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KAUNAS UNIVERSITY OF TECHNOLOGY

FACULTY OF MECHANICAL ENGINEERING AND DESIGN

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THE ANALYSIS OF FABRICS' VIRTUAL DRAPE POSSIBILITIES IN 3D MODELLING SYSTEMS

Final project for Master degree

Supervisor
Assoc. Prof. Dr. Kristina Ancutiene

Kaunas, 2016

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(Title and code of study programme)

The Analysis of Fabrics' Virtual Drape Possibilities in 3D Modelling Systems

DECLARATION OF ACADEMIC HONESTY

<u>01</u>　　　　<u>　　01　　</u>　　<u>2016</u>
Kaunas

I confirm that a final project by me, **Maneesh Kumar Mishra**, on the subject "The Analysis of Fabrics' Virtual Drape Possibilities in 3D Modelling Systems" is written completely by myself; all provided data and research results are correct and obtained honestly. None of the parts of this thesis have been plagiarized from any printed or Internet sources, all direct and indirect quotations from other resources are indicated in literature references. No monetary amounts not provided for by law have been paid to anyone for this thesis.

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MANEESH KUMAR MISHRA　　　　　Maneesh Kr. Mishra

(name and surname filled in by hand)　　　　　*(signature)*

PREFACE

Master thesis **"**The Analysis of Fabrics' Virtual Drape Possibilities in 3D Modelling Systems" has been written to fulfil the graduation requirement of MSc. Fashion Engineering, Kaunas University of Technology, Lithuania. I was engaged in researching and writing this thesis from August 2015 to January 2016.

The project was undertaken to investigate garment 3D simulation by using different 3D software. Research objective was formulated together with my supervisor, Dr. Kristina Ancutiene. Extensive investigatrion was involved in the research; however, I was fortunate enough that my supervisor was always available and willing to answer my queries.

I would like to thank my supervisor for her keen guidance during this process. I also thank to all the respondents, whose cooperation enabled me to conduct this analysis.

To my family and friends: I would like to thank you for your cooperation and benefits of the debating issues we had. If I ever lost my interest, you retained me motivated. My parents deserve a particular note of thank: your wise counsel and kind words have, as always, served me well. My beloved late mothers' last treasure words – fulfil the goal what I have been here for, motivated me all through. May god embrace her in peace and keep me encouraged to follow her words, the way I have been so far.

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SUMMARY

Maneesh Kumar Mishra. The analysis of fabrics' virtual drape possibilities in 3D modelling systems. *MSc. Fashion Engineering* final project / supervisor Assoc. Prof. Dr. Kristina Ancuitiene; Kaunas University of Technology, Mechanical Engineering and Design faculty, Material Engineering department. Kaunas, 2016. 68 p.

Fashion and garment industry, being one of the largest and most profitable industries in the world, with the current meltdown, and capital flows changing course, the industry is witnessing drastic modifications. Design and product development tools and techniques are the main stream competitive factor in this industry for the reason that apparel product prototyping has been a long-stretching process taking often countless hours of work, material, labor etc Likewise, internet shopping has grown rapidly as a compelling channel for the sale of garment products. However, consumer cannot try and therefore, high product return rates persist because garment do not exactly fit on consumers' body. Subsequently, apparel companies are focusing more on providing mass customization and three-dimensional virtual try-on for e-commerce consumers. Online apparel shopping currently provides virtual avatars created manually, but avatars are not the same as consumers' body and the apparels are not draped so well to resemble like if it were really draped.

The purpose of this research is to evaluate the fit, appearance and simulation of virtual prototyping and virtual try-on garments and develop an interchange between mechanical attributes of fabrics and the three software – Lectra Modaris 3D (three dimentional) Fit, Maya nCloth and 3Ds Max.

Drape meter mechanism similar to sprig-mass model was used during the experiment to measure the manual drape of KES-FB[1] tested fabric samples. In addition, the skirt sample of the same denim was simulated twice in Lectra Modaris 3D Fit – first, by setting the right value and second, by exchanging the values of warp and weft, to check the coefficient of variant (CV) and the impact occurred on simulation. In Autodesk Maya nCloth and 3Ds Max denim samples were simulated by manipulatively optimizing the values in order to imitate the shape similar to the real draped samples on drape meter.

After calculation of coefficient of correlation among KES-FB, draped skirt sample in Lectra Modaris 3D Fit and real drape (by drape meter), significance in results were found which indicated the suitability of Modaris 3D Fit to utilize in process. Furthermore, the results obtained in 3Ds Max were more convincing than Maya nCloth because of the availability of anisotropic[2]. Coefficient of correlation between mutual properties[3] of KES-FB and Maya nCloth e.g., bending, stretch and shear was calculated and equations of correlation were presented. Correspondingly, calculated the correlation between KES-FB and Autodesk 3Ds Max, and presented graphs of similar attributes along with equations. Obtained equations are helpful for future researchers while, unavailability of units for four out of five prominent attributes, in both the software – Maya nCloth and 3Ds Max has been a hurdle and requires further exploration on the topic.

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[1] Kawabata evaluation systems for fabrics
[2] Facilitation to set warp and weft values separately
[3] Properties available in both the computer added design (CAD) software

SANTRAUKA

Maneesh Kumar Mishra. Audinių virtualaus drapiravimosi galimybių analizė 3D modeliavimo sistemose. Magistro baigiamasis projektas / vadovas doc. dr. Kristina Ancutienė; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas, Medžiagų inžinerijos katedra. Kaunas, 2016. 68 psl.

Mados ir aprangos pramonė, būdama viena iš didžiausių ir daugiausiai pelno nešančių pramonės rūšių pasaulyje, dabartiniu nuosmukio ir besikeičiančių kapitalo srovių metu drastiškai keičiasi. Drabužių prototipų kūrimas yra daug laiko, darbo, medžiagų ir pan. išnaudojantis procesas, todėl mados ir produktų kūrimo įrankiai yra pagrindinis konkurencijos veiksnys. Dabartiniu laikotarpiu, drabužių apsipirkimo internetu poreikis išaugo, tačiau vartotojai negali gaminių pasimatuoti ir taip išsirinkti tinkančių, dėl šios priežasties dažnai drabužiai yra grąžinami. Todėl drabužius gaminančios kompanijos sutelkia vis daugiau dėmesio į masinį drabužių pritaikymo suteikimą ir virtualų 3D drabužių matavimąsi. Dabar interaktyviose drabužių parduotuvėse yra virtualios žmonių figūros, sukuriamos rankiniu būdu, kuriomis galima naudotis renkantis drabužius, tačiau virtuali figūra ir rūbai matomi ant jos neatspindimi tikroviškai.

Šio tyrimo tikslas yra įvertinti virtualaus prototipo ir virtualaus 3D drabužių matavimosi tinkamumą ir modeliavimą ir sukurti ryšį tarp mechaninių medžiagų savybių ir trijų programinių įrangų – Lectra Modaris 3D Fit, Maya nCloth ir 3Ds Max.

Medžiagos matavimo mechanizmas, panašus į spyruoklės-masės modelį, buvo naudojamas eksperimento metu išmatuojant KES-FB medžiagų pavyzdžius. Sijonas, pagamintas iš to paties džinsinio audinio, buvo sumodeliuotas du kartus Lectra Modaris 3D Fit programa – pirmiausia nustatant teisingą vertę, antra, keičiant matmenų ir audinių vertes, kad patikrintume varianto koeficientą (CV) ir įvertintume poveikį atsiradusį simuliacijoje. Autodesk Maya nCloth ir 3Ds Max programose džinso pavyzdžiai sumodeliuoti optimizuojant reikšmes, siekiant atvaizduoti panašias formas į gautas matavimo metu.

Apskaičiavus koreliacijos koeficientą tarp KES-FB, Lectra Modaris 3D Fit programa gauto sijono pavyzdžio ir tikrosios medžiagos, nustatyta, kad Modaris 3D Fit programa tinkama naudoti šiame procese. Be to, 3Ds Max programa gauti rezultatai yra labiau įtikinami už gautus Maya nCloth programa, dėl galimos anizotropijos. Koreliacijos koeficientas tarp KES-FB ir Maya nCloth bendrų savybių, pavyzdžiui, lenkimo, tempimo ir kirpimo, apskaičiuotas ir lygtys koreliacijai apskaičiuoti pateiktos. Taip pat, apskaičiuota koreliacija tarp KES-FB ir Autodesk 3Ds Max ir pateikti grafikai kartu su lygtimis. Gautos lygtys bus naudingos ateities tyrėjams, tačiau keturių iš penkių žinomų atributų nebuvimas programinėse įrangose Maya nCloth ir 3Ds Max buvo kliūtis tyrime ir reikalauja tolesnio temos tyrinėjimo.

1. INTRODUCTION

Fashion and garment industry, being one of the largest and most profitable industries in the world, with the current meltdown, and capital flows changing course, the industry is witnessing drastic modifications (Iqbal, 2013, p. 12). With the introduction of innovation, technology and broadband connectivity every sector has improved upon their downstream supply chain. In 90s, with the establishment of internet and Hotmail, garment industry started posting technical specification sheet to producers by email which cut down the cost and the waiting time for prototyping of garment which used to be time taking and expensive process. Moreover, with the debut of Lectra Modaris 3D Fit and Autodesk CAD based pattern making and garment construction became easier. Consequently, by thinking out of box, the idea of 3D simulation took birth and use of the mechanical properties of KES-FB in Lectra Modaris 3D Fit was on the go for simulation and drape.

Later on, with the evolution in garment retailing, e-commerce outturned and with the advancement, virtual try on originated, neverthess, it is not so common because of cost levied to integrate it online. Garment industry e-commerce requires evolutionary landscape in digital technology so that time and cost can be reduced. These benefits suggest more research into virtualization system to find out a more expedient way to it (Martin Christopher, Robert Lawson, 2004).

1.1 Problem

Various software – Toyobo DressingSim, Optitex 3D Runway Suite, Browzwear V-Stitcher, Autodesk etc are being used in garment industry for pattern making and simulation, and certain other graphic purposes. Nonetheless, in research and development accuracy is crucial which could not be obtained at satisfactory level so far. Solution to the virtual simulation in static and dynamic states is there which required further research in order to improve (Magnenat-Thalmann, 2010, p. 148).

Although, companies for instance, dressformer.com, metail.com, joyofclothes.com and other companies have online try on, and they are claiming to be 94-96% accurate in measurement and styling (Adeyoola, 2015). According to an article, university of Sydney is also working on to develop a mobile app with more accuracy to virtual try on (Zolfagharifard, 2015). On the other hand, all of them worked on the basis of size, color, texture, appearance, angular look on a static model which was chosen and measurements were tuned by the customer to get certain size. Try on based on fabric type, its natural drape and realistic dynamic drape remained unexplored.

1.2 Objective

A seek for virtual prototyping for garment production and retailing by using Lectra Modaris 3D Fit and virtual try on with ordinary 3D software e.g., Autodesk Maya nCloth and 3Ds Max with fabric type, natural drape of that fabric, and realistic drape is the aim of this thesis.

1.3 Organization of this Thesis

Chapter 1 covers the overview about the use of 3D simulation software, problems and objective of this thesis.

Chapter 2 describes the researches and results were already obtained earlier on similar topic.

Chapter 3 comprises of methodology used thoughout the thesis.

Chapter 4 contains the results and findings acquired using drape meter, Lectra Modaris 3D Fit, Autodesk Maya nCloth and 3Ds Max.

Chapter 5 concludes the thesis with brief summary of work outomes and a lead to future research.

2. LITERATURE REVIEW

2.1 3D Designing Systems in Apparel Industry

In order to virtually simulate the fabric and clothing more vividly, various software e.g., professional CAD (Lectra Modaris 3D Fit, Toyobo DressingSim, Optitex 3D Runway Suite, Browzwear V-Stitcher and others), Maya nCloth, 3D Max, NVIDIA, Havok and other have been used. With Modaris it is possible to reach close to the real simulation; however, it is not practicable to use online shopping due to its hefty size to access. Therefore, to reduce the percentage of error in simulation results and to find the suitable solution, in this dissertation more contemporary software shall be used to simulate the fabric (Magnenat-Thalmann, 2010).

The available software for simulating virtual clothing can roughly[4] be separated into two groups. First group of software is focused on animation and used to visualize cloth for games, movies, commercials. The second group is used for the virtual prototyping of garments in the apparel industry.

Figure 1 Fabric Simulation in Maya nCloth *Source*: **(Schilder, 2008)**

Maya nCloth used to have a cloth connect that was based on the same principle as the existing software that is mostly used in the apparel industry. The problem found that animators facing hurdle to work with it because they do not know anything about patterns. They do not have a background in fashion design. The new Maya nCloth is much easier for animators because one could just model a shape around a body, make the shape into cloth and let it drape. It is not required to stitch patterns anymore (above figure shows one of the examples created through modeling a shape around body) (N., 2010).

The second group is software for the virtual prototyping, belongs to the apparel industry. Associating fabric information, 2-D patterns and 3-D virtual mannequins, these programs let the simulation be and realistic visualization of 3-Dimensional garments, with various fabrics, motifs and color ranges (Figure 1.2) (Schilder, 2008). These programs allow garment fit to be

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[4] It is not a a clear segregation, according to need one group might be utilized in another

checked for ease, balance, sewing lines, proportions in various fabrics and sizes; and the fine-tuning of product specifications. Examples are: Lectra Modaris 3D Fit, 3D Runway from OptiTex, Autodesk 3D Max and Gerber V-stitcher. Hence, in order to gain more accuracy more research is needed.
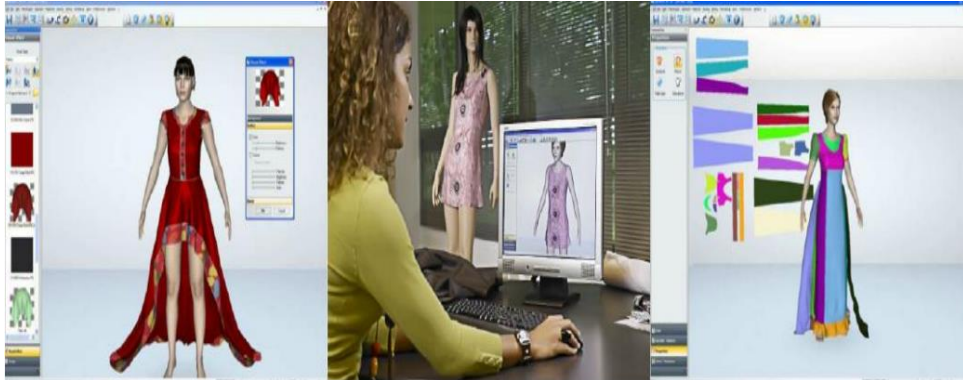
Figure 2 Fabric Simulation in Maya nCloth *Source***: (Schilder, 2008)**

In entertainment industry it is used for computer animation, commercials and movies and therefore, it is important for a virtual character to look convincing. Clothing plays an important role in that because it tells so much about a person (Kenkare, 2005).

Applications can be: garment designs for virtual actors, virtual TV or web presenters, virtual ancient people dwelling cultural heritage sites, characters in computer games, virtual teachers, etc Although, day by day the necessity of diverse kind of movies and video games leading towards advancement to the virtual world e.g., in Avtaar movie the application of Autodesk Maya nCloth, Autodesk Softimage XSI, Eyeon Fusion etc has taken place and therefore, that real sensitivity like alive people were achieved, but with very high cost expenditure (Niculescu, 2010). The process used was 3D scanning of real body and converting that into an animated character (Figure 1.3).

Figure 3 Fabric Simulation in Maya nCloth *Source***: (Tesi, 2015)**

Initially, Tom and Jerry was a TV program for kids and used to make up of manual sketches and their combination to form a motion, gradually with the evolution of 2D software it became more efficient and realistic. Nowadays with the use of 3D software video games have

been developed which are more convincing than the earlier, but still exact natural patterns are not found (Kenkare, 2005, p. 63).

CAD/CAM system in modeling tool of clothing can allow designers to experiment easily with a variety of fabrics and patterns on a 3D dynamic virtual mannequin before the actual garment is manufactured. Software, for instance, Modaris 3D fit and OptiTex are already widely used in the apparel industry for prototyping (Schilder, 2008, p. 8). Furthermore, with the advent of affordable 3D graphics hardware, to sketch up an object, a user just needs to draw on the screen with the digital pen or user"s finger like drawing on a piece of paper (Yu, 2010). Various things have been invented; nevertheless, they can widely be used in commercial purposes and would be expensive putting to try-on to business to consumer (B to C).

In textile engineering, textile modeling requirements for industrial applications are very different from requirements for entertainment and apparel design applications. In the composites domain, virtual simulation is not about the drape of cloth Instead; it is forced into a specific shape. Textile engineers focus on correctness and accuracy about the properties and behavior of cloth as a material. Kawabata is the testing lab provides six (approximately thirty-six including subcategories) different kind of properties of fabric, after having put that in e.g., Modaris it is possible to find similar results to the drape on real model; nonetheless, sometimes it looks not very natural.

In e-commerce, cloth and garment modeling offer a variety of opportunities for a typical business-to-costumer, there are already sites which are equipped to feed in one"s body measurements, and see if a certain garment fits or suits. This makes buying cloths online much easier. Intellifit has developed a virtual fitting room. You go inside, and in 10 seconds your body is scanned and provide with the measurements (Lim, 2009). Received information can be used to try clothing online, or in a shop without having to actually try them (Volino & Magnenat-Thalmann, 2000, p. 261 - 262).

Representing the cloth surface, the 2D patterns are displayed on a grid in the simulation software. Around the virtual mannequin the planar patterns are placed. A manual placement is implemented with an automatic function to bring the pattern to the closest position to the body surface. That is how on edges of each pattern together, seams will gather, an approximate initial positioning is necessary (N., 2010).

A technique for building whole-body morphable model founded on 3D body scan data by fitting high-resolution template meshes to detailed human scan data with 3D markers, which initially was useful but due to upgrade in technologies became outdated. Most of the companies that developed 3D software also have software for pattern making and designing. In other words, 3D software is an extension of the pattern making software, and before doing any 3D simulation the pattern of the garment has to be made. It uses the same principle as Lectra Modaris 3D Fit"s Modaris 3D Fit or OptiTex (Allen, 2003). Flowchart is as below:

- Data Input
- Pattern Design
- Define Stitches
- Choose Fabric, Print and Color

- Position Panels in 3D
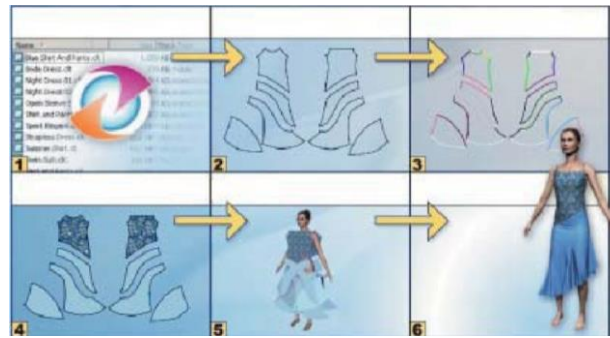
Figure 4 Fabric Simulation in OptiTex *Source*: (Schilder, 2008)

3D CAD system facilitates one to see the work from different point of views, check and correct. Moreover, there are different ways to do e.g., from 2D to 3D and 3D to 2D etc below are instances of different processes (Kenkare, 2005).

Visualization: Visualization of a garment design from concept creation to production, displayed in a standing 3D view with a rotation feature to view the model from any angle. Ability of dynamic visualization and animation of created designs is also important.

Drape Simulation: Drape simulation tools enable designers to create a virtual garment from 2D patterns over 3D true to life body image. This will drastically reduce product approval and production time by allowing the entire supply chain to visualize products accurately.
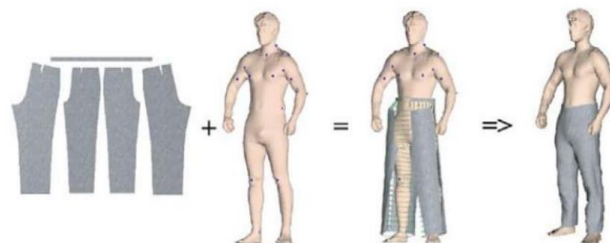
Figure 5 2D to 3D Design System *Source*: (Iqbal, 2013)

Texture Mapping: Texture mapping is one of the most successful new techniques in high quality image synthesis. Texture mapping is an efficient means to create the appearance of complexity without the tedium of modeling and rendering every 3D detail of a surface.

3D to 2D capability: 3D to 2D pattern unwrapping algorithms will allow the user to define a garment surface in relationship to the body surface using 3D body scan data. Automatic development of patterns using 3D to 2D flattening algorithms with automatic development of grades using sized body forms will become the essential tool in apparel product development.
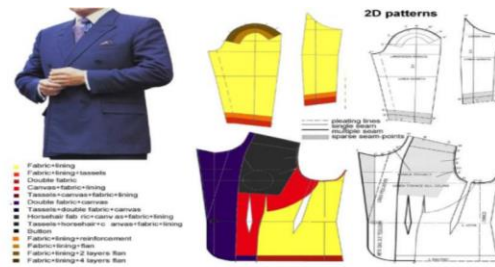
Figure 6 3D to 2D Design System *Source*: (Iqbal, 2013)

Virtual Dressing: A dressing facility, where conventionally designed pattern shapes are assembled into a garment and viewed on a 3D body form, will assist the user in mixing and matching products in the virtual environment. Virtual dressing uses a database consisting of photos, product descriptions, colors, sizes, and pricing.
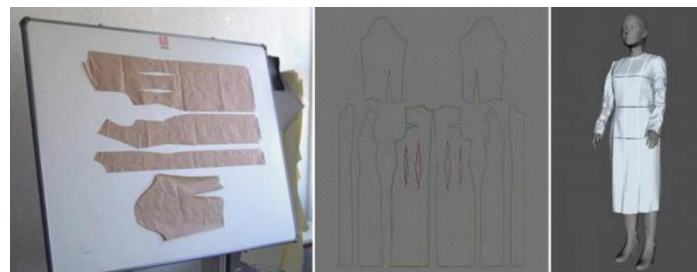
Figure 7 Manual 2D pattern to 3D Design System *Source*: (Iqbal, 2013)

Once the texturing and garment properties setting is completed the "fitting" of a garment can be accomplished by calling a mechanical simulation, which is forcing the surfaces to approach sideways the seam lines. The surface is deforming according to the shape of the body. The simulation engine first uses a simplified mechanical model, which is enhanced in speed by leaving the physical parameters and environment parameters behind the calculation. After this first simulation, where the garment is fast approached to the shape of the body, a second mechanical model is taken for the actual simulation (N., 2010).

2.2 Mechanical simulation of textile materials in 3D environment

The mechanical behavior of fabric is inherent in the nature and molecular structure of the fiber material constituting the cloth, and as well the way these fibers are arranged in the fabric structure. Fabric fibers can be organized in several ways in the cloth surface. For instance, the arrangement of fibers in woven fabrics would be distinct from the knitted and it also varies with the kind of weaving and knitting processes used to make the fabric. However, non-woven will react totally different as it contains unstructured fiber alignment (Schilder, 2008).

To test the mechanical properties of fabrics basically there are two methods are being used:

2.2.1 KES-FB (Kawabata Evaluation System for Fabrics)

By Professor Kawabata and team, the method made commercially available in year 1978. Fundamentally, it consists of six properties (Kawabata, 2015):
- Tensile
- Shear
- Pure bending
- Compression
- Surface friction
- Rouhness

2.2.2 FAST (The Fabric Assurance by Simple Testing)

FAST was developed in the 1980s by CSIRO Division of Wool Technology, Australia. It is a simpler alternative of KES-FB which uses three individual instruments (FAST-1, FAST-2 and FAST-3) as well as test method (FAST-4). They do not measure fabrics recovery from deformation but the resistance of fabrics to deform. It is used to assess the fabric making up (tailor-ability), appearance and handle properties (Hunter, 2009).

FAST-1 (compression meter) measures:

- Fabric Thickness (T)
- Fabric Surface Thickness ($ST = T_2 - T_{100}$)
- Released (relaxed) Surface Thickness

FAST-2 (bending meter) measures:

- Bending Length (BL in mm- measured at an angle of 41.5^0)
- Bending Rigidity (BR in µN.m) = 9.8×10^{-6} W $(BL)^3$; where W = fabric weight (g/m^2)

FAST-3 (extension meter) measures:

- Warp Extensibility
- Weft Extensibility
- Bias Extensibility (at 45^0)
- Shear Rigidity (N/m) = 123/EB5 (% bias extension)

Both, the Kawabata and FAST systems measure the similar low-stress fabric mechanical properties (compression, bending, extension and shear), however, they have its own measurement principles they use. Originally, the Kawabata aimed at predicting feel, handle and appearance of fabrics, whereas the FAST aimed at fabric tailorabilty. Therefore, simulation sample– denim used in this dissertation is the Kawabata tested.

2.3 Draping coefficient determination using experimental and numerical methods

2.3.1 Manual (experimental) method of Fabric drape coefficient

In order to assure the accuracy of the virtual drape of fabric, manual simulation takes place. Traditional real drape test attempted to evaluate the overall draping behavior of a cloth by measuring the number of folds and the area covered by the folds of a circular piece of cloth over a pedestal (drape meter). Tsai technique was initially been used for the real draping. In that, the cloth used to be marked with a rectangular grid of points as subsets of points to model the virtual cloth. Two cameras were used to observe the drape and from different locations of the grid points on different images, their 3D positions could be computed (Bottino A., n.d.).
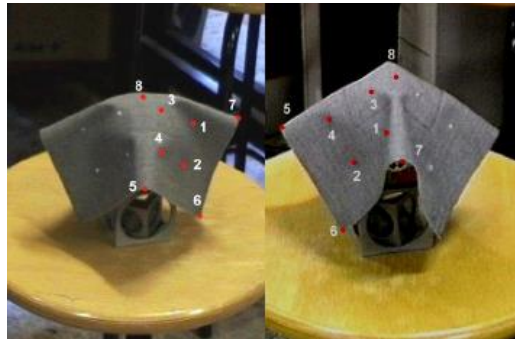
Figure 8 Two different views of the cloth in Tsai technique *Source*: (Bottino A., n.d.)

Furthermore, spring-mass model method is widely being used to measure the drape of the fabric. In this method, a fabric is constructed by a rectangular mesh of mass points with warp and weft directions, and the relations of the adjacent masses are regarded as the interactions of the spring among these masses. Division of spring occurs is three types– structure spring, bending spring and shear spring. To calculate the force of structure spring, bending spring, structure spring and shear spring in warp and weft directions can be found from the formula, $F_{int} = f_{struct} + f_{bend} + f_{shear}$. The strain and stress of each spring can then be worked out and moreover, mechanical formula can be fitted, from which the force and its direction of each mass in the spring-mass model can be obtained at each moment of fabric movement (Ruiyun Zhang, 2012).

Figure 9 Spring-mass model with real and virtual image *Source*: (Ruiyun Zhang, 2012)

2.3.2 Numerical Method (comprises of different software used for simulation)

Different kinds of fabric for different activities have been developed to guarantee optimal comfort garment. Increase in variety of synthetic fibers, new material structure (smart textiles) became immense. Nonetheless, the development of such a variety of new fabric materials has led to an increasing difficulty in evaluating fabrics according their quality and suitability (Magnenat-Thalmann, 2010). The virtual simulation of fabric can usually be divided into two categories (Schilder, 2008):

The surface of the fabric:

The look of the surface consists of color, texture and print. For the virtual simulation this means that it is about texture mapping and shading. Different stitching, embroideries and embellishments are applied on the surface of the fabric to alter or enhance the appearance. It is also fun as it is possible to play according to what one wants, however, feeding accurate fabric properties is important to get the accurate result.

The drape of the fabric:

Drape of a fabric is how a fabric falls, moves and hangs on a form (body). For the virtual simulation it means that this category is a matter of geometry, simulation and animation.

The most important factors that affect the way the fabric drapes and moves are:

- Type of fabric – Whether fabric is woven, knitted or non-woven.
- Treatment of the weft and the warp – if the weft is of a tender fiber or thread in comparison to the warp the fabric will drape loosely in the horizontal direction, noenetheless, if the weft fiber is stiffer, this will affect the horizontal drape accordingly, and the same is true for the warp.
- Cohesion between warp and weft – The lesser the cohesion the more bias fabric will give. The type of yarn and tightness of weave impacts the cohesion.
- Loosely or tightly spun fibers – The more twist yarns consist, the more bending resistance fabric will be while for the less twist will result vice-versa.
- The weave of the fabric – Different weave and the tightness of the weave affects the way fabric moves e.g., plain weave and twill weave with the same density and yarn will drape differently, twill will drape loosely than plain.
- The treatment of the fabric
- How the fabric is draped
- Amount of friction
- How the garment is cut and constructed
- Extra weight

- A pleat, tucks, gathers, padding, undergarments, pressing, steaming and elastic bands.

There are many factors that affect the way a fabric moves (Magnenat-Thalmann, 2005). If you want to accurately simulate, it is important to understand the controls that are used in animation software and identify what needs to be changed to make a fabric move properly.

For working in Lectra Modaris 3D Fit it is not needed to have information about what attributes are needed to change (as Modaris consists of the dialog box for the Kawabata properties to put in) simply put the properties and the fabric will automatically be simulated after the patterns are stitched. Other way, it is possible to choose a fabric from the fabric library and it will drape like the name of the fabric (for example– cotton).

This is not the case in Maya nCloth or 3D Max. It is needed to manually set all the parameters in order to make your fabric drape the way it is wanted. Maya nCloth now has some standard fabrics available in the preferences, but in order to get the desired outcome usually parameters have to be adjusted. The main factors which determine mechanical simulation and behavior of fabric are:

- Stiffness: While fabric is draped or is in motion, the stiffness or flexibility determines how easy the fabric bends or flexes. Stiffer fabrics have more angular bends and flexible fabrics flow in curves. In simple fabrics the stiffness is uniform all across the fabric, but stiffness may vary over the surface of more complex weaves. Attributes that affect the stiffness of a fabric are: fiber, thread and construction of the garment and the fabric.

- Cohesion: The manner in which yarns or fibers are adhere, cling or hang together in a uniform manner is cohesion of a fabric. It occurs due to the friction among fibers and yarns. It especially affects the movement of the fabric on the bias. The more cohesion, the less the fabric will give on the bias. In Maya nCloth shear stiffness can be adjusted or painted per vertex in order to affect cohesion.

- Elongation: Tightness with which yarn is spun and ability to a fiber to stretch determines the elongation of the fabric. Parameter – Restitution Tension specifies how far the links in the nCloth object can stretch before they can no longer return to their rest lengths.

- Elasticity: The elasticity of a fabric is determined by the ability of fibers to bounce back when released from tension or stretch. Adjust the stretch resistance on the whole fabric surface or paint it per vertex to change the elasticity in Maya nCloth.

- Weight: To determine the fabric behavior weight of a fabric plays an important role. It determines how a fabric moves and is affected by air flows and the motion of the body. Heavier fabric will generally follow the body inflexibly. A lighter weight fabric that is not stiff may flutter as it follows the body and seem to have a life of its own following the body. Most fabrics have the same weight on the whole surface, but other fabrics may have a different weight on different parts of a surface. Parameters that affect the weight in Maya nCloth are the thickness which can be adjusted on the whole fabric surface or painted per vertex.

- Friction: The behavior of the fabric is affected when it comes into contact with itself, other fabric or objects. If a rough fabric with a lot of friction is thrown across a form it will generally land in folds. A waterproof fabric may land in folds but the weight of the fabric will pull the folds out until the fabric is lying more or less flat. In Maya nCloth to change friction to get effect on the whole fabric surface or paint it per vertex.

- Thickness: It affects the way a fabric drapes and moves. Fines fabrics tend to drape in more folds then thicker fabrics. The thickness and the mass on the whole fabric surface or paint it per vertex.

- Attachment points: Points where fabric attaches to a body, an object or to another fabric. There are many kinds of attachments; some are more solid than others. Attachments to the body are usually not solid, but the one of a cloth attached to a flag is nConstraint menu affect the attachment in Maya nCloth. It is possible to choose from: component to component, point to surface, slide on surface, and weld adjacent borders. Each of these constraints has many parameters that can be adjusted.

For us being technophiles, technology and broadband connectivity lead to more customize and on demand lifestyle, where, everything, everywhere all the time is expected and desired. The clothing and fashion world express this on demand expectation with advanced garment customization – personalize design, fit and fabric performance. Many R&D projects and industry led innovations addressed this situation, and resulted in numerous new production processes and platforms, disappearance of intermediaries, comparatively high IT productivity and new distribution s33tructures. Consequently, virtual clothing technologies intend to innovate and benefit the apparel design and manufacturing in several ways. With the introduction and innovation of technologies – agents, product managers, designers, material engineers, pattern makers, garment collection planners, digital editing processes, intuitive user-centric interfaces, 2D pattern annotation, 3D body scanners, 3D garment simulation and visualization.
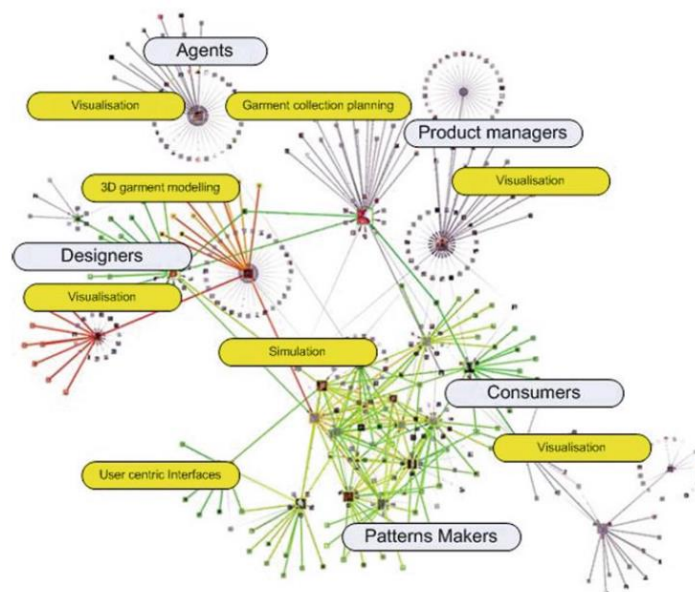
Figure 10 Actors who benefits from virtual clothing technologies. *Source*: (Iqbal, 2013)

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2.3   Summary of Literature Review

Although, the results have been discussed in literature review, obtained through previous techniques were acceptable for computer graphics purposes, while were still not adequately correct to fulfill the requirements of CAD and Virtual Prototyping applications essential by the garment industry. For fulfilling these new goals, cloth simulation techniques required some improvements and ripening, which first came through the use of implicit numerical integration methods, which allowed momentous speedup in the simulation of particle systems. These implicit integration methods were subsequently improved and adjusted to allow good simulation performance, both in the context of fast interactive garment animation and accurate simulation of complex garments (Magnenat-Thalmann, 2010).

Moreover, textile engineers focus on correctness and accuracy about the properties and behavior of cloth as a material. Kawabata is the testing lab provides six different kind of properties (approximately thirty-six including subcategories) of fabric, after having put that in e.g., Lectra Modaris 3D Fit, similar results to the real drape; nonetheless, still sometimes it looks not very natural. In this master thesis, in order to get the contemporary method and made available for the ordinary people the virtual try-on and prototyping, comparison among the real drape, drape in Lectra Modaris 3D Fit, Autodesk 3D Max (2016) and Maya nCloth (2016) has been accomplished.

3. METHODOLOGY

Performing quantitative comparison between real and virtual draping was very important for correctly mapping the physical parameters of the cloth on the model. Five Kavabata tested denim fabrics in four distinct mediums – manual (drape-meter), Lectra Modaris 3D Fit, Autodesk 3D Max and Maya nCloth; were used in process to perform the fabric simulation.

3.1 Objects of Research

Five KES-FB tested denim fabrics with twill weave were in the investigation of simulation. Swatches were named M1, M2, M3, M4 and M5 in order of their appearance. Their mechanical properties and specifications are given in the following tables (Table 1 and Table 2).

Table 1 KES-FB tested fabric mechanical properties

Notation	Bending rigidity		Tensile properties						Shear rigidity		Shear force		Coefficient of friction	
	B (1^{-6} Nm)		EMT (%)		LT (-)		WT (N/m)		G (Nm^{-1}/°)		T (N/m)		MIU (-)	
	Wp	Wt	Wp	Wt	Wp	Wt	Wp	Wt	Wp	Wt	Wp	Wt	Wp	Wt
M1	6,59	2,12	11,38	15,28	0,86	0,74	23,91	27,71	2,96	3,11	21,95	21,47	0,161	0,178
M2	2,44	0,68	4,28	15,12	0,86	0,63	8,96	23,17	2,04	2,29	15,75	18,7	0,165	0,193
M3	23,61	3	8,38	13,4	1,03	0,65	21,15	21,21	3,77	4,4	29,05	29,46	0,143	0,15
M4	3,32	2,78	36,04	25,48	0,74	0,75	65,46	46,55	2,48	2,69	19,1	18,34	0,186	0,205
M5	2,62	0,83	3,57	34,9	0,92	0,68	8	58,11	1,64	2,12	14,59	16,13	0,15	0,172

Table 2 Fabric specifications

Notation	Composition	Weave	Area density	Thickness	Density, No/cm	
	%	twill	g/m^2	mm	warp	weft
M1	98 CO, 2 EL	3/1	357	0.69	34	20
M2	65 CO, 33 PES, 2 EL	2/1	232	0.55	40	20
M3	78 CO, 20 PES, 2 EL	2/1	369	0.74	28	18
M4	97 CO, 3 EL	2/1	369	0.94	30	25
M5	78 CO, 20 PES, 2 EL	3/1	230	0.51	65	35

3.2 Draping coefficient determination methodology using Drape meter

Measurement of fabric drape started in with Pierce[5] in 1930 (Reham Sanad, 2012). Similar method is still being utilized to measure the fabric drape. KES-FB tested five denim fabrics were prepared with the radius of 18 cm. Each of the five fabrics was first cut in circular shape for investigation.

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[5] He is a scientist, developed objective tests for measuring fabric bending length which was proposed as a measure of fabric draping quality.

Figure 11 Tested circular denim sample

A circular disc with 10 cm of circumference was mounted on a stand of 20 cm, above the disc camera was fixed on tripod facing to the centre of disc (Figure 12). This whole instrument arrangement called as drape meter. One by one (M1, M2…M5) fabrics were placed on the disc and pictures were clicked circular, after cutting the swatch in circular shape with 18 cm of radius. One swatch was placed three times to figure out the error by calculating the coefficient of variant of the measurements of different componenets of specimen.
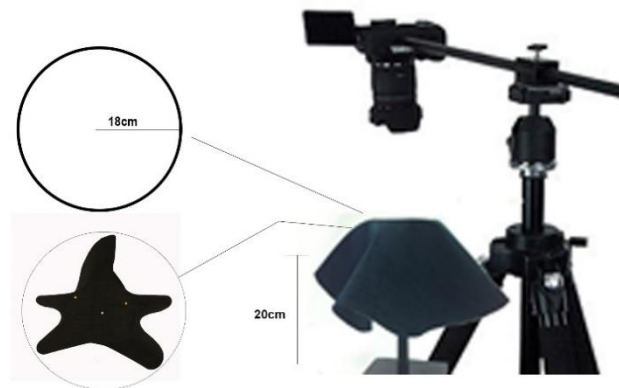
Figure 12 Drape Meter and camera setup *Source:* **KTU laboratory**

Pictures were stored to computer hard disk for computing process and further process in AutoCAD. Firstly, imported one picture of undraped denim and calculated the area. Furthermore, to measure the area of the fabrics, placed all three different pictures of each samples in AutoCAD. This process was completed to convert digital data[6] in real.

Before shooting the pictures of samples, picture of scale was clicked by putting on the disk and on the ground (20 cm down at the bottom of the stand) as shown in Figure 13.

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[6] Measurements in AutoCAD to world measurement.
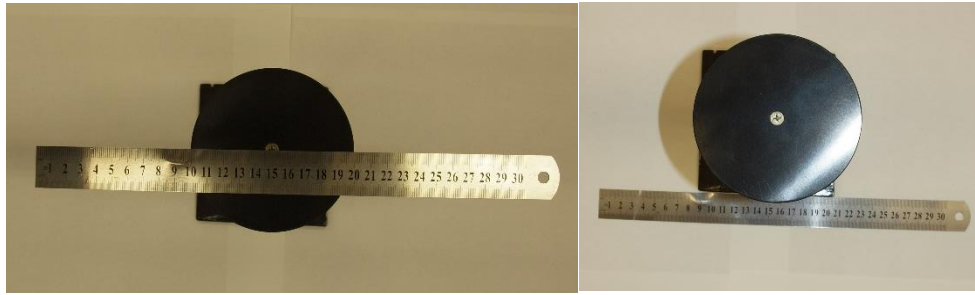
Figure 13 Screen of area measurement of draped sample _Source_: Lab

After having imported the pictures in AutoCAD, measurered the 10 cm of the real scale (Figure 13) in AutoCAD, of both the pictures – scale up and down and calculated the average for better results. In addition, calculated the the drape coefficient of each sample.

$$Coefficient\ of\ drape\ (DC) = \frac{Area\ of\ draped\ fabric\ specimen}{Area\ of\ undraped\ fabric\ specimen} \times 100$$

Average of the area of all three drapes pictures e.g., M1(1), M1(2) and M1(3) of each sample (M1, M2…M5) was calculated to determine the drape coefficient of the five samples . Above is the formula to calculate drape coefficient. Outline of picture is illustrating area of draped sample (Figure 14).
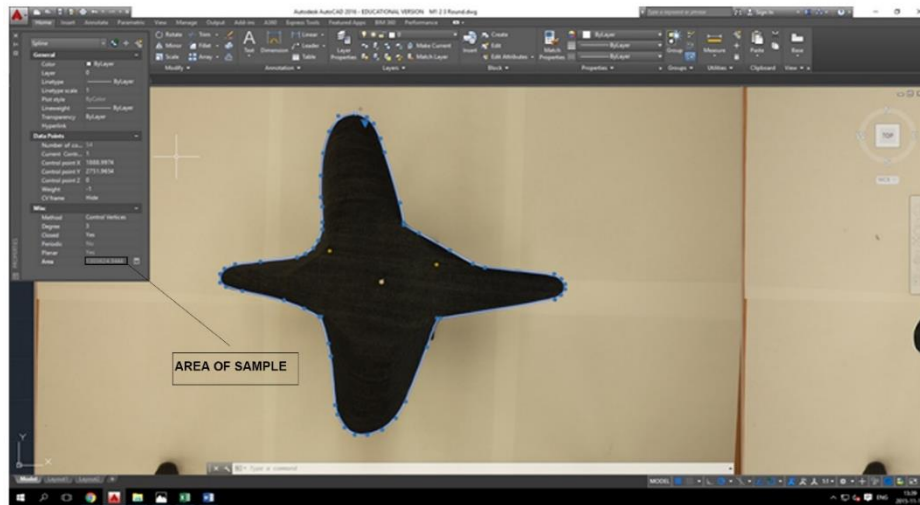
Figure 14 Screen of area measurement of draped sample _Source_: AutoCAD

3.3 Draping coefficient determination methodology using CAD Lectra Modaris 3D Fit

This was a distinct method than the above metchods. In this method KES-FB values were placed on the given dialog boxes (Figure 15).
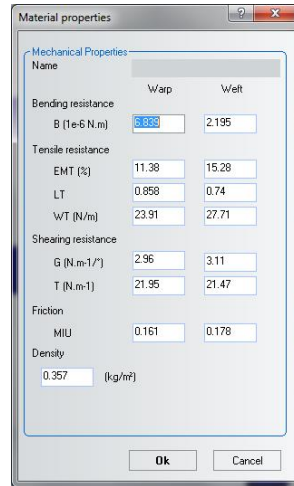
Figure 15 Modaris material properties dialog box *Source***: Lectra Modaris 3D Fit**

Since this software was made for garment industry and therefore, more accurate results were noticed.

To prepare sample, in Lectra Modaris 3D Fit, first skirt pattern was created, draped on a manequine, put the KES-FB values and simulated. Opened skirt model for patterns assembly in **Modaris** to add stitch to pieces (Figure 16). **Stitch – Add stitch:** clicked on both extremities (on each line to be sewn together):
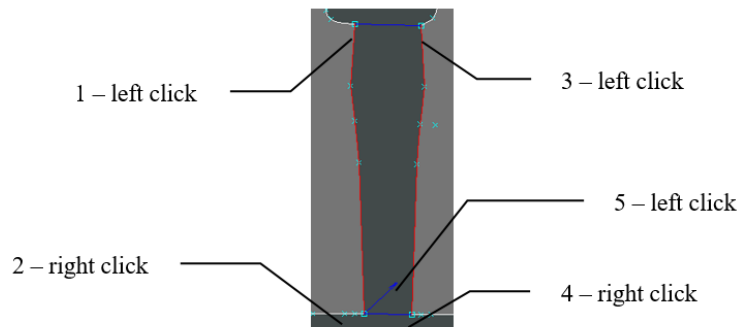
Figure 16 Attaching stitching points

Repeated the process for each line to be sewn:
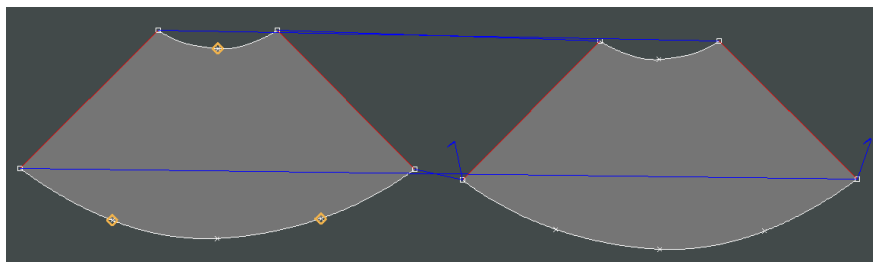
Figure 17 Stitched skirt in Modaris 3D Fit *Sourrce: M*odaris

Add slip-on points: These points added when assembly was fully defined. **Modaris 3D Fit** offers automatic garment positioning on the body. The slip-on points were (must be) positioned on an unsewn edge. Three slip on points were needed in skirt model: waist, right knee and left knee: **Stitch – Add Slip On Point (**Figure 18)**,** mark point, **TAB**:
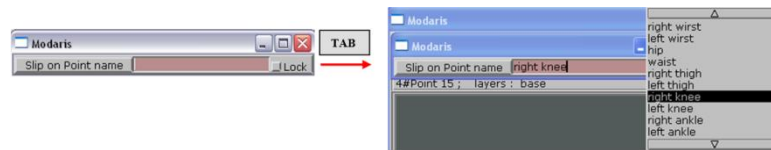
Figure 18 Adding Slip On Point

Julia with the following measurements to drape skirt on and simulate.

Figure 19 Manequine measurement (Julia) used for draping *Sourrce:* **Modaris**

Modaris 3D Fit simulates the fabric on the basis of KES-FB (Kawabata Evaluation System for Fabrics) characterization. To change the mechanical properties accordingly, released the property option and put the KES-FB values in it (Figure 20).
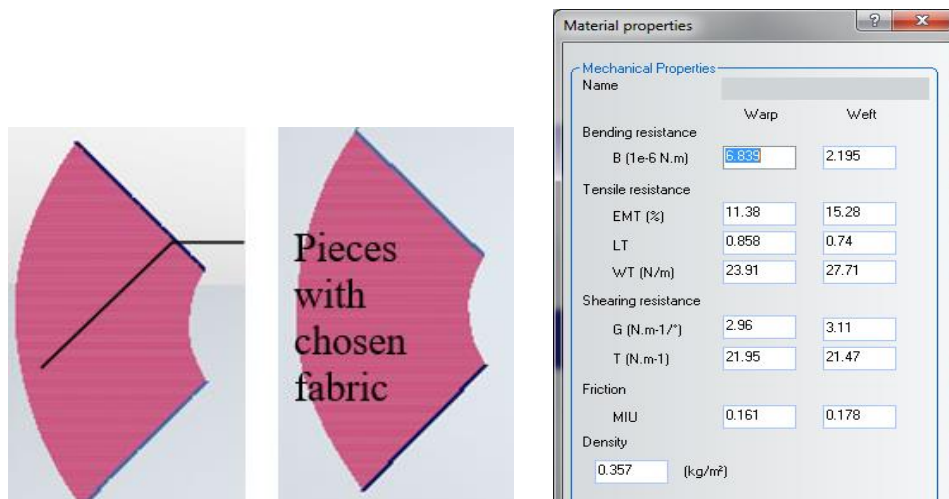
Figure 20 Placing KES-FB mechanical properties

After having saved the file**,** Mechanical properties of five different samples (M1, M2…M5) were placed one by one and simulated the skirt. Each sample was simulated thrice e.g.,

M1(1), M1(2) and M1(3), to calculate coefficient of variation. In addition, each sample was simulated by setting the reversed value (warp and weft values vice-versa) in same manner as before.

In "mechanical properties" dialog box "bending resistance" represents the amount of flexibility a triangle in fabric comprises of, while EMT is the percentage of "tensile strain". LT and WT are not so important because in other software – 3Ds Max and Maya nCloth, only "tensile strain" was taken in consideration, however, in case of Lectra Modaris 3D Fit options to place them, was available and therefore, they had been set. "Shear" was similar to stretch resistance which fends off when a fabric was tried to stretch, however, "friction" was the amount of resistant to abrasion applied to the fabric. "Area density" was mass per unit area of the fabric; the higher the area density, the heavier the fabric.

Figure 21 illustrates the states of of skirt pre and post simulation whether third picture in same figure represents length and width of skirt measured for calculation perposes required for coefficient of correlation.

Figure 21 simulated skirt on manequine *Source:* **Modaris**

Figure 22 indicates "number of nodes" acquired after simulation e.g., in first picture total number of nodes are 12. The elevated ones are "drape maximum" which has been represented as D_{max} while decline
d ones are "drape minimum (D_{min})". D_{min} has been presented with yellow color; nonetheless, D_{max} is of red color. Second snap illustrates the area of the draped skirt.
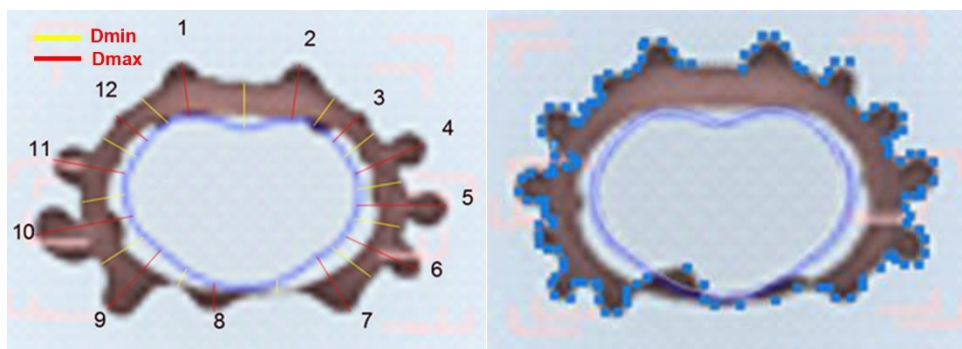
Figure 22 Represents D_{max}, D_{min} and area of skirt in Modaris

Drape coefficient of drape (DC)[7] was measured while all values from KES-FB were placed correctly and named as DC warp, however, DC weft was named when values were set vice versa. Moreover, "drape distance coefficient (DDC)" was also calculated.

$$Drape\ distance\ coefficient\ (DDC) = \frac{Average\ Dmax\ of\ skirt\ sample}{Average\ Dmin\ of\ skirt\ sample}$$

Practically performing some investigation after having simulated the fabric in Modaris 3D Fit some features were very much advantageous while some seemed lagging for instance, one could not import garments in Modaris while in Maya nCloth it was possible.

3.4 Simulation of denim fabrics draping methodology using 3Ds Max and Autodesk Maya nCloth

Similar to previous subsection, this section consists of the simulation conducted by Autodesk Maya nCloth and Autodesk 3Ds Max with 2016 version. In many techniques both the software are similar while there are some differences as well. Though, both the 3D computer graphics program are being used in making 3D animations, models and images used by video game developers, TV commercial studios, and artitechture visualization studios to create video games, animated films, TV series and visual effects, but when it comes to simulate a fabric it is different to use as this is not designed by keeping in mind about it. The user is required to choose the tools from toolsets for the certain kind of fabric simulation.

3.4.1 Simulation in 3Ds Max

3Ds Max, contains all high quality features a deleveloper needed: advanced mesh and surface modeling, production proven animation toolsets, realistic simulation effects and prepared fabrics in library, however, it could not be claimed to get the real simulation of each type of fabric.

Similar to the real draping, circular fabric samples of 18 cm of radius were prepared. After having opened the 3Ds Max, created a virtual stand (20 cm of height) and disc (18 cm of radius) same as in real, created a plane with 18 cm of radius, converted it into cloth (by selecting cloth option), as shown in Figure 23.

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[7] $Coefficient\ of\ drape\ (DC) = \frac{Area\ of\ draped\ skirt}{Area\ of\ undraped\ skirt} \times 100$
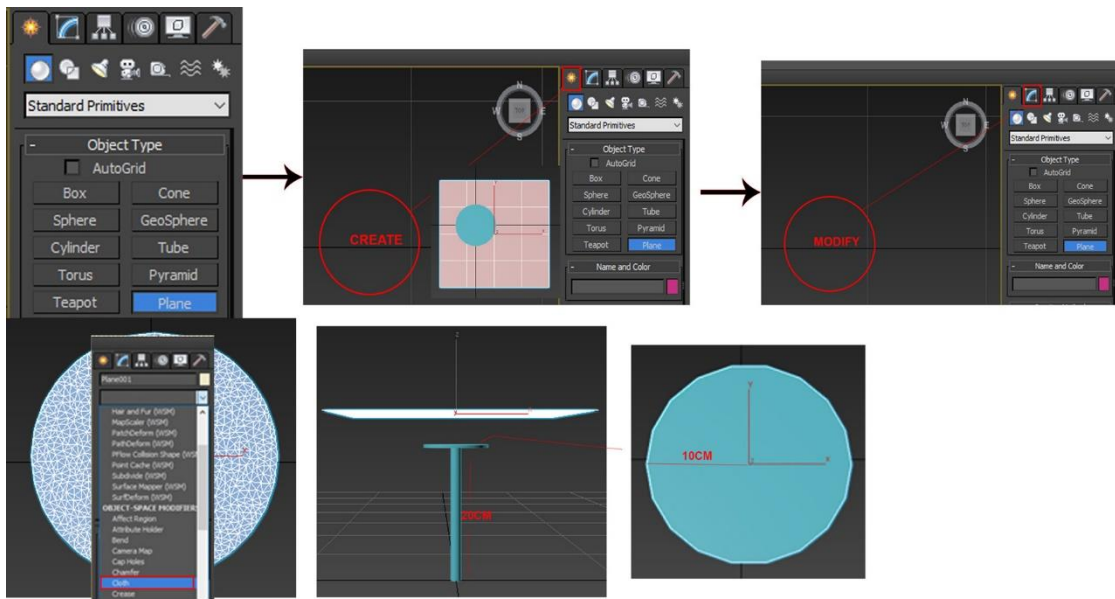
Figure 23 Screen of area measurement of draped sample *Source*: 3Ds Max

Figure 23 illustrates the process to create cloth in 3Ds Max. Selected modify option and released button on "object properties": added objects, cylinder002 and plane001. To make cylinder002 a collision object, selected it and set it as collision object by releasing "collision object" in dialog box and selected the cotton from drop down "presets" menu followed by the name plane001. Cotton property was adjusted according to KES-FB properties to make it like denim fabric.
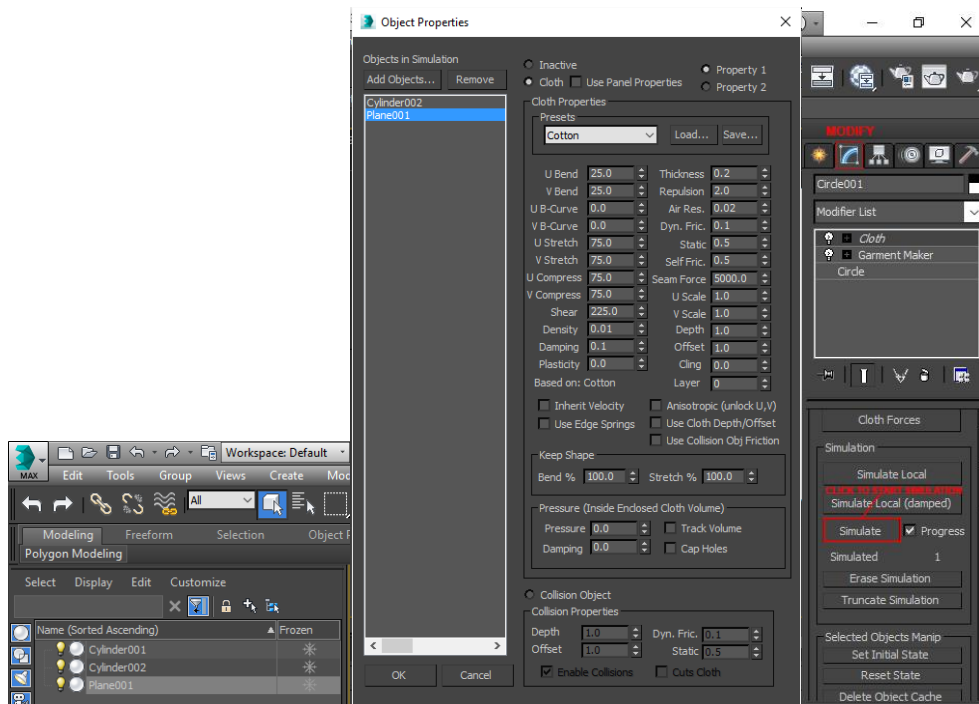
Figure 24 Screen of area measurement of draped sample *Source*: 3Ds Max

By switching anisotropic on (Figure 24), values can be changed in warp and weft according to the need. To run simulation of the fabric realease mouse on "simulate" as illustrated in third picture of Figure 24. If further simulation is needed clicked on "reset state" and repeated the process.

In object properties, there were five prominent properties were taken in account – bend, stretch, compress, shear and density. In attributes U represents warp and V weft. To change bending regisrance of the fabric change "bend" from second picture of Figure 24. The higher the bend value, the less the fabric would be able to bend.

Resistance to stretching is changed by tuning the value of "stretch", anistropic should be on to set different values in warp and weft. A larger value is stiffer, while smaller one, results stretchy.

Resistance to compress can be changed by setting the values of "compress". Compress and stretch are counterpats to one another and therefore, it is needed to assign lower value than stretch to get good results because when cloth is compressed along the length of fibers, it tends to buckle rather than shrink.

"Shear" defined how much the individual trinages could form. Higher value results in stiffer cloth fabrics. If it were to lay the edges of triange out in a straight line, this value would represent how long this line can stretch.

"Density" is the weight of the cloth per unit area in gm/cm^2. The higher the value, the heavier the cloth; for instance, denim.

3.4.2 Simulation in Autodesk Maya nCloth

In Maya nCloth simulation of graphics are so lively and resulted many award winning movies, yet, when it comes to fabric simulation it does not consist of the anisotropic option which enables user to change the mechanical properties of the fabric in both – warp and weft direcions (Figure 25). Moreover, it would not seem to provide the appearance needed and therefore, only circular sample was simulted.
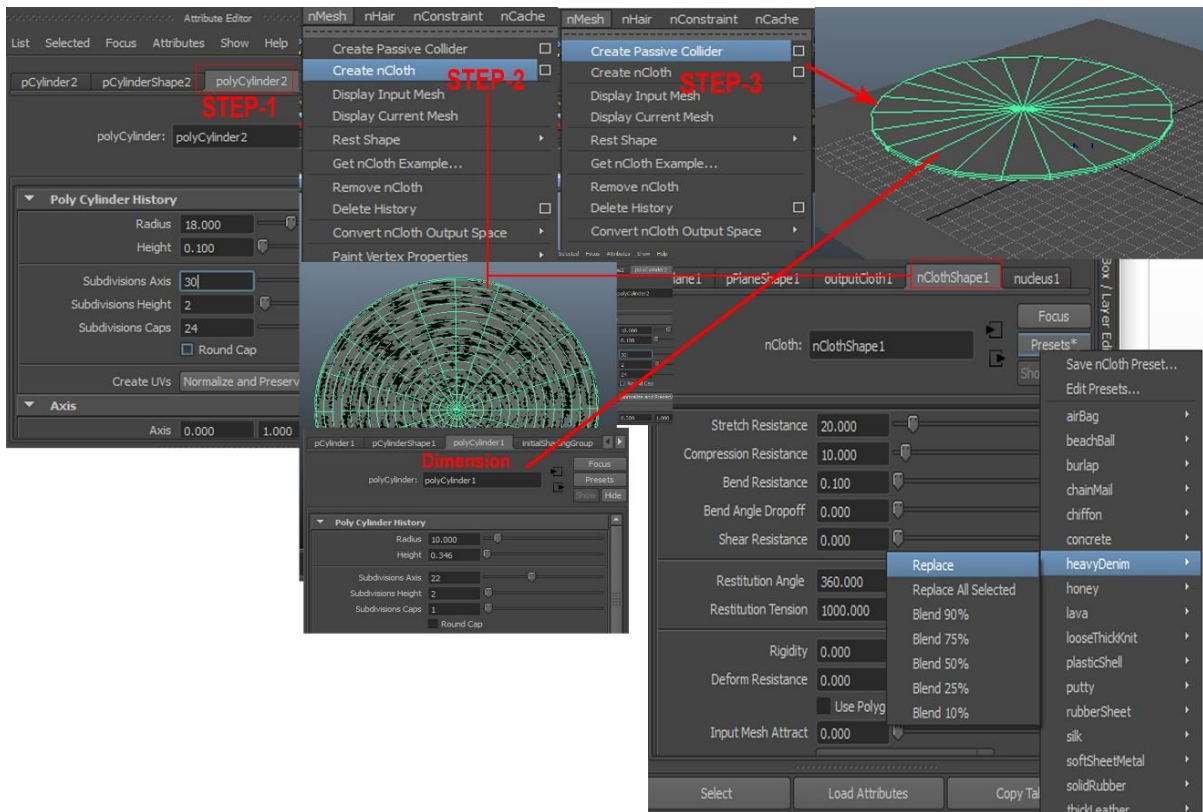
Figure 25 Screen of area measurement of draped sample *Source***: 3Ds Max**

Created "cylinder" with 0.10 cm of height and 18 cm of radius, converted in "nCloth", opened "attribute editor", changed the parameters of cloth and "passive collider", and chose "heavy denim" from available "presets" (Figure 25). In "nClothShape" tuned "heavy denim", tuned the "dynamic properties" according to the need for the samples.
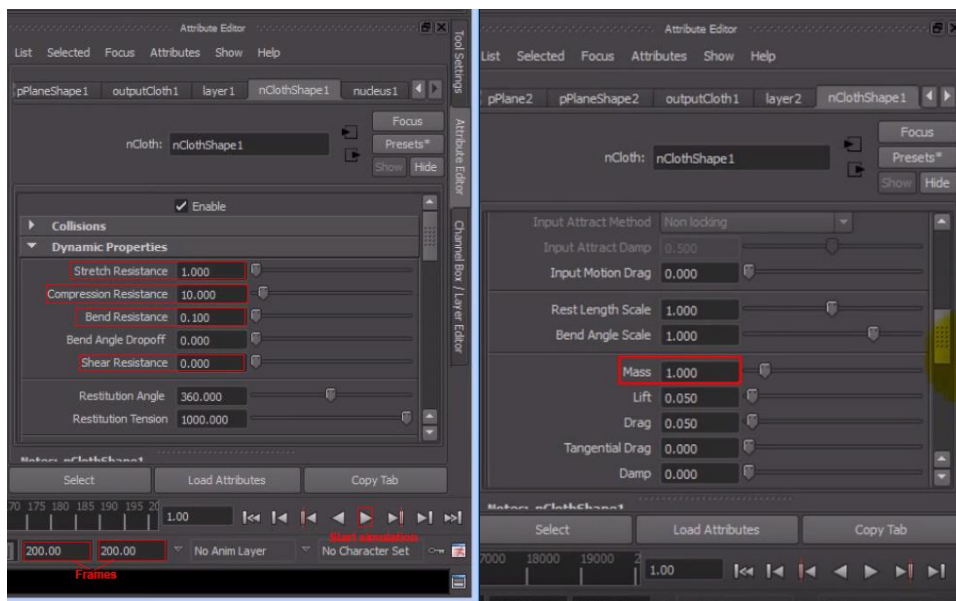
Figure 26 Attributes and Simulation in Maya nCloth

Above is Figure 26 which depicts the dialog box of "dynamic properties" of "attribute editor". In Maya nCloth also only five major properties – stretch, compress, bend, shear and mass; were considered. At the bottom of the figures, there is a highlighted "starts simulation" mark, which is clicked to start the simulation. On the left corner at the bottom of the Figure 26, there is a block which determines the numbers of frame are being taken in account for simulation process.

Stretch resistance, specifies the amount the current nCloth object resists stretching when under tension. Stretch resistance is the force applied to the current nCloth's links when they are more than their rest lengths. Stretch is applied to the geometry along the linear links between particles in an nCloth mesh. A low stretch resistance makes nCloth stretchy, like spandex, while a high stretch resistance makes nCloth tight, like burlap.

Compression resistance is the force applied to the current nCloth's links when they are less than their rest lengths. A low compression resistance makes your nCloth crumple under pressure, like crinoline, while a high compression resistance makes your nCloth resist crumpling. Having more compression than stretch keeps the structure of the current nCloth from becoming rigid, while at the same time keeping it from stretching.

Bend resistance, specifies the amount the nCloth object repels bending across edges when under strain. The higher the bend resistance makes nCloth stiff, so that it would not bend and hang off the edge of a surface, while a low bend resistance allows nCloth to act like a tablecloth hanging over the edge of the table underneath.

Shear Resistance is similar to Stretch Resistance, however, is applied to the geometry along the cross links between particles in an nCloth mesh. Shearing leads nCloth to stretch in an unequal fashion, causing distortion.

Mass determines the density of an nCloth or the weight of an nCloth when its Maya nCloth Nucleus solver's Gravity is greater than 0.0.

4. RESULTS

This section comprises of the findings achieved through the different simulation methods. Comparison among the results obtained through real drape, 3Ds Max and Maya nCloth will take place in order to get comparatively accurate method to fabric simulation. However, results achieved through Lectra Modaris 3D Fit would be presented separately.

4.1 Draping in Lectra Modaris 3D Fit

In Modaris, after having created the patterns (as mentioned in methodology) and put the KES-FB tested denim mechanical properties, skirt was simulated. Table 3 represents different parameters measured after simulation in Lectra Modaris 3D Fit while "drape coefficient real (DC real)" belongs to the real draped circular samples, has been presented to see the correlation.

Table 3 Lectra Modaris 3D Fit measured parameters

Notation	Draping coefficient		Dmax, cm		Number of	Dmin, cm	
	warp	weft	warp	weft	nodes (warp)	warp	weft
M1	24.88	25.84	7.8	8.45	11.33	4.21	4.34
M2	25.01	24.70	7.6	8.57	12.33	5.08	4.65
M3	26.06	29.11	8.67	10.87	10	3.88	4.36
M4	24.08	24.99	7.99	8.23	10.33	4.36	4.67
M5	23.62	25.38	7.85	7.71	10.67	4.43	4.4

Notation	Number of	Drape Distance coefficient			Skirt length		Skirt bottom width	
	nodes (weft)	warp	weft	DC Real	Warp	Weft	Warp	Weft
M1	10.67	1.87	1.95	35.72	88.17	86.13	77.48	73.85
M2	10.33	1.50	1.84	31.33	88.25	87.80	70.43	71.70
M3	8.33	2.23	2.49	57.49	84.98	86.85	80.44	86.39
M4	11	1.83	1.76	34.62	82.82	84.70	69.51	71.47
M5	12	1.77	1.75	26.33	82.91	85.42	68.41	71.70
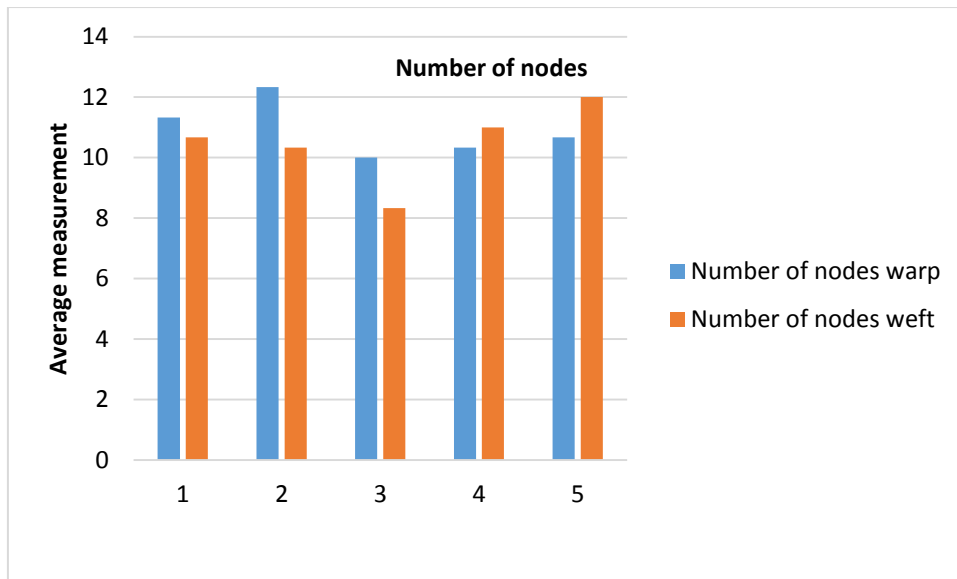
Graph 1 Modaris 3D Fit number of nodes warp and weft
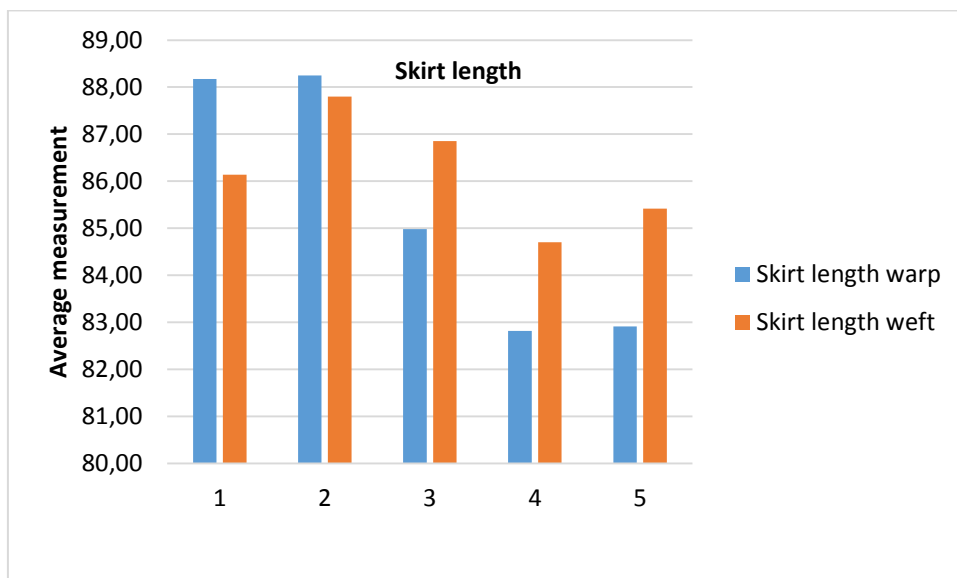
Graph 2 Modaris 3D Fit skirt length warp and weft
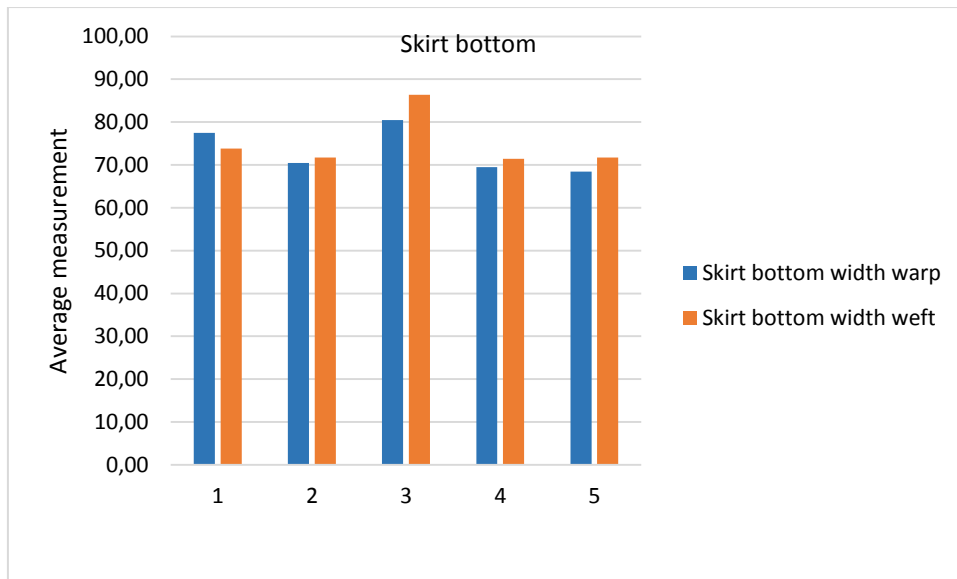
Graph 3 Modaris 3D Fit skirt bottom width warp and weft

4.1.1 Samples after having placed the value in warp direction

Figure 27 is visual presentation of each skirts simulated skirts three times in Modaris.

M1

M2

M3

M4
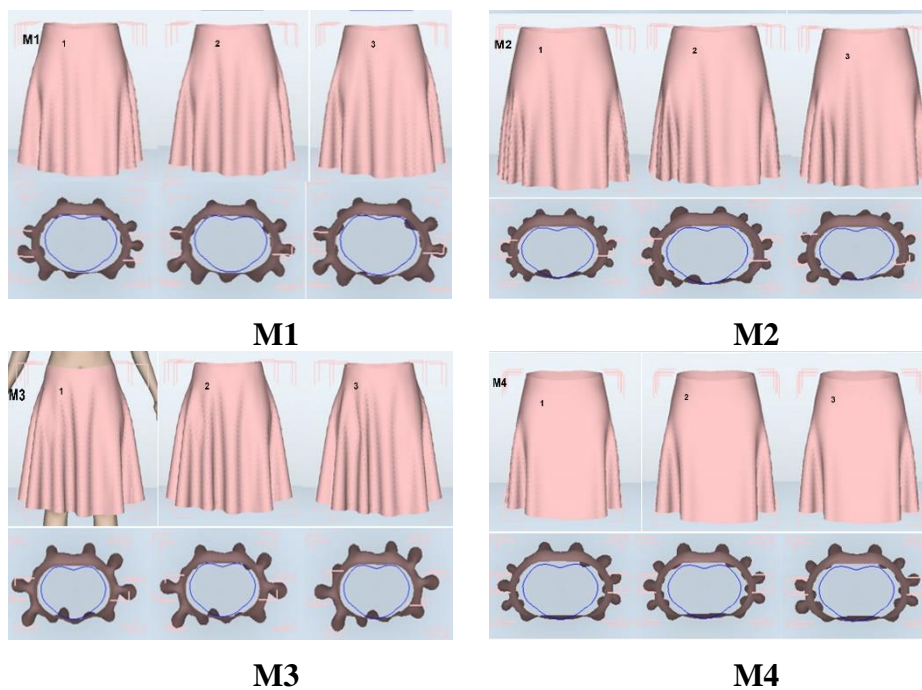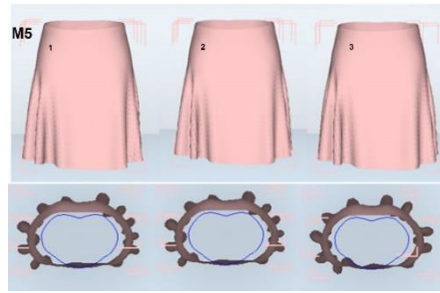
M5

Figure 27 Simulated skirts in Modaris (warp direcion)

4.1.2 Samples after having placed the reversed value (warp value in weft and weft in warp)

Following Figure 28 illustrates the simulation obtained by setting the values vice versa.

M1

M2

M3

M4
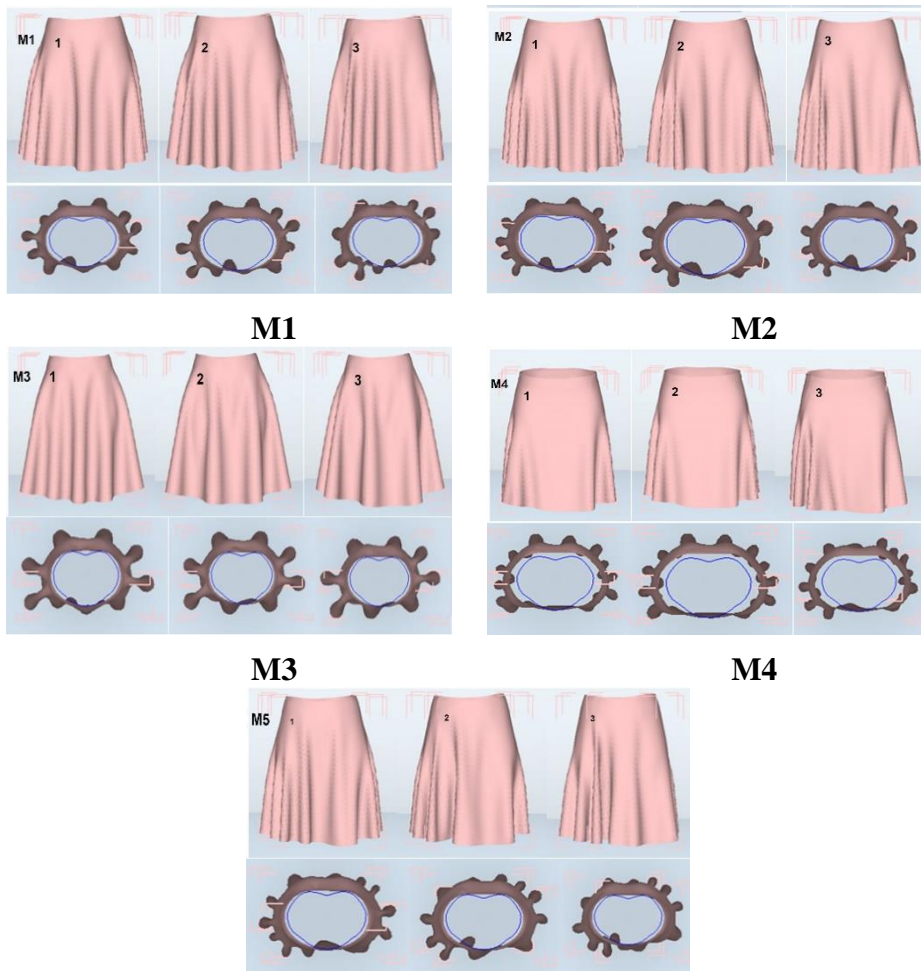
M5

Figure 28 Simulated skirts in Modaris (weft direcion)

Static simulation in Modaris resembled same as in real except when it was simulated in motion found error of approximately 4 cm (Magnenat-Thalmann, 2010, p. 148). Since simulation was done in Modaris, model was static and therefore, comparision was completed between warp and weft direction by assuming the simulation as correct and did not performed the draping by putting skirt on manequine.

Samples M1, M2...M5 respectively comprise of the average number of nodes 11.33, 12.33, 10, 10.33 and 10.67 (Table 3) when simulated in warp direction while when simulated in weft direction it was 10.67, 10.33, 8.33, 11 and 12 (Graph 1). By looking at the results obtained, samples M1, M2 and M3 in warp direction were with more nodes (smoother), however, M4 and M5 were with more nodes (smoother) in weft direction. M3 is the stiffest in both directions amonst all samples.

There is no good relation between nodes warp and all the mechanical properties except number of nodes warp and bending (B) weft, has good relation. In addition, correlation between number of nodes weft and shear rigidity (G) warp has best. While, correlation among bending rigidity (B), tensile strain (EMT) weft, WT weft, shear rigidity (G) warp and shear rigidity (G) weft, T warp and weft good, nonetheless, rest mechanical properties has no noteworthy correlation.
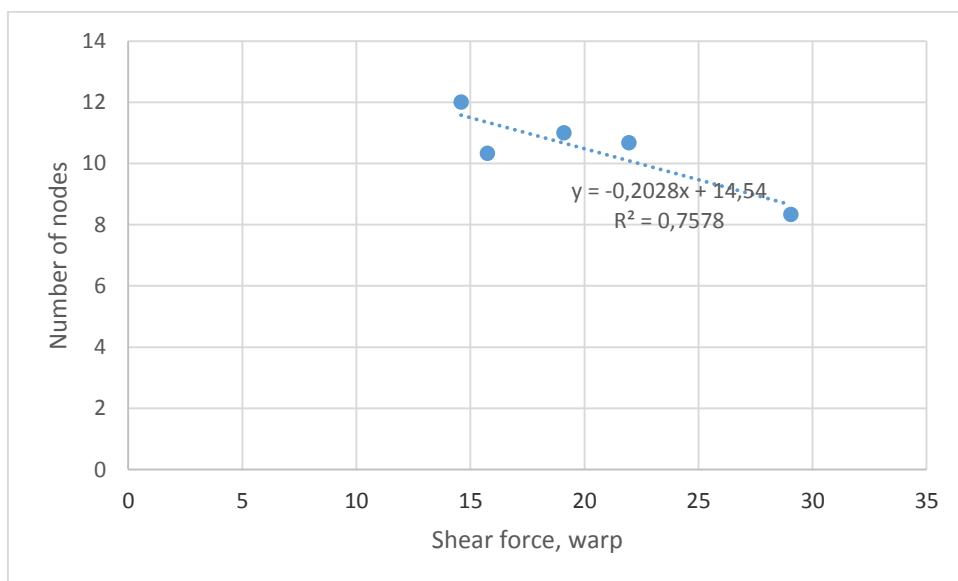
Graph 4 Correlation between shear rigidity (G), warp and Number of nodes weft

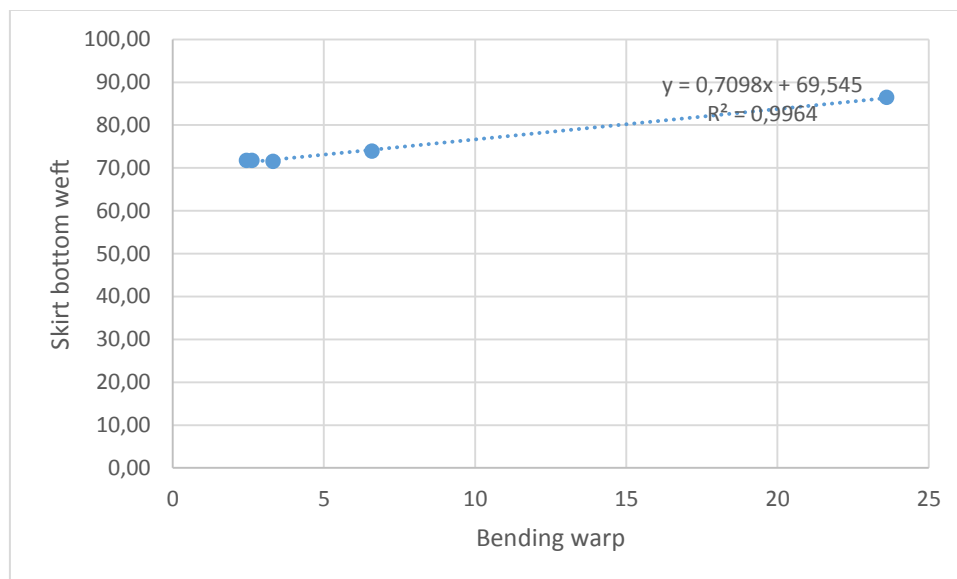### 4.1.3 Correlation between mechanical properties and Skirt bottom width warp and weft

According to the results acquired and presented in Table 4 correlation between KES-FB properties and skirt length do not look logical while with "skirt bottom width" there is higher correlation.
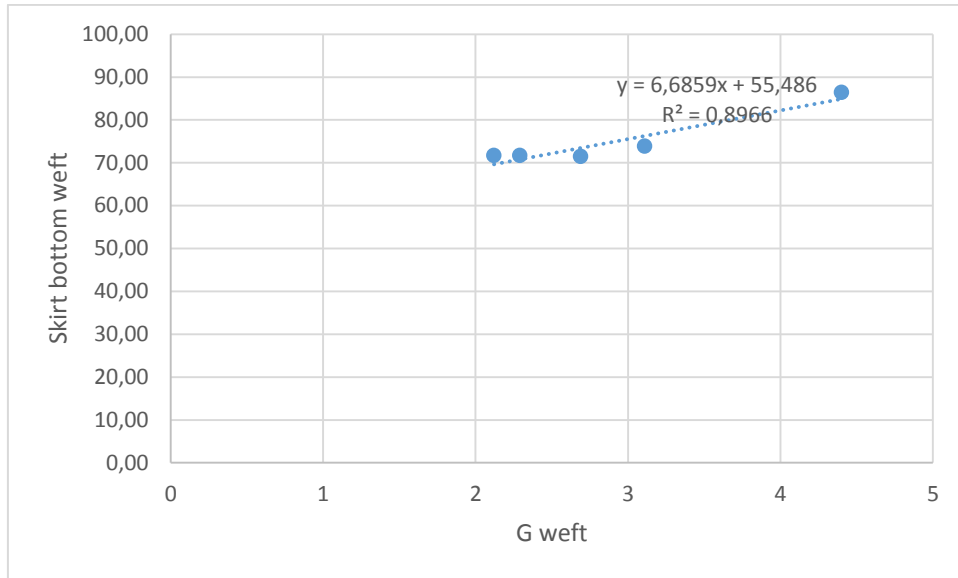
Table 4 Coefficient of correlation between KES-FB and skirt bottom and length

Properties	Skirt length (warp)	Skirt length (weft)	Skirt bottom width (warp)	Skirt bottom width (weft)
B, warp	-0.0080	0.2870	0.8538	0.9982
B, weft	-0.2530	-0.3323	0.6122	0.6023
EMT, Warp	-0.7650	-0.6793	-0.1944	-0.2095
EMT, Weft	-0.7650	-0.7102	-0.7418	-0.5172
LT, Warp	0.0764	0.4819	0.6104	0.7965
LT, Weft	-0.2536	-0.8037	-0.0723	-0.3600
WT, Warp	-0.4344	-0.6654	-0.1113	-0.1271
WT, Weft	-0.7786	-0.8012	-0.0723	-0.5444
G, Warp	0.1814	0.1922	0.9351	0.8615
G, Weft	0.0712	0.2073	0.9198	0.9469
T, Warp	0.0851	0.1626	0.9263	0.9137
T, Weft	0.1833	0.3815	0.9242	0.9660
MIU, Warp	-0.1033	-0.4292	-0.5121	-0.6378
MIU, Weft	-0.0026	-0.2942	-0.7014	-0.8232
Area Density	-0.0886	-0.3241	0.6402	0.4920
Thickness	-0.3361	-0.5152	0.1888	0.1689

Correlation between mechanical properties and Skirt bottom weft is higher than warp and therefore, scattered graphs comprise of weft values are presented. In warp direction G warp, G weft, T warp and T weft have higher correlation than the other properties. Although, in Skirt bottom width weft – Bending rigidity (B) warp, shear rigidity (G) weft, shear force (T) warp and weft also coefficient of friction (MIU) weft have significant correlation among the other properties.

Graph with trendline: $y = 0{,}7098x + 69{,}545$, $R^2 = 0{,}9964$. Y-axis: Skirt bottom weft (0.00 to 100.00). X-axis: Bending warp (0 to 25).

Graph 5 Correlation between bending rigidity (B) warp and Skirt bottom weft

Graph 6 Correlation between Shear rigidity (G) weft and Skirt bottom weft

4.1.4 Coefficient of correlation between DC warp and weft (Modaris 3D Fit), and DC real

Table 5 represents coefficient of correlation between DC warp and weft (Modaris), and DC real. Correlation between DC warp and DC real (Graph 7) and between DC weft and DC real (Graph 8) both are significant.

Table 5 Coefficient of correlation between DC warp and weft, and DC real

	DC real
DC warp	0.8652
DC weft	0.9382
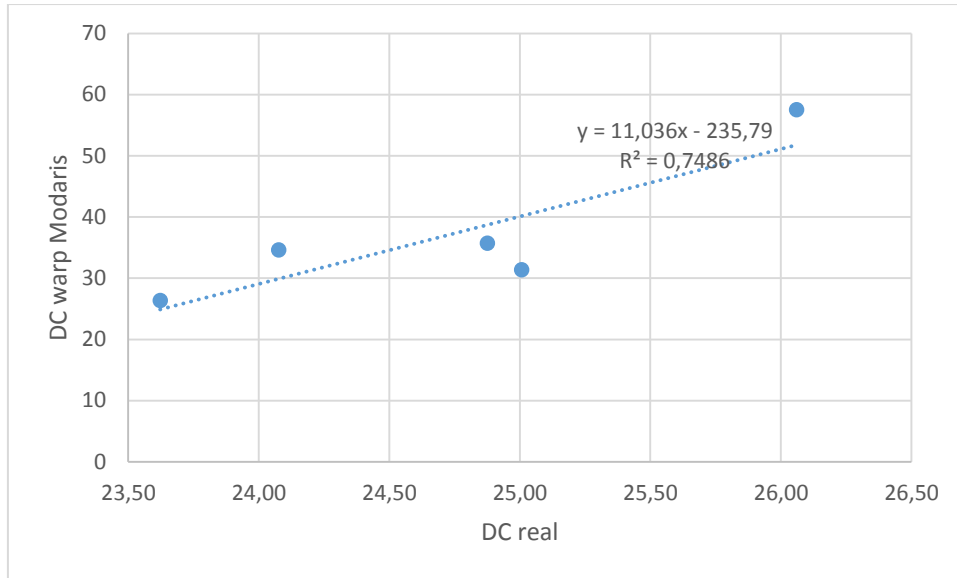
Graph 7 DC warp Modaris and DC real
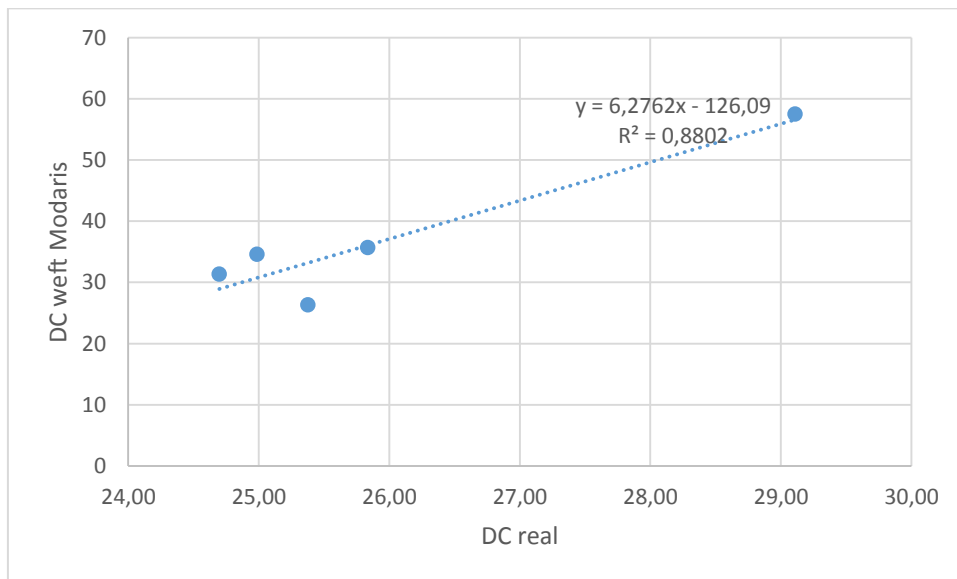
Graph 8 DC weft Modaris and DC real

Graph 9 represents Coefficient of drape in Lectra Modaris 3D Fit in warp and weft directions. The higher the coefficient of drape, the worse the drape would be. Graph below depicts better drape in warp direction than weft because of higher coefficient values in weft direction. Drape coefficient (DC^8) is comprises of area of draped and undraped skirt multiplying by

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[8] $Coefficient\ of\ drape\ (DC) = \frac{Area\ of\ draped\ skirt}{Area\ of\ undraped\ skirt} \times 100$

100.The higher the drape coefficient the lower the drapability of fabric. Hence, specimen M3 has the highest drape coefficient which portrays comparatively lesser drapebility while in weft direction the least. In contrast, M4 interprets the least drape coefficient (DC) among all, that means is the most fleixible specimen.
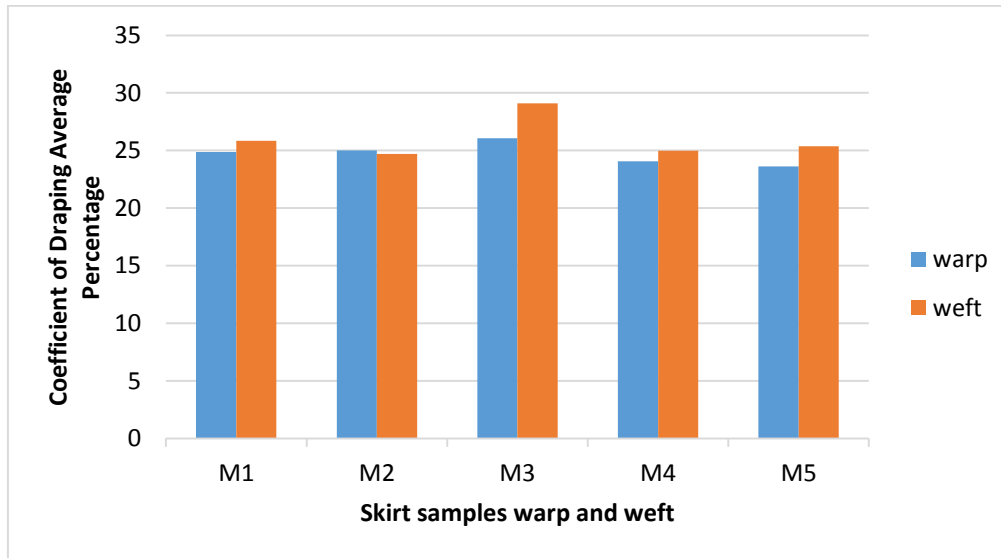
Graph 9 Coefficient of drape of skirt in Lectra Modaris 3D Fit

4.1.5 Coefficient of variance of area in Lectra Modaris 3D fit and real draping

If coefficient of variance is lesser than 7% which depicts that results are good and error is minute.

Table 6 Coefficient of variances

	Skirt length and width				Dmax and Dmin				Area of skirt		CV area
	CV length warp	CV length weft	CV width warp	CV width weft	Dmax warp	Dmin warp	Dmax weft	Dmin weft	warp	weft	Real Specimen
M1	1,56	1,12	1,56	3,33	5,99	6,93	1,34	4,53	2,24	0,42	6
M2	0,49	0,29	1	1,77	4,58	4,61	1,05	4,1	2,10	2,10	3,1
M3	1,14	0,32	0,79	0,88	2,46	2,15	6,48	0,6	2,08	2,08	0,2
M4	1,45	1,05	0,27	1,44	3	0,57	2,96	0,21	0,53	0,53	2,7
M5	1,08	0,86	0,34	3,1	3,39	3,11	8,42	4,2	1,37	1,37	7

4.1.3 Analysis of D_{max} and $D_{min,}$ drape distance coefficient (DDC) warp and weft

D_{max} warp (Graph 10) and weft (Graph 11) illustrate significance when looking at average of the values. In contrary, D_{min} results are very similar to each other and do not have significance. D_{max} warp and weft both of M3 specimen have the highest value which shows

that this is the stiffest fabric amongst all the samples. D_{max} values M1, M2 and M4 increased in warp direction while M3 and M5 were stable. Values obtained depicts that warp yarns in M1, M2 and M4 are stiffer, however, M3 and M5 comprises of the same bending resistance of yarn in both the directions – warp and weft.
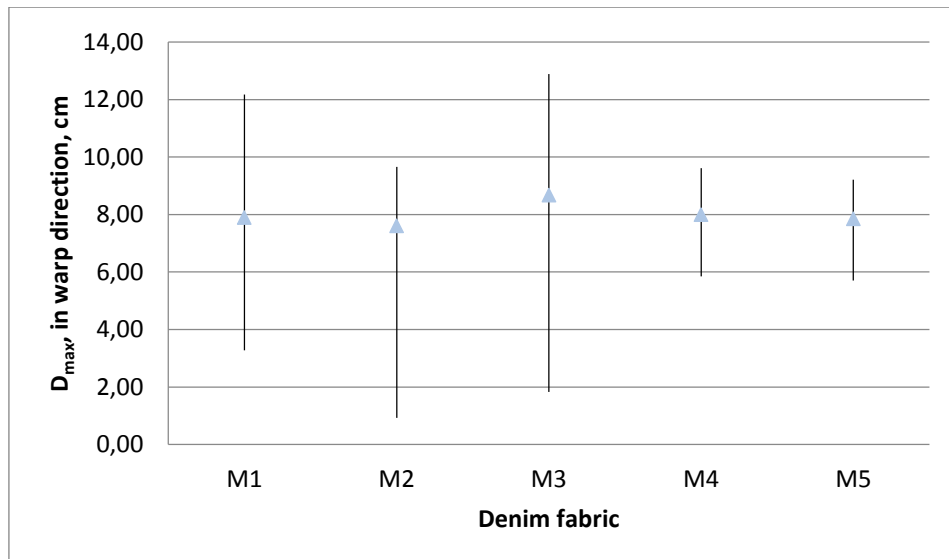
Graph 10 Dmax in warp direction
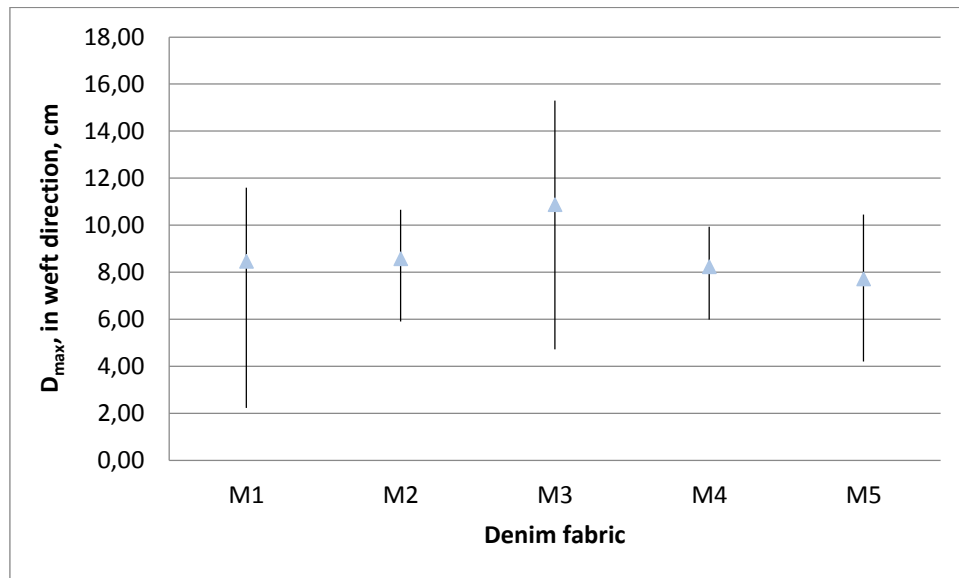
Graph 11 Dmax in weft direction

Correlation between D_{max} warp and Bending rigidity (B) warp, Shear rigidity (G) weft and Shear force (T) warp is very good, however, Bending rigidity (B) weft, Tensile linearity (LT) warp, shear rigidity (G) warp, shear force (T) warp and MIU weft is good while with rest

properties there is partial correlation. Furthermore, correlation between Dmax weft and bending rigidity (B) warp is very good while with shear force (T) and shear rigidity (G) is also good in contast with rest mechanical properties there is comparatively slighter correlation.
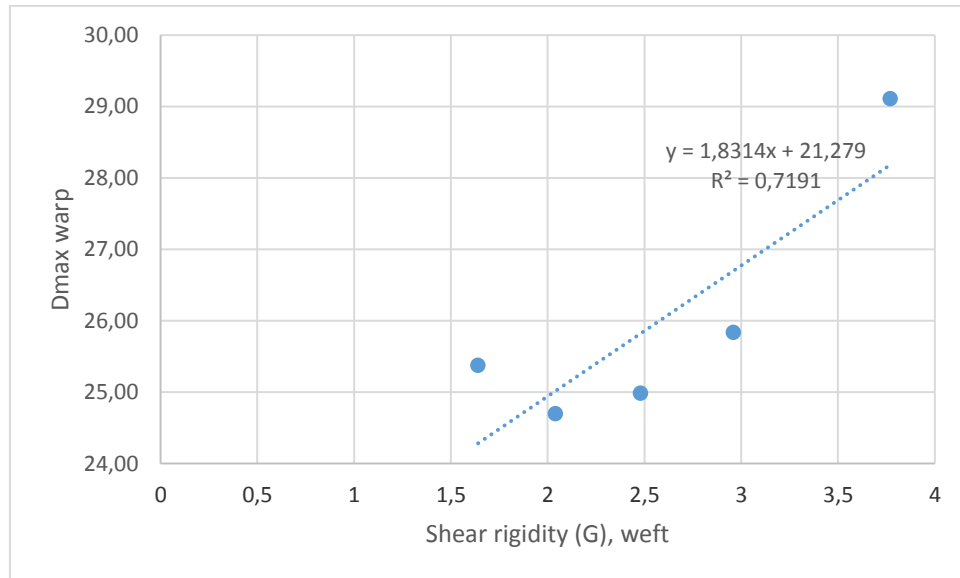
Graph 12 Correlation between Shear rigidity (G), weft and Dmax warp
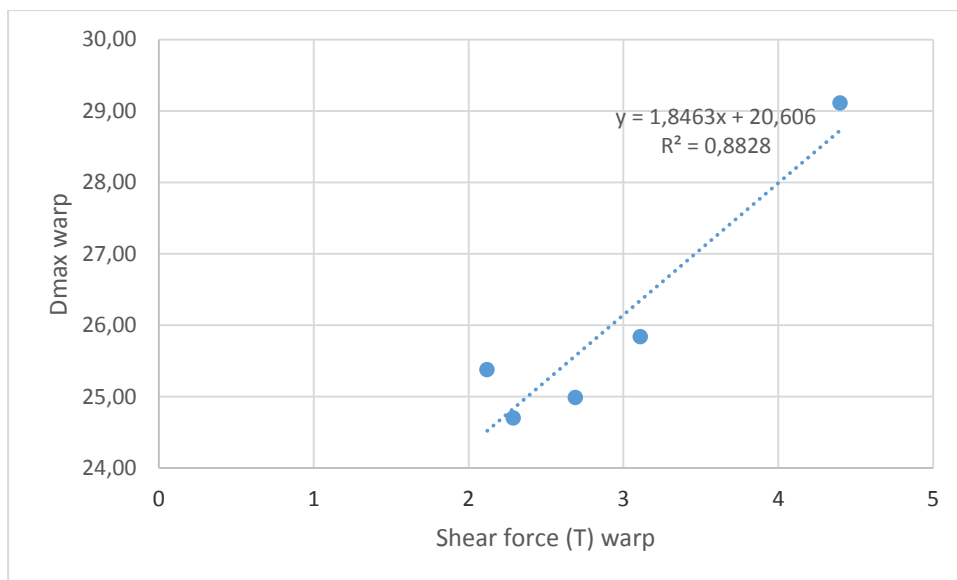
Graph 13 Correlation between Shear forces (T), warp and

Correlation between drape distance coefficient (DDC) warp and bending rigidity (B) weft, Shear rigidity warp and weft, and Shear force (T) warp is prominent.

There is significant correlation between DDC weft and B warp, G warp, T warp and T weft while there is good correlation between LT warp, shear rigidity (G) weft and MIU weft. However, with other mechanical properties there is slight correlation. Any change of the stated significance property would affect the correlation.
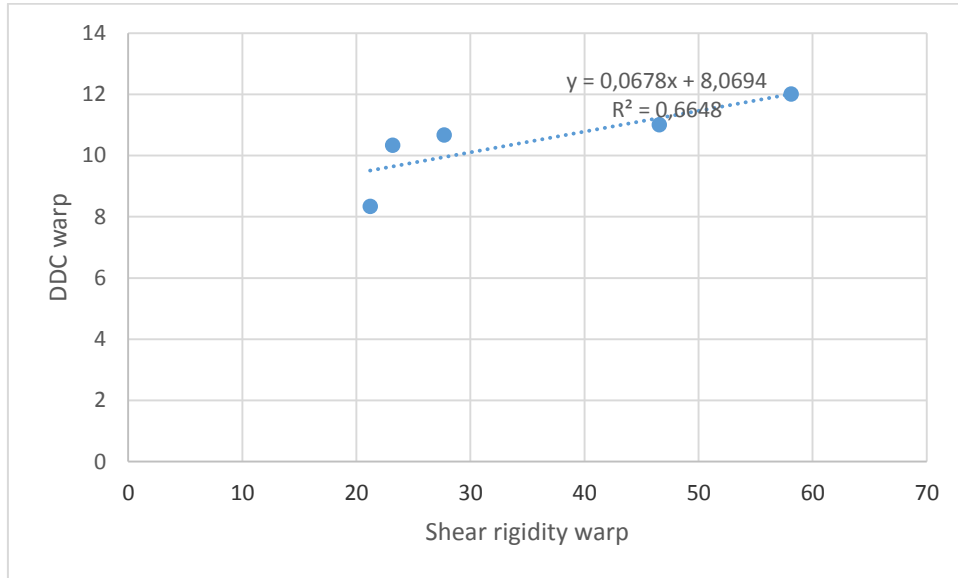
Graph 14 Correlation between G warp and drape distance coefficient (DDC) warp
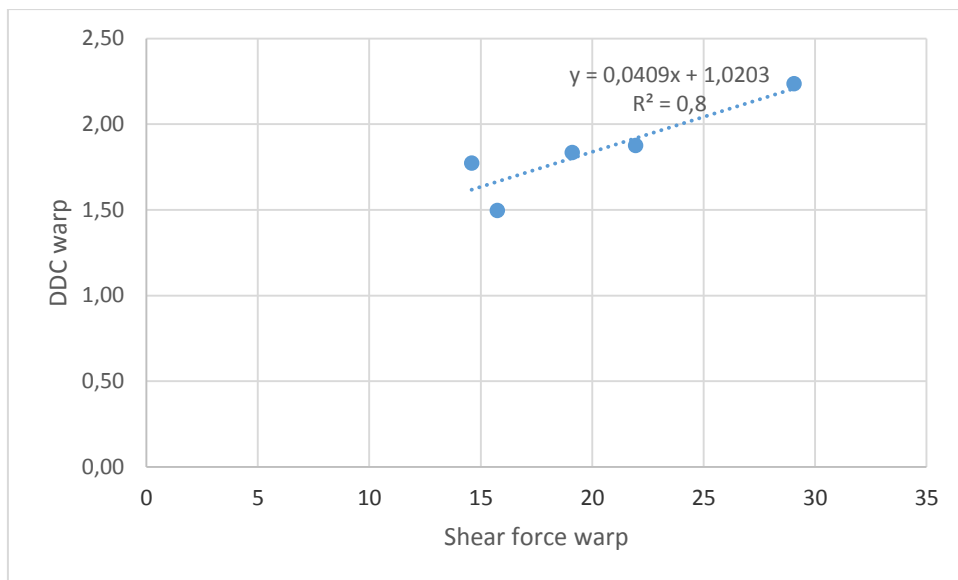
Graph 15 Correlation between Shear force (T) warp and (DDC) warp

4.2 Analysis among real drape, drape in Autodesk 3Ds Max and Maya nCloth

The real drape from the denim fabric samples by by following the approximate ratio of KES-FB properties of the samples, following pictures were found. Comparative analysis of the pictures will take place in this section.

In 3Ds Max there is anisotropic facilitation which enables a user to change desired mechanical property of fabric in warp and weft; however, in Maya nCloth it is not possible to change the properties in warp and weft. Hence, it was convenient to place the properties in 3Ds Max while to put in Maya nCloth, average of warp and weft was put. There are different fabrics fed in library of 3Ds Max e.g., cotton, silk etc while in Maya nCloth e.g., heavy denim, silk etc in the simulation process cotton was used as base in 3Ds Max, nonetheless, heavy denim in Maya nCloth. Moreover, there are no units in 3Ds Max and Maya nCloth for most of the properties except area density (in 3Ds Max) and mass in Maya nCloth. Area density of denim was placed which was derived from KES-FB and mass was recalculated accordingly to put in Maya nCloth.

Table 7 Parameters put in Autodesk 3Ds Max

Notation	Bending		Stretch Resistance		Compress Resistance		Shear Resistance
	Warp	Weft	Warp	Weft	Warp	Weft	
M1	100	32	100.4	120.1	50	50	304
M2	40.3	13	35	120.7	80	75	217
M3	300	36	70.6	110	80	75	409
M4	42	35	255	210	50	50	259
M5	35	12	25	260	50	50	188

Table 8 Parameters placed in Maya nCloth

Notation	Bending Resistance	Stretch Resistance	Compress Resistance	Shear Resistance
M1	1.8	47	28	1
M2	0.6	42	30	0.4
M3	4	45	30	2
M4	1	55	30	0.5
M5	0.8	47	30	0.3

In order to simulate the samples as shown in following figures, properties from Table 8 were set in Maya nCloth whereas, in Autodesk 3Ds Max from Table 7. There are three sets of pictures in below figures, the first is real drape, second is 3Ds Max and third is Maya nCloth.

Real
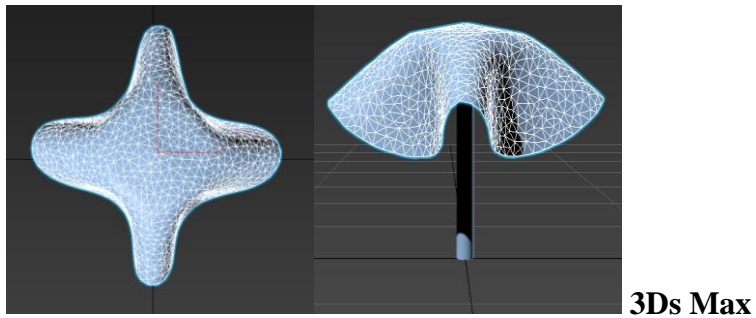
3Ds Max
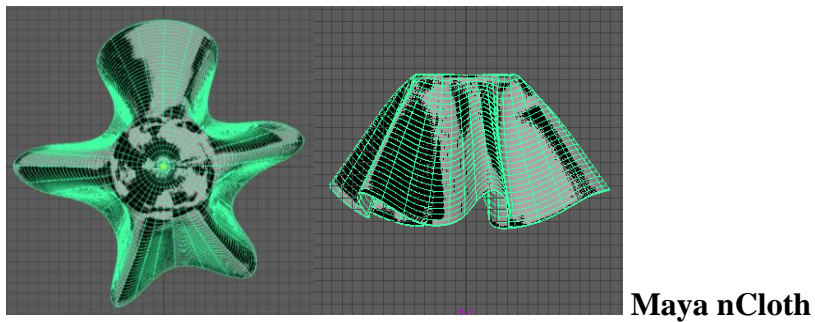
Maya nCloth

Figure 29 Picture of the denim sample M1 draped in real, 3Ds Max and Maya nCloth

By looking at first snap in Figure 29, attribute in 3Ds max and dynamic properties in Maya nCloth were optimized in order to obtain similar drape to the real. The simulation results shown in pictures for 3Ds Max, comprise of weft in horizontal direction while warp in vertical. In 3Ds Max it was possible to imitate while in Maya nCloth to get similar drape, more subsections were given in horizontal direction than vertical. After having tried to tune all possible options to change the properties, above simualaton was acknowledged, this was not similar to what was needed.
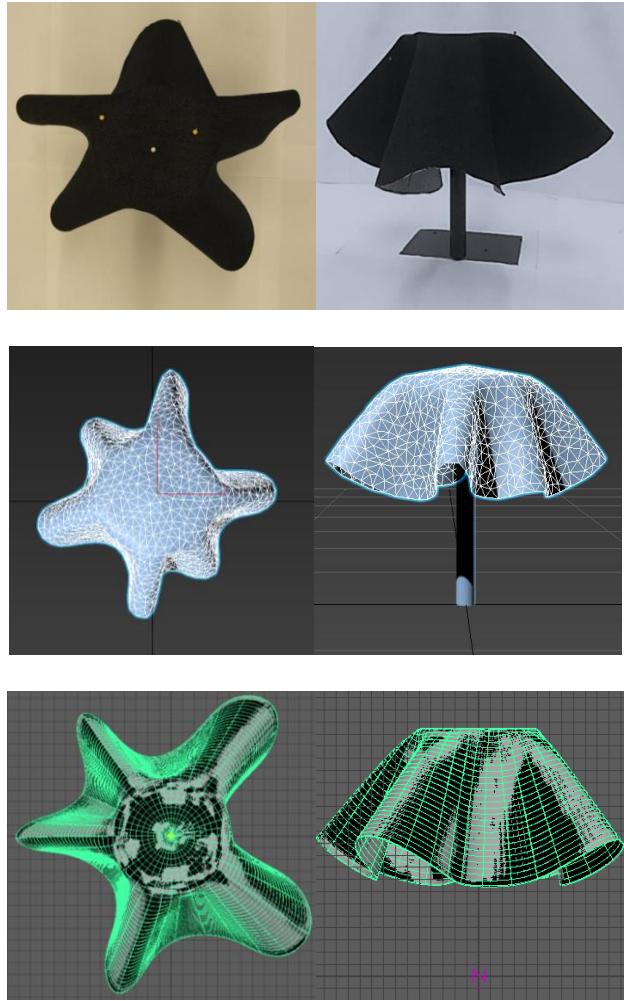
Figure 30 Picture of the denim sample M2 draped in real, 3Ds Max and Maya nCloth

In Figure 30 three of the simulations look similar in visual presentation. Hence, it is a better result than the M1.
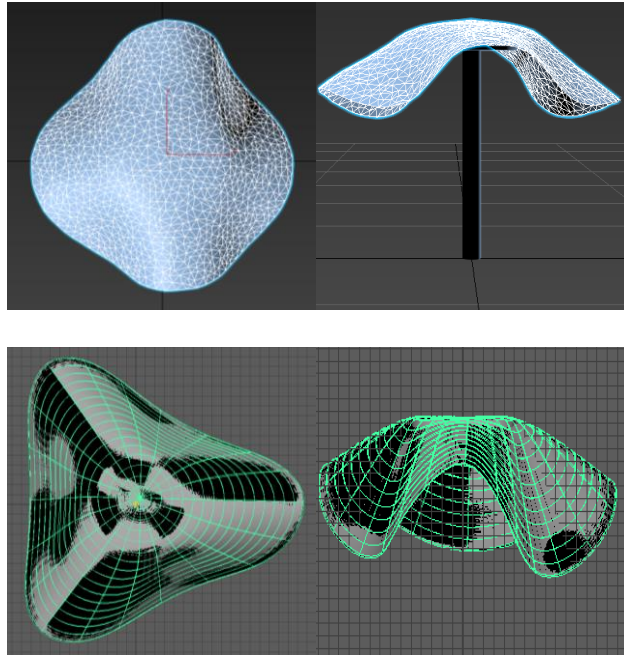
Figure 31 Picture of the denim sample M3 draped in real, 3Ds Max and Maya nCloth

Specimen M3 being the most stiff denim sample, quite similar shape were obtained in 3Ds Max while in Maya nCloth three nodes were attained which shows more flexibility.
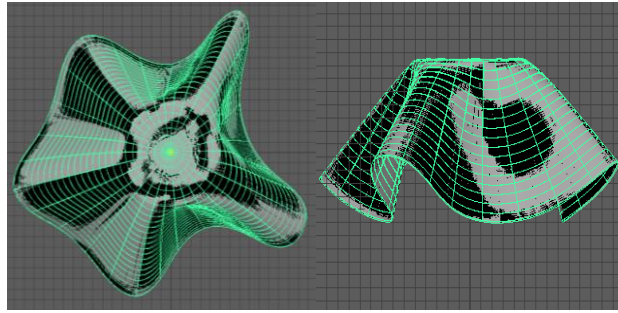
Figure 32 Picture of the denim sample M4 draped in real, 3Ds Max and Maya nCloth

In terms of M4, 3Ds Max sample resembles more flexible than in real and Maya, however, when tried to set different value, either shape was deformed or values were irrational when compared with real one.
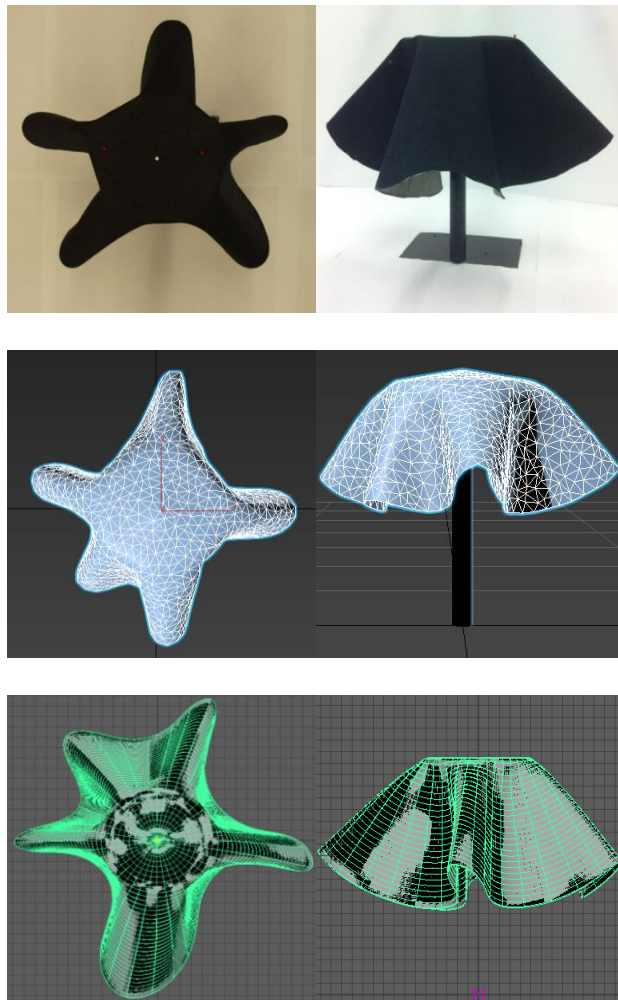
Figure 33 Picture of the denim sample M5 draped in real, 3Ds Max and Maya nCloth

In M5 when "stretch resistance" was decreased, it became flexible a bit while according to the rule that "compress" must not be higher than stretch to get good results, it was not logical to substract closer to "compress". Therefore, there is one node seems stiffer than the whole fabric.

4.3 Correlation analysis between tested denim fabrics draping and mechanical properties

The Table 9 presents the coefficients of correlation between the mechanical properties and denim fabric draping parameters.

Table 9 Table of Coefficient of Correlation with mechanical properties

Properties	DC, Warp	DC, Weft	Dmax, Warp	Dmax, Weft	Number of Nodes, warp	Dmin, Warp	Dmin, Weft	Number of Nodes, Weft	DDC, warp	DDC, weft	DC real drape
B, warp	0,8261	0,9906	0,9319	0,9636	-0,5585	-0,7315	-0,5238	-0,8953	0,8809	0,9893	0,9745
B, weft	0,4357	0,6143	0,7530	0,5956	-0,7250	-0,7970	-0,1670	-0,5688	0,8119	0,5816	0,7448
EMT, Warp	-0,2669	-0,2106	0,0855	-0,1510	-0,4022	-0,1883	0,5096	0,1185	0,1123	-0,2429	0,0043
EMT, Weft	-0,8953	-0,4293	-0,2485	-0,6702	-0,2871	0,0787	0,0764	0,7987	-0,2208	-0,6228	-0,6223
LT, Warp	0,6023	0,8118	0,6261	0,6961	-0,2616	-0,4369	-0,7077	-0,5898	0,5708	0,7838	0,6175
LT, Weft	-0,4530	-0,2854	-0,1362	-0,4210	-0,3052	-0,3434	-0,0058	0,4188	0,1203	-0,3757	-0,2267
WT, Warp	0,6023	-0,1271	0,1627	-0,0729	-0,4523	-0,2625	0,4552	0,0452	0,1940	-0,1601	0,0876
WT, Weft	-0,9181	-0,4520	-0,2488	-0,6946	-0,3273	0,0266	0,0954	0,8153	-0,1914	-0,6483	-0,6192
G, Warp	0,8344	0,8480	0,7957	0,8735	-0,4594	-0,7440	-0,4306	-0,8704	0,8362	0,8883	0,9385
G, Weft	0,8363	0,9396	0,8910	0,9319	-0,5459	-0,7810	-0,4925	-0,8940	0,8961	0,9545	0,9803
T, Warp	0,8164	0,9093	0,8663	0,9008	-0,5448	-0,7964	-0,4852	-0,8705	0,8944	0,9250	0,9637
T, Weft	0,9147	0,9412	0,8517	0,9731	-0,4191	-0,6693	-0,4703	-0,9495	0,8193	0,9859	0,9827
MIU, Warp	-0,4367	-0,6754	-0,4545	-0,5023	0,1676	0,3715	0,7920	0,3872	-0,4541	-0,6260	-0,4229
MIU, Weft	-0,5598	-0,8671	-0,6983	-0,6827	0,4177	0,6394	0,8435	0,5570	-0,7214	-0,8025	-0,6567
Area Density	0,4117	0,5078	0,6051	0,4937	-0,5883	-0,7536	-0,1956	-0,4970	0,7286	0,4952	0,6540
Thickness	0,0988	0,1607	0,4061	0,2259	-0,5472	-0,4555	0,2900	-0,2500	0,4329	0,1470	0,3843

The yellow highlighted values were seemed to have better correlation because their values were around 0.70 or above, however, after having checked with the scattered graph, which were found with highest correlation, were shown in green digits, rest values does not have probability of having remarkable correlation. Following were found with good correlation, in general, by looking at the results acquired.

4.3.1 Correlation between Mechanical properties and DC warp and weft and DC real

DC warp illustrates higher correlation with bending rigidity (B) warp, tensile strain (EMT) weft, shear rigidity (G) warp, shear rigidity (G) weft and shear force (T) warp. However, correlation between DC warp and bending rigidity weft, tensile strain (EMT) warp, tensile linearity (LT) weft, tensile energy (WT) warp, coefficient of friction (MIU) warp and weft, area density and thickness, is not good while correlation between DC warp and tensile strain (EMT) weft (Graph 16), tensile energy (WT) weft and shear force (T) weft, weft is good as values lie around the linear line.

DC weft and bending rigidity warp (B), tensile linearity (LT), shear force (T) weft and coefficient of friction (MIU) weft has good correlation, nonetheless, coefficient of friction (MIU) weft comprises of negative value and therefore, if MIU value icreases DC weft value will decrease and if MIU value decreases DC weft value will increase. Moreover, correlation

between DC weft and shear rigidity (G) warp and weft and shear force (T) warp is good, nevertheless, with rest mechanical properties is not noteworthy.

Correlation between DC real and bending rigidity (B) warp, shear rigidity (G) warp, shear rigidity (G) weft, shear force (T) warp and weft is significant while bending B weft and MIU weft is also good. Moreover, with rest KES-FB mechanical properties correlation is least. Although, MIU was not so important in draping but bending rigidity and shear were important, and therefore, any sort of change in these values would affect the drape of the fabric.
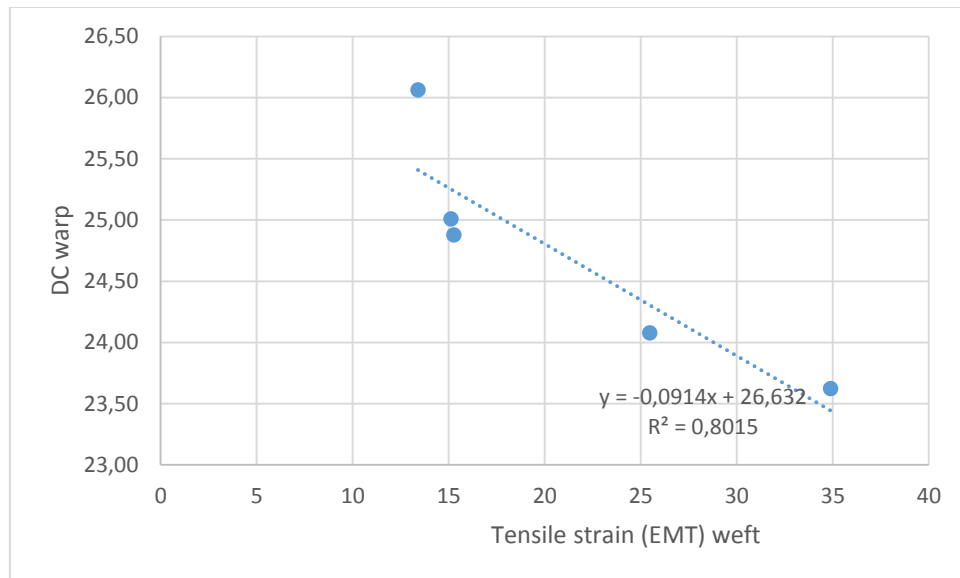
Graph 16 Correlation Coefficient between tensile strain (EMT) weft and DC warp
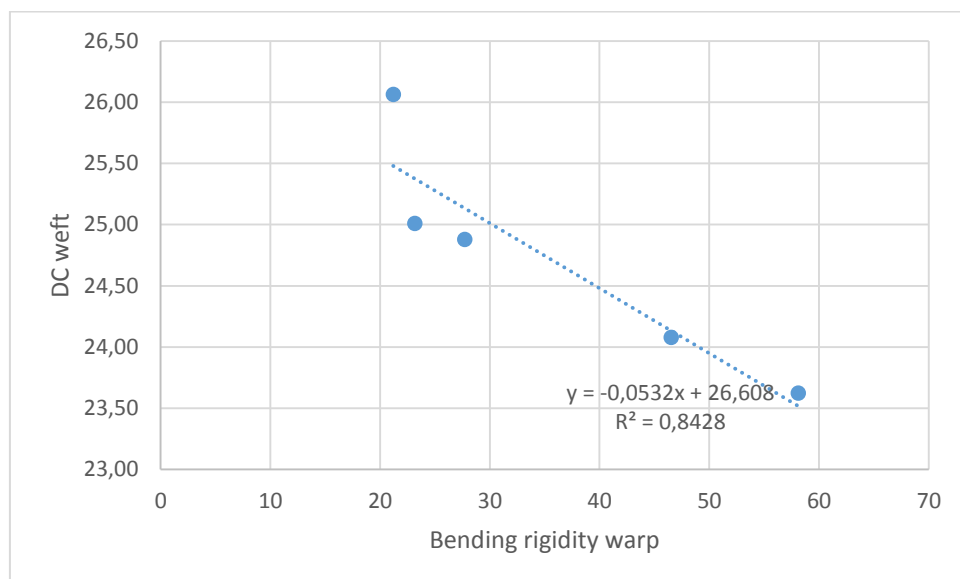
Graph 17 Correlation between DC weft and bending rigidity (B) warp

43
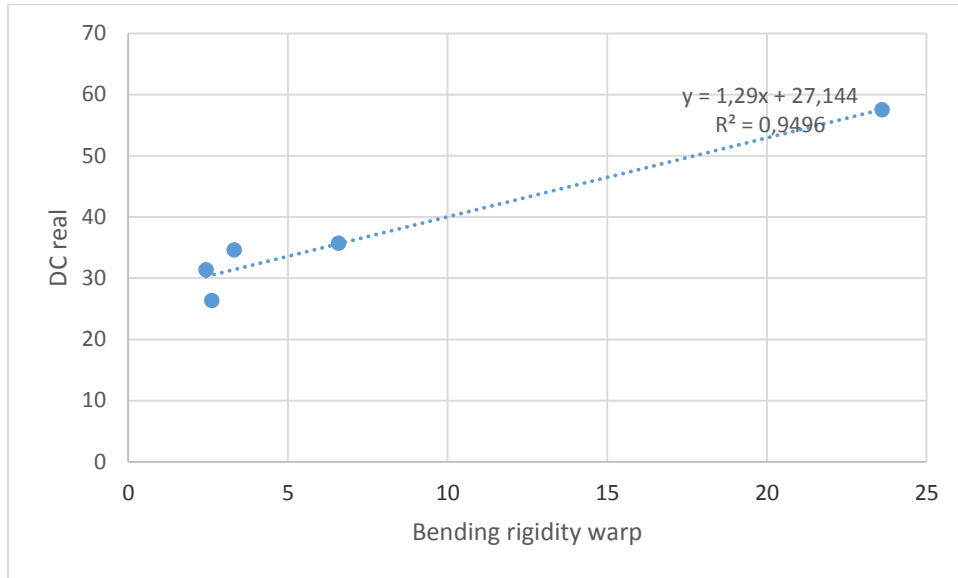
Graph 18 Correlation between bending rigidity (B) warp and DC real
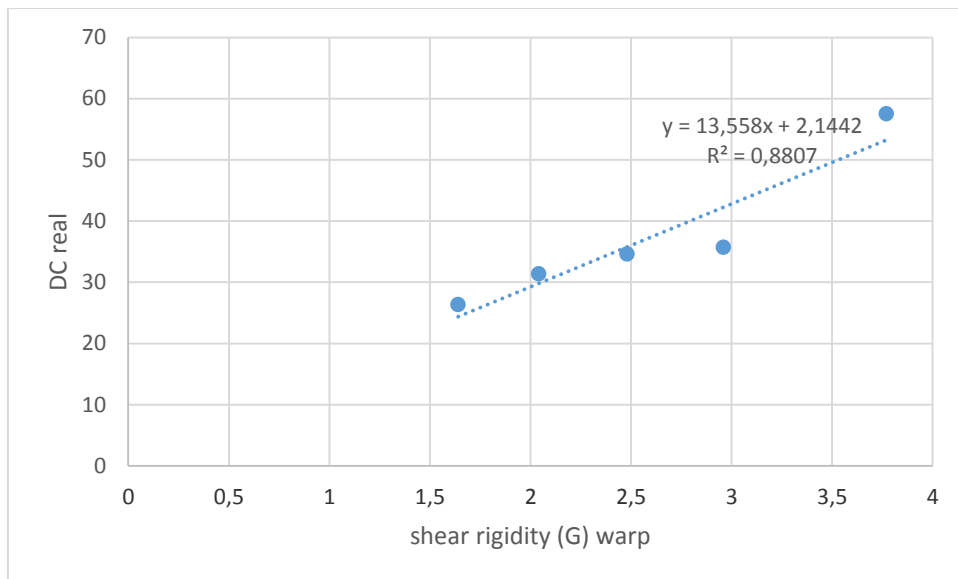
Graph 19 Correlation between shear rigidity (G) warp and DC real
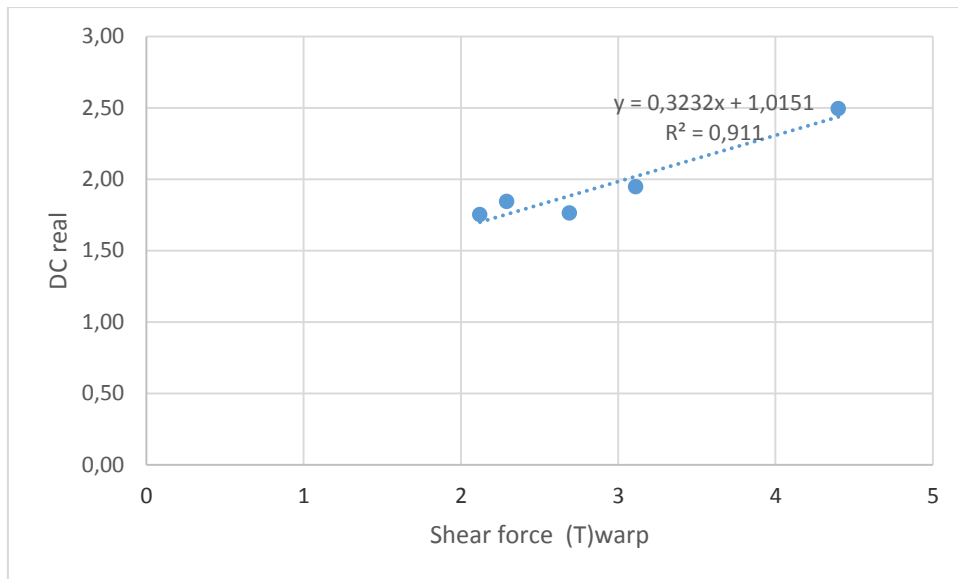
Graph 20 Correlation between Shear force (T) warp and DC real

According to (Graph 17), correlation between bending rigidity (B), warp and DC weft is good because on trendline of linear graph values are around the line. Due to negative value, if bending rigidity warp goes up, DC weft goes down and if DC warp goes down bending rigidity rises.
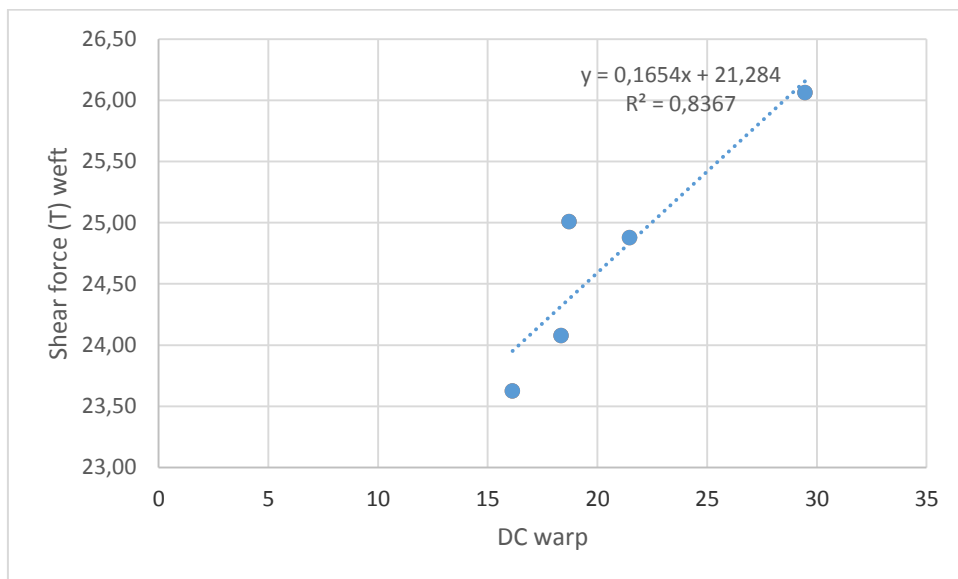
Graph 21 Correlation between Shear force (T) weft DC warp

4.3.9 Correlation between Maya nCloth properties and KES-FB properties

Table 10 Coefficient of correlation Maya nCloth and KES-FB

| Properties	Maya Bending	Maya Stretch	Maya Compress	Maya Shear
B, warp	0.9887	-0.2329	0.0696	0.9776
B, weft	0.7026	0.5267	-0.1232	0.7012
EMT, Warp	-0.1191	0.9189	0.0563	-0.1201
EMT, Weft	-0.5314	0.4550	0.3378	-0.6263
LT, Warp	0.7263	-0.6507	0.1166	0.6942
LT, Weft	-0.1812	0.8361	-0.5236	-0.1801
WT, Warp	-0.0320	0.9102	0.0378	-0.0328
WT, Weft	-0.5330	0.5727	0.2636	-0.6233
G, Warp	0.9263	-0.0299	-0.2577	0.9542
G, Weft	0.9831	-0.0942	-0.1154	0.9911
T, Warp	0.9666	-0.0371	-0.1800	0.9793
T, Weft	0.9743	-0.2653	-0.0700	0.9904
MIU, Warp	-0.5805	0.6804	0.0000	-0.5445
MIU, Weft	-0.8017	0.4833	0.0426	-0.7639
Area Density	0.6266	0.5240	-0.3465	0.6458
Thickness	0.2670	0.7905	-0.0131	0.2745

Between Maya nCloth and KES-FB properties, correlations between similar properties were calculated and equations of correlation were presented in order to make calculaton easy for future researchers.

Correlation between Bending rigidity (B) warp and Bending Maya is significant.

Equations: $B_{\text{Maya nCloth}} = 0.1526 \times B_{\text{Warp}} + 0.4624$, $R^2 = 0.9776$
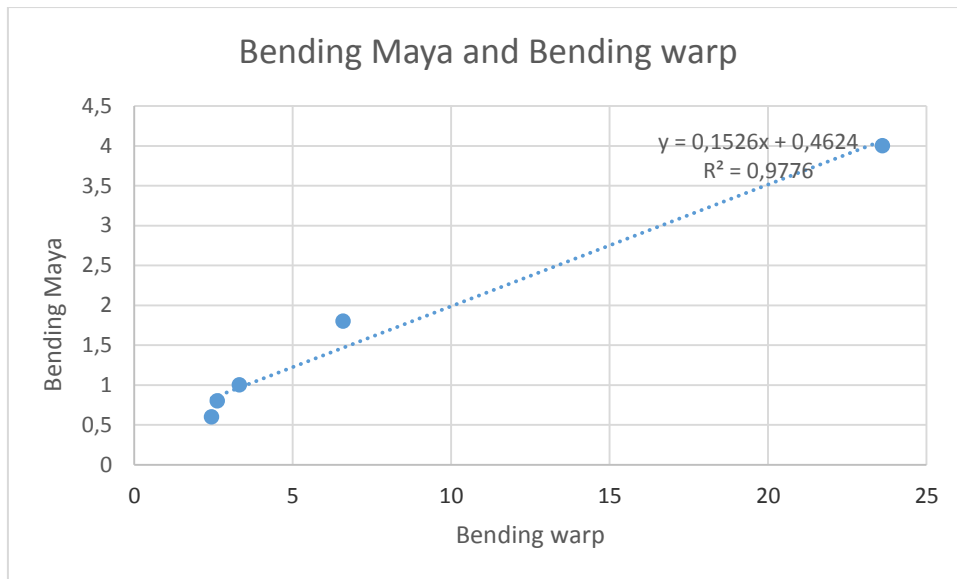
Graph 22 Bending Maya nCloth and bending rigidity (B) warp

Coefficient of correlation between tensile strain (EMT) and stretch Maya nCloth is significant.

Equations: $\text{Stretch}_{\text{Maya nCloth}} = 75.439 \times \text{EMT}_{\text{Warp}} - 4.8526, R^2 = 0.6991$
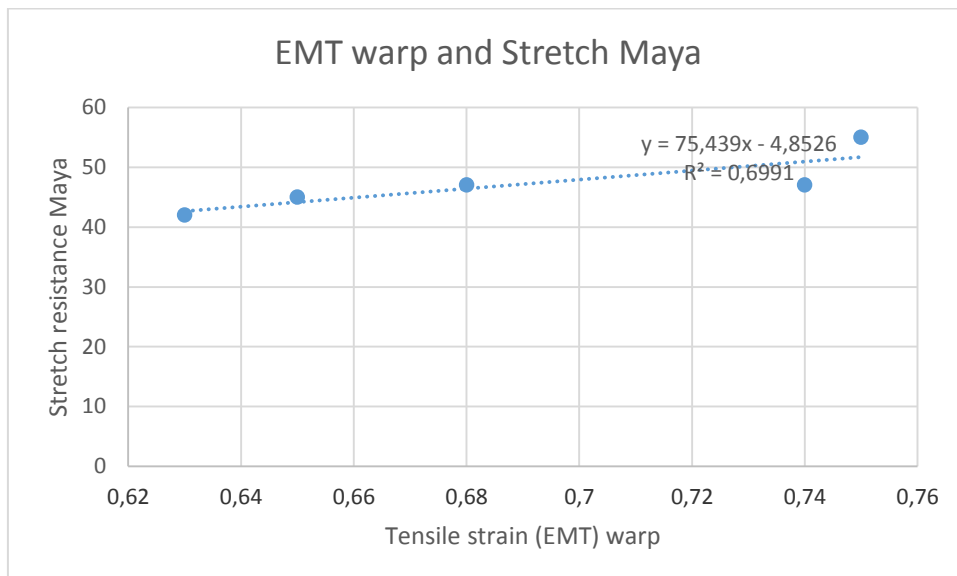
Graph 23 Tensile strain (EMT) warp and Stretch Maya nCloth

There is no significant correlation between Mechanical properties of denim and Maya nCloth compress resistance while between Maya nCloth shear resistance and shear rigidity (G) weft has higher correlation.

Equations: $\text{Shear}_{\text{Maya nCloth}} = 0.8087 \times G_{\text{Warp}} - 1.2448$, $R^2 = 0.9106$
$\text{Shear}_{\text{Maya nCloth}} = 0.7643 \times G_{\text{Weft}} - 1.3933$, $R^2 = 0.9822$
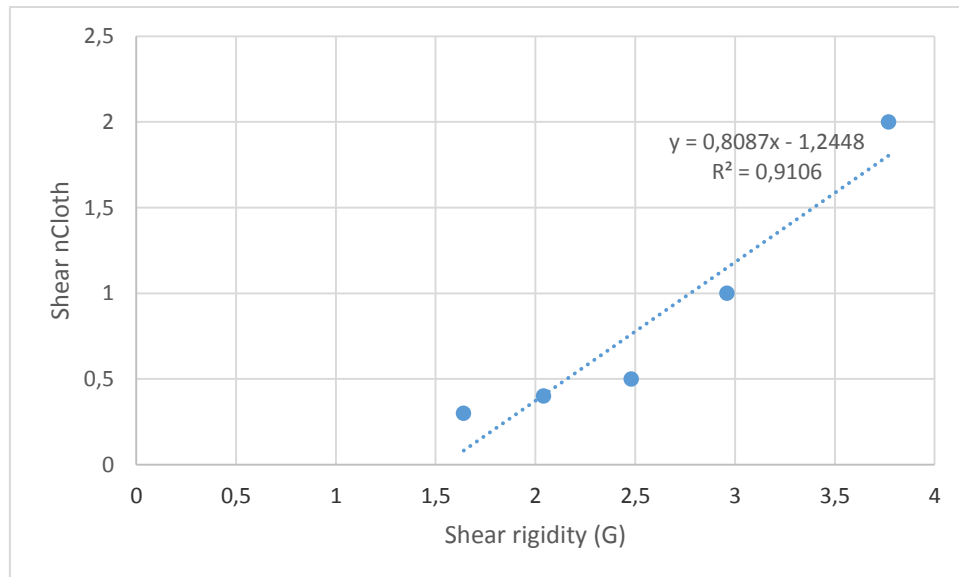
Graph 24 Shear rigidity (G) weft and Shear Maya nCloth

4.3.10 Coefficient of Correlation between 3Ds Max properties and KES-FB properties

Between Autodesk 3Ds Max and KES-FB properties, coefficient of correlation was calculated for all while graphs between similar properties were presented and equations of correlation were established in order to make calculaton easy for future researchers.

Table 11 Coefficient of correlation between 3Ds Max and KES-FB

Properties	Max Bending warp	Max bending weft	Max Stretch warp	Max Stretch weft	Max Compress warp	Max Compress weft	Max Shear
B, warp	0.9981	0.5793	-0.1259	-0.5235	0.5360	0.5360	0.9315
B, weft	0.6384	0.9803	0.6548	-0.2704	-0.0355	-0.0355	0.8118
EMT, Warp	-0.1851	0.6128	0.9961	0.2367	-0.4356	-0.4356	0.9315
EMT, Weft	-0.5604	-0.4251	0.0738	0.9943	-0.6529	-0.6529	0.0629
LT, Warp	0.7694	-0.0346	-0.7074	-0.3161	0.5454	0.5454	-0.6669
LT, Weft	-0.3003	0.5284	0.7615	0.3042	-0.8550	-0.8550	-0.0281
WT, Warp	-0.1003	0.6783	0.9971	0.1872	-0.4066	-0.4066	0.1495
WT, Weft	-0.5775	-0.3158	0.2043	0.9938	-0.7414	-0.7414	-0.6361
G, Warp	0.9002	0.8375	0.1790	-0.6846	0.3603	0.3603	0.9939
G, Weft	0.9691	0.7577	0.0645	-0.6064	0.4241	0.4241	0.9946
T, Warp	0.9432	0.8078	0.1292	-0.6120	0.3649	0.3649	0.9988
T, Weft	0.9818	0.6443	-0.0769	-0.6940	0.5735	0.5735	0.9722
MIU, Warp	-0.6140	0.1850	0.8095	0.2017	-0.3878	-0.3878	-0.3657
MIU, Weft	-0.8116	-0.1431	0.5763	0.2709	-0.3524	-0.3524	-0.6241
Area Density	0.5476	0.9980	0.6757	-0.3460	-0.1353	-0.1353	0.7774
Thickness	0.2022	0.8591	0.9392	-0.0526	-0.2189	-0.2189	0.4474

Bending (B) warp and Max bending warp, and Bending (B) weft and Max bending weft illustrates higher correlation.

Equations:
$$\text{Bending}_{3\text{Ds Max warp}} = 12.476 \times B_{\text{Warp}} + 7.1924, \ R^2 = 0.9963$$
$$\text{Bending}_{3\text{Ds Max weft}} = 10.943 \times B_{\text{Weft}} + 5.005, \ R^2 = 0.9609$$

Graph 25 Bending (B) warp and Max bending warp

Correlation between Max stretch warp and tensile properties (EMT warp, WT warp), and thickness has highest among other attributes, nonetheless, correlation between Max stretch

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weft and tensile properties (EMT weft, WT weft), and shear force (T) weft is moderately high.

Equations: $\text{Stretch}_{3\text{Ds Max warp}} = 6.9177 \times \text{EMT}_{\text{Warp}} + 9.1378$, $R^2 = 0.9921$
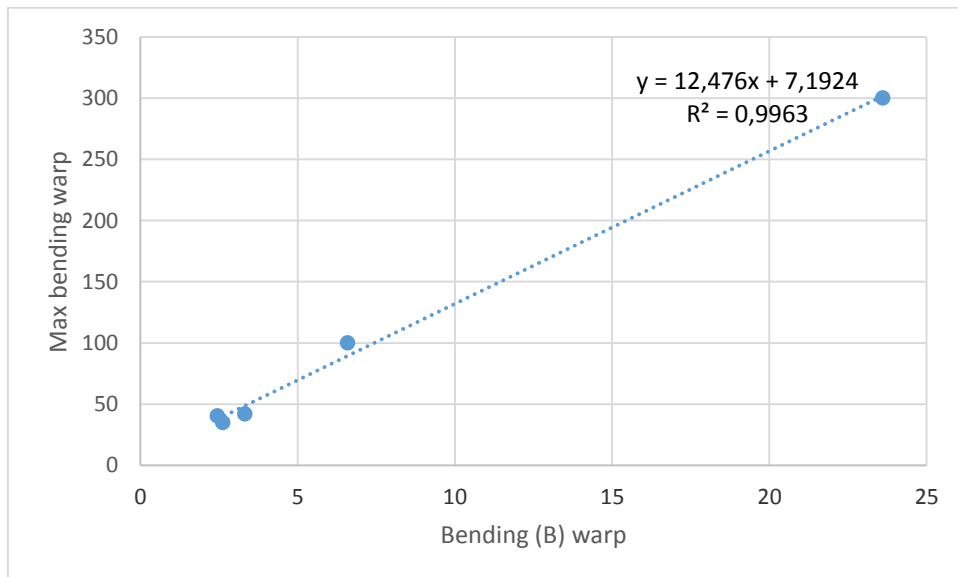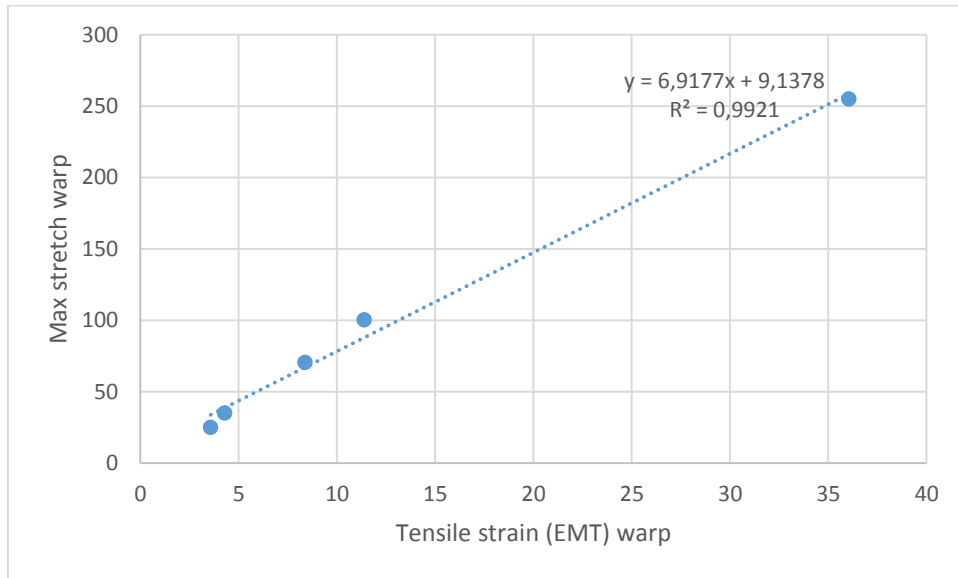 $\text{Stretch}_{3\text{Ds Max weft}} = 7.2641 \times \text{EMT}_{\text{Weft}} + 12.804$, $R^2 = 0.9887$

Graph 26 Tensile strain (EMT) warp and Max stretch warp

Correlation between Max compress warp and weft, and KES-FB properties is not substantial. Moreover, correlation between Max shear and bending rigidity (B) warp, shear rigidity (G) warp and weft, shear force (T) warp (highest), and weft is higher amongst respite other mechanical properties.

Equations: $\text{Shear}_{3\text{Ds Max}} = 103.87 \times \text{G}_{\text{Warp}} + 7.6323$, $R^2 = 0.9879$
              $\text{Shear}_{3\text{Ds Max}} = 94.578 \times \text{G}_{\text{Weft}} - 0.9559$, $R^2 = 0.9893$
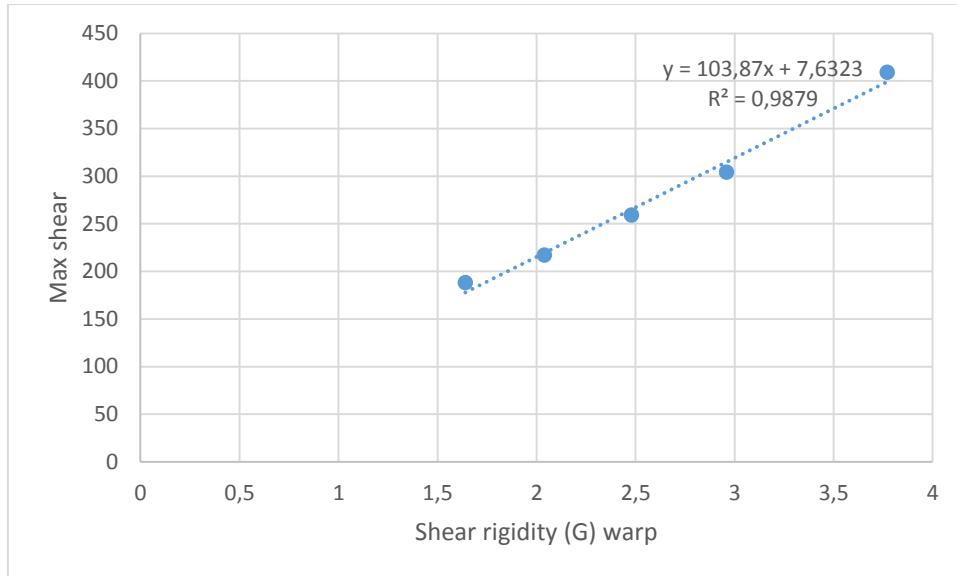
Graph 27 Shear rigidity (G) warp and Max shear

In the nutshell, it is needed to explain about the major four attributed which had more impact on fabric – bending, stretch, compress and shear; took in consideration in simulation process as well as while calculating coefficient of correlation. After having investigated all the graphs created by the values obtained through the simulation in Autodesk Maya nCloth, correlation between mechanical properties of denim sample and Maya nCloth bending properties was highest than the other three attributes – stretch, compress and shear in Maya nCloth. Nevertheless, in 3Ds Max bending warp, stretch warp and shear were respectively at fist, second and third positions in terms of correlation with mechanical properties of sample; other attributes were not with major correlation.

5. CONCLUSIONS

5.1 Summary

Although, earlier findings found many approach to virtually simulate static fabric and garment by using softaware e.g., Browzwear's V-Stitcher, Autodesk Maya nCloth, 3Ds Max, Lectra Modaris 3D Fit Modaris 3D Fit etc. However, it has been challenge to get accuracy, most of the time it resulted with percentage error (Magnenat-Thalmann, 2010). Moreover, by the use of Autodesk designing/3D software many award winning movies e.g., Hugo, Real Steel, Harry Potter, Hungfu Panda-2 etc (Wolfe, 2012).

When it comes to the more of research and development aspects, KES-FB can provide six different properties with different subcategories which could be placed in Modaris and so was done during this research, five denim fabric swatches were tested by KES-FB and simulated in Lectra Modaris 3D Fit Modarsi 3D Fit by making skirt, Autodesk Maya nCloth and 3Ds Max with rounded swatches.

5.2 Significance

This thesis is inspired by the methods used by (Magnenat-Thalmann, 2010) and (Schilder, 2008). Research was conducted to simplify the methods of virtual prototyping in garment production industry and if succeeded could be utilized in virtual garment e-commerce retailing. To an extent, results achieved by comparing real drape and virtual simulation (mainly in Maya nCloth and 3Ds Max) are satisfactory to get to the aim.

On the other hand, due to unavailablty of units in Autodesk Maya nCloth and 3Ds Max for four main properties – bending, stretch, compress and shear while unit for mass and area density is there; it is uncertain what numbers to put in order to gain the drape needed. It is only possible if real drape is already done and the shape of the drape is known, attributes in respective software can be tuned to imitate the shape of real drape. Nevertheless, it is possible to put KES-FB properties in Modaris but is heavy to put online and expensive to use for small amount of prototyping.

This thesis contributes facts to 3D virtual simulation:
- 3Ds Max consists of anisotropic which enables user to place desired extent in both the directions – warp and weft, and easy to get the similar ambiguous drape.
- Maya nCloth has veriety of vfx (visual effects) while does not have mechanism of anisotropic and therefore, it is not so easy to get the simulation results desired.
- Units for certain properties are needed whether it is not there.
- Equations of coefficient of correlation between the KES-FB properties and Autodesk Maya nCloth (Table 10); and between 3Ds Max (Table 11) are given in this research which is useful for further research in this area with denim fabric.
- Correlation between Modaris 3D Fit DC warp and DC real; and DC weft and DC real (Table 5) is given which can be used to ascertain real value if Modaris 3D fit value is given, and if real the vice versa.

5.3 Future Work

Despite the fact that this thesis provides the elementary background for 3D virtual simulation using Autodesk Maya nCloth and 3Ds Max; more work is needed in several areas.

- Apart from foremost attributes – bending, stretch, compress, shear and mass; are there somethings can lead to get the results without units though?
- How to ascertain the units in 3Ds Max and Maya nCloth?
- Would there be a certain ratio in terms of different properties which can be used for definite fabric other than in presets/library?
- The possible combined use of distinct software?

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