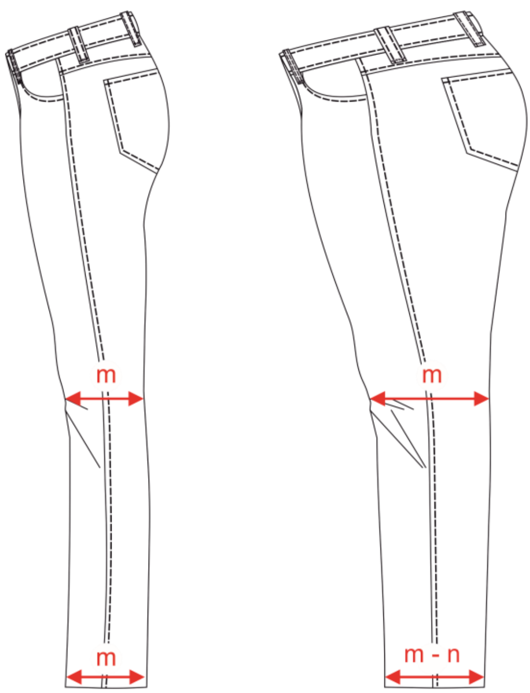


Figure 5.19. Straight fit visualization

Table 5.2. Bottom hem calculation

Knee circumference	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
Knee-n=hem	0,0	0,0	0,0	-0,5	-1,0	-1,5	-2,0	-2,5	-3,0	-3,5	-4,0	-4,5	-5,0	-5,5	-6,0

From CAD system point of view and also from a design point of view, it is necessary to create an optimal number of anchor points for different models. Example, the slim fit model requires much more anchor points than the straight fit model because it has to fit exactly. The Slim fit pattern has to have anchor points for calf height and circumference in contrast to straight fit which has enough ease in calf area in most of the customers. In addition, the straight fit model would not be a straight fit model if the pattern knee anchor points and bottom hem anchor points would not be connected with a straight line.

To avoid bad fit with customers who have a calf or calves bigger than the knee(s), The Digital Tailoring system performs measurement comparison between knee, calf and ease to fit the calves under the trousers. The required/calculated change will be imported to CAD system as alteration value.

The example set up for the straight fit model in The Digital Tailoring system (Table 5.3). From calf measurement is subtracted knee measurement;

- if the result is smaller or equal to two centimeters nothing needs to be done
- if the result is bigger than two centimeters, additional alteration value is calculated for the product

Table 5.3. Straight fit - measurement based change

Ease value	3
Calf - knee ≤ 2	NO CHANGE
Calf - knee > 2	CHANGE
Alteration value	**Calf-knee- 2**

5.4 Fabric Stretch

All the fabrics are stretching to a greater or lesser extent. Fabric provides a certain tension when stretched to fit the body and ensures comfort for the body. Therefore, the patterns are made smaller than the body dimensions - the material stretches afterward to fit the body. Therefore, the fabric mechanical properties, as well as body measurements, are crucial parameters for pattern making.

Fabrics have different stretch ratios in the warp and weft direction, so the fabrics must be tested in both directions - the length and width (83). The fabric used for the garment is specified by its specific stretch ratio for different body circumferences separately. In the Digital Tailoring system, each measurement from body scanner needs to be adjusted accordingly to provide close fitting (body-hugging) apparel. In this context, it is necessary to define precisely the pressure acting on the body. The stretch ratios are tested for every fabric separately, and these ratios can vary a lot in different body circumferences (example; in upper thighs the percentage can be 7%, in knee circumference 2%).

As a starting point for dealing with stretch were used the international ASTM Textile Standards (84) and the "Standard Test Methods for Stretch Properties of Fabrics Woven from

Stretch Yarns” (D 3107 – 03) (85). This allowed defining the different stretch percentages for different body parts.

5.5 Fabric Shrinkage

Most significant properties affecting jeans pattern construction are dimensional changes and elongation after washing/finishing.

In the past, the denim jeans were worn in a rigid, starch-finished form, but nowadays popular style of clothing requires that jeans are conditioned running them through various methods of desizing, enzymatic stone washing with or without abrasive, decolorization, neutralization, brightening and finishing (86).

The first procedure in conditioning is the pre-wash. The purpose of this step is to remove from the jeans the starch and a portion of the indigo dye. This significantly softens the denim and will prevent in later steps forming of streaks caused by the too hard material.

The second procedure for jeans post-processing can be the abrasion wash, which gives the jeans the "stone-washed" look.

All those washes are influencing the fabric in different ways, affecting especially the fabric shrinkage.

The fabric shrinkage percentage is different in different ways of finishing. For example; in the garment wash the jeans fabric can shrink in warp direction 2%, weft wise 7,5%, but in heavy wash accordingly 4% and 12%.

All this info is taken into account in The Digital Tailoring system, which outputs this info as an import file for CAD system.

5.6 Evaluation

Tailor Knowledge has been tested together with The Digital Tailoring system. Tailor Knowledge has been developed over time and it is in continues development of time.

Every pair of returned jeans was analyzed by the team to understand what had gone wrong. Most often, the reason was fabric shrinkage, because it is hard to control what happens in jeans washing and drying. Because of that every roll of fabric was controlled and tested and if necessary, the parameters of fabric shrinkage changed according to the test results.

The most difficult part in jeans production is fabric stretch parameters. The stretch parameters are connected with person age, body weight and also to fabric shrinkage. The perfect parameters for fabric stretch evolved over time.

5.7 Conclusions

To produce fitting garments to the customers, it is necessary to enrich the CRM data and 3D body scanner measurements with Tailor Knowledge. Body curve descriptor was implemented to the system to characterize every specific curve in numbers and angles needed to make a fitting garment to the customer.

Visual appearance rules were implemented to the system to secure the same look of the product in smaller and larger size people. Every customer wishes to have exactly what he/she has ordered dependent on the dimensions what he/she has. Dependent on the body dimensions, additional alterations need to be done to keep the visual appearance of the garment.

To ensure fitting jeans for customers, fabric specific changes need to be added to the order file. Fabric specific changes take into account shrinkages for every jeans' wash and drying. All the fabrics are stretching to a greater or lesser extent. Fabric provides a certain tension when stretched to fit the body and ensures comfort for the body. Therefore, the patterns are made smaller than the body dimensions - the material stretches afterward to fit the body. Thus's, the fabric mechanical properties, as well as body measurements, are crucial parameters for pattern making.

The Digital Tailoring system transfers Tailor Knowledge into a readable file for CAD MTM which allows automating work processes and makes possible Mass Customization of the clothing business.

The author had developed Tailor Knowledge database. It contains rules for body curves, for visual appearance, for fabric stretch, for fabric shrinkage, etc.

Chapter 6

6. SUSTAINABLE PRODUCTION

In a world of excess, innovation comes not just in designing something new and different, but also in designing a system which would allow avoiding waste. Waste minimization is the biggest benefit of The Digital Tailoring system. Waste minimization involves redesigning products and/ or changing societal patterns, concerning consumption and production, of waste generation, to prevent the creation of waste (87).

The most environmentally resourceful, economically efficient, and cost-effective way to manage waste is not to have to address the problem in the first place (87). The Digital Tailoring system helps to prevent waste.

A following section describes the origin of waste in garment production and how it is minimized in The Digital Tailoring system. What continues is a comparison between The Digital Tailoring system and traditional tailoring, and between mass-production and the very The Digital Tailoring system.

Thereafter follows a comparison with Levi Strauss, the predecessor of The Digital Tailoring System.

The chapter concludes with a proof of concept case study of Digitally Tailored jeans conducted by the author.

6.1 The Waste

One objective of Digital Mass Customization is to eliminate waste. Many manufacturers accept waste as a normal cost of business. In the garment industry, we can separate different types of waste:

- post-industrial waste (direct waste from manufacturing process)
- consumer returns
- unsold items
- loss of profit

A medium-sized 1,500 person woven-wear manufacturing factory in China was analyzed its waste at every step of the manufacturing process, from sample making, material receiving and inventory, through cutting/knitting, sewing/linking, and finishing, to packing. They had found:

- sample production waste: Mistakes in design communication, Craftsmanship problems - HK$300,000 per year wasted
- cutting floor waste: Wrong color or shade, Fabric faults - HK$ 350,000 per year
- sewing department waste: Machine problems, Faulty craftsmanship - HK$ 600,000 per year
- outsourcing waste: Dying, Embroidery - HK$ 80,000 per year
- problems detected during final inspection: Ironing problems, Measurement problems - HK$ 150,000 per year

Total HK$ 1, 480,000 per year (88).

Nowadays people buy clothes from stores or from the Internet. Sizing charts are essential but far from perfect, and when e-commerce shoppers cannot try on or feel the clothing, it leads to a higher return rate. Shoppers are expected to send back 30% of clothing and shoes bought online (89), which is twice the return rate of goods bought in a store (90). According to the annual return survey, the consumers returned eight percent of total sales in 2015 in the US (91).

The Digital Mass Customization minimizes the amount of returns, because every garment is produced according to the customer wishes and measurements. There are no sizes wasted, thus there is no fabric wasted for overproduction.

Fashion markets are oversaturated, and because of the extremely effective mass manufacturing, the world is full of not only new fashion items and fashion shops but also unsold clothing. Market oversaturation means that it is no longer possible to sell all produced garments to consumers (92). Unsold items form 15 to 20 percent of total fashion production (93). Unsold garments end up in landfills.

Digitally Mass Customized production model does not produce unwanted garments, thus there is zero unsold item.

Customers are no longer willing to pay the full price of clothing; many stores can find customers only by discounting. Fung Global Retail & Technology and First Insight conducted an analysis that found there is a persistent and significant gap between the planned manufacturers' suggested retail prices (MSRPs) of womenswear products tested by First Insight and the prices consumers are willing to pay for them. On average, across all womenswear categories tested between January 2013 and June 2016, consumers were willing to pay only 76% of full price (94). In reality, the industry gets 60 to 70 percent of the full price on its clothes (95).

Digitally Mass Customized cloths are sold with full price and there is no loss of profit, additionally it produces minimal amount of waste.

6.2 Digital Mass Customization Model

The 3D body scanner has opened door for a new Digital Mass Customization clothing industry (Figure 6.1).

When comparing two technologies – Digital Mass Customization versus Tailor workshop, which inherently have the same input (customer order and personal measurements) and output (customized garment) – it can be seen that Digital Mass Customization is much more economical, efficient and produces results, which correspondent to customer expectations (Figure 6.2).

In Digital Mass Customization, the measurements are collected with a 3D body scanner, which is faster and more precise than hand measurements; the pattern is generated automatically while tailor drafts them by hand. The digital patterns can be stored and retrieved easily without taking any physical room by the contrast to paper patterns that usually are not preserved by the tailors. Digital patterns are laid to the marker automatically and sent to the cutter. Tailor allocates pattern pieces one by one and cuts manually which is not so precise than machine cutting. The sewing is performed with special machinery and low labor cost. The tailors usually have a minimal amount of special machinery.

The biggest difference between Digital Mass Customization and mass-production is the input. In mass-production, the design is based on market analysis, predictions of customer needs. Standard sizes are used. Even here, Digital Mass Customization has more plusses than mass-production (Figure 6.3).

The application of the Tool will result in less fabric wasted, fewer sizes wasted (the numbers of garments that nobody wears) and reduces loss in profit through On-Demand production.

The uptake of The Digital Tailoring system would affect apparel fit all over the world, as any company despite the size and/or location could use it. The Digital Tailoring system would make possible for even small apparel manufacturer companies to be competitive and successful because it enables them to minimize the waste and maximize sales. The Tool could enable the flourishing of a completely new small special designer business sector.

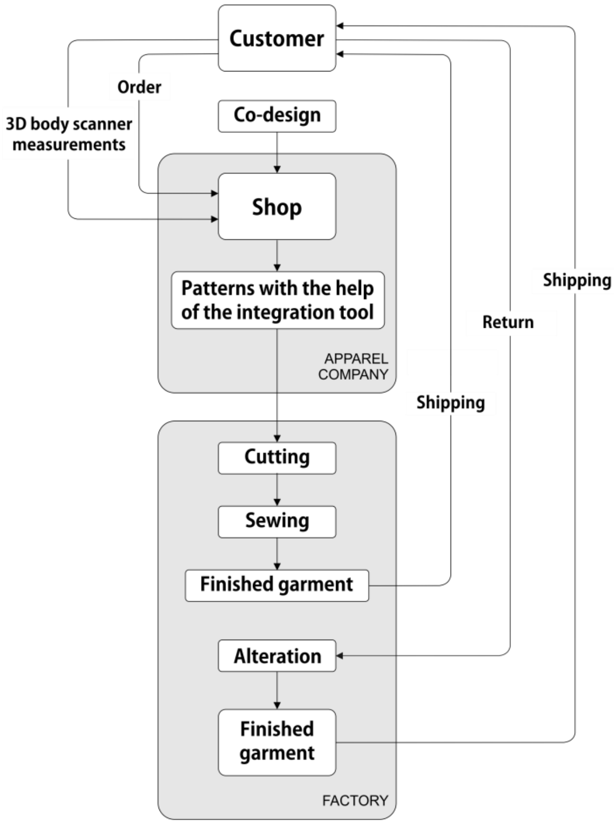
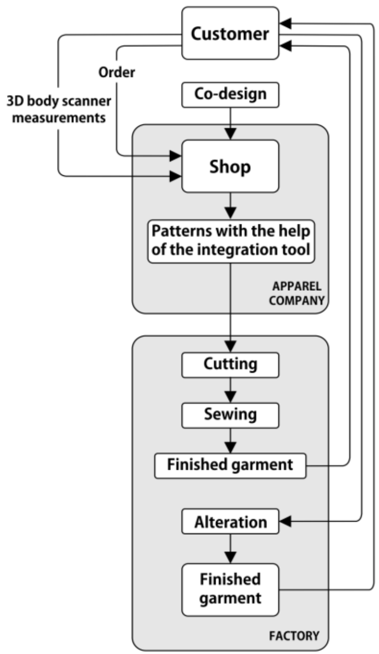


Figure 6.1 Digital Mass Customization Model

Digital Mass Customisation



	Digital Mass Customisation	Tailor workshop	
	Measurements		
+	3D body scanner - quick (~15 sec)	Hand measurments - time consuming (20-30 min)	−
+	New measurements can be extracted from program	For new measurements customer has to be invited back	−
	Design		
+	Customer can design the product	Customer can design the product	+
+	Customer can see the 3D visualization of the product right away	Customer can see the ready product in the end	−
	Patterns		
+	Computer generated - quick	Drafted by hand - time consuming	−
+	Precise	Precision depends on ruler and pen sharpness	−
+	No errors in pattern creation algorithm calculations	Calculation errors	−
+	Saved in digital file - can be reused and modified	Usually paper patterns are not preserved	−
+	Made according to the customer	Generated according to the customer	+
	Cutting / assembly		
+	Material consumption minimal.	Material consumption not so efficient.	−
+	Use on special machinery - clueing machinery, cutters	Minimal amount of special machinery	−
−	Single piece garment is being cut - cutter	Single piece garment is being hand cut	−
	Manufacturing		
+	High productivity	Low productivity	−
+	Low labor cost	High labor cost	−
+	Use of special machinery - high quality garments	Minimal amount of special machinery - quality fluctuating	−
	Prize		
−	A bit higher than average mass production product	Expensive	−
	Availability		
−	2-6 weeks	2-6 weeks	−

Tailor workshop

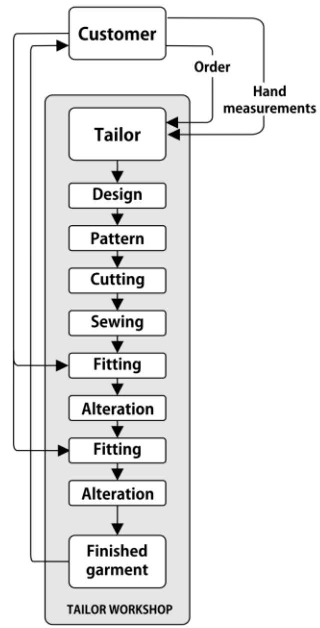
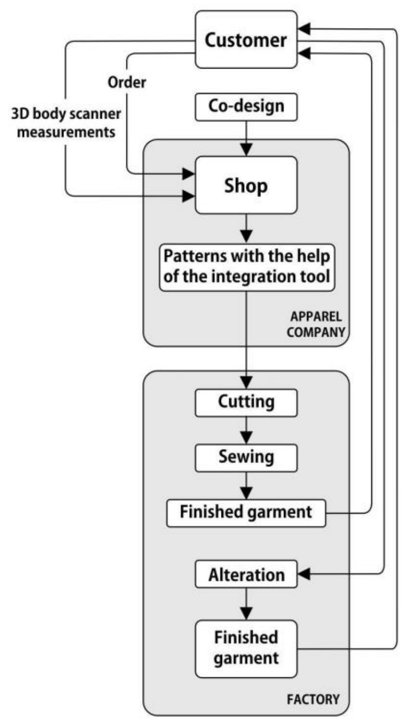


Figure 6.2 Digital Mass Customization vs Tailor workshop

Digital Mass Customisation



	Measurements		
+	3D body scanner - quick (~15 sec)	Standard sizes	−
+	New measurements can be extracted from program	National size surveys	−
	Design		
+	Customer can design the product	Customer cannot design the product	−
+	Customer can see the 3D visualization of the product right away	Customer can see the ready garment	+
	Patterns		
+	Computer generated - quick	Digital patterns	
+	Precise	Precise	+
+	No errors in pattern creation algorithm calculations	No errors	+
+	Saved in digital file - can be reused and modified	Saved in digital file - can be reused and modified	+
+	Made according to the customer	Made according to size set	−
	Cutting / assembly		
+	Material consumption minimal.	Material consumption minimal.	+
+	Use on special machinery - clueing machinery, cutters	Use on special machinery - clueing machinery, cutters	+
−	Single piece garment is being cut	Bunch of garments is being cut in one shot	+
	Manufacturing		
+	High productivity	High productivity	+
+	Low labor cost	Low labor cost	+
+	Use of special machinery - high quality garments	Use of special machinery - high quality garments	+
	Prize		
−	A bit higher than average mass production product	Low	+
	Availability		
−	2-4 weeks	Right away	+

Mass-production

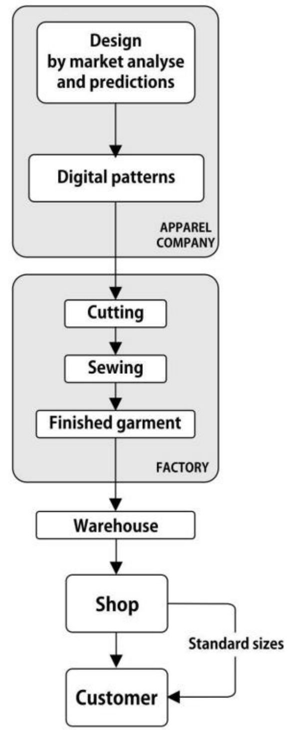


Figure 6.3 Digital Mass Customization vs Mass-production

6.3 The Digital Tailoring System compared with Levi Strauss

All the previous The Digital Tailoring systems have been semi-automated and with bore 3D technology. They have required human intervention because there has not been a system, which would translate the 3D body scanner measurements into correct values for CAD system.

The 3D body scanner captures measurements on the human surface while different trained persons measure differently and they might not be consistent. Levi did not use the 3D body scanners at first, which caused inaccuracy in customer measurements and non-fitting jeans in the end.

In the beginning (1994-1998) Levi used only four measurements to make and alter the jeans - waist, hip, inseam and rise. The customer tried on the prototype jeans and fit modifications could be made according to four initial measurements based on customer preference, such as tighter, looser fit, shorter, longer and so on (66). Four measurements do not allow to make all the necessary changes to the customer jeans to put them to fit to the customer.

Plain measurements (taken by a tailor or 3D body scanner) do not describe the body curves. Body curve information is vital because subjects with the same chest, waist and hip measurements can appear completely different (Figure 6.4) and they need different patterns. Levi used a "C-Index" to estimate such body shape. The "C-Index" is used by some anthropometrics as a mathematical descriptor of the body shape. Body shapes range from a perfect cylinder to a double cone. The C-Index helps to define the body shape in the region of the waist. C-Index is preferably calculated using the following formula:

$$C - Index = (SR\ Waist\ \times 0{,}0254)/(0{,}109\ \times \sqrt{\frac{SR\frac{Weight}{2{,}2}}{(SR\ Height \times 0{,}0254)}})$$

where SR Height is the "self-reported) height (e.g., the height reported by the customer) and SR Waist is the self-reported waist size (96). In reality, this does not work. In the Digital Tailoring system developed by the author the body curves are translated to computer algorithm in Body Curve Descriptor (section 5.1).

Levi did not take into account garment compression. Trousers are most often smaller than any real person's measurements to shape the body and provide wearing comfort. Thus, the measurements from the scanner have to be manipulated to produce fitting clothing. The author of this research had built fabric stretch calculator inside of The Digital Tailoring System (section 5.4).

The most important and difficult issue of the measurements concerns the "ease" values. Ease is an extra value added to the body dimensions to:

- allow movement (wearing ease) and
- create the desired silhouette (design ease) (41)

All garments require ease. Wearing ease is the absolute minimum amount of ease that needs to be added to a garment, which would allow moving without being too constricted.

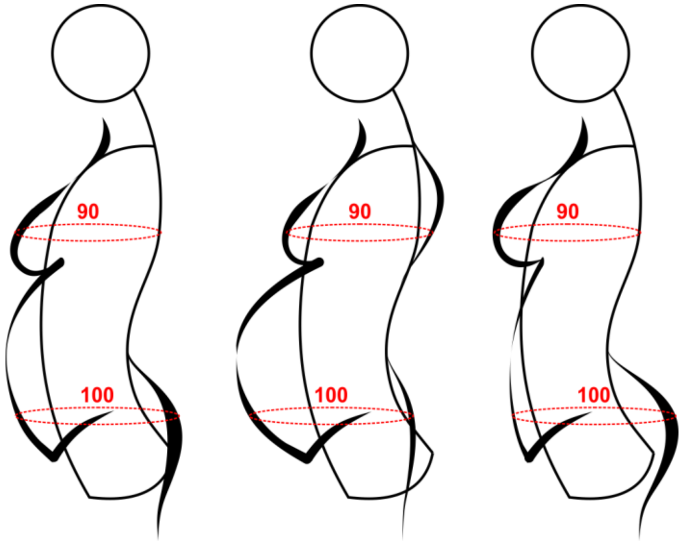


Figure 6.4. Women with different body curves

Design ease is any extra value that is intentionally added to a garment by the designer to achieve a certain look. Design ease will define the silhouette of a garment; whether it will be close-fitting, fitted, semi-fitted, loose-fitting or very loose-fitting.

Unfortunately, there does not exist data about Levi s solution. The changes connected with visual appearance are solved in Built-In Tailor Knowledge (section 5.3).

The biggest manufacturing challenge in jeans production is fabric shrinkages in washing. This was one of the biggest reasons of returns in Levi Strauss solution. The author of this research tried to solve the issue with adding fabric shrinkage values to the marker files (section 5.5), but because jeans shrink differently in every wash and also dependent on which part of the fabric roll the jeans are cut out, then the issue is not completely solved.

In addition, quite often customers are offered special alteration options, for example, extra leg length for trousers (for men or women wearing high heel shoes), longer or shorter jacket or sleeve lengths as some customers prefer the latter longer than the standard lengths judged ideal for the jackets. All such information needs to be added to the input file for CAD.

6.4 Case study – Nomo Jeans Corporation

The preliminary version of the Digitally Tailored jeans was conducted for Incognito Ballistic who had sold the research to Finnish company Nomo Jeans Corporation OY who had tested it in practice.

Founded in September 2010, Helsinki-based~~,~~ NOMO Jeans produced made-to-measure jeans. The globally unique concept combines Finnish design, latest technology, and centuries-old craftsmanship. NOMO reached the 1000 customer milestone in December 2011, after less than 3 months of opening its first shop (97).

Nomo Jeans had five stores in three different countries – Finland, Germany, and Dubai. The turnover was 6 million euros with 4,5 years.

Nomo Jeans had produced over 15 000 digitally Mass Customized jeans with The Digital Tailoring system. The Digital Tailoring system design and architecture was evaluated through controlled experiment and testing with customer jeans. The Digital Tailoring system had developed throughout the time to correspond to customers and factories needs.

The customer could choose from base models for women and men and then design the exact jeans by selecting the details of the jeans, including color, effects, stitching colors, pocket fabrics, pocket styles, and so on. Exact measurements were taken with a 3D body scanner. The selected co-design options and measurements were combined in The Digital Tailoring System and imported to CAD pattern generation system and then sent to manufacturing facilities in Finland Estonia, or China. The ready-made jeans were delivered to the customer’s home.

It had many happy customers, example Aalto University lecturer Jaana Palmu said: “The results are amazing! They fit me perfectly, just like the 3D simulation!” (98).

6.5 Conclusion

The Industrial Revolution which started from about 1760 has led to the transition to new manufacturing processes. This transition included going from hand production methods to machines. Information technology applications started the fourth Industrial Revolution or second machine age going from machines to robots. Technology has made possible new products and services that increase the efficiency and pleasure of our personal lives.

Digital Mass Customization enables to reduce the number of consumer returns, avoid unsold items and loss in profit through On-Demand production.

The Digital Tailoring has lots of benefits in front of traditional tailoring. Measuring is quicker and more precise, pattern making is automatic and customer pattern is saved in a digital file which can be quickly cut out with cutter, manufacturing is performed with high productivity.

The Digital Tailoring has also benefits in front of mass-production. The biggest are customization according to customer wishes and measurements, and On-Demand production which enables to produce less waste.

Chapter 7

7. CONCLUSIONS

In this thesis, several results can be distinguished that are summed up below and combined with an assessment of the research results.

7.1 Summary of Research Findings

Profitable Mass Customization requires success in two broad areas. The first is identifying opportunities for customization that create value for the customer and are supported by smooth, swift, and inexpensive transactions for both consumers and producers. The second is achieving a manageable cost structure and cost level for the producer even when manufacturing complexity increases (99).

The research answers the question:

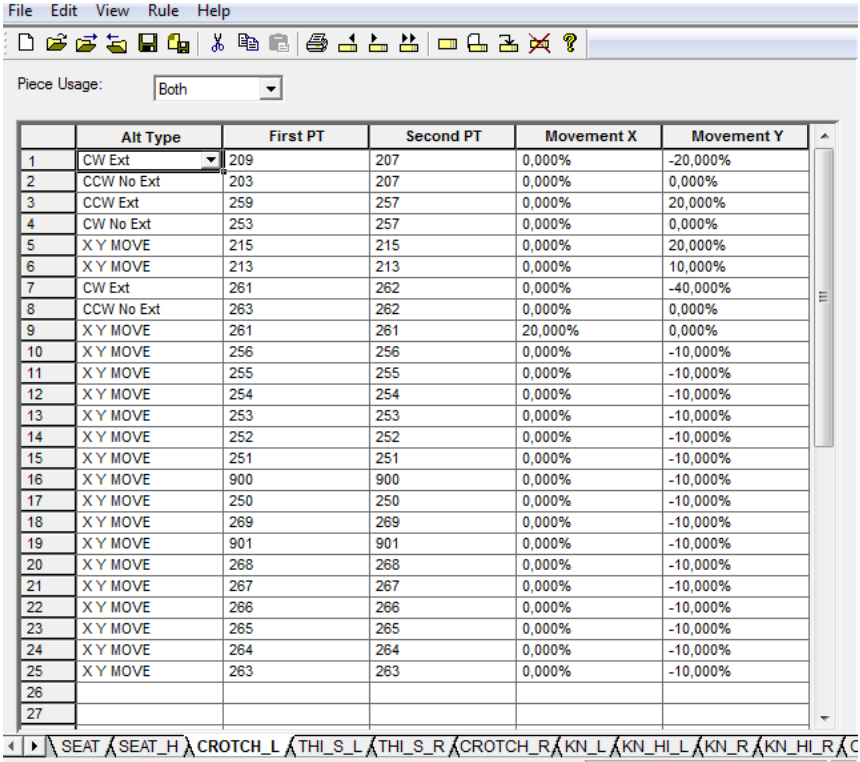
> How to produce Made-to-Measure garments seamlessly by designing a system that combines 3D body scanning measurements, customer order and Tailor Knowledge, and translates the information into a format readable by CAD systems, so that the customer can co-design the garment and it fits the customer?

To solve this issue, assisting questions were posed. The answers given below sum up the research findings of this thesis. The sequence of research questions is listed in section 1.4.

Q1: The most vital part of The Digital Tailoring system is MTM CAD program. It makes possible pattern alteration according to customer measurements, requirements and technological need. The MTM CAD enables to build the garment from co-design options. The content of The Digital Tailoring CAD import file is defined by the MTM CAD knowledge base. It defines the CAD system API which is taken into consideration in the development of The Digital Tailoring system. The MTM CAD foundation for The Digital Tailoring system is the Gerber Accumark® MTM because it is the most advanced programmable MTM module and allows quick custom data import from a server.

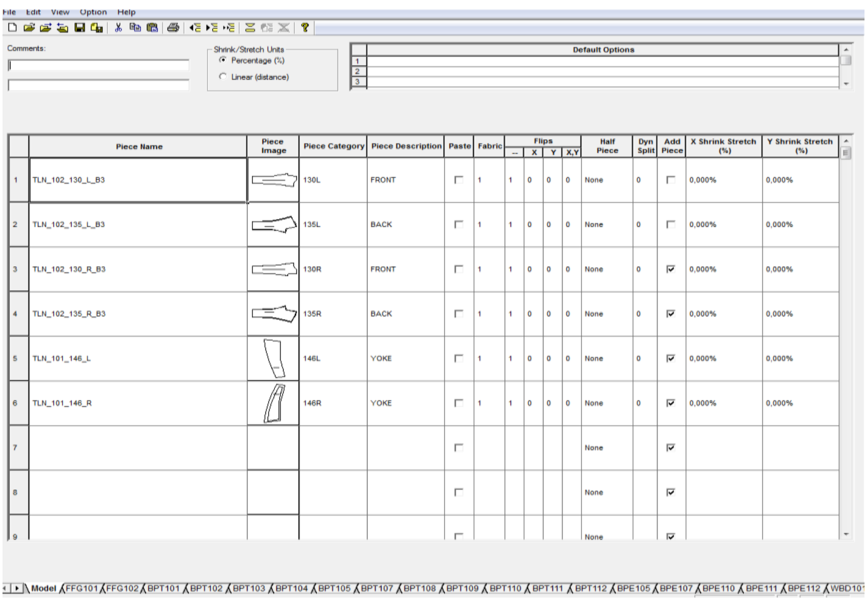
The measurement extraction from 3D body scanner is specified by the measurements needed for pattern alteration.

The author created the Alteration knowledge base for different countries (Finland, Germany, and UAE), a total of 204 rules (Figure 7.1); Pattern knowledge base for different countries (Finland, Germany, and UAE), a total of 24 models with 1680 pattern pieces (the author created also those models and pattern pieces) (Figure 7.2); Knowledge base for Lay Limits / Annotation (Figure 7.3); MTM knowledge base (Appendix 3).



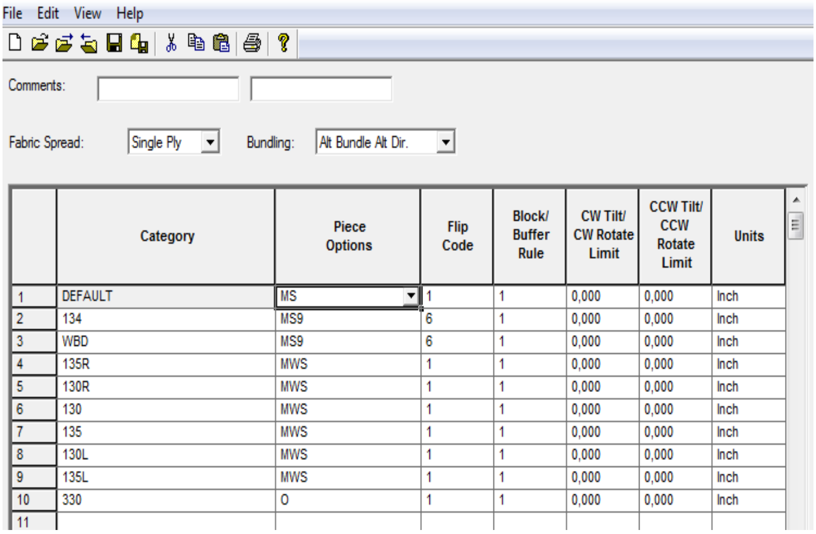
	Alt Type	First PT	Second PT	Movement X	Movement Y
1	CW Ext	209	207	0,000%	-20,000%
2	CCW No Ext	203	207	0,000%	0,000%
3	CCW Ext	259	257	0,000%	20,000%
4	CW No Ext	253	257	0,000%	0,000%
5	X Y MOVE	215	215	0,000%	20,000%
6	X Y MOVE	213	213	0,000%	10,000%
7	CW Ext	261	262	0,000%	-40,000%
8	CCW No Ext	263	262	0,000%	0,000%
9	X Y MOVE	261	261	20,000%	0,000%
10	X Y MOVE	256	256	0,000%	-10,000%
11	X Y MOVE	255	255	0,000%	-10,000%
12	X Y MOVE	254	254	0,000%	-10,000%
13	X Y MOVE	253	253	0,000%	-10,000%
14	X Y MOVE	252	252	0,000%	-10,000%
15	X Y MOVE	251	251	0,000%	-10,000%
16	X Y MOVE	900	900	0,000%	-10,000%
17	X Y MOVE	250	250	0,000%	-10,000%
18	X Y MOVE	269	269	0,000%	-10,000%
19	X Y MOVE	901	901	0,000%	-10,000%
20	X Y MOVE	268	268	0,000%	-10,000%
21	X Y MOVE	267	267	0,000%	-10,000%
22	X Y MOVE	266	266	0,000%	-10,000%
23	X Y MOVE	265	265	0,000%	-10,000%
24	X Y MOVE	264	264	0,000%	-10,000%
25	X Y MOVE	263	263	0,000%	-10,000%
26					
27					

Figure 7.1 Alteration knowledge base



	Piece Name	Piece Image	Piece Category	Piece Description	Paste	Fabric	Flips --	Flips X	Flips Y	Flips X,Y	Half Piece	Dyn Split	Add Piece	X Shrink Stretch (%)	Y Shrink Stretch (%)
1	TLN_102_130_L_B3		130L	FRONT	☐	1	1	0	0	0	None	0	☐	0,000%	0,000%
2	TLN_102_135_L_B3		135L	BACK	☐	1	1	0	0	0	None	0	☐	0,000%	0,000%
3	TLN_102_130_R_B3		130R	FRONT	☐	1	1	0	0	0	None	0	☑	0,000%	0,000%
4	TLN_102_135_R_B3		135R	BACK	☐	1	1	0	0	0	None	0	☑	0,000%	0,000%
5	TLN_101_146_L		146L	YOKE	☐	1	1	0	0	0	None	0	☑	0,000%	0,000%
6	TLN_101_146_R		146R	YOKE	☐	1	1	0	0	0	None	0	☑	0,000%	0,000%
7					☐						None		☑		
8					☐						None		☑		
9					☐						None		☑		

Figure 7.2 Pattern knowledge base



	Category	Piece Options	Flip Code	Block/ Buffer Rule	CW Tilt/ CW Rotate Limit	CCW Tilt/ CCW Rotate Limit	Units
1	DEFAULT	MS	1	1	0,000	0,000	Inch
2	134	MS9	6	1	0,000	0,000	Inch
3	WBD	MS9	6	1	0,000	0,000	Inch
4	135R	MWS	1	1	0,000	0,000	Inch
5	130R	MWS	1	1	0,000	0,000	Inch
6	130	MWS	1	1	0,000	0,000	Inch
7	135	MWS	1	1	0,000	0,000	Inch
8	130L	MWS	1	1	0,000	0,000	Inch
9	135L	MWS	1	1	0,000	0,000	Inch
10	330	0	1	1	0,000	0,000	Inch
11							

Figure 7.3 Lay Limits knowledge base

Q2: To produce MTM garments seamlessly it is necessary to combine 3D body scanning measurements and customer order and translate the information into a format readable by CAD system so that the customer can co-design the garment. The author has developed a system which makes Mass Customization seamless, creating a link between the 3D body scanner, customer order and the CAD software (first end) and CIM production system (back end), which allow to translate 3D measurements and customer orders into import files to MTM CAD system.

Chapter 4 introduces the CIM model for Digitally Mass Customized garments. It describes how to automate data collection from 3D body scanner and sales system for the readable format for CAD MTM system so that no data needs to be entered manually. The output of the system is Digitally Mass Customized cloth.

Q3: An important part of The Digital Tailoring system is built-in Tailor Knowledge. To produce fitting garments for customers, it is necessary to enrich the 3D body scanner measurements with Tailor Knowledge.

The Digital Tailoring system consist of knowledge to modify customer patterns as the tailor would do, making possible Digital Mass Customization of the clothing business. Chapter 5 answers the question of how the artifact takes into consideration personal characteristics.

7.2 The main result of the thesis

The main result of the thesis is The Digital Tailoring system for creating garments for a specific individual from 3D body scan measurements and customer co-design choices. Input for the system is a specific customer order together with 3D body scanner measurements. Output is customized patterns and technical documentation. The key component of the tool is a set of rules, which enable to translate "tailor-knowledge" into computer algorithm (Paper I, IV). The Digital Tailoring system has made possible to produce customized garments according to individual needs/tastes/wishes of each customer (Mass Customized garments) and to apply mass-production methods for Mass Customization products to reduce production costs.

Thus, the result of this research is a new approach to garment manufacturing and marketing transforming clothing production into a demand-driven, knowledge-based, high tech industry.

The author developed measurement extraction profiles for 3D body scanner software (Paper V) for men and women for different countries (Finland, Germany, and UAE) and for different body types.

The Digital Tailoring system results in less fabric wasted, fewer sizes wasted (the numbers of garments that nobody wears) and reduced loss in profit through On-Demand production.

The uptake of The Digital Tailoring system would affect apparel fit all over the world, as any company, despite the size and/or location, could use it. The Digital Tailoring system would make possible for even small apparel manufacturer companies to be competitive and successful because it enables them to minimize the waste and maximize sales. The Tool could enable the flourishing of a completely new small special designer business sector.

The research of the thesis indicates that the developed CIM model for Mass Customized clothing production together with The Digital Tailoring system is an adequate solution to improve resource efficiency, production and management efficacy, and increase competitiveness.

Digital Mass Customization enables to increase revenues and gain a competitive advantage, improve cash flows, and reduce waste through On-Demand production.

7.3 The future work

The near-future work of the author is to continue the development of the digital pattern database for industrial clients:

- customers design themselves from presented co-design options
- database stores standard size and grading steps from size to size (in development)
- database stores fabric specifications and marker requirements (in development)

The result will be ready markers for production factories.

In longer perspective, there are many possible research directions, since the rapid development of all technologies, especially the tailoring and information processing technologies, poses constantly new problems and new perspectives.

For instance, 3D body scanners based rapid customized production makes quite possible (and profitable) the stealing of the results – custom-made garments - and selling them under fake trademarks, the more that factories in China can copy products very quickly.

The fourth Industrial Revolution in the garment industry is robotized Mass Customization. The preliminary version of The Digital Tailoring system and other Information technology applications enable to automate information handling for Mass Customized products before the production. The second stage is production robotization. It starts with storage robots giving correct fabric rolls to spreader according to the output of The Digital Tailoring system. The spreader lays the fabric plies to the spreading table and counts the fabric consumption, reporting it to the ERP system. The spreader hands over the data to the cutter, etc. The whole process ends with packing robots giving the Mass Customized garment to be delivered to the customer to the delivery robots.

This and many other development perspectives make The Digital Tailoring research very exciting for the future!

As a further note, all the figures in the thesis are drawn by the author.

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KOKKUVÕTE

Rohkem kui kakskümmend aastat on saadaval olnud “Made-to-Measure” tarkvara, mis võimaldab lõiget korrigeerida vastavalt kliendi kehakujule ja mõõtudele. Selle süsteemi kõige suuremaks miinuseks on keeruline ülesseadistus ning manuaalne kliendi tellimuse ja kehamõõtude sisestamine. Seda kasutatakse enim meeste ülikondade ja särkide mass-personaliseerimist pakkuvates firmades. Protsess algab mõõtude võtmisega, mille põhjal määratakse kliendile suurusnumber. Kliendile proovitakse vastava suurusnumbriga toodet selga ning hinnatakse, milliseid muudatusi on vaja veel teha, et toode istuks perfektselt. Järgnevalt sisestatakse muudatused manuaalselt “Made-To-Measure” süsteemi, mis genereerib kliendispetsiifilise lõike. See saadetakse vabrikusse ning 2-4 nädala pärast on toode kliendile üleandmiseks valmis. Kogu kirjeldatud protsess on aeganõudev, ebatäpne (manuaalne mõõtmine ja andmete sisestamine) ning mõnele inimesele lausa ebamugav, kuna rätsep peab manuaalselt inimest kompama, et mõõte võtta.

Juba viimased 15 aastat on olnud turul 3D kehaskännerid, mis võimaldavad vaid paari sekundiga inimesest 3D kujutise loomist ja sellelt mõõtude eraldamist. Algselt olid need seadmed väga kallid, kuid viimaste aastate jooksul on hind langenud kümme korda, mis on võimaldanud 3D kehaskännerid kasutusele võtta rõivatööstuses. Hetkeliselt arendatakse juba keha skaneerimise võimalusi mobiilirakenduste abil (3D sensorid).

Antud doktoritöö käigus arendas autor välja süsteemi, mis teeb võimalikuks digitaalse rätsepakunsti. Digitaalne rätsepakunst algab inimese 3D kehaskaneerimise ja kliendi tellimuse võtmisega. 3D kehaskaneerimise tulemused ning tellimus lähevad automaatselt järgnevasse süsteemi, kus neid analüüsitakse ja töödeldakse ning lisatakse „rätsepakunsti“ saladused CAD süsteemi tarbeks. Süsteemi väljundiks on personaliseeritud lõike(d) ning tehniline dokumentatsioon, mis on vajalik tootmiseks.

Doktoritöö raames lõi autor ainulaadse funktsioneeriva prototüübi, mis võimaldab 3D kehaskaneerimise tulemused ja kliendi tellimuse töödelda CAD süsteemi imporditavaks failiks. Prototüübi üheks oluliseks osaks on kliendi tellimuse ja 3D keha mõõtude rikastamine „rätsepa teadmistega“. Tulemuseks on kliendi soovide ja mõõtude järgi valmistatavad rõivad. Süsteemi katsetati edukalt personaliseeritud teksapükste tootmisel Soomes, Saksamaal ja Araabia Ühendemiraatides. Ühtekokku valmis 15 000 teksapaari.

Doktoritöö raames arendas doktorant välja:

- prototüübi
- mass-personaliseeritud lõigete andmebaasid (Soomele, Saksamaale ja AÜ-le)
- algoritmide andmebaasid muutmaks baaslõiked kliendi mõõtude järgi kohanduvaks (seda eraldi eelmainitud riikidele)
- MTM (Made-to-Measure) andmebaasi
- algoritmid 3D kehaskäneeringust mõõtude tuletamiseks

Väljaarendatud süsteem on skaleeritav kogu rõivatööstusele. Süsteem võimaldab rõivatootjatel säästa kangast (õmblusvarude minimeerimine), toota ainult suuruseid, mida klientidel on vaja, ning kliendi rahulolu, mis omakorda võimaldab suurendada rõivaste müüki. Ennekõike võimaldab uudne süsteem rõivaettevõtetel ära kaotada suured laod valmistoodangu ladustamiseks ning toota inimestele spetsiaalselt disainitud, hästi istuvaid rõivaid.

ABSTRACT

Made-to-measure technology of industrial garment production has been available for more than twenty years. It enables to alter patterns according to customer measurements. The biggest minus of this system is the complicated system set up and manual insertion of customer orders and measurements. It is used mainly by companies, which produce Mass Customized men's suits and shirts. The process begins with manual measuring by a vendor, according to which the base size of the customer is assigned. The customer tries on a suit of a designated size and gives feedback about product comfort to the vendor. The trained vendor makes an assessment about which changes need to be done to the suit so that it would fit the customer perfectly. The vendor then inserts the customer order, measurements, and alterations to the Made-to-Measure system, which generates a customer specific pattern according the inserted data. The latter is sent to a factory, which delivers the product after 2-4 weeks. The process described is time-consuming, imprecise (manual data insert), uncomfortable for customers, because the tailor needs to touch the customer when measuring.

3D body scanners have been available for the last 15 years, which enables to measure the customer with just a few seconds. At first, the 3D body scanners were expensive and that is why they could not be taken into regular use by apparel companies. Now the price has dropped, enabling companies start using the 3D body scanners. At the moment, mobile apps are being developed which allow to 3D body scan and extract measurements.

This thesis describes the development of a system that makes possible The Digital Tailoring. The Digital Tailoring begins with customer 3D body scanning and order placement. 3D body scanning measurements and order are directed automatically to another system where the data is analyzed, processed and enriched with "tailor-knowledge" for the CAD system. The output of the system is mass-personalized patterns and documentation for production.

Within the framework of this thesis, a unique functional prototype was created by the author, which enables to process 3D body scanning measuring results and customer orders into a readable format for the CAD system. The most important part of the system is 3D body scanner measurements and order enrichment by "tailor-knowledge". The process results in clothes which are designed and produced according to the customer. The latter has already been successfully proven in industrial practice in three countries (Finland, Germany, Arab Emirates). Altogether 15 000 pairs of jeans were produced in a three years' time, using the system created by the author of the thesis.

On the framework of this thesis, the author created:

- prototype (The Digital Tailoring system)
- pattern knowledge base for different countries
- lay limits/annotation knowledge base
- alteration knowledge base for different countries
- MTM knowledge base; and
- developed measurement extraction profiles for 3D body scanner software

All the existing apparel software systems could be made more efficient with The Digital Tailoring system. The main benefits of the Tool are: less fabric wasted, fewer sizes wasted (the numbers of garments that nobody wears) and reduced loss in profit through On-Demand production.

The result of this research is a new approach to garment manufacturing and marketing transforming clothing production into a demand-driven, knowledge-based, high tech industry.

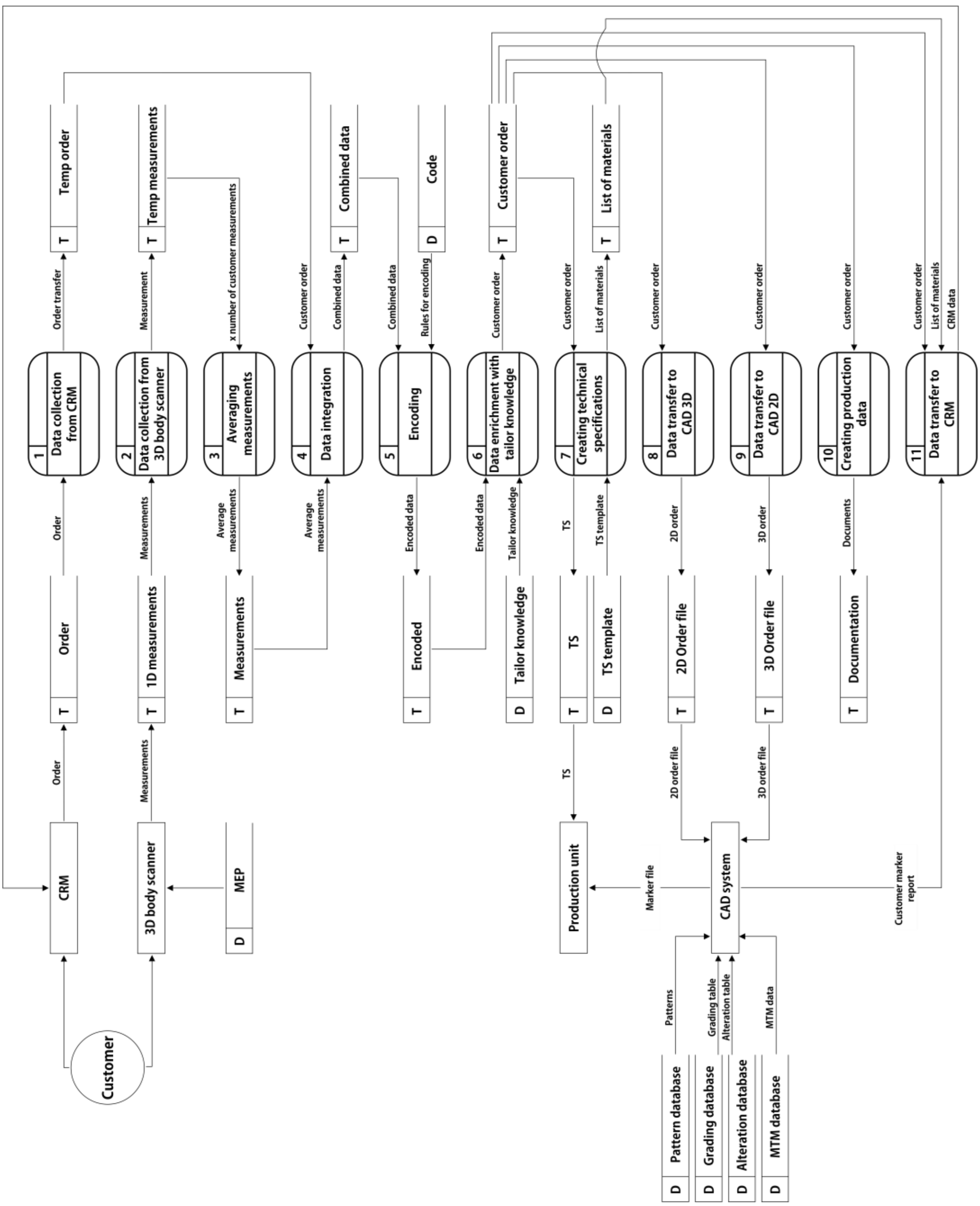
APPENDIX 1

SizeStream measurement file

#SizeStream Measurements
#Stored on Tuesday, March 10, 2015 16:17:51
#SizeStream Core Measurements
#format - Measurement Valid (1 = valid), Measurement Name, Measurement
#
1 Collar Circumference: 31.936
1 Neck Circumference: 38.418
1 Back Shoulder Width Through Back Of Neck: 43.028
1 Back Shoulder Width at 45 Degree Angle: 43.008
1 Front Shoulder Width: 44.639
1 Chest / Bust Circum Tape Measure: 87.761
1 Underbust Circum Tape Measure: 78.473
1 Bust Girth With Drop Tape Measure: 83.632
1 Bust To Bust Length: 13.56
0 Opt Small of Back Waist Tape Measure: 0.
1 Horizontal Waist Tape Measure: 81.545
1 Horizontal Waist Height: 111.35
1 Stomach FP Circum Tape Measure: 80.218
1 Stomach Max Circum Tape Measure: 85.332
1 Abdomen Circum Tape Measure: 89.78
1 Hip Circum Tape Measure: 98.751
1 Seat Circum Tape Measure: 96.916
1 Crotch Height: 88.526
1 Crotch Length Full: 55.698
1 Front Vertical Rise: 19.415
1 Center Trunk Length Tape Measure: 146.31
1 Shoulder Slope Left: 25.807
1 Shoulder Slope Right: 24.649
1 Arm Length Left: 63.375
1 Arm Length Right: 61.834
1 Sleeve Length Left: 83.313
1 Sleeve Length Right: 82.219
1 Bicep Circumference Left: 25.702
1 Bicep Circumference Right: 26.543
1 Elbow Circumference Tape Measure Left: 24.835
1 Elbow Circumference Tape Measure Right: 26.384
1 Forearm Circumference Left: 23.592
1 Forearm Circumference Right: 24.98
1 Wrist Circumference Left: 15.673
1 Wrist Circumference Right: 16.125
1 Side Neck to Bust length Left: 27.348
1 Side Neck to Bust length Right: 27.361
1 Outside Leg Length Left: 110.11
1 Outside Leg Length Right: 110.3
1 Inseam Left: 89.243
1 Inseam Right: 89.423
1 Thigh Circumference Left: 53.126
1 Thigh Circumference Right: 54.102
1 Knee Circumference Left: 34.944
1 Knee Circumference Right: 35.768
1 Calf Circumference Left: 34.912
1 Calf Circumference Right: 34.833
1 Ankle Circumference Left: 22.075
1 Ankle Circumference Right: 23.597
1 Subject Height: 182.93
1 Torso Volume: 38997
#SizeStream Landmarks
#format - Landmark Valid (1 = valid), Landmark Name, Landmark x y z
#

1 NeckRight -31.544 1577.9 -146.66
1 CollarFront 28.244 1580.7 -79.054
1 CollarBack 28.244 1614.5 -172.021
CollarLeft 83.188 1598.6 -128.51
1 CollarRight -26.7 1596.5 -122.54
1 OverArmFront 28.321 1406. -16.019
1 OverArmBack 28.321 1406. -229.11
1 OverArmLeft 272.53 1406. -128.24
1 OverArmRight -215.89 1406. -156.85
1 ShoulderLeft 228.13 1511.8 -150.12
1 ShoulderRight -175.6 1511.8 -160.82
1 ArmpitLeft 185. 1395.9 -146.75
1 ArmpitRight -134.62 1384.6 -156.81
1 BustFront 18.406 1339.8 5.7686
1 BustBack 18.406 1339.8 -219.52
1 BustLeft 169.89 1339.8 -102.15
1 BustRight -133.07 1339.8 -164.39
1 UnderBustFront 16.099 1290.5 2.3239
1 UnderBustBack 16.099 1290.5 -203.21
1 UnderBustLeft 157.14 1290.5 -111.34
1 UnderBustRight -124.94 1290.5 -123.42
1 StomachFPFront 9.078 1121.8 13.755
1 StomachFPBack 9.078 1121.8 -179.37
1 StomachFPLeft 163.82 1121.8 -96.203
1 StomachFPRight -145.66 1121.8 -101.14
1 StomachMaxFront 9.5782 1079.3 12.666
1 StomachMaxBack 9.5782 1079.3 -188.28
1 StomachMaxLeft 174.81 1079.3 -78.161
1 StomachMaxRight -155.66 1079.3 -107.4
1 WaistFront 9.5981 1079.3 12.86
1 WaistBack 9.5981 1113.4 -180.89
1 WaistLeft 172.21 1096.9 -87.453
1 WaistRight -153.01 1098.9 -98.261
1 AbdomenFront 5.1731 1034.4 16.606
1 AbdomenBack 5.1731 1034.4 -197.35
1 AbdomenLeft 180.36 1034.4 -78.081
1 AbdomenRight -170.02 1034.4 -81.332
1 HipFront 5.0196 922.05 15.987
1 HipBack 5.0196 922.05 -199.43
1 HipLeft 198.12 922.05 -66.366
1 HipRight -188.08 922.05 -91.443
1 SeatFront 6.0003 969.25 11.964
1 SeatBack 6.0003 969.25 -199.12
1 SeatLeft 193.57 969.25 -54.338
1 SeatRight -181.57 969.25 -85.91
1 UpperLeftThighFront 108.04 834.36 16.231
1 UpperLeftThighBack 108.04 834.36 -143.72
1 UpperLeftThighLeft 197.75 834.36 -65.471
1 UpperLeftThighRight 18.329 834.36 -71.348
1 UpperRightThighFront -101.59 834.36 3.5121
1 UpperRightThighBack -101.59 834.36 -161.55
1 UpperRightThighLeft -10.475 834.36 -70.773
1 UpperRightThighRight-192.71 834.36 -91.443
1 MidLeftThighFront 112.23 674.91 -25.467
1 MidLeftThighBack 112.23 674.91 -158.13
1 MidLeftThighLeft 177.41 674.91 -94.935
1 MidLeftThighRight 47.048 674.91 -110.12
1 MidRightThighFront -111.27 674.91 -29.007
1 MidRightThighBack -111.27 674.91 -159.08
1 MidRightThighLeft -44.919 674.91 -77.704

APPENDIX 2



Customer
CRM
3D body scanner
D MEP
T Order
T 1D measurements
T Measurements
T Encoded
D Tailor knowledge
T TS
D TS template
T 2D Order file
T 3D Order file
T Documentation
1 Data collection from CRM
2 Data collection from 3D body scanner
3 Averaging measurements
4 Data integration
5 Encoding
6 Data enrichment with tailor knowledge
7 Creating technical specifications
8 Data transfer to CAD 3D
9 Data transfer to CAD 2D
10 Creating production data
11 Data transfer to CRM
T Temp order
T Temp measurements
T Combined data
D Code
T Customer order
T List of materials
Production unit
CAD system
D Pattern database
D Grading database
D Alteration database
D MTM database
Order
Measurements
Order transfer
Measurement
x number of customer measurements
Customer order
Combined data
Rules for encoding
List of materials
CRM data
Average measurements
Encoded data
Tailor knowledge
TS
TS template
2D order
3D order
Documents
2D order file
3D order file
Marker file
Customer marker report
Patterns
Grading table
Alteration table
MTM data

APPENDIX 3

An example of MTM structure for men skinny fit jeans. Similar knowledge bases are for different styles and separately for men and women.

Options and suboptions

Back pocket	Front pocket	Beltloops
BPT251	FBT251	BLS251
BPT252	FBT252	BLS252
BPT253	FBT253	BLS253
BPT256	FBT254	BLS254
BPT257	FBT255	BLS255
BPT258	FBT256	BLS256
BPT259	FBT257	BLS257
	FBT258	BLS258
	FBT259	BLS259

Waistband	Length	Front fastening
WBD251	CFS251	FFG251
WBD252	CFS252	FFG252
WBD253	CFS253	
WBD254	CFS254	
WBD255	CFS255	
WBD256	CFS256	
WBD257	CFS257	
WBD258	etc	
WBD259		

Hem	Model manipulation	Inseam manipulation
HEM251	HWH_95	IML000
HEM252	HWH_90	IML005
HEM253	HWH_85	IML010
	etc	etc

Seat back angle	Double Stitch	Pocket embroidery
SBA_01	SSG251	BPE251
SBA_02	SSG252	BPE252
etc	SSG253	BPE253

Factory	Washing	
TLN	FIN	
CHI	LVL	

Alterations, measurements, models, base files and alteration library list

Alteration	Measurement	Model

_02/_78(Y)	Waist	251
_60/_76(Y)	Seat	252
_70/_71(Y)	Knee_left	
_70/_71(X)	Knee_right	
03_FR_MODI	Thigh_95_left	**Base file**
04_OUTSIDE	Thigh_95_right	M_251
05_WAI_H_B	Thigh_75_left	M_252
06_WAI_H_F	Thigh_75_right	
09_70/71_Y	Calf_left	**Alteration Library**
10_70/71_X	Calf_right	MEN_SKINNY
107/207(Y)	Calf_height_left	MEN_SKINNY
115/162(Y)	Calf_height_right	
157/257(X)	Ankle	
157/257(Y)	Inseam	
159/259(X)	Outseam	
162/262(X)	CrotchLength_front	
170/270(X)	CrotchLength_back	
170/270(Y)		
171/271(X)		
ADD_FM		
ADD_INS		
ADD_OUT		
BUTTOCKS 1		
BUTTOCKS 2		
B_LOW		
B_WAIS_EXT		
BACK_MODY		
BOTTOM_WID		
BOTTOM_H_L		
BOTTOM_H_R		
BPT_LENGHT		
BPT_WIDTH		
CALF_HIG_L		
CALF_HIG_R		
CALF_L		
CALF_R		
CR_DEPT		
CROTCH_L		
CROTCH_R		

APPENDIX 4

Publication I

Elbrecht, Pirjo; Palm, Knut-Joosep (2016). Information Processing For Mass Customized Clothing Production. *2016 IEEE Tenth International Conference on Semantic Computing (ICSC).* IEEE, pp 362−365 (1).

Information Processing For Mass-Customized Clothing Production

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***Abstract*—In this paper is presented a solution for integrating different information from different inputs (3D scanner, Customer Order information) as a combined input for Computer Integrated Manufacturing (CIM) based factory suitable for customized mass production. For this, research was carried out in an industrial enterprise which produced mass-customized jeans for real people in the real markets. It had 5 stores in three different countries - Finland, Germany and United Arab Emirates. Over 15 000 mass-customized pairs of jeans were produced. The company turnover was six million Euros in three years' time. Author developed procedures for Computer Integrated Manufacturing by creating interfaces between 3D body scanning, Customer relationship management system (CRM), CAD system (patterns, alterations, MTM) and manufacturing (communication between factories (in China and Europe)), as well as automating pattern creation from orders and measurements, and testing and improving the scalability of the processes.**

Keywords—Mass-customization; Computer Integrated Manufacturing; Made-to-measure; Information processing; CAD

I. Introduction

All the clothing manufacturers are pursuing two goals:

- produce customized garments according to individual needs/taste/wishes of each customer (mass-customized garments)
- apply mass-production methods for mass-customization products to reduce production costs.

These two goals are contradictory, individual needs/taste of each customer means a lot of custom information for each customer, which is difficult to take into account in mass production. The problem solved in this research is: create methods and technology that maximally allows to consider individuality and individual needs/tastes of each customer in mass production, create methods of customized mass production of clothing. The problem is still too difficult to be solved for all types of garments; here is considered one type of garment - jeans and presented solution for customized mass production, which has been already tested in industrial practice.

II. Theoretical Framework

The main research method in this paper is Design Science.

Design is both a process (set of activities) and a product (artifact) in Information System research. The design process is a sequence of expert activities that produces an innovative product. The evaluation of the artifact then provides feedback information and a better understanding of the problem in order to improve both the quality of the product and the design process. This build-and-evaluate loop is typically iterated a number of times before the final design artefact is generated [1].

Humans are consuming more energy every year. In 1961 the World average food energy consumption was 2,253.9 kcal/person/day, in 2003 it was 2800 kcal/person/day, which means that people are going bigger in body size. The company is observing and analyzing the 3D body scanning results all the time and making adjustments in patterns according to the statistical outcome.

New factories have new requirements, which needs to be implemented to the process. New machineries prerequisite new methods implemented to the process.

A. Computer Integrated Manufacturing

Computer Integrated Manufacturing (CIM) uses computers to regulate the entire production process that involves manufacturing planning and control, Manufacturing Engineering, manufacturing processes and indirect elements such as purchase order processing, finance, and accounting. Manufacturing planning and control consist of shop floor control, inventory control, etc. Manufacturing Engineering includes CAD/CAM, Computer Aided Process Planning (CAPP), etc. Manufacturing process includes robots, material handling systems, etc. Usage of CIM in textiles or in any industry results:

- in lower manufacturing costs,
- better production control,
- better customer responsiveness,
- higher product quality,
- reduced inventories,
- greater flexibility,
- smaller lot size production, etc [2]

CIM has been widely used in textiles due to rapid changes in market demand and product modification, for better use of materials, personnel, reduction in inventory, better control of production and management of total manufacturing operation, manufacture of high quality products at low cost, elimination of paper and the costs associated with its use, automation of communication within a factory and increase in speed, facilitate simultaneous engineering etc.

978-1-5090-0662-5/16 $31.00 © 2016 IEEE
DOI 10.1109/ICSC.2016.51

B. Mass production model

The objectives of mass production are to achieve economies by standardizing products and developing efficient processes thereby producing more of each product at one time selling at a lower price [3].

Mass production businesses are specialized in a one or several related product types. In this way, it was easier to achieve both the number of specialized pieces of equipment (machinery), as well as the skills of the employees needed to produce a single product type. The basic steps in mass production are as follows:

- One design, one pattern, and one specification are developed.
- The pattern is graded into a size range (e.g. 32-50).
- Multiple products are cut and prepared at the same time according to the production order.
- Workers are divided between production steps.
- Several single articles are being sewn as a group.
- Materials and accessories for production are ordered in bulk to save money through a high number of orders, to ensure that materials and accessories are available when orders are received.
- The entire order to delivery time is based on the time it takes to order materials, assemble the product, deliver the product to the customer.

C. Mass-customization model

Mass-customization aim is for the customers to get an exact product that they want, when they want it, and at a reasonable price. During the last 20 years, the choice has become a central ingredient of consumer purchasing selections.

It is crucial that to adopt mass-customization, an apparel organization has to bring many changes in the operations. Roughly we can categorize these changes into three groups:

- First, technological development (CAD, the 3D body scanning, digital printing, etc.).
- Second in terms of implementing flexible manufacturing systems, CIM tools, and techniques.
- Third, organizational changes in terms of flexible culture and empowering workers by assigning more responsibilities.

By implementing these kinds of business strategies under mass-customization umbrella concept, it will shorten product life and development cycles as well as letting manufacturers respond more quickly and flexibly to changing customers' drives. Finally, customers will have access to a variety of high-quality, customized garment while manufacturers can reduce excess inventory and markdowns. Mass-customization is a paradigm shift from the Product-Centric approach (made-to stock) to the Customer Centric Approach (made-to-order), where customers' involvement also shift from purchase to the development of the product.

Most importantly, when we are comparing the investment threshold for the same production outputs in mass-production and mass-customization products, then it is significantly smaller in mass-customization product. Thus, the profit is considerably bigger with the same production outputs amounts.

III. RELATED APPROACHES

In clothing industry have been several attempts to create MTM production technology.

A. Levi Strauss Co

Levi Strauss Co. was a pioneer in creating a customization concept for jeans in 1994, but they ended the concept in 2003. In the beginning, it was aimed at the woman but later also for men. Personal Pair jeans were customized mostly on fit, but also on look based on the five-pocket variety. In a store, four initial measurements were taken from waist, hip, inseam and rise by trained fit specialist. The measurements were entered into a computer, which suggested a prototype pair of jeans. The customer tried on the prototype jeans, and fit modifications could be made according to four initial measurements based on customer preference, such as tighter, looser fit, shorter, longer and so on. Fitting of two or three prototypes was usually sufficient to find the perfect fit for the customer. The order with the final fit was sent via modem to Levi Strauss´ factory in Mountain City, Tennessee, where a dedicated team of sewing operators constructed the jeans (see Figure 1. Levi process).

In 1997, from Levi´s "Personal Pair" emerged Original Spin. The Original Spin had much more options for customization in addition to the fit.

The process began at a kiosk, where the shopper registered and entered personal data. The measurements were still taken with measuring tape, until opening of the 15th Original Spin store, where in August 1998 was introduced the Tc2 body scanner to take measurements [4].

After the scan, the sales person utilized the information to offer a variety of appropriate styles to try according to personal preferences such as loose or close. The sales person entered the selection data into the customer´s profile, and the file was transferred to remote manufacturing facility.

However, despite good reputation and feedback, at the end of 2003 Levi Strauss discontinued Spin program without further explanations. This was caused by the bad business situation of Levi Strauss. To cut costs the last US factory producing the customized jeans was finally closed [5].

B. Bodymetrics

The first Bodymetrics boutique opened in Selfridges (London) in 2004 which targeted a largely female customers with private-label jeans and authorization with other denim brands. On 2006, a second boutique opened in Harrods, expanding the service to include women's tailoring for brands like Vivienne Westwood and Nick Holland.

Bodymetrics was using the 3D body scanner to provide three services: made-to-measure jeans, Body-shape jeans, and online virtual try-on.

With made-to-measure jeans, the scan is used to create a pattern for the jeans, which are hand-tailored to the exact lines and contours of the customer's body. The jeans are ready in three to six weeks, at which time the customer has a final fitting with a Bodymetrics tailor. The jeans were produced in Far East or North America.

Today, this company does exist, but their concept has changed. They are using 3D body scan to determine the best jeans for customer shape, size and style from leading brands: 7 for all Mankind, J. Brand, AG, Citizens of Humanity, Hudson, Paige and more [6].

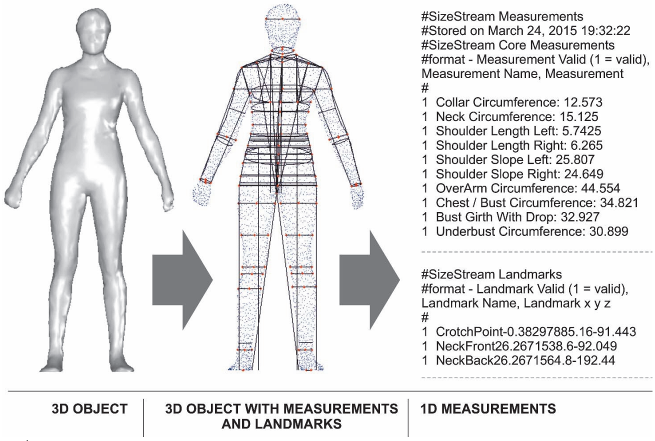

Figure 1 .1D Measurement formation

C. *Missing link(s) in data flow (Integrator)*

All the previous Digital Tailoring systems have been semi-automated and several lack of 3D technology. They have required human intervention because there has not been a system, which would translate the 3D body scanner measurements into correct values for a CAD system. Neither rules about "tailor knowledge". Tailor knowledge is a set of computer rules to make or change customer patterns so that they would meet the customer order and measurements.

The 3D body scanner captures measurements on the human surface while different trained persons measure differently and they are not consistent. The 3D body scanners are 76% more accurate than measurements from the most skilled hand-measuring experts [7]. Levi did not use the 3D boy scanners at first, which had caused inaccuracy in customer measurements and not fitting jeans in the end.

At the moment, the 3D body scanner measurement extraction program creates a 1D measurement file. This file contains only information about 1D measurements and landmark coordinates (see Fig. 1) – it does not describe body curves, neither does it take into account tailor knowledge. Customer order information (e.g. model, fabric, etc.) and preferences (e.g. additional length for high heels) are missing.

The tailor's knowledge needs to be applied to the scanned measurements before those measurements can be fed into CAD system. For instance, the waist measurement of the trousers has to be a little bit smaller (if they are worn without belt) to keep the trousers in the required place.

The 3D body scanner measurements do not take into account garment compression. Women's trousers are most often smaller than any real woman's measurements to shape the body and provide wearing comfort. Thus, the measurements from the scanner have to be manipulated (reduced) to produce fitting clothing.

The most important and difficult issue of the 3D body scanner measurements concerns the "ease" values. Ease is extra value added to the body dimensions to:

- allow movement (wearing ease)
- create the desired silhouette (design ease).

All garments require ease. Wearing ease is the absolute minimum amount of ease that needs to be added to a garment, which would allow to move without being too constricted.

In addition, quite often customers are offered special alteration options, for example, extra leg length for trousers (for men or women wearing high heel shoes), longer or shorter jacket or sleeve lengths as some customers prefer the jackets longer than the standard lengths judged ideal for the jackets. All such information needs to be also added to the input file for CAD.

1D measurements do not describe the body curves and CAD system does not know what to do with landmark information. Body curve information is vital because subjects with the same chest, waist, and hip measurements can appear completely different (see Fig 2).

The problem in the focus of this paper is the fact that in the clothing industry does not exist a link between the 3D body scanner, customer order and CAD software which would allow to translate 3D measurements and customer order into import file to CAD system (Fig. 3). It is missing Integrator.

IV. The Integration Tool

The key for Digital Mass Customization is the Integration Tool (Integrator). The Integration Tool is automatic order processing system. It takes two kind of information as input:

1. Customer's order.
2. Customer's 1D measurements from the scanner(s).

With this information, the Integration Tool can output different files and documentation needed for manufacturing:

1. Unique customer specific *Order file* for CAD 2D program
2. nique customer specific *Order file* for CAD 3D program
3. *Tech Spec* for mass-customization product.
4. Different documents requested in the manufacturing process.

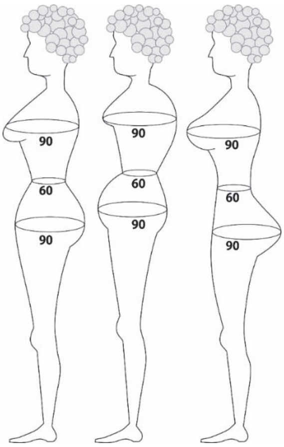

Figure 2. Women with different body curves

Customer order input information for the Integration Tool can come from different places: from cloud meaning that the orders are read in from cloud-based CRM system or from server meaning that the orders are read in from Operations Management system. The customer 1D measurements are read in from the server. The resulting output is pushed back into the cloud or server defined by the user.

The Integration Tool adds tailor knowledge:

- Modifications required to establish the wearing comfort.
- Modifications required to establish product nice appearance on the customer.
- Modifications based on customer measurements
- Modifications based on materials chosen by the customer.
- Modifications based on body curves.

The information about body curves will be transferred to CAD program through the Integration Tool, which would take the 3D body scanner 1D measurements and landmark information and transform this information into a suitable form of measurements, alterations, models or options required for CAD program.

CONCLUSIONS

With the help of the Integration Tool, it is possible to prepare and produce mass customized clothing with mass-production efficiency. The Integration Tool targets the enormously increased productivity and higher quality standards, as well as acceleration in global fashion processes by making possible considerably more resource- and cost-efficient production.

The development of the Integration Tool for Mass Customized Clothing Production, with the latter making use of the technology enabling a seamless information flow between the 3D body scanner and CAD system and containing tailor knowledge and customer order information. The Integration tool enables:

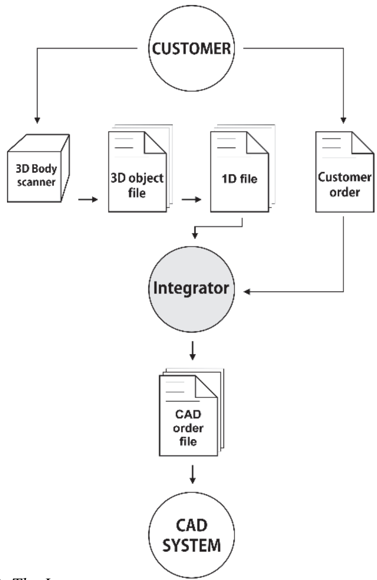

Figure 3. The Integrator

- To produce customized garments according to individual needs/taste/wishes of each customer (mass-customized garments)
- To apply mass-production methods for mass-customization products to reduce production costs.

As the main finding, the research suggests the Integration Tool as the best solution for the apparel industry to improve resource efficiency, production and management efficacy, and increase competitiveness.

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Publication II

Elbrecht, Pirjo; Palm, Knut-Joosep (2014). Precision of 3D Body scanners. *18th International Conference on Intelligent Engineering Systems, Tihany, Hungary. July 3-5 2014.* IEEE, 127−132 (2).

Precision of 3D Body scanners

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Abstract - Precise measurements are the key for making digitally tailored garments. Therefore, it is necessary to have the measurements defined by the measurement profile which would relate to apparel basic block construction. A block is a foundation pattern constructed to fit a particular human. A block should be drafted to fit an individual figure using personal measurements [1]. The block algotytm is defined as script to the CAD system (Gemini) or exisiting pattern is altered by CAD systems (Optitec, Lectra, Gerber, etc.) to fit a specific figure using individual dimensions.

The data recorded by body scanner can be very accurate dependent on the equipment (infrared, white-light, depth sensor) and the amount of sensors (lasers/sensors/lights) used. The accuracy of dimensions obtained depends on the measurement extraction profile and how exactly the scanner recognises the body surface. At the moment, there may happen that two different versions of body scanners from the same firm can produce results with 1-4 cm difference in circumference measurements.

After considering over 11 000 body scans, I have come to the discovery, that the scanners do not detect proficiently crotch area (the area of the human body where the limbs join the torso. It is often considered including the groin and genitals) and measurement extraction profiles do not let to map crotch point as it is built in the individuals block.

We have to have a standardized "human" prototype as a tool compare results produced by different scanners in order to secure the accuracy of the scanner data and measurement extraction profiles.

I. Introduction

Patterns for tailor made garments are drafted by skilled pattern makers according to what they have measured and observed. This task requires considerable expertise and experience and thus induces high labor costs. With the improvement of CAD/CAM technologies the computer software can make it more efficient to generate clothing patterns [2] and based on the mathematical expressions for required measures, the computerized construction of clothing patterns can be realized [3]. Besides, the computer-generated human models help to visualize the fitting results of the designed clothes the virtual environment [4] and [5] due to the consistency of computer programs, patterns are created according to the same rules repeatedly. Moreover, the data can be stored and retrieved with ease. It has the flexibility of generating a different type of clothing pattern rapidly without taking the measures again.

Digitally tailored garment is designed, patterned and prepared for the factory digitally according to the customer body dimensions taken by the body scanner, 2D digital camera, or direct input so that one unique garment could be manufactured with mass production efficiency. The process is fully automated starting with placing the customer order to the digital tailoring system and ending with cutting machine cutting the fabric into pattern pieces automatically (Fig 1. Digital tailoring chain). The process does not require any human intervention, thus reduces labor costs and processing time. The digital tailoring system improves not only customers' satisfaction but also the manufacturers' profits.

The integration tool allows the body measurements to be analyzed and sent to CAD systems. The integration tool is established on background information that experienced pattern makers have. The integration tool is necessary to combine the customer Co-Design options and measurements. The system has built-in "tailor knowledge" which is the key element for creating fitting Made-to-Measure products.

There has been significant progress in 3D body scanner quality and measurement extraction software, but the software still does not enable production of *Made-to-Measure* clothing in smooth and user friendly way with dedicated personnel having only pattern maker education.

Software for 3D visualization of customer's body is not yet very suitable for mass customization. Fitting visualization techniques to the complex and largely varying forms of human bodies is a difficult task even with contemporary body scanners and computer technology. It is very hard to simulate in 3D programs the tightness of the jeans and how it would affect the wearer's body shape in jeans. Various interactions between body shapes, pattern shapes and properties of fabrics used in the production create many fitting issues. The development and testing of methods and technologies to overcome these problems in production processes is still in its infancy. [6]

In this study I will describe problems with body scanner measurement extraction (Tc2), the importance of measurement extraction profile correspondents to the basic block and lack of standards to control the precision of the body scanner. They all are stopping to develop the digital tailoring system further in this industry and are causing big losses to the companies.

II. Body Scanner

A 3D body scanner is a useful tool that efficiently and accurately analyzes the human body and its form. Once the person is scanned, the produced data will be sent to a computer and visualized on the screen. The output of the body scanners is a cloud of points, transformed in a triangulated mesh through the use of particular algorithms in order to support the 3D visualization of the human body and the extraction of meaningful body landmarks and measurements [7] after that software automatically detects human body landmarks and produces measurements accordance to the measurement extraction profile. Once a person's body is captured using a body scanner, it could be retrieved and any part of his/her body can be measured any number of times without actual contact with the measured person. Scan data can be saved in a special format to be processed by CAD system or integration tool that allows

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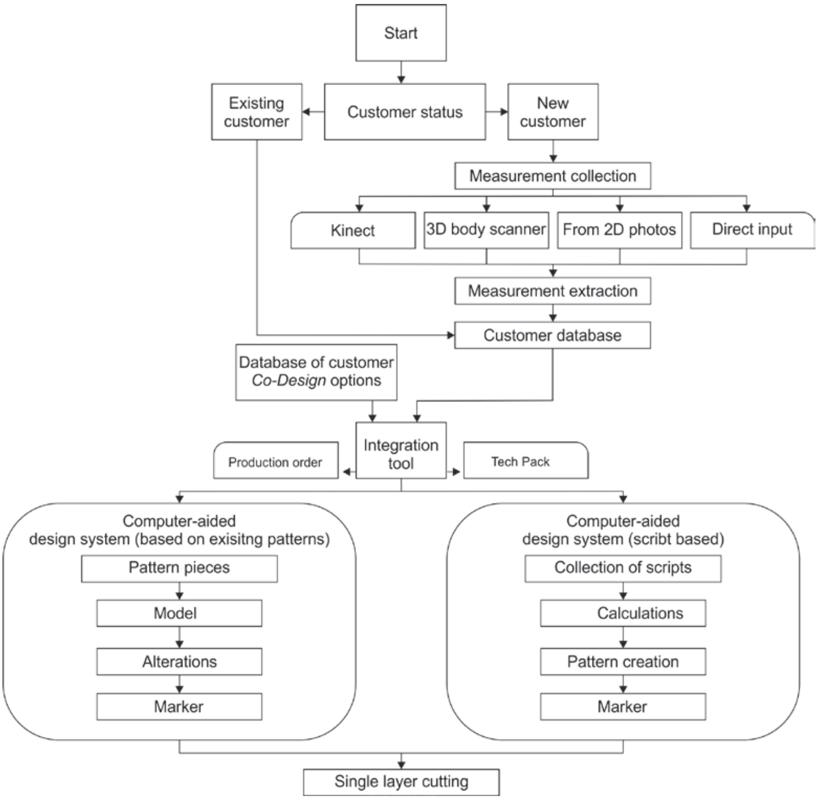


Figure 1. Digital tailoring chain

the body measurements to be analyzed and directed into the CAD system.

A. Existing standards

Quality of scan-derived anthropometric measurements is one of the main worry for users of 3D body scanners. Scan-extracted body dimensions are not always comparable with those obtained by traditional methods (example tape measure). Combining scan extracted measurements and those acquired by the traditional methods to make one table may cause problems in terms of the comparability of the data. An international standard ISO 20685 has been developed to establish a protocol for evaluating the comparability between scan extracted measurements and those obtained by the traditional methods (3-D scanning methodologies for internationally compatible anthropometric databases). ISO TC159/SC3/WG1 has been working to develop international standards related to the quality control of anthropometric data. Considering the present situation, ISO TC159/SC3/WG1 plans to make an international standard that establishes a protocol for evaluating the accuracy of 3D shape measurements and repeatability of landmark locations. The accuracy of scan extracted measurements is affected by more factors than that of traditional measurements as shown in Fig. 2. [8]

B. Problems in Everyday Work

I have worked with body scans almost three years - every day. In these three years, I have noticed that the quality of scans has gone down. One of the reasons is the new low cost body scanner (Tc[2] KX16), which came to the market in 2012.

C. Body Measurements are Dependent on the Scanner Type Used

The body scanner precision needs to be analysed more. There are lots of researches which are comparing body scanner measurements against hand measuring, but none where measurements produced by different scanners would be compared.

In this study two Tc[2] scanners are compared:

* NX16 - on the market from 2007
* KX16 - on the market from 2012

The test group contained 20 people. The whole body of

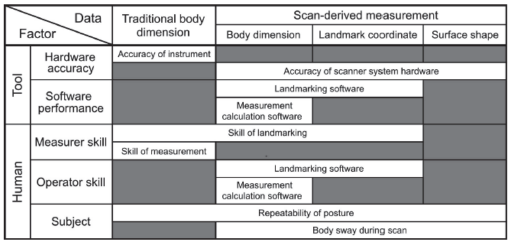


Figure 2. Factors that affect the accuracy of anthropometric data

each participant was first scanned with the NX16 and then in the same day with a KX16 in order to compare lower body measurements from seat to calves. All the scans were inspected visually and crotch point position modified if needful before the measurement extraction. The biggest variation in two different scanner measurements appeared on knees (7,63%, ca 3 cm) and calves (6,9% ca 3cm). If these results are transferred to ready-to-wear clothing sizes this creates a difference in two - three sizes (based on Finnish national survey [9]).

Results in the table show that all the participants had with KX16 left side always bigger than the right side (average difference was 2.46%). In the same time with NX16 body scanner sides were rather the same or left side slightly smaller.

The average difference in lower body measurements from two scanners is 2.1%. We obtained similar results when we compared two other NX16 and KX16 body scanners.

Please see the results in table 1. The percentages are highlighted which are bigger than +/- 3%.

From this follows, if a person is scanned with the NX16 body scanner, he or she would get tighter fitting garment than with the KX16 body scanner.

Questions arise; which scanner is more precise? Can we say that the body scanner is detecting measurements precisely? Can we produce fitting garments using body scan measurements?

TABLE 1. Body scanner measurement comparison between KX16 and NX16

Measurement	Average difference % (KX16-NX16)	MAX difference % (KX16-NX16)	MIN difference % (KX16-NX16)	Fluctuation between min max % (KX16-NX16)
Hips_Full	0,99	2,63	-1,36	**4,00**
Hips_Width	0,56	2,53	-2,46	**4,99**
Seat_Full	1,12	1,90	0,00	1,90
Seat_FrontX	-0,14	0,65	-1,24	1,89
Seat_BackX	-0,75	0,35	-2,40	2,75
Seat_Width	0,68	1,64	-0,74	2,37
Knee_Left	**5,06**	**7,63**	**3,73**	**3,90**
Knee_Right	1,97	**5,46**	0,71	**4,76**
Knee_Height_Left	0,45	**3,94**	-1,19	**5,13**
Knee_Height_Right	0,33	**3,94**	-1,49	**5,43**
UnderKnee_Left	**4,76**	**6,10**	**4,04**	2,06
UnderKnee_Right	1,47	2,23	0,61	1,63
UnderKneeHeight_Left	0,22	1,52	-1,93	**3,45**
UnderKneeHeight_Right	0,92	2,19	-0,06	2,25
Calf_Left	**5,67**	**6,90**	**4,73**	2,17
Calf_Right	1,84	**3,42**	0,69	2,73
Calf_Height_Left	0,78	2,52	-0,76	**3,28**
Calf_Height_Right	1,39	**3,36**	-0,11	**3,46**
Outseam_Left	-0,11	0,07	-0,30	0,37
Outseam_Right	0,14	0,41	-0,11	0,51
Inseam_Left	0,04	0,70	-0,49	1,19
Inseam_Right	0,12	0,77	-0,31	1,09
Thigh_95_Left	**3,68**	**5,24**	1,85	**3,39**
Thigh_95_Right	2,02	**4,34**	0,46	**3,88**
Thigh_90_Left	**3,28**	**5,13**	2,08	**3,05**
Thigh_90_Right	1,60	**3,59**	0,06	**3,53**
Thigh_85_Left	**3,50**	**5,22**	2,35	2,87
Thigh_85_Right	1,83	**3,53**	0,71	2,82
Thigh_80_Left	**3,38**	**5,72**	2,04	**3,68**
Thigh_80_Right	1,92	**3,87**	0,35	**3,53**
Thigh_75_Left	**3,28**	**5,85**	1,19	**4,66**
Thigh_75_Right	1,65	**3,64**	0,22	**3,42**
Thigh_70_Left	**3,71**	**5,45**	1,60	**3,85**
Thigh_70_Right	1,90	**3,28**	0,31	2,97
Thigh_65_Left	**4,91**	**6,72**	**3,06**	**3,66**
Thigh_65_Right	2,41	**3,76**	1,08	2,68
Thigh_60_Left	**5,09**	**6,97**	**3,52**	**3,46**
Thigh_60_Right	2,17	**4,33**	0,87	**3,46**
Thigh_55_Left	**4,96**	**5,99**	**4,01**	1,98
Thigh_55_Right	1,93	**3,04**	0,94	2,10
Thigh_50_Left	**5,44**	**6,31**	**4,67**	1,64
Thigh_50_Right	1,97	**3,50**	0,62	2,88
Average difference	**2,10**			

Left side average difference from NX16 %	**4,36**
Right side average difference from NX16 %	**1,90**
Difference between sides from NX16 %	**2,46**

Figure 3. Corrupt measurements

Units = centimeters	Front	Left	Up
CrotchPoint	0.0	-0.0	68.7
LeftArmpit	7.6	15.5	121.9
RightArmpit	4.8	-16.2	121.8
BackNeck	-9.8	1.7	138.2
LeftSideNeckPoint	-3.1	11.6	137.2
RightSideNeckPoint	-3.3	-8.1	137.7
FrontCenterNeckPoint	4.1	1.7	132.5
LeftShoulderPoint	-1.7	20.7	131.0
RightShoulderPoint	-0.3	-18.5	133.0

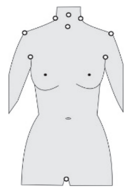


Figure 5. Landmark presentation in excel and body image

D. Corrupt Measurements Due to The Twisted Body Sides

The placement of the measurements is twisted and wrong on the 3D avatar that are made by KX16 (Fig 3. Corrupt measurements). The corrupt measurements due to the twisted body sides is caused by false body landmark detection by measurement extraction profile. The body landmarks are placed to an incorrect place and creating wrong placement of the measurements, thus the majority of the measurements are erroneous. Example: the right outseam is found on the half way on the right front side and the left outseam is found on the half way on the left back side, also the inseam is corrupt. This error does not occur with NX16.

The problem occurs more often with the corpulent ladies, a-symmetric ladies who have placed the underwear inadequate or it is too squeezing for them. The problem is solved sometimes but not always by rescanning the customer with underwear placement straightened (modified) or underwear changed.

E. The Crotch Point

It is hard to get information about how different body scanners are detecting the crotch point landmark. From the literature several definitions are found (see also Fig 4):

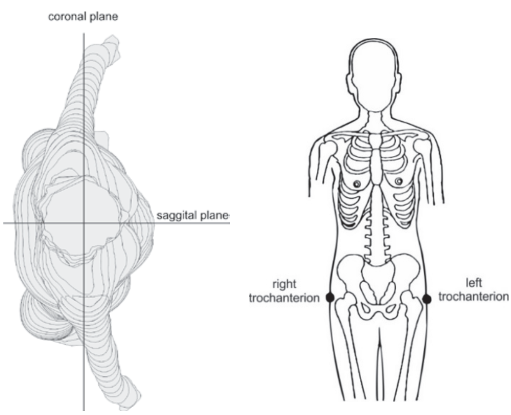


Figure 4. Crotch point

- a set of three-dimensional body scanned data is projected onto the coronal plane, locally maximum and minimum points on the silhouette curves can be used to extract crotch point [10];
- point calculated midway between the right and left trochanteric landmarks at the level of crotch height as measured with the anthropometric [11].

The same question has asked from Tc^2 support and the answer was: The crotch landmark is not defined. It is automatically built into the software.

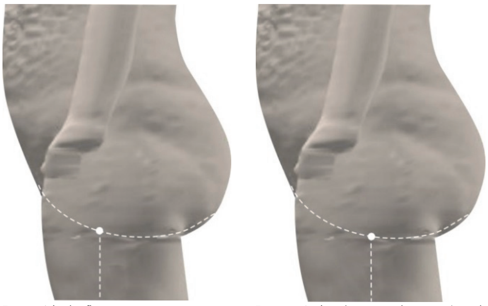
Half explanation can be found in Tc^2 MEP Editor Tutorial:

> Landmarks Select extracts a list of 9 landmarks located on the body and writes them out to a text file. The number of landmarks extracted is displayed as the value of the measurement.
>
> The output text file is written in the .ord directory with the name of the subject as the file name and .landmarks as the file extension. The Xyz values all reference a point on the floor directly below the crotch point.
>
> This is a Landmarks file opened with Excel. The columns are labeled with Front, Left, and Up meaning x, y, and z.
>
> The landmarks in the picture are circled with red for clarity. They are not usually displayed this way on the computer monitor (Fig 5. Landmark presentation in excel and body image).

It does not say how it can be found from widthwise (on the line from the front waist point to the back waist point) on the horizontal level of the crotch (see Fig 6. Crotch level on the horizontal level).

When the crotch landmark is extracted with scanner measurement extraction profile it is expected to be in the same place in person's different scans that are taken

Figure 6. Crotch level on the horizontal level



Person 1 in the first scan   Person 1 in the second scan (crotch fluctuation 2,5cm)

Figure 7. Crotch point fluctuation in different scans

consequently (body scanner can be set to take three scans in a row from one person).

In reality, the crotch point is fluctuating (see Fig 7. Crotch point fluctuation in different scans) and causing significant differences in front and back side measurements that are related to the crotch point. That is causing balance problems in garment fitting, which might cause even remake for the whole garment.

Example; The most important measurement for clothing items which lean on waist (jeans, trousers, skirts) is the waist circumference. It sets the waist height, front and back rise, vertical rises and also the balance of the product. They all have an important role that the product would feel comfortable and fitting [12].

The crotch point should be placed proportionally in the same position for different persons on the horizontal level. At the moment the placement is very different depending on the landmark definition (Fig 8. Crotch point position in different people).

In clothing construction, the crotch includes the space of a pair of trousers (jeans, shorts, slacks) where the feet link together. The lowermost of the crotch outlines one end of the inseam (Fig 9. Crotch point in trousers).

To produce fitting garments, the crotch point in the horizontal level cannot fluctuate and should be in relation with the middle point of the inside leg which would be the center point of the front thigh and back thigh cross-section. See Fig 10. Recommended crotch point.

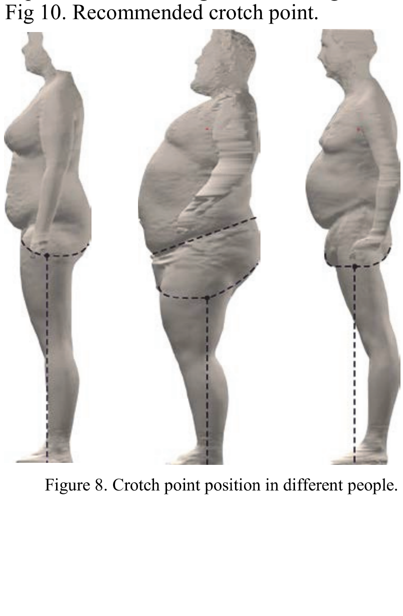


Figure 8. Crotch point position in different people.

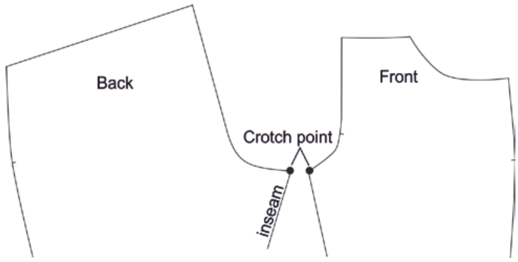


Figure 9. Crotch point in trousers

III. Conclusions

First of all – different companies´ body scanners should be compared against each other.

To obtain precision of measurements made with different companies' body scanners, we need to develop "dummy" that would allow us to control the accuracy of the body scanners and the measurement extraction profiles. Everybody has to have the same understanding about 1 millimeter. It is not acceptable, that the body scanners in the market are not ready for the customer and are producing millions of euros losses to everybody who are trying to the startup company based on new technology. They have to hire a person who would solve these issues with scanners inside of the integration tool throw programming. The new body scanners in the market need to be controlled by accreditation institute who would give certificates if they would correspond to the standard. Good step is development of the ISO TC159/SC3/WG1. Still, damage is allready done.

Crotch point landmark detection methods have to be public so that companies could fix any issues concerning crotch point.

Inseam placement on a horizontal level, also the front crotch and back crotch starting point should be the middle point of the inside leg which would be the midpoint point of the front thigh and back thigh cross-section.

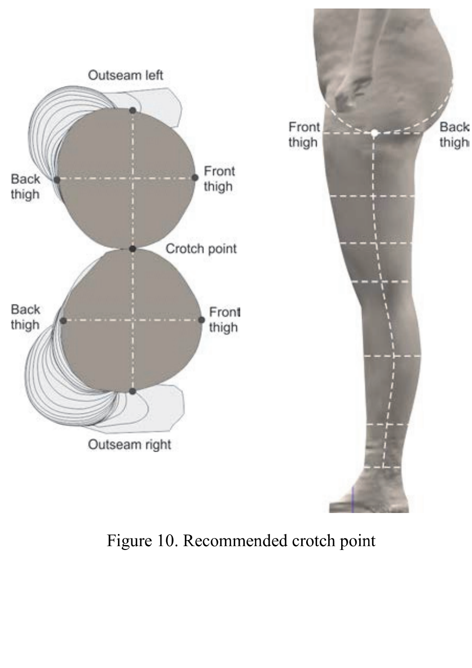


Figure 10. Recommended crotch point

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Publication III

Elbrecht, Pirjo; Henno, Jaak; Palm, Knut-Joosep (2013). Body Measurements Extraction from 3D Scanner Data. In: Wen J. (Ed.). Mechatronics and Control Engineering (372−377). Trans Tech Publications Ltd. (Applied Mechanics and Materials; 339) (3).

Applied Mechanics and Materials *Online: 2013-07-15*
ISSN: 1662-7482, Vol. 339, pp 372-377
doi:10.4028/www.scientific.net/AMM.339.372

Body Measurements Extraction from 3D Scanner Data

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Keywords: Digital tailoring, 3D scanners, body scanning, body dimensions, made-to-measure, measurements extraction, computer-aided anthropometry, trousers, skirts, block

Abstract.The growing power of computing, development of methods of 3D graphics for human body modeling and simulation together with development of 3D image capture technologies using 3D scanners has caused rapid development of digital tailoring - a complex of methods where *made-to-measure* clothing is produced starting with 3D scanning of a customer, extraction of essential measurements from obtained data cloud and then automatic production of a garment corresponding to exact measures of the customer. Extraction of exact measures from the ca 200000 data points produced by 3D scanner is a complex problem and not yet well investigated.

Introduction

The growing power ofcomputing, development of methods of 3D graphics for human body modeling and simulation together with development of 3D imagecapture technologies using 3D scanners is rapidly changing ways how we obtain our garments – suits, trousers, skirts etc. The previously commonly bought from shops *ready-to-wear* garments,which were constructed to fit the manufacturer's definition of an abstract 'average customer' and therefore did not fit well any concrete customer are replaced with *made-to-measure* garments, created according to customers personal measures obtained through 3D scanning of his/her body and computational processing of obtained data to get essential measurements needed in the tailoring process[1].

Precise measurements are the key for fitting *made-to-measure* garments; therefore it is necessary to have measurement definition which would correspondto apparel basic block construction. A block is a foundation pattern constructed to fit a specific human.A block should be drafted (tailor)or altered (CAD/CAM systems) to fit an individual figure using personal measurements.

Dataproducedby body scanner is very precise, but protocols for locating body measurements need to be perfected. Traditional body measurements are based on landmarks on the body, which are often identified or located by visual inspectionand a computer must be programmed for every case. And the biggest problem is lack of understanding why we are taking measurements for certain products and how we are using them.

After considering over 10 000 body scans I have come to conclusion, that there is need to change measurements definition for hip circumference and to add an extra measurement – widest part of the lower body, because of the changes in the body types and also commondesireto have more tightly fitting clothing.

This paper investigates computation of the waist position from ca 200000 data points obtained with 3D body scanning for different body shapes and genders. The main research problem is:

Where should be measured hip circumference? Are the existing standards for hip circumferencecompetent?

Used hardware

For obtaining human measurements there are two commonly used methods:

- the traditional tape measure,
- software-extracted computer-aided anthropometry, performed with three-dimensional scanner.

This study uses software-extracted computer-aided anthropometry, which is the result of 3D body scanning in the point data cloud. The point data cloud is used for creation of critical landmarks and anthropometric data.

3D Body Scanner.A 3D body scanner is a useful tool that effectively and accurately analyzes the human body and its shape. Once a scan is taken, the produced data will be sent to a computer and visualized on the screen. In the next step, software automatically locates body landmarks and generates measurements. Once a person' s body is captured using a body scanner, it could be retrieved and any part of his/her body can be measured any number of times without actual contact with the measured person.Scan data can be saved in a special format to be read by CAD system or integration tool that allows the body measurements to be analyzed and directed into the CAD system.

Dataproducedby body scanner is very precise, but protocols for locating body landmarks still need to be perfected. Traditional body measurements are based on landmarks on the body, which are often identified or located by palpitation, while a computer must be programmed for every eventuality. This affects the percentage accuracy of measurements of the body scanner since certain body landmarks are difficult to identify. This is one of the major reasons for incorrect locations of waist, stomach, and crotch point measurements.

Scanners used. TheKX-16 utilizes thetechnology with infra-red depth sensors placed around the body at four specific heights and four specific angles to give complete and accurate body scans. The scanner features an attached changing room and includes the full suite of [TC]2 Body Scanning software functionality including automatic body measurements at more than 400 points; manual measurement capabilities. The KX-16 also offers color scan data acquisition; low sensitivity to room light or sharp color contrasts on the scan subjects; and generation of more than two million data points at full-body resolution.

The NX-16 uses safe white light for the scan and provides exceptional accuracy when compared to manual measurements. The process of scanning is private and safe. The scan is taken in 8 seconds, and data density is 600 000 to 800 000 points [2].

Software

The TC^{2}3D body measurement softwareprovides an easy and user-friendly interface to extract the measurements and manipulate the data. The Measurement Extraction Profile (MEP File) is modifiedaccording to the identified measurement points.The definitions of the measurements are customizable and exported to other formats such as for CAD systems.

The software also allows batch processing of measurement extraction when required. This removes the manual portion of repeatable tasks by removing the need for user intervention.

Printing the scan results is also available for those who would require a hard copy for reference purposes. The print output is customizable to allow you to see only what you require.

Previously used methods

In the literature have been used several hip definitions for apparel:

ISO 8559:1989 Garment construction and anthropometric surveys - Body dimensions[3]

*Definition*2.1.12, hip girth: The horizontal girth measured round the buttocks at the level of the greatest lateral trochanteric projections, with the subject standing upright.

*Instrument:*no measuring instrument is specified

United States Air Force Research Laboratory Report Caesar: Summary Statistics For The AdultPopulation (Ages 18-65)Of The United States of America[4]

*Section:*Hip circumference, maximum

*Definition:*Maximum hip circumference is measured parallel to the standing surface.

*Method:*Subject stands erect, looking straight ahead. Subject’s feet are placed in footprints adhered to the standing surface (the footprints are positioned approximately 10cm apart at the heels and rotated 33° at the toes)

*Note:*The measurer and recorder take this measurement as a team. The tape is placed around the subject’s torso approximately 2cm above the maximum protrusion of the buttocks (visual inspection will often suggest the approximate area of the maximum circumference). The measurer and recorded use each other to establish that the plane of the tape is horizontal at all times. The tape is moved up and down from the starting point at approximately 1 cm intervals as directed by the measurer, who reads the tape and tracks each measurement until the maximum circumference is located. (The measurements will increase approaching the maximum circumference, and decrease as you move away from the maximum, so the measurer makes a mental note of each of the values until the circumference begin to decrease and each successive measurement is smaller than the last.) The measurer and recorder return to the level of the maximum value, where the measurement is made and recorded.

In some cases, the maximum circumference will occur over a fairly broad area of the torso. In such case, the level is defined as the midpoint of the area at which the maximum circumference occurs. Also, occasionally a subject´s waist may be larger than his or her hip. In these instances the maximum hip circumference is defined as the maximum circumference which also is below the top of the pelvis.

*Instrument:*Steel tape measure.

Measurer´s handbook: US army and Marine Corps anthropometric surveys, 2010-2011[5]

Section:6.4.17 Buttock Circumference

*Definition:*The horizontal circumference of the trunk at the level of the maximumprotrusion of the right buttock.

*Drawn landmarks:*Buttock point, right lateral and left lateral.

*Undrawn landmarks:*Buttock point, posterior.

*Method:*Participant stands erect on a table with heels together. Ask theparticipant to hold up the right leg of the shorts to expose the landmark. Stand at theparticipant’s right, and use a tape to measure the horizontal circumference of the trunkat the level of the maximum protrusion of the right buttock. The tape should pass overthe posterior buttock point (not drawn) and the buttock point landmarks drawn on theright and left hips. If necessary, ask male participants to adjust the genitalia so as tointerfere as little as possible with the tape. Exert only enough tension on the tape tomaintain contact between the tape and the skin.

*Instrument:*Steel tape measure.

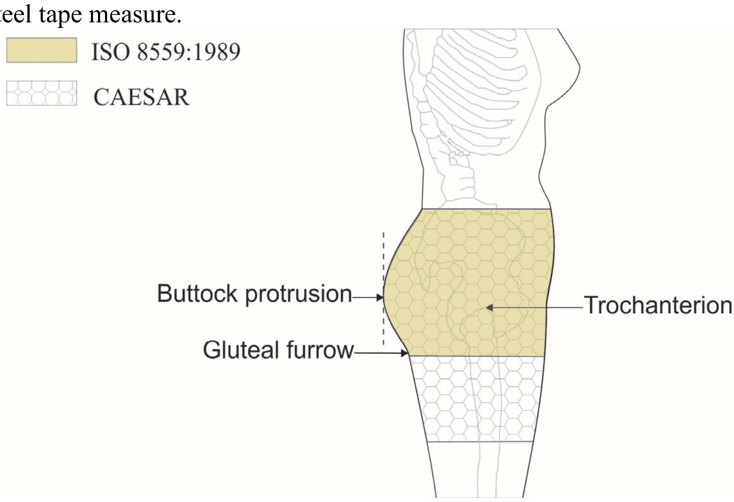


Fig. 1. Zones of hip circumference according to different standards

Body scanner measurements versus construction

A block is a foundation pattern constructed to fit a specific human. A block should be drafted to fit an individual figure using personal measurements.

The trousers block consists 5 horizontal lines – waist line, seat line, crotch line, knee line, bottom line.All horizontal lines except seat line are used as direct measurements from the human. For the sake of general convenience the seat height is calculated:

- ¼ of body rise measurement, measured up from crotch line (English construction bases)
- 1/10 of half hip circumference + 3cm, measured up from crotch line (German construction bases)

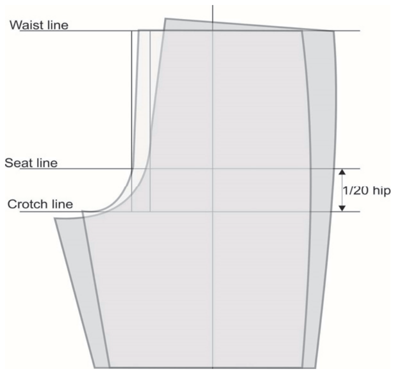
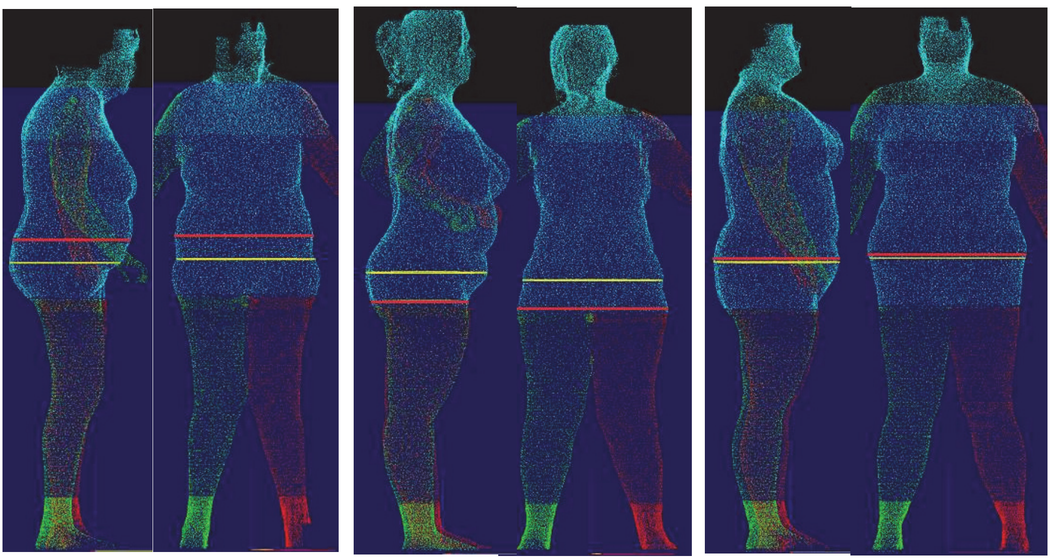


Fig. 2. Trousers block

In reality the heightof the hip varies in the humans and it should not be calculated. See figure3. In the figures the hip is marked with red line, buttock with yellow.



Hip = 114,7
Buttock = 111,5
Hip height = 15,5
Buttock height= 9
Following german construction calculation, the seat height should be **8,7**

Hip = 121,8
Buttock = 121,1
Hip height = 0,6
Buttock height= 7,9
Following german construction calculation, the seat height should be **9,1**

Hip = 135,4Buttock = 135,1
Hip height = 13,5
Buttock height= 12,5
Following german construction calculation, the seat height should be **9,8**

Fig. 3. Placement of hip circumference with different body types.

Other aspect in trousers construction is the seat line width which is measured to the seat line. It is ¼ of hip measurement. Theoretically it is correct, but when the seat height in the human is not as defined in calculation above, then all the other measurements related to hip are false, also the width of the product in the "seat" level. To conclude, in trousers block it is very important where the hip circumference and height is defined.

For trouser construction, it is necessary to take into use an extra measurement "widest part in lower body" to ensure that the trousers opening is long enough and the product would come over the widest part in the lower body (Fig.4).

The skirt block consists 3 horizontal lines – waist line, hip line, bottom line. All horizontal lines are used as direct measurements from the human.

According to ISO definition for the hip circumference, it should be found round the buttocks at the level of the greatest lateral trochanteric projection. In reality, the largest circumference can be found also in the upper part of the thighs. It is necessary to take into use extra measurement "widest part in lower body" to construct skirt for fuller females.

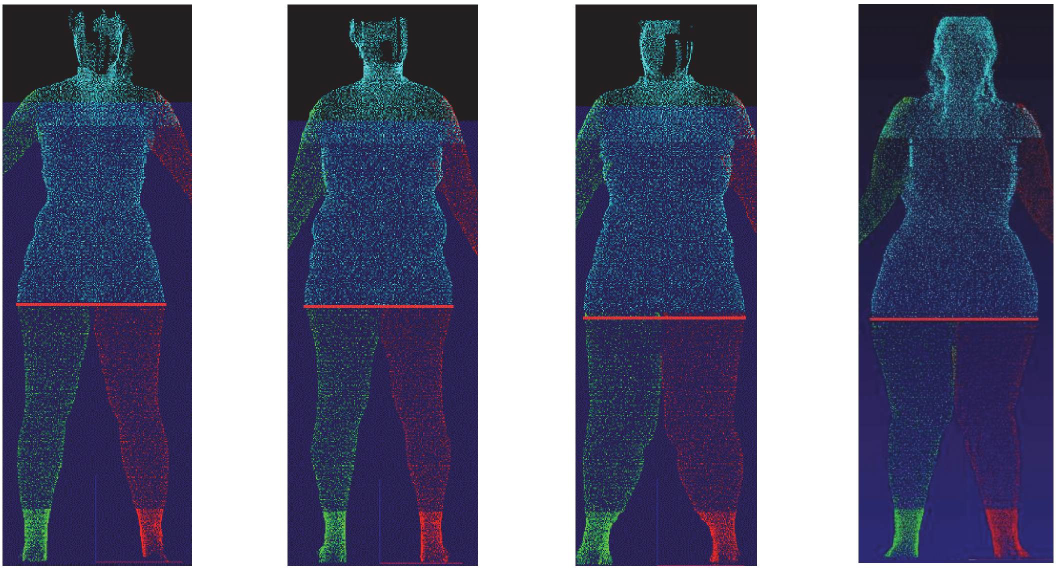


Fig. 4. Widest part in lower body

Conclusions

The hip circumference for trousers construction should be measured round the buttocks at the level of the greatest lateral trochanteric projections higher from the fork.

Figure 5 gives a profile of one leg with the trunk cut in half. C is the place where the leg-seam unites the top and undersides, and the curved line ACB (dotted line) shows the actual fork quantity. By reference to figure 6 it will be seen that while CD is the fork quantity on the front the curved line EF of the seat on the back must be also added to this to give the exact quantity required to fit figure 5, from A to the front at 3.[6]

Two new measurements should be added to ISO standard:

- widest part in lower body
  Definition: The horizontal largest circumference measured round the lower body between waist and knee.
  Instrument: Body scanner.

- height of the widest part in lower body
  Definition: The height of the horizontal largest circumference measured round the lower body between waist and knee.
  *Instrument:*Body scanner.

The existing standard for hip circumference (ISO 8559:1989) should be adjusted and improved.

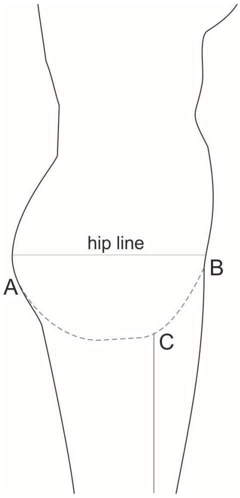


Fig. 5. Trunk cut in half

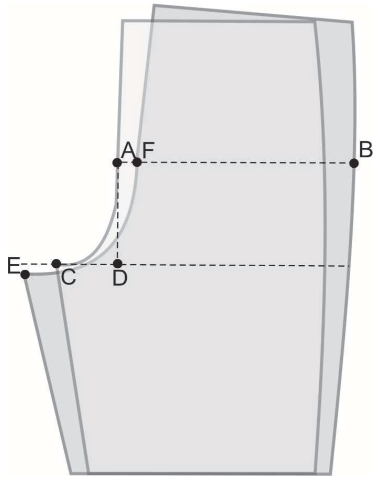


Fig. 6. Trouser construction

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Publication IV

Elbrecht, Pirjo; Henno, Jaak; Palm, Knut-Joosep (2013). The Data Integration Tool for Digitized Tailoring. 17th IEEE International Conference on Intelligent Engineering Systems. IEEE, pp 193-196 (4).

The Data Integration Tool for Digitized Tailoring

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Abstract—The biggest problem when using the made-to-measure manufacturing method is the time for production preparation. To produce a made-to-measure garment using mass customization it is necessary to integrate several subsystems: 3D Body Scanner and CAD system; customer co-design options and CAD system; web shop, 3D body scanner and CAD system; garment production and CAD system. Here is introduced a tool for integration of these different subsystems. Use of this tool allows producing many made-to-measure products in time comparable with time needed for production of ready-to-wear products.

I. Introduction

Many companies struggle with missing or inadequate practices for IT systems and configuration systems. Manufacturing capabilities are often better than corresponding IT capabilities. Mass customization business model often struggles with proper change management of organization, processes and people.

The biggest problem when using the made-to-measure manufacturing method is the time for production preparation. To produce a made-to-measure garment using mass customization it is necessary to integrate several subsystems: 3D Body Scanner and CAD system; customer co-design options and CAD system; web shop, 3D body scanner and CAD system; garment production and CAD system. For integration of these different a subsystem is introduced here a tool, which allows to produce many made-to-measure products in time comparable with time needed for production of ready-to-wear products.

A. Mass production meets custom-fit

Not all predictions of great visionaries become true - at least not in the predicted time frame. Famous futurist Alvin Toffler predicted more than thirty years ago that in twenty years all people will become creative consumers, who design the products they need, their own clothes etc [1]. Expanding this vision, Stan Davis introduced in 1987 the term “Mass Customization” [2], which can be described as “Design, Create Your Own” - a practice of manufacturing where customer is an active participant, co-designer of products and services, so that the final product will correspond to needs and desires of each individual customer. While this vision has not yet come true 100%, we can see many elements of it in several fields of production (e.g. when buying a new car). And lately (although more than thirty years later) this mode of production is also emerging in industrial production of clothes and footwear, where the 3D scanning and following methods of production have made possible participation of consumers as co-designers of goods they need. The methods and production operations are still industrial, which ensures that the processes are stable but flexible and responsive. And as a result the costs associated with customization allow prices that are comparable with non-customized mass-market products [3].

As a result of this course of moving from standard mass production of made-to-wear garments to the custom fit production, requirements for the apparel industry have constantly changed over years. It is necessary to have proper tools for making custom-fit products [4].

This paper describes tools needed for mass production of made-to- measure products in apparel business.

II. Problems With CAD Software For Apparel Production

Nowadays all the major CAD/CAM software developers are focused on creating 3D-based software, which is very good for visualization for the end customer and also for virtual prototyping, but it cannot be used for made-to-measure mass customization. In mass customization process nobody has time to preview and make modifications to every customer separately. The perfect fit has to come with seconds in order to be economically effective and create customer’s trust in the company. Mass customization in manufacturing, marketing and management means use of flexible computer-aided manufacturing systems, which allows customer to co-design the final product. Such systems combine the low unit costs of mass production processes with the flexibility of individual customized design [5].

There has been big progress in 3D body scanner quality and measurement extraction software, but the software still does not enable production of made-to-measure clothing in smooth and user friendly way with dedicated personnel having only pattern maker education.

Software for 3D visualization of customer’s body is not yet very suitable for mass customization. Fitting visualization methods to the complex and largely varying shapes of human bodies is a difficult task even with contemporary body scanners and computer technology. It is very hard to simulate in 3D programs the tightness of the jeans and how it would really affect the wearer’s body

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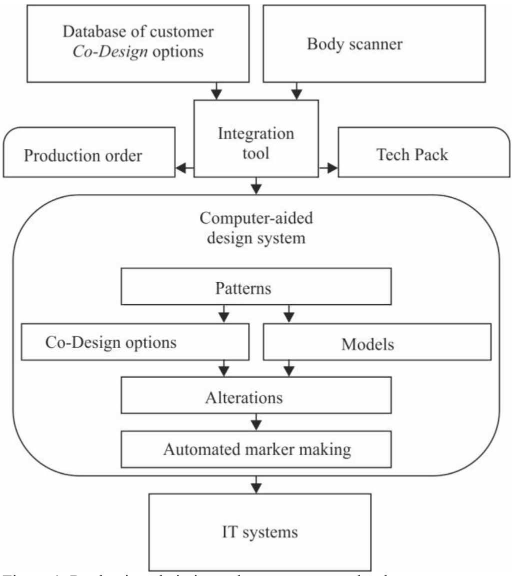

Figure 1. Production chain in made-to-measure technology

shape in jeans. Various interactions between body shapes, pattern shapes and properties of fabrics used in production create many fitting issues which should be resolved. The development and testing of methods and technologies to overcome these problems in production processes is still in its infancy.

III. The Technologies

To implement mass customization strategies in the apparel industry, it is necessary to have:

- a body measurement technology for collecting body measurements – a 3D body scanner;
- database of customer co-design options (model, fabric, wash and effects, front and back pockets, beltloops, labels, front fastening, extra length etc);
- the integration tool for digitized tailoring that combines the body measurements with the customer co-design options after the customer measurements are analyzed and modified; output of the integration tool is the input for CAD systems, tech pack and production order;
- computer-aided design (CAD) systems for apparel - pattern design, made-to-measure, automated marker making program;
- different patterns according to choices of customer co-design options and models that can be altered according to the customer's body measurements;
- IT systems which assist with accurate and rapid production and delivery.

A. The 3D Body scanner

Emergence of non-contact scanners for 3D objects for creating exact 3D models of scanned objects has greatly changed many traditional technologies. Application of 3D scanning for obtaining exact measures of human body has caused appearance of a new methods in apparel retailing – made-to-measure clothing; size consultation services in department stores; mannequins, which take the shape of scanned object and visualization services. The 3D body scanner is very useful tools that allows effectively and accurately analyze the human body and its shape proportions. Once a scan is taken, the obtained data cloud will be sent to the computer and visualized on the screen. Software automatically locates important body landmarks (e.g. the small-of-back point) and generates measurements. The created 3D model of the customer's body can be measured any way and however often without need for further contact with the customer. Scan data is saved in a special format to be read by the CAD system and analyzed by some special-purpose software, e.g. as proposed in [6].

Measurement extraction with body scanner is very precise, but methods for locating body landmarks still need improvements. Traditional tape measuring is based on landmarks on the body, which are often identified or located by touching the person, while a computer measurement extraction profile has to be programmed for every eventuality. This affects the accuracy of measurements since certain body landmarks are difficult to identify and as a result appear incorrect locations of waist, stomach, and crotch. The automated body measurements extraction by computers continually improves, but is still not perfect.

B. Database of customer co-design options

Database of co-design options is the collection of design elements composed by the head designer. Customers can choose design elements in order to combine their made-to-measure product. Head designer can also limit or define elements, which can be used together with certain fabrics or options.

The database of co-design options is the base for co-operation of the trained designer and the customer in the process of creating solutions - a suitable design. This co-operation makes sure that the final result will correspond to customer's desires and accepted [7].

In mass production, designer cannot meet with every customer and find the best solutions from the co-design options. The design should be created in cooperation of the customer and salesperson. It is more demanding task than picking the options and models together.

The information about customer choices is entered to the customer database, where it is exported to the integration tool as weekly production batch, together with all the other customers of the week.

C. Computer-aided design systems for made-to-measure products

A very important component of the automated creation of custom fitted apparel patterns is CAD technology. Most apparel CAD systems (Lectra Systems, Gerber Technologies, Assyst and Optitex) have several preparatory activities in common which will allow automatic pattern alterations based on individual measurements. Although these systems have different interfaces, the basic underlying theory is the same. It starts with development of standard size patterns and alteration points. Pattern maker generates and stores sets of alteration sequences which will modify a pattern geometrically according to customer measurements and body shape. The output is the marker file, which will be automatically directed to the cutter. Thus a made to measure system uses digital information created by 3D scanning and in the following processing about measurements and pattern shapes for creation, modification, filing, storing and reuse of patterns [8].

IV. The Integration Tool For Digital Tailoring

The integration tool allows the body measurements to be analyzed and sent to CAD systems. The integration tool is based on background knowledge which experienced pattern makers have.

The integration tool is necessary to combine the customer co-design options and measurements. The system has built-in "tailor knowledge", which is the key element for creating fitting made-to-measure products.

A. Co-Design options

According to the customer co-design options an order is created. Every single option is analyzed by the integration tool and taken into account in the further process of creating output file for CAD system, production order and technical specifications.

B. Gender

According to the gender, the integration tool is designed to know which measurement extraction profile (MEP file) to use for extracting measurements from the customers 3D body scan data. According to the set of measurements and model chosen by the customer, the integration tool defines the body type and measurements to be used in the creation of patterns.

The co-design options (fabric, wash, effects, model, pockets, etc.) which are imported from database are coded according to the gender because of the limitations of the CAD system.

C. Model

Every model corresponds to the certain characteristics which define the look of the overall style. In the models it is the design ease. Design ease together with customer measurement gives in certain places the same results as the readymade product measurements (see Fig. 2).

Sometimes it is necessary to modify the design ease. Example 1. If the customer knees are smaller than the calves, it is necessary to increase the value of design ease in knee area (2cm, see Fig. 3) to fit the calves under the jeans, since the pattern lines from knee to bottom hem have to be straight in tight fitting jeans.
Example 2. If the customer knee circumference exceeds certain value, it is necessary to decrease the value of design ease in bottom hem, because the visual appearance of the jeans in straight fit jeans.

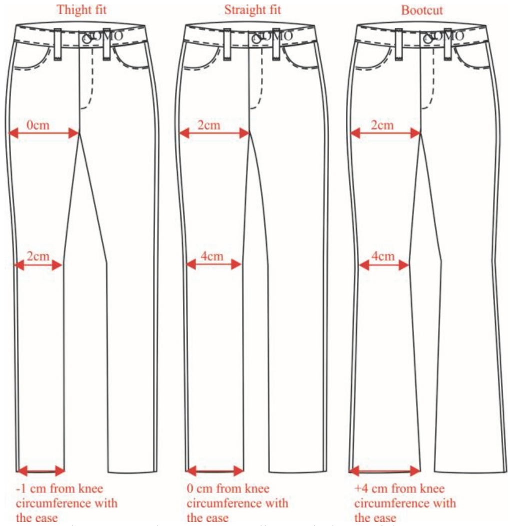

Figure 2. Design ease according to designer vision

The integration tool knows how to deal with different body types and how to manipulate models so that they would look the best with different in customers. The adjustments needed to the model and measurements are made and analyzed in the integration tool.

D. Fabric stretch

All the fabrics are stretching to a greater or lesser extent. Fabric provides a certain tension when stretched to fit the body and ensures comfort for body, therefore the patterns are made smaller than the body dimensions - the material stretches afterwards to fit the body. Therefore, the fabric mechanical properties as well as body measurements are crucial parameters for pattern making.

Fabrics have different stretch ratios in the warp and weft direction, so the fabrics must be tested in both directions - the length and width [9]. The fabric used for the garment is specified by its specific stretch ratio for different body circumferences separately. In the integration tool each measurement from body scanner needs to be adjusted

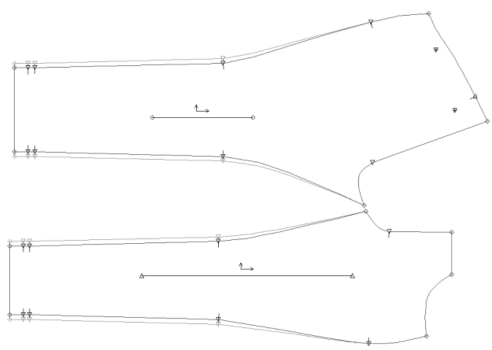
Figure 3. Increased circumference in knee and bottom hem area to fit the calves under the jeans (outer lines are marking the new pattern).

accordingly to provide close fitting (body-hugging) apparel. In this context, it is necessary to define precisely the pressure acting on the body. The stretch ratios are tested for every fabric separately and these ratios can vary a lot in different body circumferences (example; in upper thighs the percentage can be 7%, in knee circumference 2%).

As a starting point for dealing with stretch were used the international ASTM Textile Standards [10] and the "Standard Test Methods for Stretch properties of Fabrics Woven from Stretch Yarns" (D 3107 – 03) [11]. This allowed to define the different stretch percentages for different body parts.

E. Fabric shrinkage

Most significant properties affecting jeans pattern construction are dimensional changes and elongation after washing/finishing.

In the past the denim jeans were worn in a rigid, starch-finished form, but now-adays popular style of clothing requires that jeans are conditioned running them through various methods of desizing, enzymatic stonewashing with or without abrasive, decolorization, neutralization, brightening and finishing [12].

The first procedure in conditioning is the pre-wash. The purpose of this step is to remove from the jeans the starch and a portion of the indigo dye. This significantly softens the denim and will prevent in later steps forming of streaks caused by the too hard material.

The second procedure for jeans post-processing can be the abrasion wash, which gives the jeans the "stone washed" look.

All those washes are influencing the fabric in different ways, affecting especially the fabric shrinkage.

The fabric shrinkage percentage is different with different ways of finishing. For example; in the garment wash the jeans fabric can shrink in warf direction 2%, welf wise 7,5%, but in heavy wash accordingly 4% and 12%.

All this info is taken into account in the integration tool, which outputs this info as import file for the CAD system.

F. Quality assurance measurements

It is required that factories forward product measurements to assure the fit and size of the product. When the product is washed after sewing then there is need for two sets of measurements – before wash and after wash measurements of the garment.

For the production, it is necessary to know the length of the front fastening to attach appropriate zipper or certain amount of buttons to the product.

All those calculations are made in the integration tool. The tool also calculates needed quantities of fabric, thread, labels, zippers, studs, buttons, etc.

This data is output for the production order and technical specifications.

V. Summary

Here were described basic elements of a tool for integration different subsystems: 3D Body Scanner and CAD system; customer co-design options and CAD system; web shop, 3D body scanner and CAD system; garment production and the CAD systems; these all are elements of a made-to-measure production method. The tool helps to solve the biggest problem when using the made-to-Measure manufacturing method - the time for production preparation. The introduced here tool for integration of these different subsystems allows producing many made-to-measure products in time comparable with time needed for production of ready-to-wear products.

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Publication V

Elbrecht, Pirjo; Henno, Jaak; Palm, Knut-Joosep (2013). Waist circumference measurement extraction from 3D scanner data. *In: Advanced Materials Research (725−731). Switzerland:* Trans Tech Publications Ltd (5).

Advanced Materials Research *Online: 2013-08-30*
ISSN: 1662-8985, Vol. 739, pp 725-731
doi:10.4028/www.scientific.net/AMR.739.725

Waist Circumference Measurement Extraction from 3D Scanner Data

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Keywords: Digital tailoring, 3D scanners, body scanning, landmarks, measurements extraction, computer-aided anthropometry, waistline extraction

Abstract. The growing power of computing, development of methods of 3D graphics for human body modeling and simulation together with development of 3D image capture technologies using 3D scanners has caused rapid development of digital tailoring - a complex of methods where *made-to-measure* clothing is produced starting with 3D scanning of a customer, extraction of essential measurements from obtained data cloud and then automatic production of a garment corresponding to exact measures of the customer. Extraction of exact measures from the ca 200000 data points produced by 3D scanner is a complex problem; in the following are considered methods for solving waistline determination and waistline circumference measurement finding.

Introduction

The growing power of computing, development of methods of 3D graphics for human body modeling and simulation together with development of 3D image capture technologies using 3D scanners is rapidly changing ways how we obtain our garments – suits, trousers, skirts etc. The previously commonly bought from shops *ready-to-wear* garments, which were constructed to fit the manufacturer's definition of an abstract 'average customer' and therefore did not fit well any concrete customer are replaced with *made-to-measure* garments, created according to customers personal measures obtained through 3D scanning of his/her body and computational processing of obtained data to get essential measurements needed in the tailoring process.

The most important measurement for clothing items which lean on waist (jeans, trousers, skirts) is the waist circumference. It sets the waist height, front and back rise, vertical rises and also the balance of the product. They all have important role that the product would feel comfortable and fitting.

Most human beings can identify where their waist is, and yet there is no universal, repeatable and comparable way to measure waist circumference precisely. This situation is caused partly by large anatomical variation in human body shapes, and partly by the differing meanings of 'waist' in different applications.

How the definition of the waist measurement meets the customer wished waist and the different levels of waist – low, regular or high waistline?

This paper investigates computation of the waist position from ca 200000 data points obtained with 3D body scanning for different body shapes and genders. The main research problem is: Where are the optimal places for different level of waistlines (low, regular and high) in the front and back of the body from the point of view of perfectly fitting garment construction?

Used hardware

For obtaining human measurements there are two commonly used methods:

- the traditional tape measure,
- software-extracted computer-aided anthropometry, performed with three-dimensional scanner.

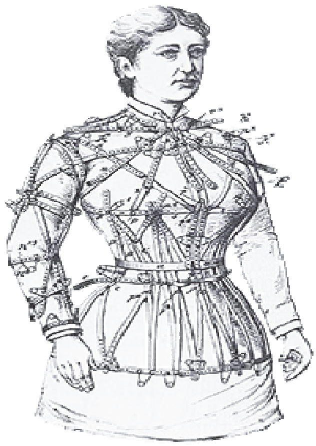

Fig. 1. Tape measuring [1]

Fig. 2. ProVision bodyscanner [2]

This study uses software-extracted computer-aided anthropometry, which is the result of 3D body scanning in the point data cloud. The point data cloud is used for creation of critical landmarks and anthropometric data.

3D Body Scanner. The 3D body scanner is a useful tool that enables effectively and accurately analyzes the human body and its shape proportions. Once a scan is taken, it will be sent to the computer and visualized on the screen. In the next step, software automatically locates body landmarks and generates measurements. Once a person's body is captured using a body scanner, it could be retrieved and any part of his/her body can be measured any number of times without actual contact with the measured person. Scan data can be saved in a special format to be read by CAD system or integration tool that allows the body measurements to be analyzed and directed into the CAD system.

Measurement extraction with body scanner is very precise, but protocols for locating body landmarks still need to be perfected. Traditional body measurements are based on landmarks on the body, which are often identified or located by palpitation, while a computer must be programmed for every eventuality. This affects the percentage accuracy of measurements of the body scanner since certain body landmarks are difficult to identify. This is one of the major reasons for incorrect locations of waist, stomach, and crotch point measurements.

Scanners used. KX-16 utilizes the technology with infra-red depth sensors placed around the body at four specific heights and four specific angles to give complete and accurate body scans. The scanner features an attached changing room and includes the full suite of [TC]2 Body Scanning software functionality including automatic body measurements at more than 400 points; manual measurement capabilities. KX-16 also offers color scan data acquisition; low sensitivity to room light or sharp color contrasts on the scan subjects; and generation of more than two million data points at full-body resolution.

The NX-16 uses safe white light for the scan and provides exceptional accuracy when compared to manual measurements. The process of scanning is private and safe. The scan is taken in 8 seconds, and data density is 600 000 to 800 000 points [3].

Software

The TC^2 3D body measurement software provides an easy and user-friendly interface to extract the measurements and manipulate the data. The Measurement Extraction Profile (MEP File) is modified according to the identified measurement points.The definitions of the measurements are customizable and exported to other formats such as for CAD systems.

The software also allows batch processing of measurement extraction when required. This removes the manual portion of repeatable tasks by removing the need for user intervention.

Printing the scan results is also available for those who would require a hard copy for reference purposes. The print output is customizable to allow you to see only what you require.

Previously used methods

In the literature have been used several waist definitions for apparel:

ISO 8559:1989 Garment construction and anthropometric surveys - Body dimensions [4]
Definition:

2.1.11, waist girth: The girth of the natural waistline between the top of the hip bones (iliac crests) and the lower ribs, measured with the subject breathing normally and standing upright with the abdomen relaxed.

Instrument: no measuring instrument is specified

Remark: only one waist height is required, thus the waist is assumed to be horizontal with the floor. In real life, there are very few people who would correspond to this definition in any waist level.

United States Air Force Research Laboratory Report Caesar: Summary Statistics For The Adult Population (Ages 18-65) Of The United States Of America [5]

Section: Waist circumference preferred

Definition: Maximum circumference of the waist at the subject's 'preferred' waist level. *Method:* subject stands fully erect with the weight distributed equally on both feet and the arms hanging freely downwards. The subject's feet are placed in footprints adhered to the standing surface (the foot prints are positioned approximately 10cm apart at the heels and rotated 33 degrees at the toes). The subject's preferred waist level is marked by using an elastic band.

Note: Preferred waist level is established by the subject, who places an elastic band at the level he or she would prefer to wear the waist of their pants.

Instrument: Steel tape measure.

Japanese Standard JIS Z 8500:2002 Ergonomics - Basic human body measurements for technological design [6]

Definition: 5.2.44, Waist circumference (ISO 7250, 4.4.10): horizontal circumference of trunk at a level midway between the lowest ribs and the upper iliac crest.

Method: Subject takes standing posture. Subject is asked to relax the abdominal muscles

Instrument: Tape measure

Unfortunately, these do not help to find the human being preferred waist. This research investigates lower body garment landmarks for defining preferred waistline for different body shapes, unequal fat deposition, race and gender.

Parameters used for waistline detection

Wasteline detection is based on several parameters of customer's body.

Small of back is the inward curvature of a portion of the lumbar and cervical vertebral column.

Often the small of back identifies the center point of the regular waistline. Product waistline cannot rise to the negative angel of the back, resulting bad fitting garments in the small of back area. (Fig.3). For larger figures the product waistline should start from the small of back area to ensure the comfort of the product.

Product waistline should be higher from the back lowering towards to front. The angel between center back and center front is increasing value starting from high waistline (Fig. 10). Example: In the same human, the angel between center back point and front point in high waistline is 10 degrees, in regular waistline 15 degrees and in low waistline 20 degrees.

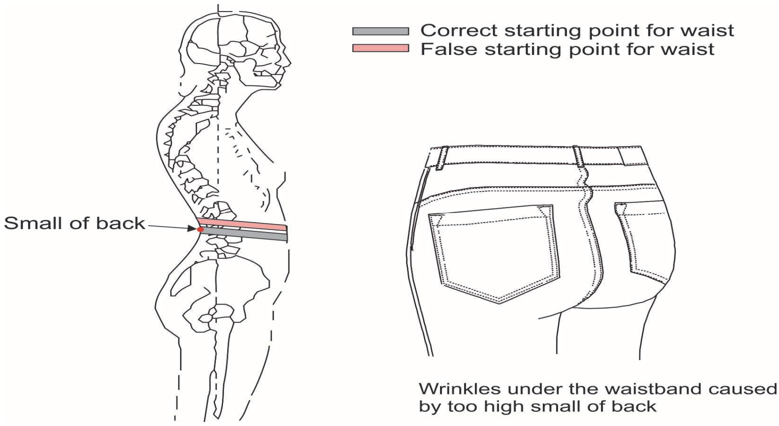

Fig. 3. Small of back

For different people the small of back point appears in different positions.

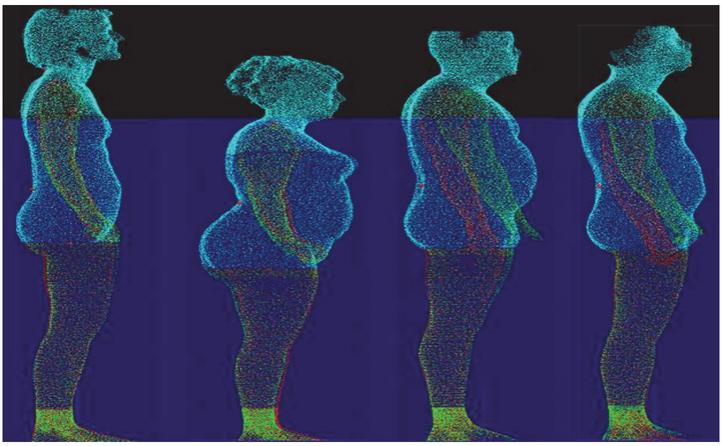

Fig. 4. Small of back of different human beings in 3D scanner images

The seat back angle is a very important indicator for the placement of the product waistline.
Seat back angle is the angle (in degrees from vertical) of a line drawn between the rear most point of the seat and the small of the back.

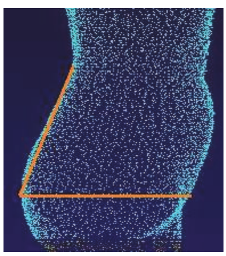

Fig. 5. Seat back angle

The deeper is the seat back angle and the shape of the back curve (form sharp angles) on the small of back level, the closer are the preferred waistlines of the different designs to each other (high, regular, low), see Fig. 6, 7.

The closer in are the preferred waistlines of the different designs to each other (high, regular, low), the bigger is the center back point angel in degrees to center front height (Fig. 6, 7).

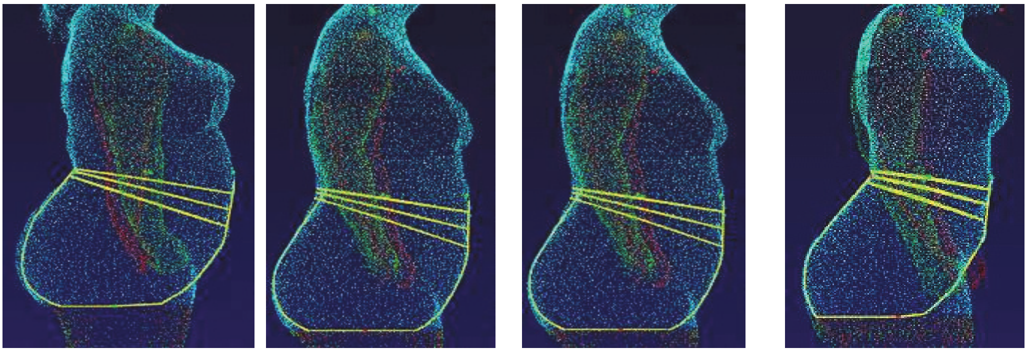

Fig. 6. Preferred waistlines (high, regular, low) at the small of back level (female)

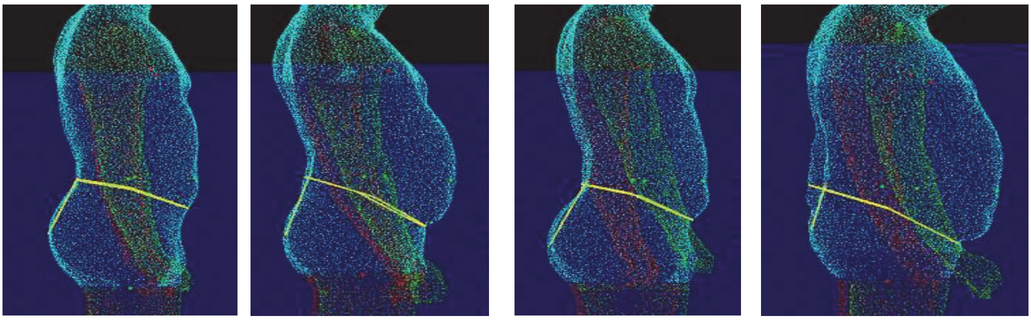

Fig. 7. Preferred waistline[1] at the small of back level (male)

It is caused by the fact that in the smallest place of the back the waist stays up and do not slide down when sitting or bending down. Most humans do not like when their buttock cleavage is showing and it is for general public not ethical neither esthetical to show it to the others - except for some designer trends (Fig. 8, 9).

Fig. 8. Buttock cleavage in the painting [7]

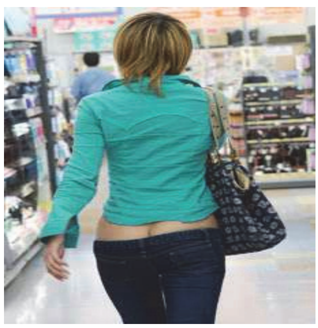

Fig. 9. Buttock cleavage in the jeans [8]

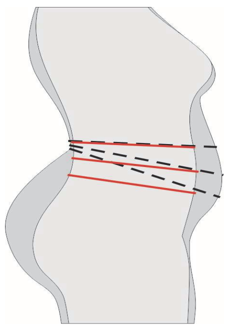

Fig. 10. Front rise comparison

When the shape of the back curve on the small of back level is flat and long, then the different waistlines are distributed more distant from each other (Fig. 11, 12).

[1] Males with big belly have one suitable waistheight, except when they are using suspendors.

The angel between the smallest back and center front is less than in the curvier small of back subjects.

It can be explained with the fact that some females want to have the same front rise (preferred waist on the level high, regular, low), but because of the different shape of the small of back area, the starting point of the back is different (Fig.10).

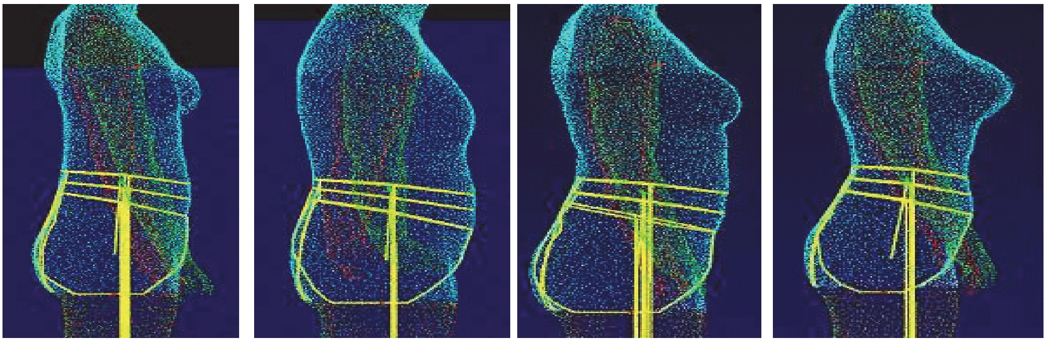

Fig. 11. Preferred waistlines (high, regular, low) at the small of back level (female)

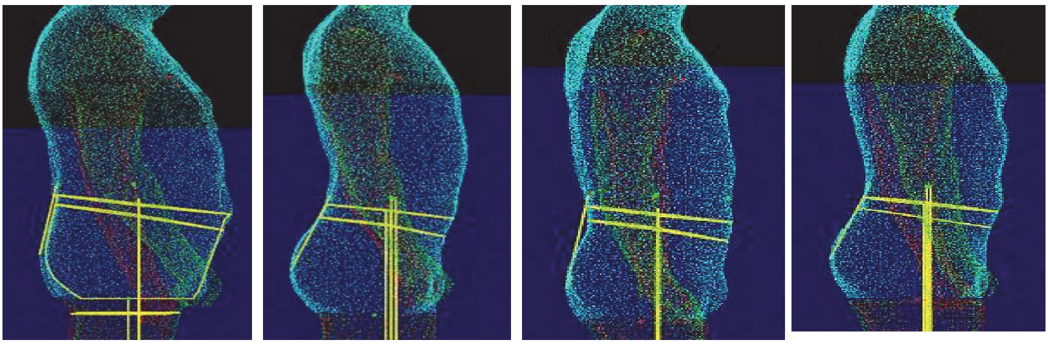

Fig. 12. Preferred waistlines (regular, low[2]) at the small of back level (male)

Center front point

For men with big belly there is only one possible place for waistline centrer front point to be positioned (trousers). The right place is under the belly in the narrowest place in the front (Fig. 13).

Here are investigated waistlines for the trousers worn without suspenders.

The waistline centrer front point can not be higher because the product waistline does not stay without external help in the belly curve and the trousers are more comfort to wear.

When the waisline would be placed on the belly then most males would complain that the trousers are pressing too much to the stomach. Trousers waist circumference should be bigger, but then they should be worn with suspenders otherwise they will drop down.

[2] Males do not have high waistline usually.

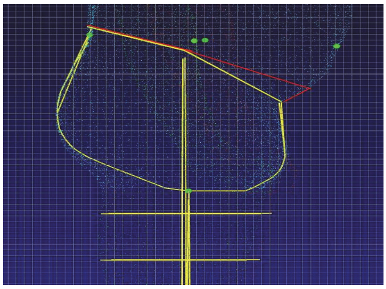

Fig. 13. Yellow line represent´s the preferred waist position for big belly male

Summary
The most important measurement for clothing items which lean on waist (jeans, trousers, skirts) is the waist circumference. It is very important that the waistlines would follow the human body natural curves and pumps.

To achieve the preferred waist in different humans, it is necessary to create different measurement extraction formulas for waist circumference. There does not exist one perfect formula. In this work have been used 10 different measurement extraction formulas for creating three different levels of waistlines. Some examples of possible waist measurement extraction:

High waistline for females

- Upper limit of small of back point height referenced to starting point = 2,0 cm
- Lower limit of small of back point height referenced to starting point = 0 cm
- Upper limit of center front point height referenced to small of back point = -10 degrees
- Lower limit of center front point height referenced to small of back point = -12 degrees

Regular waistline for females

- Upper limit of small of back point height referenced to starting point = 0 cm
- Lower limit of small of back point height referenced to starting point = 0 cm
- Upper limit of center front point height referenced to small of back point = -14 degrees
- Lower limit of center front point height referenced to small of back point = -16 degrees

Low waistline for females

- Upper limit of small of back point height referenced to starting point = 0 cm
- Lower limit of small of back point height referenced to starting point = 2,0 cm
- Upper limit of center front point height referenced to small of back point = -18 degrees
- Lower limit of center front point height referenced to small of back point = -20 degrees

The measurement extraction software has to be improved to stand up for the demand of apparel business.

References

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[2] http://www.thetechherald.com/articles/3D-airport-body-scanner-labelled-as-virtual-strip- search

[3] http://www.tc2.com/index_3dbodyscan.html

[4] International Organization for Standardization, Garment Construction and Anthropometric Surveys ± Body Dimensions, Reference No. 8559-1989, International Organization for Standardization, Geneva, 1989.

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[7] http://en.wikipedia.org/wiki/File:C_W_Eckersberg_1841_-_Kvinde_foran_et_spejl.jpg

[8] http://allthingswildlyconsidered.blogspot.com/2012/05/huge-hooter-safety-hazard-taping.html

CURRICULUM VITAE

Name:	**Pirjo Elbrecht**
Date and place of birth:	**16.04.1984, Tartu**
E-mail:	**pirjoelbrecht@gmail.com**

EDUCATION

2014 –2015 **IT College** Tallinn, Estonia
IT Systems Development

2010 –… **Tallinn University of Technology** Tallinn, Estonia
Information and Communication Technology (Ph.D.)

2006 – 2009 **Tallinn University of Technology** Tallinn, Estonia
Master of Science in Engineering (MSc) in Technology of Materials with specialization in clothes manufacture (production manager), with a focus on:

- Fiber science, textile chemistry, high-performance fibers
- CAD/CAM – Lectra, Modaris, Diamino, Kaledo, CorelDraw
- Production management, brand development
- Fashion design, quality engineering, manufacturing technology and quality control of apparel, apparel design, apparel manufacturing processes, textile testing, placement, protective clothing design

2003 – 2006 **Technical School of Light Industry** Tallinn, Estonia
Technical Design and Technology of Apparel, with a focus on:

- Pattern construction (base patterns, modelling the base patterns)
- Garment construction
- The technology of sewing, technical grading.
- Drawing
- CAD&CAM software - Lectra
- Draping

PROFESIONAL MEMBERSHIP

- **Member of the IEEE** – The world´s largest professional association for the advancement of technology.
- **IEEE Technical Committee on RFID**
- **Member of the ASTM** - ASTM International, known until 2001 as the American Society for Testing and Materials (ASTM), is an international standards organization that develops and publishes voluntary consensus technical standards for a wide range of materials, products, systems, and services.

ACADEMIC EMPLOYMENT

2015 – 2017 **Tallinn University of Technology** Tallinn, Estonia
Post: Lecturer of "2D and 3D technologies in garment industry"
Task: Teaching new technologies and 2D and 3D software's.

2012 – 2013 **Tallinn University of Technology** Tallinn, Estonia
Post: Lecturer for the subject Computer-assisted manufacturing in apparel industry
Task: The textile- and clothing manufacturing pipeline, from design to retail, focus on the communication of information.

2008 – 2009 **Tallinn University of Technology** Tallinn, Estonia
Post: Author of a study program
Task: "The development of internet-based learning material for "Pattern making I" syllabus". Anthropology. Human body composition assessment. Garment evolution and classification. Requirements for clothing. Pattern making systems. Garment construction of basic structures of the different methodologies. Modeling patterns. Preparing templates.

EMPLOYMENT

2010 – … **incognito ballistic LLC.** Milano / Tallinn, Estonia
Post: CAD/CAM engineer
Type of company: Industrial, power sport and transportation design
Task: Developing Product Lifecycle Management (PLM) to produce fitting unique one of a kind garment for 3D measured customers. Mainly processes between customer 3D body scanning until ready marker files for the production. Pattern development – Estonian police, Lithuanian police, security companies.

- Hilding Anders (http://www.hildinganders.com/) visualization consultant. Hilding Anders is leading manufacturer of beds and mattresses in Europe, Russia and Asia. Project leader for On-Demand production line. The goal is To build automated on-demand production line for small-series production. It starts with Made-to-Measure CAD integration with ERP system. The information is forwarded to the storage robot. The storage robot holds the fabrics. According to the production order, the storage robot delivers the fabric rolls to the cutter. All the products are cut out with single ply cutter, assembled and produced according to the production order.
- Beijing Luthai Youqian E-Commerce Co., Ltd. - Made-To-Measure shirt system for UTAILOR (http://www.utailor.com.cn/). Beijing Luthai Youqian E-Commerce Co., Ltd. engages in manufacturing and online retailing of customized shirts for men. The company

operates a web based platform and smart phone application where customers can customize shirt designs. The company was founded in 2014 and is headquartered in Beijing, China. The company operates as a subsidiary of Lu Thai Textile Co., Ltd. Customers can make an appointment and order conveniently through Utailor, Vshop, Jingdong Flagship Store or 400 telephone. The Company provides customized service for clients in high quality. Since “UTAILORE”, one of its high-end men’s clothing was pushed to the market, repeat purchase rate from its customers, old and new, is rising consistently. Now, its business expands from high-end shirt

2010 – 2014 **Nomo Jeans Corporation** Helsinki, Finland

Post: CAD/CAM engineer

Type of company: NOMO makes computer-assisted Made-To-Measure jeans. They take your precise measurements with the 3D body scanner. They will keep your measurements for your future purchases, which can be easily done in their web shop. The company had 5 shops in three different countries.

Task: Assist and lead NOMO Jeans in creating processes for Customer fit by creating interfaces between scanning, WebStore, pattern creation and manufacturing, automating pattern creating from orders and measurements and test and improve the scalability of the processes. Solve problems with the way.

2007 – 2010 **Amanjeda** Tallinn, Estonia

Post: Patternmaker

Type of company: Fashion (Haute Couture, Made-To-Measure, Pret A Porter

Task: working with the head designer in developing the line and executing designer aesthetic. Executing and creating a development pattern from designer sketch and inspiration images (creating neat and highly organized patterns). Working with complicated designs in all types of fabric and garment styles. Work closely with sample makers and execution of first samples through production. Communicating with clients and manufacturers; making technical drawings; developing the Made-To-Measure program (FitNet).

2003 – 2007 **incognito ballistic LLC.** Milan / Tallinn, Estonia

Post: Patternmaker

Type of company: Industrial, power sport and transportation design

Task: Making patterns for the world top race teams, casual and race wear, corresponding to the fashion designer's vision. Communicating with manufacturers; making technical drawings.

PEER-REVIEWED PUBLICATIONS

- Elbrecht, Pirjo (2016). Information Processing For Mass Customized Clothing Production. 2016 IEEE International Conference on Semantic Computing (ICSC), Laguna Hills, California, USA, February 3-5, 2016
- Elbrecht, Pirjo (2014). The precision of the 3D body scanners. IEEE 18th International Conference on Intelligent Engineering Systems (INES) July 3-5, IEEE, Hungary
- Elbrecht, Pirjo (2013). Use of the 3D body Scanner Data in The Digital Tailoring. In: Proceedings of the 4th International Conference on the 3D body Scanning Technologies: Long Beach CA, USA, 19-20 November 2013. Hometrica Consulting - Dr. Nicola D´Apuzzo
- Elbrecht, Pirjo (2013). The Digital Tailoring system for digitized tailoring. IEEE 17th International Conference on Intelligent Engineering Systems (INES) June 19-21, IEEE, Costa Rica
- Elbrecht, Pirjo (2013). Body measurements extraction from 3D scanner data. Advanced Materials Research. Thomas Wohlbier, TTP USA, 2013
- Elbrecht, Pirjo (2013). Waist circumference measurement extraction from 3D scanner data. Pirjo Elbrecht. Advanced Materials Research. Thomas Wohlbier, TTP USA, 2013
- Elbrecht, Pirjo (2012). Made-To-Measure jeans. In: Proceedings of the Asian Workshop on the 3D body Scanning Technologies: 1st Asian Workshop on the 3D body Scanning Technologies, Japan, Tokyo, 17-18 April 2012. Hometrica Consulting - Dr. Nicola D´Apuzzo, 134 - 138.
- Elbrecht, Pirjo (2010). Implementational anthropometric studies. In Info- ja kommunikatsioonitehnoloogia doktorikooli IKTDK neljanda aastakonverentsi artiklite kogumik. Infotrükk OÜ, 2010

INVITED ORAL PRESENTATIONS

- IEEE International Conference on Semantic Computing (ICSC), Laguna Hills, California, USA, February 3-5, 2016
- 18th IEEE International Conference on Intelligent Engineering Systems. July 3-5, 2014 in Tihany, Hungary.
- The 4th International Conference and Exhibition on the 3D body Scanning Technologies. 19 to 20 November 2013, in Long Beach, California, USA.[8]
- 17th IEEE International Conference on Intelligent Engineering Systems. June 19-21, 2013 in Costa Rica.
- World Congress on Industrial Materials -Applications, Products, and Technologies April 1-2, 2013. Beijing, China
- 2013 Electromechanical and Control Engineering Symposium on the Asia-Pacific region March 26 to 27, 2013. Hong Kong, China

[8] This speech was pointed out in the Wear organization newsletter as one of the two highlight speeches of the conference. http://www.bodysizeshape.com/newsletterWEAR

- Asian Workshop on the 3D body Scanning Technologies. 17 to 18 April 2012, In Tokyo, Japan

PROJECTS

- Aalto University and Nomo Jeans Use 3D Visualization for a Custom Fit (2013) http://www.browzwear.com/aalto-university-and-nomo-jeans-use-3d-visualization-for-a-custom-fit/#!

COMMITTEES / REVIEWER

Commission of the master degree (2015).
Reviewer of the Master´s Thesis of:

- Training material: methodologies for grading the basic block. Agnes Uustallo (2015)

Supervisor for Master´s Thesis of:

- Improving the fit with the use of the 3D body scanners. Maarja Karu (2015)

AWARDS AND ACHIEVEMENTS

IT Academy scholarship for Information and Communication Technologies Student 2013
The National Doctoral School in Information and Communication Technologies grant 2011
The National Doctoral School in Information and Communication Technologies grant 2010

SKILLS AND ACTIVITIES

- CAD/CAM for apparel:
  - ✓ Lectra systems – Modaris, Diamino, FitNet (Made-To-Measure), Kaledo (experience 18 years)
  - ✓ GERBER technology – Pattern Processing, Marker Creation, Plotting and Cutting, Accumark Explorer, MTM (Made-To-Measure). Versions 8.4, 8.5 and 10 (experience 8 years)
  - ✓ Human solutions – Assyst, Anthroscan, CadCam, Vydia, MTM, PLM
  - ✓ Gemini
- CAD/CAM:
  - ✓ CorelDraw,
  - ✓ AutoCad
- Body scanner related software:
  - ✓ Tc^2
  - ✓ MEP – measurement extraction profile
  - ✓ SizeStream
- Other computer skills**:**
  - ✓ Abobe Photoshop,
  - ✓ Microsoft office - Word, Excel, PowerPoint
  - ✓ Dreamweaver
- Driving license: A; B

ELULOOKIRJELDUS

Nimi:	**Pirjo Elbrecht**
Sünnipäev ja koht:	**16.04.1984, Tartu**
E-mail:	**pirjoelbrecht@gmail.com**

HARIDUS

2014 – 2015	**Eesti Infotehnoloogia Kolledž** IT süsteemide arendus	Tallinn, Eesti
2010 –…	**Tallinna Tehnikaülikool** Info- ja kommunikatsioonitehnoloogia õppetool (PhD)	Tallinn, Eesti
2006 – 2009	**Tallinna Tehnikaülikool** Magistrikraad materjalitehnoloogia õppekaval, spetsialiseerumisega rõivaste tootmisele	Tallinn, Eesti
2003 – 2006	**Tallinna Kergetööstustehnikum** Modelleerija	Tallinn, Eesti

PROFFESIONAALNE LIIKMELISUS

- **IEEE liige** – Maailma suurim professionaalide kutseliit.
- **IEEE RFID tehnilise kommitee liige.**
- **ASTM** liige- ASTM International on tuntud kui Ameerika Standardikeskus, mis loob, arendab ja publitseerib tehnilisi standardeid suurele hulgale erinevatele materjalidele, toodetele, süsteemisele ja teenustele.

AKADEEMILINE TEENISTUSKÄIK

2015 – 2017	**Tallinna Tehnikaülikool** **Amet:** Lektor/insener. CAD / CAM süsteemid rõivatööstuses	Tallinn, Eesti
2012 – 2013	**Tallinna Tehnikaülikool** **Amet:** Lektor. CAD / CAM süsteemid rõivatööstuses	Tallinn, Eesti
2008 – 2009	**Tallinna Tehnikaülikool** **Amet:** E-õppe programmi kaasautor. E-õppe materjalide väljatöötamine ainele "Konstrueerimine I"	Tallinn, Eesti

TEENISTUSKÄIK

2010 – …	**incognito ballistic LLC.** **Post:** CAD/CAM insener	Milan / Tallinn, Estonia
2010 – 2014	**Nomo Jeans Corporation** **Post:** CAD/CAM insener	Helsinki, Finland
2007 – 2010	**Amanjeda** **Post:** Lõigete tehniline disainer	Tallinn, Estonia
2003 – 2007	**incognito ballistic LLC.** **Post:** Lõigete tehniline disainer	Milan / Tallinn, Estonia

EKSPERTHINNANGU SAANUD PUBLIKATSIOONID

- Elbrecht, Pirjo (2016). Information Processing For Mass Customized Clothing Production. 2016 IEEE International Conference on Semantic Computing (ICSC), Laguna Hills, California, USA, February 3-5, 2016
- Elbrecht, Pirjo (2014). The precision of the 3D body scanners. IEEE 18th International Conference on Intelligent Engineering Systems (INES) July 3-5, IEEE, Hungary
- Elbrecht, Pirjo (2013). Use of the 3D body Scanner Data in The Digital Tailoring. In: Proceedings of the 4th International Conference on the 3D body Scanning Technologies: Long Beach CA, USA, 19-20 November 2013. Hometrica Consulting - Dr. Nicola D´Apuzzo
- Elbrecht, Pirjo (2013). The Digital Tailoring system for digitized tailoring. IEEE 17th International Conference on Intelligent Engineering Systems (INES) June 19-21, IEEE, Costa Rica
- Elbrecht, Pirjo (2013). Body measurements extraction from 3D scanner data. Advanced Materials Research. Thomas Wohlbier, TTP USA, 2013
- Elbrecht, Pirjo (2013). Waist circumference measurement extraction from 3D scanner data. Pirjo Elbrecht. Advanced Materials Research. Thomas Wohlbier, TTP USA, 2013
- Elbrecht, Pirjo (2012). Made-To-Measure jeans. In: Proceedings of the Asian Workshop on the 3D body Scanning Technologies: 1st Asian Workshop on the 3D body Scanning Technologies, Japan, Tokyo, 17-18 April 2012. Hometrica Consulting - Dr. Nicola D´Apuzzo, 134 - 138.
- Elbrecht, Pirjo (2010). Implementational anthropometric studies. In Info- ja kommunikatsioonitehnoloogia doktorikooli IKTDK neljanda aastakonverentsi artiklite kogumik. Infotrükk OÜ, 2010

KUTSUTUD SUULISED ETTEKANDED

- 18th IEEE International Conference on Intelligent Engineering Systems. July 3-5, 2014 in Tihany, Hungary.
- The 4th International Conference and Exhibition on the 3D body Scanning Technologies. 19 to 20 November 2013, in Long Beach, California, USA.[9]
- 17th IEEE International Conference on Intelligent Engineering Systems. June 19-21, 2013 in Costa Rica.
- World Congress on Industrial Materials -Applications, Products, and Technologies April 1-2, 2013. Beijing, China
- 2013 Electromechanical and Control Engineering Symposium on the Asia-Pacific region March 26 to 27, 2013. Hong Kong, China
- Asian Workshop on the 3D body Scanning Technologies. 17 to 18 April 2012, In Tokyo, Japan

[9] This speech was pointed out in the Wear organization newsletter as one of the two highlight speeches of the conference. http://www.bodysizeshape.com/newsletterWEAR

PROJEKTID

- Aalto University and Nomo Jeans Use 3D Visualization for a Custom Fit (2013) http://www.browzwear.com/aalto-university-and-nomo-jeans-use-3d-visualization-for-a-custom-fit/#!
- On-Demand tootmisliini arendamine.

KOMMITEED / ARVUSTAJA

Magistri kaitse komisjoni liige (2015)
Retsensent magistitöödele:

- Training material: methodologies for grading the basic block. Agnes Uustallo

Magistritöö juhendaja:

- Improving the fit with the use of the 3D body scanners. Maarja Karu

AUHINNAD JA SAAVUTUSED

IT Academy scholarship for Information and Communication Technologies Student 2013
The National Doctoral School in Information and Communication Technologies grant 2011
The National Doctoral School in Information and Communication Technologies grant 2010

OSKUSED

- Väga heal tasemel inglise keel Hea arusaamine saksa keelest.
  - ✓ Lectra süsteemid – Modaris, Diamino, FitNet (Made-To-Measure), Kaledo (kogemust 15 aastat)
  - ✓ GERBER technology – Pattern Processing, Marker Creation, Plotting and Cutting, Accumark Explorer, MTM (Made-To-Measure). Versions 8.4; 8.5 and 10 (kogemust 8 aastat)
  - ✓ Human solutions – Assyst, Anthroscan, CadCam, Vydia, MTM, PLM
  - ✓ Gemini
- CAD/CAM:
  - ✓ CorelDraw,
  - ✓ AutoCad
- Body scanner related software:
  - ✓ Tc^2
  - ✓ MEP – measurement extraction profile
  - ✓ SizeStream
- Teised arvutioskused**:**
  - ✓ Abobe Photoshop,
  - ✓ Microsoft office - Word, Excel, PowerPoint
  - ✓ Dreamweaver
- Juhiload: A; B