

ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE
ENGINEERING AND TECHNOLOGY

**EXPLORING CONSUMERS' VIRTUAL GARMENT FIT SATISFACTIONS TO
PREDICT THEIR ACTUAL SATISFACTIONS**



Ph.D. THESIS

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Department of Textile Technology

Textile Engineering Programme

DECEMBER 2018

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DECEMBER 2018

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MEMNUNİYETİNİ TAHMİN ETMEK İÇİN KULLANILMASI**

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To my mom and dad,



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December 2018

Evrin BÜYÜKASLAN
Textile Engineer



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ABBREVIATIONS

BMI	: Body Mass Index
BS	: Body Satisfaction
CAD	: Computer Aided Design
CAD	: Computer Aided Manufacturing
FAB	: Fabric Analyzer by Browzwear
SiroFAST	: Fabric Assurance for Simple Testing
FOM	: Fabric Objective Measuring
FS	: Fit Satisfaction
FTU	: Fabric Testing Utality
HCA	: Hierarhical Cluster Analysis
KES	: Kawabata Evaluation System
KMO	: Kaiser-Meyer-Olkin
MLM	: Multilevel Linear Model
PCA	: Principle Component Analysis
PDS	: Pattern Design System
RBS	: Real Body Satisfaction
RFS	: Real Fit Satisfaction
RTW	: Ready to Wear
SCT	: Social Comparison Theory
VBS	: Virtual Body Satisfaction
VFS	: Virtual Fit Satisfaction



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EXPLORING CONSUMERS' VIRTUAL GARMENT FIT SATISFACTIONS TO PREDICT THEIR ACTUAL SATISFACTIONS

SUMMARY

Garment fit satisfaction is a very complicated phenomena due to its numerous components and has always been a problem for clothing companies since consumers often complain about poor fitting. However, this issue became more significant due to high return rates of online shopping which is often associated with the fit of the garment. Virtual try-on technology is a useful tool to minimize fit issues encountered during and after online purchasing. Virtual try-on technology enables consumers to see and evaluate how a specific cloth would actually look on their own bodies. During a virtual try-on experience, consumers are expected to evaluate the garment fit by looking at a virtual image. This image consists of a virtual cloth created by a simulation software and a virtual model that represents consumer's body. For a life-like experience, virtual model must be an accurate and realistic simulation of consumer's body which is often attained by 3D body scanning.

Occasions for the virtual try-on technology to be used for online shopping have been already discussed in academia and industry during the last decade, but these expectations have not been met due to expensive and inaccessible 3D body scanners. However, 3D body scanning technology has evolved since then. Nowadays, to scan an object, a surface or a human body, is as easy as using a mobile phone or a portable scanner. Even though, it is not yet that common, using virtual try-on technology for online shopping is now around the corner. When the virtual try-on technology is fully ready for the market, it can be possible for consumers to decide whether to buy a cloth depending on their fit satisfactions of a virtual garment. This anticipation makes virtual fit satisfaction as important as real fit satisfaction.

In this dissertation, factors affecting consumers' virtual fit satisfactions were heeded and a further exploration of *virtual fit satisfaction* notion was pursued. The research model offered by LaBat and DeLong (1990) was the keystone when exploring the factors that affect consumers' virtual fit satisfactions. According to their research, consumers' garment fit satisfactions depend on some internal factors (directly related to the cloth and the consumer) and external factors (related to the fashion trends and beauty perception of societies and fashion industry). The model offered by LaBat and DeLong cannot be directly implemented to understand the factors that affect consumers' virtual fit satisfactions since the virtual try-on conditions are considerably different than actually wearing the cloth and assessing its actual fit. Hence, for this dissertation, these internal and external factors were modified and additional factors which are only applicable for virtual context were included. These novel factors offered in this dissertation were consumers' virtual body satisfactions, virtual try-on acceptance, 3D body scanning experience and the 3D fabric properties which are derived from actual fabric properties. The relationship between these novel factors and consumers' virtual fit satisfactions were questioned and tested by an experimental set-up. Moreover, the association between consumers' virtual fit satisfactions and other

factors which are also present during an actual try-on scenario, such as consumers' body measurements, product liking and online shopping attitudes were also investigated.

Although virtual fit satisfaction is important and influential, it is actually a tool to ensure consumer's satisfaction with the real fit of the garment. Before the virtual try-on technology, it was almost impossible to predict whether the consumer would be satisfied with the fit of the garment or to what extent he/she would be satisfied after an online purchase. In this study, consumer's virtual fit satisfaction was sought as a useful tool to predict consumer's actual fit satisfaction by incorporating internal factors (consumers' body measurements, body satisfactions and fabric properties). Ultimately, in this dissertation, a research model to predict consumers' real fit satisfactions was offered, experimentally measured, and statistically tested.

Garment fit satisfaction is highly subjective since personal preferences are involved. People may like or dislike the fit of a garment due to its design that consists of its silhouette, line, color and texture (or fabric). In this study, the impact of fabric properties on consumers' fit satisfactions was particularly investigated. To do that, other design elements (silhouette, line and color) were fixed, and only fabrics have been altered. Eventually, fourteen woven fabrics were collected, and their critical properties (thickness, weight, bending rigidity, shear rigidity, elongation, drape coefficient, surface friction and roughness) were measured by various testing instruments. Afterwards, fabrics were statistically clustered into four groups according to their measured fabric properties. Following this objective clustering, seven of the fabrics were extracted due to their subjective likeness to the other fabrics within the same cluster. Finally, seven circular skirts which have the same color (black) and same measurements (medium size), but different woven fabrics were produced by a professional seamstress.

For the garment fit experiments, forty-five medium size subjects were recruited in Cornell University. Subjects' body satisfactions, product likenesses, online shopping attitudes were measured by an online survey. Then, each subject was 3D body scanned with their underwear, and their 3D body scans were exported to a commercial 3D garment simulation software to be assigned as virtual models during virtual try-on. After 3D body scanning, each subject tried on four different skirts (one skirt from each cluster) and evaluated their actual fits. Subjects also saw the simulation of each skirt before wearing and evaluated their virtual fit on their own avatar. By doing so, subjects were intended to have an ideal virtual try-on experience during an online shopping scenario. At the end of the experiments, subjects' virtual fit technologies used throughout the experiments (3D body scanner and virtual try-on) were measured.

Collected data was analyzed by using SPSS v.25 statistical software. The first objective of this research was to investigate the factors affecting the virtual fit satisfactions of the consumers. Pearson's correlation test was conducted to explore the correlation between subjects' virtual fit satisfactions and; body measurements, virtual body satisfactions, liking of the cloth design, interaction with virtual fit technologies, attitudes toward product type, and 3D fabric properties. The strongest correlation of subjects' virtual fit satisfactions was found with their virtual body satisfactions at hips level ($r(180) = .50$). It was followed by their belly, hip-thigh and waist measurements ($r(180) = -.34, -.29, -.28$, respectively), and finally their liking of the cloth design ($r(180) = .33$). A weak correlation was found between consumers' virtual fit satisfactions and their interaction with 3D body scanner and virtual try-on technology ($r(180) = .26$

and .24, respectively) (All correlations were significant at $p=0.01$ level). On the other hand, no significant correlation was found between consumers' virtual fit satisfactions and 3D fabric properties.

The second objective of the study was to develop a statistical model to predict consumers' real fit satisfactions and to test its validity. In this study, various skirts were fitted on numerous subjects hence, it was appropriate to use multilevel linear regression instead of simple regression. Therefore, a multilevel linear model (MLM) with maximum likelihood estimation was developed. Subjects' real garment fit satisfaction was assigned as dependent variable; and subjects' body measurements, body satisfactions, virtual fit satisfactions, and fabric properties were assigned as predictor variables. The results of the analysis showed that subjects' virtual fit satisfaction was the strongest predictor of their real fit satisfaction ($F(1, 80.72) = 55.00, p < .01, \beta = 0.54$). The second-best predictor was fabrics' bending rigidity in weft direction ($F(1, 155.26) = 13.33, p < 0.01, \beta = -0.37$). Subjects' waist height and overall body satisfactions were also significant to predict their real fit satisfactions ($F(1, 37.67) = 6.23, p < 0.01, \beta = 0.28$, $F(1, 41.58) = 5.71, p < 0.05, \beta = 0.24$, respectively). Ultimately, subjects' real fit satisfactions were predicted by the developed MLM by using their virtual fit satisfactions, body measurements, body satisfactions and fabric properties. According to the results, subjects' real fit satisfactions and their predicted fit satisfactions were strongly correlated ($r(180) = .775, p < .01$). Furthermore, cross validation was established to test the efficacy of the developed prediction model. For cross validation, collected data were partitioned into two groups randomly. 80 percent ($N=148$) of the data were used for training the model and 20 percent ($N=32$) were used for testing. A linear regression equation was obtained by running the developed MLM with the training data. Afterwards, obtained regression equation was used to predict subjects' real fit satisfactions in the preserved test data. According to the cross-validation, the predicted and actually measured real fit satisfactions were strongly correlated ($r(32) = .83, p < 0.01$). In addition to correlation analysis, a paired t-test was conducted between subjects predicted and actually measured real fit satisfactions. According to the paired t-test results, no significant difference was found between these two groups ($t(1, 31) = 1.86, d = .23, p = 0.073$). The correlation and paired t-test analysis are strong indicators that the developed MLM works well to predict consumers' real fit satisfactions.

Another objective of this study was to compare consumers' real and virtual fit satisfactions. The correlation between subjects' real and virtual garment fit satisfactions were explored by Pearson's correlation test and the means were compared by paired t-test. The results showed that subjects' real and virtual garment fit satisfactions were highly correlated ($r(180) = .63, p < 0.01$). Even though the correlation was high, a significant difference between subjects' real and virtual fit satisfactions were detected for some of the skirts particularly. This brings an answer to the final objective of the study which was to understand how different fabrics affect consumers' garment fit satisfactions in real and virtual context. The results showed that whilst consumers' grasp the fabric related fit alterations in real context, they do not perceive it in virtual context.

Finally, the decline of subjects' body satisfaction level after being exposed to their 3D body scan images was also notable. This decrease was remarkable especially for waist and hips area.

In this dissertation, garment simulation technology was used to create an online purchasing scenario. Moreover, consumers' garment fit satisfactions were measured with respect to the subjectivisms of the garment fit whereas literature often adopt an objective approach. Factors affecting the virtual fit satisfaction of consumers were empirically explored, and a statistical model to predict consumers' real fit satisfactions were successfully developed by incorporating their virtual fit satisfactions.

The research methodology used in this dissertation study can be used to predict consumers' real fit satisfactions for other cloth types or styles by adjusting variables, and consequently increase online shopping and reduce garment returns related to fit issues.



SANAL GIYSİ DURUŞU MEMNUNİYETİNİN GERÇEK GIYSİ DURUŞU MEMNUNİYETİNİ TAHMİN ETMEK İÇİN KULLANILMASI

ÖZET

Kıyafet gibi denenerek satın alınması tercih edilen ürünlerin internet satışı nispeten yeni ve bir o kadar da problemlili bir konudur. İnternet üzerinden satın alınan her dört kıyafetten biri iade edilmektedir (Briggs, 2013). İade sebeplerinin başında kıyafetlerin giyen kişinin bedenine uygun olmaması ve duruşu gösterilmektedir (Kim, 2008).

Son yıllarda, sanal giyinme (virtual try-on) teknolojisi, internet üzerinden yapılan kıyafet alışverişlerinde giysi duruşuna (fit) bağlı olan sorunların giderilmesi için çözüm olarak önerilmektedir. Sanal giyinme; tüketicinin vücudunun sanal benzetiminin (simulation) oluşturulması ve bu benzetimin bilgisayar ortamında sanal kıyafetlerle giydirilmesi olarak tanımlanabilir. Sanal giyinme teknolojisinin giyim sektöründe kullanılması henüz sık karşılaşılan bir durum olmasa da önümüzdeki yıllarda giderek yaygınlaşacağı düşünülmektedir. Sanal giyinme teknolojisini test eden İngiliz perakende firması ASOS, internet alışverişlerinde ürün iade oranlarının yüzde elli oranında azalttığını belirtmiştir (Dunn, 2015).

İnternet alışverişinin giderek yaygınlaşması ve buna bağlı olarak giysi duruşunun daha sık karşılaşılan bir problem olarak ortaya çıkması bu tezin motivasyonu olmuştur. Son on yıl içerisinde internet alışverişlerinde karşılaşılan giysi duruşu sorununu ele alan pek çok akademik araştırma yapılmıştır. Ancak bu araştırmaların çoğunda, giysi duruşu tüketiciler tarafından değil, giyim tasarımı veya teknolojileri konularında uzman kişiler tarafından değerlendirilmiştir. Bir diğer dikkat çeken nokta da üç boyutlu giydirmeye teknolojisinin internet alışverişi için kullanılmasından ziyade ürün geliştirme amacıyla kullanımına yönelik araştırmaların yaygınlığıdır. Bu doktora tezi, tüketici bakış açısının dikkate alınması ve sanal giyinme teknolojisinin internet alışverişine yönelik değerlendirilmesi açısından farklılık göstermektedir.

Giysinin bedene uygunluğu, farklı ve pek çok sayıda faktöre bağlı olduğu için oldukça karmaşık bir konudur. 1990 yılında LaBat ve DeLong, tüketicilerin giysinin duruşundan memnuniyetlerini etkileyen faktörleri içsel ve dışsal faktörler olarak sınıflandırmışlardır (LaBat & DeLong, 1990). İçsel faktörler; kıyafet, tüketici ve bu ikisinin etkileşimine bağlı olan faktörler olarak tanımlanabilir. Dışsal faktörler ise moda endüstrisi ve toplum tarafından belirlenen, güzellik algısına bağlı olan ancak giysiyi giyen kişiden bağımsız olan faktörlerdir. Dışsal faktörlerin giysi duruşu memnuniyetine etkisinin ölçülmesi döneme ve topluma bağlı olduğu için daha zordur. LaBat ve DeLong (1990) tarafından önerilen modeldeki içsel faktörler göz önünde bulundurularak deneylerin planlanması yapılmıştır. Bu sebeple tüketicilerin giysi duruşu memnuniyetine etki eden içsel faktörleri detaylandırma ihtiyacı doğmaktadır. İçsel faktörler kişiye bağlı olarak beden memnuniyeti; kıyafet-kişi ilişkisine bağlı olarak da beden ölçüleri ve kıyafet olarak sınıflandırılabilir. Kıyafet etkeni ise kendi içinde alt kavramları olan bir başlıktır. Kıyafetin ölçüleri ve kıyafet tasarımı (siluet, kontur, renk

ve doku özellikleri) giysi duruşu memnuniyetine etki eden bu alt faktörler olarak sayılabilir.

Yakın zamanda sanal giyinme kavramı tüketicilerin bilgisayar ekranına bakarak giysi duruşundan memnuniyetlerine karar verme durumunu beraberinde getirecektir. Sanal giysinin duruşuna bağlı olarak tüketiciler ürünü satın almaya veya almamaya karar vereceklerdir. Sanal giysi duruşu memnuniyeti bu sebeple başlı başına yeni bir kavramdır ve bugüne kadar sanal giysi duruşu memnuniyetine etki eden faktörler üzerine henüz bir araştırma yapılmamıştır. Bu doktora tezinde, tüketicilerin sanal giysi duruşu memnuniyetine etki eden faktörler, DeLong ve LaBat'in gerçek kıyafet duruşu memnuniyetine yönelik önerdikleri model esas alınarak geliştirilmiş ve etkileri istatistik yöntemlerle test edilmiştir. Sanal giyinme gerçek hayatta kıyafeti denemekten oldukça farklı bir tecrübedir. Dolayısıyla bu model için yeni faktörler önerilmiştir. Bu yeni faktörlerin başında sanal beden memnuniyeti gelmektedir. Sanal giyinme esnasında, ideal durumda, kişi kendi bedenini bilgisayar ortamında üç boyutlu olarak görmektedir. Kişinin sanal ortamdaki bu görüntüsünden memnuniyeti; sanal giysi duruşundan memnuniyetini etkileyen bir faktör olarak önerilmiştir. Bunun dışında, sanal giyinme sürecinde kişi üç boyutlu giydirmeye teknolojileriyle etkileşim halindedir ve bu teknolojilere karşı tutumları sanal giysi duruşu memnuniyetine etki edebilir. Bu teknolojilerin başında üç boyutlu vücut tarayıcıları gelmektedir. Mevcut teknolojilerle, kişinin vücut benzetiminin en gerçekçi şekilde oluşturulması için üç boyutlu tarayıcıyla taranması gerekmektedir. Etkileşim halinde olunan bir diğer teknoloji de üç boyutlu giydirmeye programı aracılığıyla sağlanan sanal giydirmenin kendisidir. Son olarak sanal giyinme esnasında kumaşlara dokunup hissetme imkânı yoktur. Normal şartlarda bu kumaşların tutum özelliklerini objektif olarak değerlendirmek için bazı mekanik ve fiziksel özellikleri kullanılmaktadır. Bu özellikler giydirmeye programlarına üç boyutlu kumaş özellikleri olarak aktarılmakta ve algoritmalarında sanal kıyafeti oluştururken kullanılmaktadır. Farklı kumaş özelliklerinin sanal ortamda da gerçek hayatta olduğu gibi farklı giysi duruşu göstermeleri beklenmektedir. Dolayısıyla üç boyutlu kumaş özellikleri de sanal giysi duruşu memnuniyetini etkileyen bir diğer faktör olarak önerilmiştir.

Tüketicilerin sanal giysi duruşundan memnun olması durumunda ürünü satın alması olasıdır. Daha sonrasında ürünü temin eden tüketici, ürünü deneyecek ve gerçek giysi duruşunu değerlendirecektir. Bu değerlendirmenin sonucu da gerçek giysi duruşu memnuniyeti olarak adlandırılabilir. Dolayısıyla sanal giysi duruşu memnuniyetinin gerçek giysi duruşu memnuniyeti ile pozitif yönde bir ilişkisinin olması beklenir. Bu doktora tezinde de, sanal giysi duruşu memnuniyetinin, gerçek giysi duruşu memnuniyetini tahmin etmek için kullanılması öngörülmüştür. Sanal giysi duruşu memnuniyeti tek başına tahmin eden değişken (predictor variable) olarak kullanılabilir. Ancak bu değişkenin LaBat ve DeLong'un önerdiği modelde diğer içsel faktörlerle (kumaş özellikleri, beden ölçüleri ve beden memnuniyeti) birleştirilmesi, ve bu değişkenlerin de tahmin eden değişken olarak kullanılması durumunda gerçek giysi duruşu memnuniyetini daha iyi/yakın tahmin edeceği öngörülmüştür. Dolayısıyla gerçek giysi duruşunu yüksek oranda tahmin edecek bir istatistiksel modelin geliştirilmesi hedeflenmiştir.

Bu tezin temel iki amacı: 1) tüketicilerin sanal giysi duruşu memnuniyetlerine etki eden faktörlerin belirlenmesi/test edilmesi; 2) tüketicilerin gerçek giysi duruşu memnuniyetlerinin, sanal giysi duruşu memnuniyetlerini kullanarak tahmin edilmesi olarak özetlemek mümkündür. Bu amaçlar göz önünde bulundurularak deneylerin tasarımı gerçekleştirilmiştir. Deney tasarımı gerçekleştirilirken dikkat edilen bir diğer

nokta da sanal giydirmeye teknolojisinin gerek kumaş zelliklerini yeterince yansıtamaması ynndeki arařtırma ve tespitlerdir. Dolayısıyla farklı zelliklerdeki kumaşların gerekte ve sanal ortamda nasıl bir giysi duruşu sergiledikleri ve tketiciler tarafından giysi duruşlarının nasıl deęerlendirildięi nemslenmiřtir. Daha nce de izah edildięi gibi, giysi duruşuna etki eden isel faktrlerden biri de kıyafetin tasarımıdır. Tasarım ise siluet, kontur, renk ve doku zelliklerinin bir bileřimidir. Eęer kumaş zelliklerinin giysi duruşuna etkisi arařtırılmak isteniyor ise, dięer bileřenlerin sabitlenmesi deneysel tasarım aısından gereklidir.

Deneyleer iin, giysi duruşu problemlerinin daha ok alt beden kıyafetlerde yařanması sebebiyle, alt beden kıyafet gruplarından birinin seilmesi uygun grlmřtr. Kumaşların dkmllk zellikleri giysi duruşuna etki eden temel zelliklerden biridir. Dolayısıyla farklı dkmllk zelliklerine sahip kumaşların kullanılması benimsenmiřtir. Bu sebepten tr de dkmllk zellięinin ortaya ıkacaęı dairesel etek modeli kıyafetin silueti iin uygun grlmřtr. Renk olarak ise ntr bir renk olan siyah tercih edilmiřtir. rn grubu ve renk belirlendikten sonra on drt farklı dokuma kumaş temin edilmiřtir. İlk olarak bu dokuma kumaşların zellikleri farklı test yntemleriyle llmřtr. Kumaşların  boyutlu giydirmeye programlarında gereęe en yakın olarak oluřturulması iin bklme ve kayma direnlerinin, ve esneme zelliklerinin atkı ve zlg ynnde ayrı ayrı tespit edilmesi ve programa girilmesi gerekmektedir (Bu programlar kendi ktphanelerinden uygun kumaşın seilmesi seeneęini de sunmaktadırlar. Ancak, kumaş zelliklerinin yarattıęı farkların bu alıřma iin esas alınması sebebiyle, gerekte llen deęerlerinin kullanılması uygun grlmřtr). Bahsedilen zellikler dıřında kumaş kalınlıęı, gramajı ve srtnme katsayısının da programa girilmesi gerekmektedir. Kumaşların esneme ve kayma zellikleri, mukavemet cihazıyla; bklme zellikleri, Shirley kumaş sertlik test cihazıyla; srtnme katsayısı ve yzey przllk zellikleri ise bu lm amaları iin geliřtirilen test cihazlarıyla llmřtr. Bunun dıřında kumaşların dkmllk katsayısı deęeri de Cusick dkmllk cihazı kullanılarak hesaplanmıřtır. Daha sonra bu on drt kumaş, llen zelliklerine gre R programında hiyerarřik olarak (hierarchical cluster) drt grupta kmelenmiř, her gruptaki kumaşların tutum zellikleri iki tekstil teknoloji uzmanı tarafından sbjektif olarak deęerlendirilmiř, ve grup ierisinde birbirine ok benzer olan kumaşlar elenmiřtir. Sbjektif eleme yapılmasının sebebi, etekleri deneklerin giyecek olması ve birbirine ok benzer olan kumaşların giysi duruşu deęerlendirmelerinin de ok benzer olacaęıdır. Sonu olarak drt farklı kmeye dahil yedi farklı kumaş, giysi duruşunu deęerlendirmek zere, aynı llere sahip daire etekler olmak zere dikilmiřtir. Daire etekler baz bedeni olarak tercih edilen Medium (M) beden olarak dikilmiřlerdir.

18-35 yař aralıęı arasında M beden giyen kadınlar en sık internet alıřveriři yapan yař grubu olması sebebiyle tercih edilmiřtir. Deneyleere farklı etnik gruplarda ve eęitim dzeylerinde, kırk beř kadın denek katılmıřtır. Deneyleer Cornell niversitesi'nin etik kurul onayıyla, Cornell BodyScan Lab'da uygulanmıřtır. Her bir denek laboratuvara tek tek aęırılmıřtır. Denek laboratuvara geldięinde ilk olarak kendi i amařlılarıyla  boyutlu vcut taraması yapılmıř; demografik zellikleri, beden memnuniyeti, internet alıřveriř alıřkanlıkları, hazır giyim kıyafetlerinin kendi bedenlerine uygunluęu, moda zevki gibi deęiřkenler evrimii bir anketle llmřtr. Daha sonra deneęe kendi bedeni  boyutlu olarak ekrandan gsterilmiř ve sanal beden memnuniyeti buna baęlı olarak llmřtr. Sonraki etapta, deneęe her bir kumaş kmesinden bir etek olacak řekilde toplamda drt farklı etek verilmiř ve etekleri giymesi istenmiřtir. Deneęin vcut tarayıcısından elde edilen avatarına bu drt etek

ayrı ayrı sanal olarak giydirilmiştir. Sanal etekler oluşturulurken daha önceden ölçülen kumaş özellikleri kullanılmıştır. Denekler her bir eteğin önce sanal giydirmesini görmüş ve etek duruşunu 7'li Likert ölçeğinde bel, karın, basen ve etek ucu bölgeleri için ayrı ayrı değerlendirmiştir. Daha sonra aynı eteğin gerçeğini giymiş ve aynı değerlendirmeyi bu sefer aynaya bakarak yapmıştır. Bu işlem dört etek için tekrarlanmıştır. Deneyin sonunda denneğin üç boyutlu giysi duruşu teknolojilerine yönelik değerlendirmeleri ölçülmüştür. Her bir deney yaklaşık bir saat sürmüş ve deneklere deney sonunda on beş dolar ödeme yapılmıştır.

Elde edilen veriler SPSS v.25 istatistik analiz programında analiz edilmiştir. Araştırmanın ilk amacı olan sanal giysi duruşu memnuniyetini etkileyen faktörleri tespit edebilmek için ölçülen her bir bağımsız değişkenin (beden ölçüleri, sanal beden memnuniyeti, etek tasarımına karşı tutumu, sanal giyinme teknolojilerine karşı tutumu, ürün grubuna karşı tutumu, ürün grubu internetten satın alma davranışı ve 3 boyutlu kumaş özellikleri), bağımlı değişken (sanal giysi duruşu memnuniyeti) ile ilişkisi Pearson's korelasyon testi ile ölçülmüştür. En yüksek korelasyonun, basen bölgesi için ölçülen sanal beden memnuniyeti olduğu tespit edilmiştir ($r(180) = .50$). Daha sonra karın, basen-kalça ve bel çevresi ölçüleri ile negatif yönlü ilişkisi tespit edilmiştir (sırasıyla: $r(180) = -.34, -.29, -.28$). Deneklerin etek tasarımına karşı tutumu, sanal giysi duruşu memnuniyetleriyle pozitif ilişkili bir değişken olarak saptanmıştır ($r(180) = .33$). Deneklerin sanal giyinme teknolojilerine karşı tutum ve sanal giydirme memnuniyeti arasında ilişki tespit edilmiş olsa da bu ilişkinin derecesi azdır ($r(180) = .26$). (Tüm korelasyonlar için p değeri 0.01'den küçüktür). Bir diğer tespit edilen durum da, giydirme programına girilen kumaş özelliklerinin sanal giysi duruşu memnuniyeti ile ilişkisi olmadığıdır. Başka bir deyişle, farklı kumaşlara göre oluşturulan sanal giysilerin, giysi duruşu memnuniyetleri kumaş farklılığından etkilenmemiştir.

Bu araştırmanın bir diğer temel amacı da tüketicilerin gerçek giysi duruşu memnuniyetini tahmin edecek bir istatistik model geliştirmek ve başarı oranını test etmektir. Farklı etekler farklı denekler tarafından giyilip değerlendirildiği için çoklu doğrusal regresyon modelinin (multilevel linear regression model) kullanılması uygun görülmüştür. Çoklu regresyon modellerinin hiyerarşik yapısına göre etekler birinci katmanda, denekler ikinci katmanda yer almaktadır. Bu analizde tahmin yöntemi olarak en büyük olasılıklı kestirimi (maximum likelihood estimation) yöntemi kullanılmıştır. En nihayetinde, gerçek giysi duruşu memnuniyeti tahmin değişkeni olarak; denek numarası rassal değişken olarak; beden ölçüleri, beden memnuniyeti, kumaş özellikleri ve sanal giysi duruşu memnuniyeti tahmin eden değişkenler olarak tanımlanmış ve analiz gerçekleştirilmiştir. Tahmin modelinin geçerliliğini test edebilmek için çapraz geçerlilik (cross validation) yöntemi uygulanmıştır. Bu amaçla verinin yüzde sekseni ($N=148$) ile çoklu regresyon modeli kurulmuş ve kalan yüzde yirmisi ($N=32$) ile de modelin geçerliliği test edilmiştir. Çoklu regresyon modeline göre, en kuvvetli tahmin eden değişkenin sanal giysi duruşu memnuniyeti olduğu tespit edilmiştir ($F(1, 88.720) = 49.292, p < 0.01, \beta = .55$). Kumaşların atkı yönünde bükülme direncinin en iyi ikinci tahmin eden değişken olduğu gözlenmiştir ($F(1, 131.055) = 11.174, p < 0.01, \beta = -.38$). Oluşturulan çoklu regresyon modeli, verinin kullanılmayan yüzde yirmilik kısmını tahmin etmek için kullanılmıştır. Tahmin edilen ve gerçekte ölçülen giysi duruşu memnuniyeti arasında çok yüksek korelasyon bulunmuştur ($r(32) = .83, p < 0.01$). Ayrıca tahmin edilen ve gerçekte ölçülen giysi duruşu memnuniyeti arasında eşleştirilmiş t-testi (paired t-test) yapılmış ve iki grubun aritmetik ortalamaları arasında istatistiksel olarak bir fark gözlenmemiştir ($t(1, 31) =$

1.86, $d=.23$, $p= 0.07$). Ölçülen aritmetik ortalama farkının ($d= .23$) düşük olması da modelin tahmin etme başarısının yüksek olduğunu göstermektedir.

Ayrıca, deneklerin sanal giysi duruşu memnuniyetlerinin gerçek giysi duruşu memnuniyetlerinden istatistiksel olarak daha düşük olduğu görülmüştür ($t(1, 180)= 2.69$, $p< 0.01$, $d= .21$). Oldukça dökümlü (bükülme direnci 0.5-3 mikroNm civarı) veya oldukça sert (bükülme direnci 7 mikroNm üzerinde) olan kumaşlardan oluşturulan sanal ve gerçek eteklerin giysi duruşu değerlendirmesi arasında istatistiksel olarak fark gözlenirken, orta derecede dökümlü kumaşlarda (3-7 mikroNm) fark gözlenmemiştir. Bu araştırmada kullanılan kumaşlara göre, 3 boyutlu giydirmeye programının 3-7 mikroNm aralığında bükülme direnci gösteren kumaş benzetimlerinde başarılı olduğu, ancak diğer kumaşlarda yeterince başarılı olamadığı gözlenmiştir. Ayrıca gerçek eteklerin giysi duruşu değerlendirmeleri, kumaş farklılıklarından ötürü, birbirlerinden farklı iken aynı eteklerin sanal giysi duruşu değerlendirmelerinin farklı olmadığı sonucu istatistiksel olarak tespit edilmiştir. Bu da giydirmeye programlarının kumaş özelliklerini yansıtmakta henüz yeterince başarılı olmadığı sonucunu beraberinde getirir. Bir diğer tespit de deneklerin kendi vücutlarını üç boyutlu ortamda gördükleri zaman özellikle bel, kalça ve basen bölgeleri memnuniyetlerinin anlamlı bir oranda azaldığı tespit edilmiştir.

Sonuç olarak, bu araştırma literatürden farklı olarak giysi duruşunu değil daha subjektif bir kavram olan giysi duruşu memnuniyetini sanal ve gerçek ortamlarda tüketici perspektifini esas alarak ölçmüştür. Üç boyutlu tarayıcıların daha ulaşılabilir olması sebebiyle önümüzdeki yıllarda internet alışverişlerinde kullanımı çok olası olan sanal giyinme ve tüketicinin sanal giysi memnuniyetine etki eden faktörler araştırılmış ve etkileri ölçülmüştür. Sanal giyinme teknolojisinin nihai hedefi gerçek hayatta kişilerin giysi duruşundan memnun olmasını sağlamaktır. Bu amaçla sanal giysi duruşu memnuniyeti ve diğer içsel faktörler kullanılarak, kişilerin giysi duruşunu başarıyla tahmin edebilecek bir istatistiksel model geliştirilmiştir.

Bu çalışmanın, tüketicilerin gerçek hayattaki giysi duruşu memnuniyetlerini tahmin edebilecek bir model geliştirmesi açısından hem tüketiciye hem de giyim sektörüne fayda sağlayabileceği düşünülmektedir. Örneğin bir giyim firması, bu çalışmadaki metotları kullanarak, müşterisinin giysi duruşundan memnuniyetini sanal giydirmeye teknolojileriyle internet aracılığıyla ölçtüğü takdirde, giysinin kumaş özelliklerini kullanarak, kişinin kıyafeti gerçekten denediğinde ne kadar memnun olabileceğini tahmin edebilir. Bu sayede internet üzerinden satın almalarda geri dönüş oranlarını minimize edip, maliyetlerini ciddi oranda azaltabilir. Bu çalışma ile giyim ve tekstil ürünlerinin internet üzerinden alışverişlerinde en yaygın ürün iadesi sebebi olan giysi duruşunun optimize edilmesi hedeflenmiş, deneylerle oluşturulan senaryoda bu hedef gerçekleştirilmiştir.



1. INTRODUCTION

After the debut of internet, retailing strategies of companies had started to shift to electronic commerce (e-commerce). U.S. Department of Commerce (www.doc.gov) reported e-commerce sales in U.S. in 2016 as \$391 billion. The largest product category of e-commerce sales was computer and consumer electronics (\$76 billion) and it was followed by apparel and accessories category (\$60 billion) (Miller & Washington, 2017). Online shopping was found convenient by consumers because it sweeps away the necessity to go to a physical store to buy a certain product. However, high return rates are one of the biggest limitations of online shopping. A research done by Internet Retailer in 2013, reviewed the return rates of top merchants' online activities and found that the highest return rates belonged to apparel industry with a statistics of 20-30 percent of the products being returned (Briggs, 2013). Another study revealed that return costs of apparel sector reached up to \$ 1.4 billion by 2016 (Rivero & Zhu, 2016).

Poor garment fit is one of the main reasons of the product returns (Kim, 2008), and majority of consumers hesitate to buy garments online due to their fit concerns (Kim, 2008). Various technologies such as 3D body scanning and virtual try-on have been offered over years to reduce return rates by increasing consumers' garment fit satisfaction (Sayem, Kennon, & Clarke, 2010). Some studies show that 3D visualization of products decreases consumers' perceived risk during online shopping and increases their purchase intention (Park, Lennon, & Stoel, 2005). Garment fit satisfaction is a very complicated phenomena as it depends on internal and external factors. External factors are shaped by apparel industry and society while internal factors are self-centric and depend on one's self (LaBat & DeLong, 1990). Virtual garment fit is relatively a new notion that emerged after introduction of 3D fit technologies. Virtual garment fit can be described as the fitness of the virtual cloth on a virtual body. Virtual body can be either a direct avatar (virtual model) created by using a 3D body scanner; a parametric body model obtained by manually inserting body measurements of the model to the simulation software; or a statistical body model

created by learning from a scan database (Istook, 2011), (Pishchulin, Wuhrer, Helten, Theobalt, & Schiele, 2017). Currently, there are some commercial software to display garment fit virtually (Sayem et al., 2010), and some apparel companies (e.g. Target, Kohl's and JCPenney) already use these software for their product development (Lee & Park, 2017). Aside their product development attribute, these software offer solutions for various end-users such as online apparel retailers and online shoppers (Kim & LaBat, 2013b). Loker and her colleagues' scenario (2008) describes how these technologies could be beneficial for consumers and clothing companies. In their scenario, they encourage readers to imagine that they possess a smart card with their 3D body scan file in it, and they can just plug the smart card into the computer and go online, select the style they want to virtually try-on, and finally view the virtual garment on their own virtual body model (Loker, Ashdown, & Carnrite, 2008). In this dissertation study, this scenario was actualized in order to see how a virtual garment fit would actually be assessed by consumers. The objectives of this study were developed by reviewing the literature, considering customer demands and trajectory of the apparel industry. One of the main objectives was to understand factors that affect virtual garment fit satisfaction of consumers and compare it with their real garment fit satisfaction. This first objective brought an important question along with it: Why should we investigate consumers' virtual fit satisfaction mechanism? The fundamental purpose of this thesis emanates as an answer to this question. It is important to understand consumers' virtual fit satisfactions to have a prediction about their actual garment fit satisfactions. Thus, the other objective was to predict consumers' real garment fit satisfactions.

1.1 Purpose of the Thesis

The fundamental purpose of this dissertation is:

- 1) To predict consumers' real garment fit satisfactions by employing a statistical model.

Consumers' garment fit satisfaction is a long discussed and studied phenomena. However, consumers' virtual garment fit satisfaction is relatively new. Therefore, the other study objectives are:

- 2) To explore factors affecting consumers' virtual garment fit satisfactions,

- 3) To compare consumers' virtual garment fit satisfactions and real garment fit satisfactions.

As mentioned in introduction part, fabric simulation is very challenging, and it is one of the biggest concerns of simulation software users and providers. During an online shopping, consumers are not able to touch or feel the fabric, so they cannot sense the fit differences that stem from the fabric itself. Hence, the other objective is:

- 4) To understand how different fabrics, affect consumers' garment fit satisfactions in real and virtual environment.

1.2 Significance of the Thesis

Real and virtual fit comparison of garments have been explored and reported in journals, conferences as well as thesis studies (Lim, 2009), (Jevsnik, Pilar, Stjepanovic, & Rudolf, 2012), (Kim & LaBat, 2013a), (Song & Ashdown, 2015). However, they are often either objective comparisons, or subjective comparisons of experts or study participants who view virtual garments on someone else's virtual body model, but not on their own. On the other hand, most of these studies compare real fit and virtual fit. However, consumers' garment fit satisfaction is a more complex and subjective term than the garment fit itself as consumers and their individualities are involved to the evaluation process.

Another significant, yet undiscovered, aspect of virtual try-on technology is its correlation with fabric properties. It is expected that fabrics drape well and fit realistically on consumers' virtual bodies during virtual try-on. 3D garment simulation software enable users to create virtual fabrics by inserting their actual fabric properties. But it is still a question how consumers perceive virtual fit of the garments created by using different fabric properties. Is virtual try-on technology adequate to display the fit differences of garments made from different fabrics? How does consumers fit satisfaction vary for different fabrics during virtual try-on? Virtual garment fit is relatively a new phenomenon and yet there aren't many systematic researches to analyze fabric properties and their influences on virtual garment fit satisfaction.

As explained in the introduction part, virtual try-on is expected to be used for online shopping in the next few years. According to this anticipation, understanding virtual garment fit and its components will become more important for clothing companies.

Hopefully, academia and clothing industry will benefit from the outcomes of this study by having an insight of the factors affecting consumers' virtual fit satisfactions. On the other hand, in this study, a statistical model is offered to predict consumers' real fit satisfactions by using their virtual fit satisfactions and some other variables. Since the product returns after online shopping are mostly due to poor garment fit, a close prediction of consumers' real fit satisfactions can be very critical to reduce return rates, increase online sales and finally elevate profits.

1.3 Theoretical Background

Textile and apparel industry have been using computer technology for many years (Hu, 2011). However, 3D technology applications are relatively new. 3D technologies draw textile and apparel researchers' attention during the last decade because, efficient utilization of this technology is expected to speed up the production and reduce the manufacturing costs (Hu, 2011).

3D technologies influence clothing industry by transforming the product development stage and introducing new practices such as virtual try-on (Lee & Park, 2017). Product development is strategic, creative, technical, production and distribution planning of the goods with respect to the delivery time (Keiser & Garner, 2012). Fashion industry is being challenged by the shortened fashion cycles and rapidly changing consumer demands. Thus, optimizing product development is crucial to reduce costs and diminish production spans. 3D technologies emerge as an optimization tool by minimizing the number of samples required before production. It was predicted in 1998 that, 3D technologies would reduce the number of samples required before production and eventually cut down the production time and costs (Hardaker & Fozzard, 1998). This prediction was actualized to a certain extent in the last twenty years (Song & Ashdown, 2015). However, this progression has been relatively slow for apparel industry due to challenges in fabric simulation (Papahristou & Bilalis, 2017).

E-retailing has been another platform where 3D technologies are expected to boost online apparel sales by reducing number of returns (Kim, 2008). ASOS, the biggest e-retailer in UK, reported that adapting virtual try-on technologies to their online store reduced the return rates by fifty percent (Dunn, 2015). Currently, there are a few commercial 3D technology providers and start-ups trying to minimize fit and size

related issues of online shopping (Gill, 2015). However, prevalence of 3D technologies for online shopping is not very high yet, and by 2018 there aren't many apparel retailers that offer 3D technologies to their customers to overcome the fit related issues during online shopping (Brook, 2015).

3D body scanners have been thought as an auxiliary tool for online shopping to improve garment fit since the early days of online apparel shopping (Ashdown, Loker, Schoenfelder, & Lyman-clarke, 2004), (D'Apuzzo, 2007). In the last ten years, scanned body images were integrated with CAD systems to create virtual simulations. Nowadays, many fashion companies use 3D garment simulation software such as Modaris (by Lectra), O/Dev (by Optitex), V-stitcher (by Browzwear), Vidya (by Assyst), Clo 3D and Marvelous Designer, and using 3D body scanners to develop their products (Gill, 2015). Even though fashion companies are familiar with garment simulation, fashion consumers are still not familiar with this technology. It is still not clear how consumers would adapt to virtual try-on technology. By 2018, the essential issues that needs to be answered for consumers to accept this new technology are summarized as:

- 1) To understand consumers' garment fit perceptions in virtual and real settings and minimize the discrepancy of these two mediums,
- 2) To understand consumers' psychology and shopping attitudes when imposed to their body image in virtual environment,
- 3) To implement tactile features of different fabrics to virtual environment.

This dissertation study purposes to embrace a large scope by investigating the issues stated above. Accordingly, literature review was designed according to the key concepts related to these issues.

1.3.1 Garment fit

1.3.1.1 Definition

Garment fit is a very complicated notion because fabrics which are 2D materials in nature are compelled to drape over a 3D human body form during fitting (Bona, 1994). It is defined as the relationship between garment dimensions and body dimensions (Daanen & Reffektrath, 2007), and it evolves with time, hinges on fashion culture and subjective perception of fit (Yu, 2004). A cloth should conform to the body surface

while having enough space for movement though being wrinkle free and look neutral to give the sensation that it is a part of the wearer (Chambers & Moulton, 1961). According to Frost (1988), fit accommodates visual, physical and functional evaluation of a cloth (Frost, 1988). Hazen (1998) says that a good fitting garment should be manipulative by showing wearer's body to be more symmetrical and proportional than it actually is (Hazen, 1998). Ashdown and Locker's definition is a combination of Frost's and Erwin's definition, and it states that a well-fitting garment should be wrinkle-free while having some design ease and functional ease (Ashdown & Loker, 2010). When dressed up, consumers are probably not aware of these garment fit definitions. However, some cloths still looks good and feels right to them. As the words imply, visual evaluation of a cloth is usually described with *look*, whereas the interaction with the body is described with the word *feel* (Frost, 1988). Appearance of a cloth, being associated with the look, can be either assessed by the wearer herself or by an external spectator. However, feel can be only assessed by the wearer (Frost, 1988). In other words, an external spectator judges the fit of a cloth only by looking at its appearance on the wearer, while the wearer includes her feelings. This distinction introduces two different fit evaluation approaches (Shin, 2013):

- 1) Fit according to the wearer,
- 2) Fit according to the observer,

During product development, observers (often designers or fit technicians) plays a key role for garment fit, whereas the key role belongs to the weaver when purchasing the garment. In literature, garment fit from consumer perspective has been explored way less than the observer perspective (Pisut & Connell, 2007), (Gill, 2015), (Shin, 2013). Eventhough online apparel shopping has gradually expanded over the last five years, there aren't enough studies to explore virtual garment fit from consumer perspective (Kim & LaBat, 2013b). Thus, a need to study virtual garment fit from consumer perspective still exists.

Majority of female consumers decide whether a garment fits well by monitoring if the garment allows them to move freely and drape smoothly on their bodies (Howarton & Lee, 2010). Technical evaluations like seam and grain line orientation are less important for consumers (Howarton & Lee, 2010). The definition of good and bad fitting garments varies for consumers as well. According to some consumers, a bad

fitting garment makes them look thicker while a good fitting garment shows them slimmer. On the other hand, for some consumers, a gratifying length and tightness of the garment determine its fit quality (Shin, 2013).

Shin (2013) studied consumers' garment fit perception and identified five prominent themes: aesthetic fit, physical fit, functional fit, social context and social comfort (Shin, 2013), (Shin & Damhorst, 2018). *Physical fit* is associated with tightness and length of the garment while *functional fit* is more related to its comfort features. *Aesthetic fit* is described as overall appearance of the garment on the wearer's body and it is associated with attractiveness and fashion trends (Shin, 2013). Some consumers include *social context* to their fit perceptions by saying that the cloth should be appropriate for the occasion. Consequently, according to these consumers, appropriateness/misappropriateness of the cloth generates a social comfort/discomfort (Shin, 2013). The conceptual model of consumers' fit perception identified in Shin's study (2018) is given in Figure 1.1.

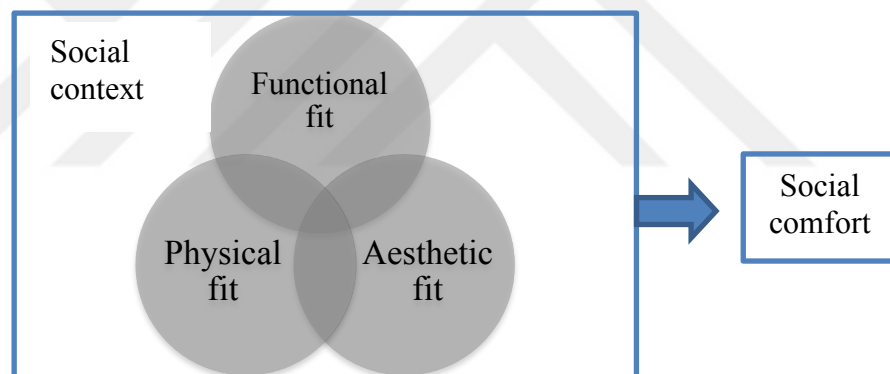


Figure 1.1 : Conceptual model of consumers' fit perception (Shin & Damhorst, 2018).

1.3.1.2 Evaluation of garment fit

Fit evaluation can be classified according to the testing protocol where the test subject can be either in dynamic state, quasi-static state or static state (Zakaria & Gupta, 2014). During dynamic fit evaluation test, subjects are asked to conduct several tasks and perform any forms of motion while static evaluation requires the subjects to stand still at a specific position (Zakaria & Gupta, 2014).

The garment fit evaluation can be also classified according to the nature of the evaluation method such as objective or subjective evaluation (Yu, 2004). Objective fit evaluation requires a deep technical knowledge and a set of equipment to measure

the fit quantitatively. Hence, it is widely used for academic purposes, whereas subjective fit evaluation is steadily established by apparel manufacturers, fashion brands and finally by the consumers (Fan, Hunter, and Yu , 2004)

Objective fit evaluation

Numerous instrumental analysis methods have been offered over years to objectively measure garment fit (Yu, 2004). Objective fit evaluation methods may be classified as: Moiré optics, waveforms, pressure mechanics, computer fit modelling and algebraic evaluations (Yu, 2004). *Moiré optics* is a non-contact system that is used to measure the contours of a cloth (Meadows, Johnson, & Allen, 1970). In this system, a light source and a moving frame with grid plates are used in order to create moiré fringes on the person that is wearing the cloth. The contours of the cloth is extracted according to the moiré fringes map by calculating the depth of the fringes on certain body locations (Yu, Yeung, & Lam, 1998). *Algebraic evaluation* is essentially the distances, areas and volumes between the cloth and the body. In other terms it is the mathematical calculation of the total ease allowance (Ng, Chan, Pong, & Au, 1996). *Waveforms* are similar to algebraic evaluation in principle. Waveforms are derived from the cross-sectional distances between the body and the cloth in certain areas such as bust, waist line and hips. These distances are measured with alternative techniques in literature such as digitizing by Vectron measuring apparatus, acoustic theory or symmetrized dot patterns (Taya, Shibuya, & Nakajima, 1995).

The methods stated above are non-contact methods to measure the garment fit. In 2002, a new method was introduced by Yu et.al. (2001) which is an in-contact measuring system (Yu, Fan, Qian, & Tao, 2001). In their research, Yu et. al. (2001) manufactured a soft mannequin from flexible polyurethane and soft rubber to substitute the soft form of lower body. They suggested that the cloth pressure on an actual body can be predicted by using linear equations derived from the measured pressure on this soft mannequin. This technique was later adopted by scholars that explore compression garments especially (Yu, Fan, Qian, & Tao, 2004), (Wang et al., 2011).

In 2004, Ashdown and her colleagues used 3D body scanners to analyze the fit of a garment (Ashdown et al., 2004). In their study, they 3D scanned subjects with a pair of pants and assessed the garment fit by looking at their 3D scans (Ashdown et al., 2004). In that study, the measurement was done objectively but the fit evaluation was

done subjectively. Later, in 2008, Petrova and Ashdown (2008) carried on the work, and this time they objectively measured the ease allowance of pants from the 3D scans (Petrova & Ashdown, 2008). Scholars often benefited 3D body scanners to measure ease allowances, develop customized garment patterns and evaluate garment fit (Xu, J., Zhang, 2008), (Song & Ashdown, 2010), (Bye & McKinney, 2010), (Lu, Song, & Li, 2013), (Gu, Xu, Su, & Liu, 2015).

Subjective fit evaluation

Objective fit evaluation is considered to be a quantitative assessment while subjective evaluation is qualitative (Yu, 2004). Geršak (2002) stated that the garment fit is qualitatively assessed according to aesthetic appearance of a garment drape and the visual form of its 3D shape (Geršak, 2002).

Apparel manufacturers and brands use often live models or dress forms to evaluate garment fit subjectively (Bye & LaBat, 2005). Fit evaluations with live models are more reliable than the dress forms since actual human bodies involve to assessment (Song & Ashdown, 2010). Whether the dress is displayed on a dress form or a live model, the subject rating scales are often engaged to evaluate the garment fit (Yu, 2004).

Subjective fit evaluation scales

Users associate garment fit often with its tightness and length (Shin, 2013). Parallel with this statement, developed garment fit evaluation scales were often designed to assess tightness and length of a garment. To best of our knowledge, the oldest garment fit evaluation scale in literature dates back to a master thesis published in 1973 (Vanderpoorten, 1973). In this thesis, Vanderpoorten (1973) developed a garment fit rating scale, as she named it back then, for a dress. In this scale, the dress was viewed from side, back and front, and evaluators were asked to rate certain elements of the dress (e.g. front length of bodice part, bust tightness, sleeve length) on a three points scale (good, fair or poor) (Vanderpoorten, 1973). Later, Lesko (1982) developed a fit evaluation scale for a bodice. In that study, subjects evaluated tightness/looseness and shortness/lengthiness of various parts of the bodice (i.e. neck, front, back and sleeves). Additionally, scale included questions about the sizes and angles of the darts, drop of the neckline, and seam lengths and positions (Lesko, 1982).

Fit evaluation scales alter according to the garment type and the style. Therefore, it is not possible to find an all-inclusive fit evaluation scale in literature. The majority of the garment fit evaluation scales were designed for performance garments since fit is assumed to be critical especially for this type of garments. Most of these performance based scales evaluate dynamic fit where participants are asked to do specific tasks with respect to the design purposes of the garments (Tan, Crown, & Capjack, 1998), (Huck, Maganga, & Kim, 2006), (Gordon, Lastovich, Bye, & LaBat, 2014).

1.3.2 Consumers' garment fit satisfaction and its components

Garment fit is defined as the relationship between garment dimensions and body dimensions (Daanen & Reffektrath, 2007), whereas garment fit satisfaction corresponds to consumers' evaluation of a particular garment on their particular body parts such as waist, hips etc. (LaBat & DeLong, 1990), (Shin & Damhorst, 2018). Fit satisfaction and fit preferences are highly correlated notions as consumers make free choices (preferences) to maximize their satisfactions (Shim & Bickle, 1993). Consumer satisfaction is defined as the evaluation of the outcomes occurred after using a product or a service, and if the outcomes meet the expectations or standards of the consumer, product/service is assumed to be satisfactory (Conant, Brown, & Mokwa, 1985). On the other hand, consumer dissatisfaction occurs when the outcomes are negative and the expectations of the consumer are not met (Engel, Blackwell, & Miniard, 1990).

It should be noted that garment fit satisfaction is not identical to clothing satisfaction. Clothing evaluation has three dimensions according to Francis and Dickey (1984), namely: expressive satisfaction, instrumental satisfaction and market satisfaction (Francis & Dickey, 1984). Style and color represent expressive meaning, while fit and size are instrumental, and finally price is a marketing attribute (Francis & Dickey, 1984). According to this definition, fit satisfaction embraces instrumental satisfaction level of individuals, and it shouldn't be confused with clothing satisfaction.

In 1990's, numerous scholars studied the factors that affect fit preferences of individuals (LaBat & DeLong, 1990), (Hwang, 1996), (Anderson et al., 1999). As mentioned in the introduction part, LaBat and DeLong's study is a keystone to systematically analyze the fit preferences of individuals (LaBat & DeLong, 1990). In their study, LaBat and DeLong (1990) questioned the factors affecting the fit

satisfaction/dissatisfaction of consumers in all aspects. According to their model in Figure 1.2, consumers' satisfaction/dissatisfaction of a garment fit is influenced by external and internal factors. Internal factors mainly depend on the consumer herself while external factors depend on time and society (LaBat & DeLong, 1990) .

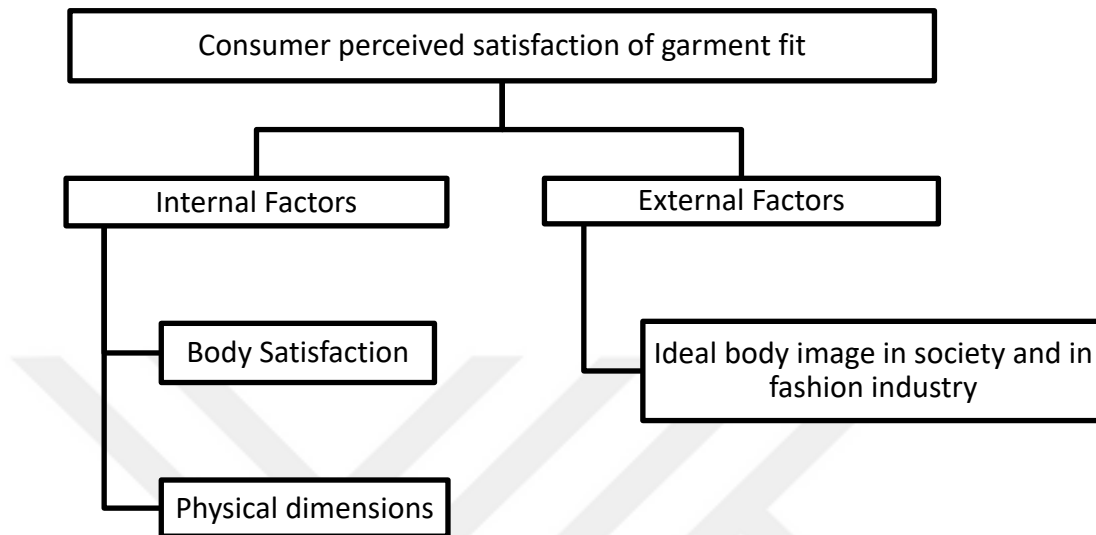


Figure 1.2 : Factors affecting consumers' garments fit satisfactions (LaBat & DeLong, 1990).

1.3.2.1 External factors

The impact of physical dimensions of a cloth on consumers' fit satisfaction has been the main research area of the scholars before 1990s. However, as mentioned by Shim and Bickle (1994), looking into only physical features of a product may hinder psychological effects and motives behind consumer behavior (Shim & Bickle, 1994). After 1990s, the connections between consumers' fit satisfaction and notions like body image, ideal beauty and fashion figure started to be stressed.

According to Solomon (1983), products may have a symbolic meaning and these meanings may stimulate the society, and eventually this interaction may affect the product satisfaction (Solomon, 1983). In other words, for clothing aspect, the interaction of society and the wearer may have an impact on garment fit satisfaction.

Ideal body image

It is important to understand ideal body image because it has an impact on garment fit satisfaction (LaBat & DeLong, 1990). As LaBat and DeLong suggested, when a fashionable garment do not fit, the consumer may accuse her own body which causes negative feelings about herself (LaBat & DeLong, 1990).

Ideal beauty perception had transformed over three thousand years and had distinct meanings for different societies (Yang, Celestino, & Koeppel, 2015). Beauty perception changes parallel with the advances in societies. For instance, emanation of social protests and feminism in 60s brought androgynous look as the beauty norm of the day (Romm, 1987). On the other hand, scholars agree that each society generates an ideal body figure itself (LaBat & DeLong, 1990). For instance, a study done in 2002 showed that Caucasians favor a thinner body while African American has less tendency to do so (Gluck & Geliebter, 2002).

The differentiation of ideal beauty between societies diminished due to the impact of social media (Ridolfi, Myers, Crowther, & Ciesla, 2011). Celebrities have millions of followers from all over the world and they are influential for them. Social media or in general mass media now impose how the perfect body should look like (Pritchard & Cramblitt, 2014). On the other hand, people who are entitled by media to have ideal bodies that do not represent the majority of the public (Bell, 2016).

There are many studies in the literature that demonstrate positive association between body dissatisfaction and fashion media exposure (Grabe, Ward, & Hyde, 2008), (Hawkins, Richards, Granley, & Stein, 2004), (Swiatkowski, 2016). Nowadays, millions of people follow the fashion models and take them as role models. For example in 2017, only in US, almost 24 million people watched Victoria Secret (intimate wear company) fashion shows (Statista, 2017b).

Ready to wear (RTW) companies, probably the biggest influencer of the fashion industry, also play an important role for the perception of ideal body by the sizing standards they develop and the advertisements they use (Kinley, 2010). McVey's (1984) study is an early example to show how apparel brands influence consumers' perceptions (McVey, 1984). This study suggests that consumers tend to blame themselves when they encounter a poor-fitting but expensive and fashionable garment, and eventually they start to believe that they are not good enough (McVey, 1984). For RTW companies, fit models represent the average costumer and base size is shaped according to the fit models, and bigger/smaller sizes are graded according to the base size (Bougourd, 2007). As a consequence, the sizing system developed according to a fit model brings an issue that it only fits a specific body type.

It should be noted that there is a positive movement at the moment to endorse diversity of body figure and appearance. Two luxury fashion houses (LVMH and Kering) announced in September 2017 that they won't hire any super-skinny models for their fashion shows and ads (Samuel, 2017). Pirelli calendar, which is well-known for being publicized every year with nearly nude pictures of the famous and beautiful women, debuted with a new issue in 2016. The pictures in 2016 calendar were not supermodels but successful women with diversified professions, and they weren't actually representing the ideal beauty perception of today (Rodulfo, 2015). Serena Williams (professional tennis player), an African American with a muscular body, being the cover of Vogue America (April 2015) is another example of this movement to alter ideal body perception of societies (Joseph, 2016).

Eventhough there is a positive movement, ideal beauty perception remains as a constant problem for societies. Hwang's study (1996) confirms that women between 18-25 are dissatisfied with their bodies and pursuit of the ideal body has a significant effect on this dissatisfaction (Hwang, 1996). Internalization of the standards imposed by the society is one of the main reason for body dissatisfaction (Johnson, Lennon, & Rudd, 2014). The foundation of this dissatisfaction is explained mostly by social comparison theory (SCT). According to SCT, people have a propensity to compare themselves to others to endeavor "the ideal" or "the normal" (Festinger, 1954). As explained so far, the comparison with the ideal body may cause a dissatisfaction about one's self and this dissatisfaction may consequently decrease the garment fit satisfaction of the person.

1.3.2.2 Internal factors

Body satisfaction

Body satisfaction notion has been used interchangeable with body cathexis in the literature. Body cathexis notion was first used by Jourard and Secord and defined as the satisfaction or dissatisfaction of one's own body (Secord & Jourard, 1953). After Secord and Jourard's study (1953), scholars started to focus on factors affecting the body satisfaction levels of individuals. A study done in 1976 suggested that face accounts most for the general appearance satisfaction and it is followed by the weight (Mahoney & Finch, 1976). However, a following study found that weight was the essential antecedent for general appearance satisfaction (Garner, 1997).

Kaiser (1990) mentioned that self-feelings may influence the clothing preferences and attitudes of the consumers (Kaiser, 1990). Fit preferences of two women with same height, weight and body measurements may be different (Alexander, Connell, & Presley, 2005). Later, LaBat (1987) associated these self-feelings with body satisfaction and linked it to the garment fit satisfaction for the first time (LaBat, 1987). In her studies she showed that, women are less satisfied with their lower body parts and, consequently, they have the highest dissatisfaction with the garment fit at thigh, hips and buttocks (LaBat, 1987), (LaBat & DeLong, 1990).

After 1990s, numerous researchers focused on the body satisfaction/dissatisfaction correlation to garment fit satisfaction, clothing preferences and body shape (Shim, Kotsiopoulos, & Knoll, 1991), (Hwang, 1996) (Alexander et al., 2005), (Pisut & Connell, 2007), (Manuel, Connell, & Presley, 2010). Hwang's dissertation (1996) elaborately investigated the association of body satisfaction with clothing benefits sought and clothing behavior (Hwang, 1996). This study found that women that are satisfied with their weight and lower body parts tend to be more satisfied with garment fit at thigh and hips areas (Hwang, 1996). Kim and Damhorst (2010) proved that women with higher body dissatisfaction is more likely to have concerns with garment fit during an online shopping (Kim & Damhorst, 2010). Shim et. al.'s (1991) study distincts from others as it explored the correlation between body satisfaction and clothing attitude, and shopping behavior of male consumers and it still confirmed a positive correlation between body satisfaction and clothing attitude of men (Shim et al., 1991).

Alexander et. al. (2005) studied the correlation between clothing fit preferences of women between 18 to 30 years old and their garment fit satisfactions. She found that female participants with a higher body satisfaction at certain body parts were more confident to wear garments which reveal those parts of their bodies (Alexander et al., 2005). Since fitted garments reveal the body features, studies confirm that women with higher body satisfaction appreciate tight clothes more than the women with lower body satisfaction (Pisut & Connell, 2007).

Since studies showed that women have different satisfaction levels for different body parts, researchers questioned if body satisfaction level significantly varies also for different body shapes. According Manuel et.al. (2010) study, women with a rectangular body shape were more satisfied with their lower and upper body than the

women with a pear- shaped body (Manuel et al., 2010). Another study reports that body satisfaction level of women with inverted triangular and hourglass body shapes were significantly higher than those with rectangular and pear shaped bodies (Pisut & Connell, 2007).

Physical dimensions

Physical fit (dimensional fit) notion emanates from the dimensional relation between the cloth and the wearer (Yu, 2004). Tightness, length and size of the cloth are the three most common words used by the consumers to describe the physical fit (Shin, 2013). Tightness of a garment is closely related to garment ease. As mentioned earlier, garment ease can either depend on the design or the necessary space for the wearer to function easily. Design ease is more subjective as one consumer may prefer a loose fit design while another one prefers a skinny fit design (Presley, Connell and Alexander, 2005). Studies prove that the clothing preferences are related to body measurements and body shape of the subject as well as her fashion taste (Apeagyei, 2008), (Pisut & Connell, 2007). However, the garment ease needed for the wearer to function comfortably (functional ease) is more objective. Functional ease is highly correlated to fabric properties and these fabric properties determine the physical fit of a garment (Yu, 2004). Two garments with same measurements and same style may look and function differently if their fabrics are different. In other words, garment fit is also a function of fabrics' mechanical and drape properties (Thi, Ngoc, & Anh, 2010).

1.3.3 Online apparel shopping and approaches to minimize garment fit issues during online shopping

Clothing online sales were always behind electronics, hardware and office supplies until 2014 (Russell, 2017). However, apparel industry started to transform lately. For instance, regardless of the product category, global online retail value is estimated to be almost \$3000 billion by 2018 (Garcia, 2018), and surprisingly more than 10 percent of it is expected to account for clothing and apparel category (Orendorff, 2018). Eventhough apparel online shopping numbers are increasing, studies show that consumers still prefer in-store shopping over online shopping when clothing and footwear is considered (PwC, 2017). For instance, H&M, one of the biggest apparel retailers in the world, reported that their online sales' value was \$3.7 billion in 2017

which is only 12.5 percent of their total sales for that year (Business Insider Nordic, 2018).

One of the biggest obstacles of online apparel shopping, and probably the biggest reason why in-store shopping is still greater than online shopping, is that; in retail shopping, information gathering and desire for the product is strongly connected to touching the product (Peck & Childers, 2003). However, as mentioned by Rodrigues et.al. (2017), this feature is missing for online shopping (Rodrigues, Silva, & Duarte, 2017).

For online sales, fashion brands often prefer to display their products as a picture which consists of a fashion model wearing the product. This state brings an issue together: consumers consistently struggle during online shopping because they cannot see bodies similar to their own. On the other hand, this situation may cause a discrepancy on consumer perception of her own body and the ideal body offered by the retailer (Kim & Damhorst, 2010), (Shin & Baytar, 2013).

Return rates of apparel online shopping is an indicator that consumers are not very satisfied with the product information they gather during online shopping. Online shopping return rates of apparel products are five times more than actual store returns (Winkler, 2017). According to industrial and academic researches garment fit is one of the biggest reason of apparel returns (Kim, 2008); (Shin, 2013), (Rivero & Zhu, 2016), (Ratcliff, 2014), (Winkler, 2017).

1.3.3.1 Improving sizing systems

Unfortunately, the sizing of clothing is quite complicated, especially for the consumers. The main reason of this complication is that sizing labels vary for countries, genders, companies and product groups (Chun, 2007). In addition to complicacy of labeling systems, consumers are also confused as they fit into different sizes of different brands due to vanity sizing. Size specifications of an apparel brand are determined according to the demographics of the target customers. After selecting a fit model that reflects the average measurements of target customers, the smaller/bigger sizes are graded according to brand's target costumers' measurements (Chun, 2007). As a result of this process, consumers encounter clothes from different brands that has the same size label but different measurements (Ashdown, 2007). To minimize this confusion, size standardization is offered by multiple standards

organizations such as ASTM in US. Establishing a reliable size standardization requires a large-scale and long-term anthropometric study. ASTM 5585-11 (Standard Tables of Body Measurements for Adult Female Misses Figure Type, Size Range 00–20) was first developed in 1994 based on O'Brien and Shelton's study (O'Brein & Shelton, 1941) and the earlier sizing system which dates back to 1950s (U.S. Department of Commerce, 1958).

Following the technological innovations, especially the 3D body scanning technology, size standardizations were updated with more recent anthropometric data (Robinette, Daanen, & Paquet, 1999). At the beginning of 2000s, some leading apparel brands sponsored a project named SizeUSA. Over ten thousands subjects from twelve different cities in US were scanned by 3D body scanners (The Textile Clothing Technology Corporation, 2003). These large-scale body scanning projects provided a deeper understanding of the average anthropometry of the society. After national studies such as SizeUSA, SizeFrance, SizeMexico, some companies adjusted their size specifications according to the outcomes of these studies (Zernike, 2004).

Recently, human body has been subjected to alterations due to changing ideal beauty perception and eating habits (Bozsik & Bennett, 2018). Human Solutions Company is working on Size North America, to obtain most recent body measurements of Americans and scan eighteen thousand men, women and children (Human Solutions, 2018).

1.3.3.2 Online size and fit recommendation

A couple of years ago, apparel brands were only providing their size charts as a guide in their web sites. However, some costumers didn't know their body measurements precisely or wasn't sure how to measure their bodies. Nowadays, some apparel brands are offering alternative solutions to their customers. These new solutions are mostly based on 3D scan data provided from earlier large scale surveys (Gill, 2015). Some fashion brands, for instance Mango, ASOS and Zara, are collaborating with several online technology providers to offer the correct size to their consumers during online shopping. These interfaces usually ask costumers to enter some of their body measurements (mostly height, weight, bust, waist and hip girth) to offer the most appropriate size of the product.

After 2010, there have been many start-ups to offer solutions for online fitting issues. The leader online technology providers were listed by Gill (2015) as Fits me, Metail, Fit Analytics GmbH, Model My Outfit, Qvit and TrueFit (Gill, 2015). However, the ground has been slippery and some of these start-ups closed down while some of them changed strategy. By 2018, the leading companies offering size and fit recommendation interfaces to the consumers are given below:

Fit Analytics GbBH

Fit Analytics is a Berlin based company established in 2010. Fit Finder is the size recommendation interface that uses the big data provided by collaborating brands and costumers. Fit Finder uses machine learning to analyze the data. Previous shopping history of costumers are recorded and used for the future shopping activities. Many fashion retailers (e.g. Mango, ASOS, North Face, Puma, Tommy Hilfiger) work with Fit Finder to recommend proper garment size to their costumers (Fit Analytics GmbH, 2018). To be able to get a size recommendation, costumers are asked to enter their height, weight, age and body shape. This information is saved by Fit Finder and matching size is recommended to the costumer. Fit Finder saves data from different retailers and collects them in a data pool. When a costumer enters her body specifications, Fit Finder scans this pool to find similar customers and their previous purchases with an information about their return rates. Finally, Fit Finder offers the costumer the best size by making a deduction of these information (Fit Analytics GmbH, 2018).

True Fit

True Fit company has named their size recommendation interface as True Fit Confidence Engine. Similar to Fit Finder, costumers are asked to insert their height, weight and age. However, costumers are also asked to select an apparel brand which they think its products fit best to their body figure. True Fit collects data (size specs, style attributes etc.) from hundreds of apparel brands worldwide and stores it through TrueFit Genome interface. According to their web site, they have the largest connected apparel fit and style data (True Fit, 2018) in the world. Macy's, Levi's, American Eagle Outfitters, Nordstrom are some of the big brands that collaborate with True Fit to recommend size to their costumers (True Fit, 2018).

Rakuten Fitsme

UK/Estonian based start-up Fitsme was acquired by Rakuten (Japanese e-commerce company) in 2015. Rakuten Fitsme offers several services for apparel sector. Fit Origin is the size recommendation interface driven by body data and garment data similar to the other companies explained above. Gant and Mud Jeans are some apparel brands that utilize Fit Origin to recommend sizes to their online costumers (Rakuten Fitsme, 2018).

1.3.3.3 Online visualisation of garment fit

3D garment fit simulation technology has been often used by apparel companies during product development. Garment manufacturers and designers have been using 3D garment fit simulation technology to speed up product development stage and eventually minimize their costs (Park, Kim and Sohn, 2011). Target, Kohl's, JCPenney are only a few of the apparel brands to use this technology for product development (Lee & Park, 2017). Although garment fit simulation technology found a wide acceptance among the apparel brands, its presence for online shopping has been limited. Online visualization technologies aim to create the most accurate virtual models of the consumers and simulate a realistic garment on them, in other words they propose the consumer to virtually try-on the garment (Kim & LaBat, 2013b). *Virtual try-on* is described as an online (web) activity where users can choose garments online and try-on the virtual garments on the created/exported 3D models (mannequins) (Cordier, Seo, & Magnenat-Thalmann, 2003), (Volino, Cordier, & Magnenat-Thalmann, 2005) .

For online shopping, creating avatars of costumers is very critical and challenging. The most realistic avatars can be obtained by 3D body scanning technology (Magnenat-Thalmann, 2010). Other approaches to create avatars either depend on the photographs of the body or the size charts (Liu, Zhang, Ming, & Yuen, 2010). The photographic approach is based on taking pictures of orthogonal views (side, front etc.) of the body and extracting body silhouette by using image processing technique (Wang, Wang, Chang, & Yuen, 2003). However, size chart method is more feasible for online interfaces, thus it is often preferred by companies that offer online virtual try-on technologies (Liu et al., 2010).

In Gill's review published in 2015, four companies were mentioned to offer virtual try-on technologies online (Fitsme, Qvit, Metail and Model My Outfit), (Gill, 2015). However, in 2018, only Metail is operating. Metail is a UK based company, and it aims to cooperate with apparel brands to extend virtual try-on experience to their customers during online shopping. In order to virtually try-on a garment, users are asked to enter several information about their bodies such as height, weight, bra size and body shape, and pick a profile photo from the offered library to create their avatar. After creating their avatar, they can scroll down in the brand's website to pick a garment they would like to virtually try-on. When the garment is selected, Metail interface displays how the garment will look on the virtual model of the user. Aside the virtual try-on, the interface also gives size recommendation and fit information (tight/loose) of the recommended size (Metail, 2018).

1.3.4 3D garment simulation

Garment simulation, 3D garment simulation and virtual garment simulation notions have been used interchangeably in textiles and clothing researches to define the creation process of virtual garments or 3D garments. Garment simulation is described as the three dimensional depiction of a cloth in virtual environment (Magenat-Thalmann, 2010).

Researchers have been working on garment simulations almost over three decades. The early attempts to simulate a cloth dates back to 1987 (Terzopoulos, Platt, Barr, & Fleischer, 1987). Garment simulation favors the computer graphics, animation and game sectors to create virtual garments on animated characters (Volino et al., 2005). Besides graphic designing, garment simulation has significant advantageous for garment manufacturers, retailers and apparel consumers.

First of all, garment simulation technology is an effective tool for product development. Traditionally, product development starts with a 2D sketch and it is followed by prototyping until a final decision is made on the product design and the garment fit (Keiser & Garner, 2012). The traditional method for product development is time consuming and expensive due to multiple prototypes prepared during the process (Bye & Labat, 2005). Besides, most of the manufacturers are located overseas which makes the communication and sample transaction between apparel manufacturers and the retail companies troublesome (Magenat-Thalmann, 2010).

Adoption of garment simulation technology helps manufacturers and retailers to see the garment on a computer screen before actually producing it and to make any necessary amendments digitally (Park, Kim, & Sohn, 2011), therefore it is already being used by some of the leading apparel retailers (Lee & Park, 2017).

Secondly, there is a growing demand for customized garments that embrace specific needs of consumers (Lu, Wang, Chen, & Wu, 2010). Mass customization is a marketing approach to overcome this demand (Kotler, 1989), (Pine, 1993). For mass customization three steps are prominent: body dimension collection, garment pattern generation and fabric cutting (Lu et al., 2010). Garment pattern generation has long been achieved by CAD/CAM systems (Hu, 2011). However, with the integration of 3D technologies, now it is possible to simulate garments on individual customers in virtual environment (Lim, 2009), (Satam, Liu, & Lee, 2011).

Finally, garment simulation technology emerges as the most sophisticated technology to boost online shopping for clothing (Bohnhoff, 2016). Garment simulation technology can offer consumers a dressing room experience without actually going to a store and enhance their shopping involvement during an online purchase (Loker et al., 2008), (Kim & LaBat, 2013b).

1.3.4.1 Modeling the cloth

Since 1980's researchers have embraced alternative models to simulate clothes (House & Breen, 2000), (Magenat-Thalmann, 2010). As stated by Magenat-Thalmann : "The mechanical properties of fabrics account for how the fabric will react to a deformation" (Magenat-Thalmann, 2010). Breen et.al.'s study (1994) was a pioneer to incorporate fabric mechanical properties to create fabric simulations. In their study, a cloth was modelled as a collection of particles that were the intersection points of warp and weft yarns and these intersections were subjected to mechanical forces such as gravity, bending, trellising (shearing), stretching and collision (Breen, House, & Wozny, 1994). Other studies followed this particle-based simulation principle and benefitted from the mechanical and drape behavior of fabrics to create fabric simulations (Bottino, Laurentini, & Scalabrin, 2001), (Volino & Magenat-Thalmann, 2005).

Most of the contemporary commercial 3D garment simulation software use mass-spring (particle-based) models to create garment simulations (Power, 2013). Users of

these software are either asked to insert fabrics' mechanical properties or, select a fabric from the software library. This library has fabric alternatives with predetermined mechanical properties. The modelling principle of the mass-spring simulation was well presented by Jiang and peers (Jiang, Guo, Ma, & Shi, 2018). In mass-spring model, fabric surface is thought as a mash of warp and weft yarns. The vertices of this mash are imagined as particles that are vulnerable to the impact of the forces. According to the model, each particle has its own coordinates, mass and velocities. In this theoretical approach, particles are thought to connect with linear springs. Each spring is responsible of different forces (external and internal) acting on fabric. The external forces are gravity, air resistance and friction, and the internal forces are tension, shearing and bending (Jiang et al., 2018). This relationship is illustrated in Figure 1.3.

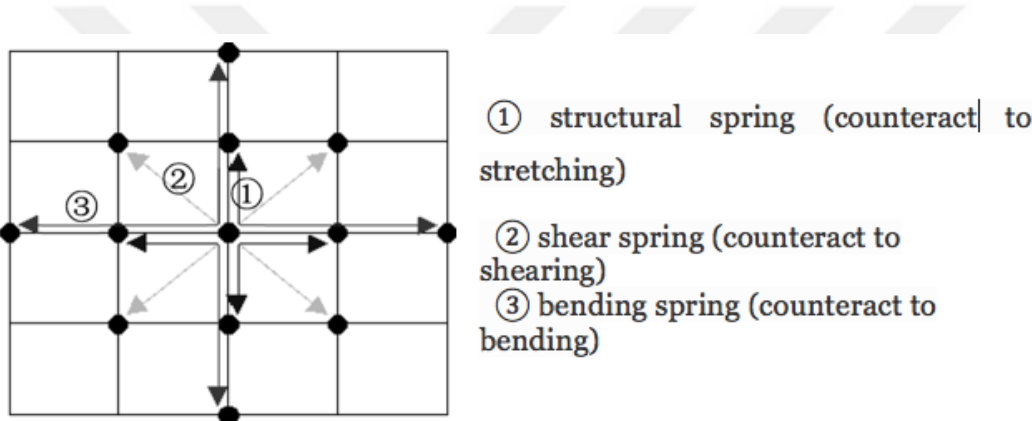


Figure 1.3 : Forces acting on particles in mass-spring model used for cloth simulation (Jiang et al., 2018).

As summarized by Luible and Magnenat-Thalmann (2007), realistic fabric simulations depend on two factors: accurate computational models and explicit input of fabric mechanical properties (Luible & Magnenat-Thalmann, 2007). Hence in the following section, fabrics' mechanical properties and the systems to measure these properties are summarized.

1.3.4.2 Mechanical properties of fabrics

Mechanical properties of fabrics are the measures to understand fabrics' behaviors under various forces. These mechanical properties are often categorized into four groups: Compression, tensile, bending and shear properties. The forces applied on a fabric to measure these properties are simply illustrated in Figure 1.4.

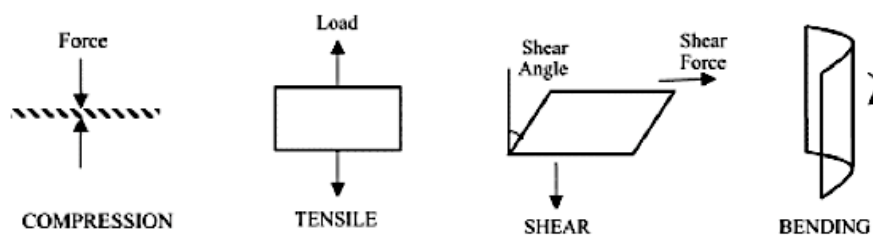


Figure 1.4 : Forces applied on fabric surfaces to measure their mechanical properties (Chan et al., 2006).

Thickness of fabric under various loads reflects its fullness and softness properties and it is correlated with its *compression* properties (Wang, Liu, & Hurren, 2008). *Tensile properties* of fabrics give an insight about the strength and elongation properties of the fabrics. *Elongation* is the extension percentage (%) of the fabric on its axial direction, and it is calculated by measuring the sample length increase when it is subjected to a force. *Shearing* is critical for garment fit, since it contributes to the fabrics' conformation behavior on complex surfaces such as body counters (Skelton, 1976). Shear is often pronounced for woven fabrics because it is a result of yarn slippage at the interlacing points of warps and wefts (Wang et al., 2008). When a woven fabric's two parallel edges are subjected to equal but opposite stresses, the warp and weft yarns rotate (shear) along the fabric plane axis and yarn slippages occur at their intersections (Skelton, 1976), (Sanad & Cassidy, 2015). *Bending* is described as the flexing capability of a material, and resistance to this bending action is called *bending rigidity* (or flexural rigidity). Bending rigidity is correlated to the aesthetic and the comfort properties of the fabrics (Wang et al., 2008). Finally, the smoothness and softness properties of fabrics are associated with the surface characteristics of the fabrics (Moorthy & Kandhavadi, 2015). Resistance to sliding motion when being pulled over a surface is described as fabric's surface friction (Sanad & Cassidy, 2015), and it has considerable importance on subjective assessment of a cloth (Moorthy & Kandhavadi, 2015). *Surface friction* properties of a fabric can be either measured as static friction or dynamic friction. Static frictional force is the maximum force required to move and slide a static fabric under a load, and the dynamic frictional force is the average force required to sustain sliding (Moorthy & Kandhavadi, 2015). For the wear conditions, dynamic friction is critical because fabrics do not stay still on human body and there is a constant friction among the human body and the fabric (Moorthy & Kandhavadi, 2015). The friction coefficient alone may not be enough to describe

the fabric smoothness or surface properties (Kim & Slaten, 1999), (Moorthy & Kandhavadi, 2015). Therefore, *surface roughness* is also measured often along with the surface friction. The surface roughness is defined as the average distances between the troughs and peaks on the fabric surface (Cassidy, 2002).

Fabric objective measuring (FOM) systems

Over years, researchers developed some instruments to objectively measure fabrics properties. Kawabata Evaluation System (KES-FB) and Fabric Assurance by Simple Testing (SiroFAST) are widely accepted instruments to measure fabrics' mechanical properties (Postle, 1999). These instruments are often used for research purposes due to their high costs and difficult interpretation of their test reports (Kim & Slaten, 1999). Therefore, usage and acceptance of FOM systems are small among the apparel industry. On the other hand, some researchers also advise that hand properties of fabrics should be evaluated subjectively since the hand assessment of fabrics is an aesthetic preference of individuals (Brand, 1964).

Kawabata evaluation system (KES-FB)

KES-FB is actually a set of instruments that measure sixteen different mechanical properties of fabrics. KES-FB consists of four different instruments, and each instrument measures particular behavior of fabrics (Kawabata & Niwa, 1991).

Tensile and shear properties of the fabrics are measured with KES-FB1 (tensile and shear tester). The only difference between shear and tensile testing is the orientation and the magnitude of the force applied on the fabric sample. For *shear testing*, a fabric sample at dimensions of 5 cm x 20 cm are cut and clamped along one of the longer edges. Thereafter, the fabric is subjected to a constant tension (10 gf/cm) until it reaches to a shear angle of 8° . The same sample that was used for shear testing is now pulled in the vertical direction to the long edges to measure tensile properties (Kawabata & Niwa, 1991), (Postle, Kawabata, & Niwa, 1983).

For bending test, KES-FB2 (bending tester) is used. For this test a 20 cm long test sample is clamped between two chucks which are located 1 cm apart. One of the chucks is stable while the other one moves to bend the fabric sample with a speed of 5 mm/sec. At the end of the test, the bending moment- curvature curve is plotted to show the bending behavior of the fabric.

Compression is tested by KES-FB3 (compression tester), and it actually is the opposite concept of the tensile testing. In this test, a fabric sample is placed between two plates, and the upper plate slowly (approximately 1mm/min) moves to compress the fabric until the pressure on the fabric reaches up to 50 gf/cm². When the pressure reaches up to 50 gf/cm², the force is removed, and fabric is allowed to recover.

Finally, KES-FB4 (surface tester) measures, friction and roughness properties of the fabric surface. To measure these properties, a sample is placed on a surface and the surface is moved slowly. During this motion, a probe measures the surface roughness while a tension device measures the required force to overcome the friction force to move the fabric.

Fabric assurance by simple testing (SiroFAST)

SiroFAST is advantageous over KES-FB since it is less expensive, easy to operate and interpret the results (De Boos & Tester, 1994). However, unlike KES-FB, SiroFAST instruments are not designed to measure the surface properties (surface friction and roughness) of the fabrics. SiroFAST system consists of three individual instruments to measure fabrics' mechanical properties.

SiroFAST-1 (Compression meter) is designed to measure fabric thickness under two different loads (2 gf/cm² and 100 gf/cm²). SiroFAST-2 (Bending meter) measures bending properties of fabrics. There are alternative standards to measure fabrics' bending properties such as cantilever method and hanging loop method (ASTM International, 2014). SiroFAST-2 uses cantilever bending method. In this method a strip of fabric slowly slides over a flat surface. One edge of the fabric is allowed to hang freely under its own weight until it makes a 41.5° angle with the edge of the flat surface. The bending length is measured automatically by an auxiliary light detector attached to the device. The schematic diagram of SiroFAST-2 bending meter is given in Figure 1.5 .

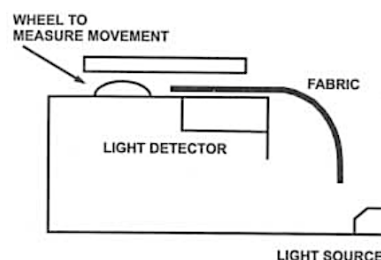


Figure 1.5 : Schematic diagram of SiroFAST-2 (De Boos & Tester, 1994).

Finally, SiroFAST-3 (extensibility meter) measures elongation of fabrics under three different loads (5, 20 and 100 gf/cm). The elongation can be measured in warp and weft directions. To measure elongation of the fabrics in warp and weft directions, 15 cm x 5 cm fabric samples are prepared at the first place. Elongation under different loads are automatically calculated by the displacement meter and reported to the user. The elongation is denoted as E5, E20 and E100 in SiroFAST. SiroFAST-3 is also used to measure the shear rigidity of the fabrics. To measure the shear rigidity, bias cut fabric samples are pulled with a load of 5 gf/cm (or ~5 N/m). The bias elongation of the samples are used to calculate the shear rigidity (CSIRO, 1990), (Wang et al., 2008). Table 1.1 shows the tests that can be conducted by using SiroFAST.

Table 1.1 : Summary of SiroFAST tests and measured fabric properties (De Boos & Tester, 1994), (Wang et al., 2008).

Test	Instrument	Property	Description	Unit
Compression	SiroFAST-1	T	Thickness of fabric under 2 gf/cm ² and 100 gf/cm ² pressure	mm
		B 1	Bending stiffness of fabric (warp direction)	μN
Bending	SiroFAST-2			B 2
		Shear	SiroFAST-3	G
Tensile	SiroFAST-3			E5-1, E20-1 and E100-1
		E5-2, E20-2 and E100-2	Fabric extension in weft direction under 5, 20 and 100 gf/cm stress, respectively	%

1.3.4.3 Commercial 3D garment simulation software

Parallel with the developments in garment simulation and 3D scanning technologies, various companies have started to offer commercial 3D garment simulation software for two different aspects: animations & graphics or garment fit (Volino et al., 2005). The graphics & animation applications require much computing power than garment fit applications because the graphic characters move and interact with each other. On

the other hand, accuracy of the simulation for graphic applications is not as critical as garment fit applications (Loker et al., 2008). As mentioned in Volino and Magnenat-Thallmann's early review (2005), the simulation software for animation & graphics were based on mass-spring models (mechanical model) operating with some of the mechanical properties of the fabrics but they didn't have any additional function for designing a garment (Volino et al., 2005). These types of simulation software were listed as MayaCloth, Reactor, Stitch, SimCloth, 3d Studio Max and Dynamics (Volino et al., 2005). Currently Maya and 3ds Max software are owned by the same company (AutoDesk) and the garment simulation function on Maya is called "nCloth" and "Cloth" on 3ds Max (AutoDesk®, 2018). "Cloth" is now integrated with a design function called Garment Maker which allows user to create basic 2D garment patterns by the software and virtually stitch them together (AutoDesk®, 2018). Finally, Blender is an open source software which is especially designed for game and animation purposes but users can also create simple clothing for their animated characters (Blender, 2018).

As mentioned earlier, for more complex garment designs and simulations, there are alternative commercial software packages which are specifically developed for apparel purposes (Sayem et al., 2010), (Gill, 2015). Some of them are given below.

Marvelous designer

Marvelous Designer was especially designed to create complicated garment designs for animation and game industry. Since the software is suitable for complex garment designs, it is appropriate for fashion and apparel use as well, and consequently this feature makes it a transition software between the animation and apparel practices. The software allows users to create 2D patterns and virtually stitch them to create a 3D garment. It has all of the design functions that is necessary for pattern creation and it is compatible with 3ds max and Maya, thus, virtual characters could be exported through these external software (Marvelous Designer, 2018).

Clo 3D

Eventhough Clo 3D is relatively newer than the other simulation software, it has successfully penetrated to fashion industry and fashion education. They vary from their competitors by enabling its users to create simulations for alternative product groups which has a fabric content such as hats (Clot3D, 2018).

O/Dev by Optitex

Optitex is one of the pioneer companies to develop 3D garment simulation software for apparel purposes. Optitex offers O/Dev software to create 2D patterns by its pattern making suite and simulating the garment on the virtual model by its 3D product creation suite. The software enables its users to create a parametric model or export a 3D body scan (Optitex, 2017). There are multiple fabric options in their fabric library, and users are entitled to change the fabric properties manually. An add-in, Fabric Testing Utility (FTU), could be additionally purchased to test the fabric properties (Optitex, 2016).

Modaris 3D by Lectra

Lectra is one of the early adopters to offer CAD systems for apparel practices, and in 2013 they expanded their business by introducing Modaris 3D to the market. As similar to other software, Modaris allows user to change fabric properties and create realistic 3D garment simulations. One of their advantage is that many companies have a familiarity with the Lectra CAD systems that makes their transition to its 3D simulation software easier (Lectra, 2014).

V-stitcher by Browzwear

V-stitcher is the 3D garment simulation software of Browzwear Company. Adidas, Nike and Columbia are listed under their client list (Browzwear, 2018). Browzwear company has also developed its fabric measuring instrument named Fabric Analyzer by Browzwear (FAB). Users can easily measure thickness, bending and extension properties of the fabrics and directly use the measured data to create more realistic simulations (Browzwear, 2018).

Vidya by Human Solutions

Human Solutions Company, which is actually specialized in 3D body scanning, has introduced its 3D garment simulation software Vidya before 2008 (Luible, 2008). Human Solution integrates its pattern making and body scanning experience gained over years to their 3D garment simulation software, Vidya (Human Solutions, 2018c).

1.3.5 Virtual body models

1.3.5.1 Approaches to create virtual body models

For an effective virtual try-on experience, it is necessary to have an accurate and realistic human body model. There are alternative methods to model the human body. As summarized by Wang and Shen (Wang & Shen, 2018) ; these methods are:

Virtual body models based on anatomy

In an anatomical approach, as the name implies, human body is modelled according to its anatomical structure which consists of four layers: skeleton, muscle, fatty tissue and skin. Geometry, deformation and the texture of each layer is modelled individually to represent their anatomical features (Dong, Clapworthy, Krokos, & Yao, 2002).

Virtual body models based on photographic images

In this method, researchers capture the body image often with taking pictures from different perspectives and obtaining the cross-section of the body at various coordinates in order to interpret the 3D shape of the body (Seo & Magnenat-Thalmann, 2003), (Liu et al., 2010), (Zhu, Mok, & Kwok, 2013).

Virtual body models by 3D modeling programs

Some CAD programs such as Maya, 3ds Max, Blender are used to create virtual body models. Usually side, front and back photographs of a reference model is viewed in the software, and the 3D model is usually created by modifying a cylindrical shape according to the reference photograph (Crossley, Cornelissen, & Tovée, 2012).

Virtual body modeling by using parametric data

Parametric modeling systems use multiple body measurements to create 3D body models. In earlier attempts of parametric approach, created body models were very much cartoon-like. However, recently scanned body databases have started to be used to create parametric models. In this novel approach, thousands of 3D body scans are collected and statistically analyzed in terms of body measurements and shapes. While creating a brand-new 3D body model, the body measurements of the real model are matched to the 3D scans in the database. Afterwards, the matching 3D scans are assembled and modified to create the 3D body model of the real model (Baek & Lee, 2012).

Virtual models obtained by 3D body scanning

3D body scanners have been investigated by scholars for their usage for apparel purposes since 1995 (Jones, Li, Brooke-Wavell, & West, 1995). Earlier 3D body scanners were very expensive (\$40,000-\$410,000) and immobile (Ashdown et al., 2004). Recently, with the introduction of depth perception cameras to create human body models (Tong, Zhou, Liu, Pan, & Yan, 2012), prices and mobility of the 3D body scanners transformed tremendously. In the following section, contemporary 3D body scanning technologies are summarized.

1.3.5.2 Latest 3D body scanners

The latest 3D body scanners on the market capture the 3D body surface most often by using light projection or image capturing techniques (Gill, 2015). Modern 3D body scanner prices vary between \$1,000-\$20,000 and they can scan as fast as 1 to 10 seconds (Gill, 2015).

Table 1.2 presents contemporary 3D body scanners often used for apparel purposes, and the following section summarizes the working principles of these 3D body scanners.

Table 1.2 : Apparel focused 3D body scanners.

Company Name	Model	Number of sensors	Scanning System	Source of information
Human Solutions	Vitus	8	Laser light	(Human Solutions, 2018b)
Human Solutions	Ditus MC	12	Structure light (infra-red)	(Human Solutions, 2018a)
Size Stream	SS20 3D	20	Structure light (infra-red)	(Size Stream, 2018)
Styku	Styku	1	Structure light (infra-red)	(Styku, 2016)
TC²	TC2-19R	3	Structure light (infra-red)	(TC2, 2018b)
TC²	TC2-105	8	Structure light (white light)	(TC2, 2018a)

Laser line systems

In this system a strip of laser light is projected onto the human body in a chamber which is surrounded by cameras in every corner. The laser line deforms by the object's shape, and cameras record the deformation. The recorded images are digitized by the 3D body scanner's software in X-Y-Z coordinates and displayed on the computer screen. Finally, the images from multiple cameras are dispatched to create one single body model (Ashdown et al., 2004). Earlier versions of this type of scanners were extremely expensive, however, technology providers reduced the costs after the introduction of cheaper alternatives (Gill, 2015). The laser line scanners are generally used for research purposes as they are very accurate and have high resolutions (Yu, 2004).

Structured light systems

This kind of scanning systems are sometimes called white light scanning systems because they use a regular light source often white and sometimes red (Daanen & Ter Haar, 2013). These systems work according to optic principles as illustrated in Figure 1.6. A grating (a grid like object) is placed in front of the light source and the light is projected onto the body surface. Part of the light is blocked due to grid structure of the grating while the unblocked light creates some patterns (fringes) on the body surface. Irregular shape of human body deteriorates these fringes and the resulting fringe patterns are captured by a camera. Finally the captured images of deteriorated fringe patterns are used to depict the body contour (Yu, 2004).

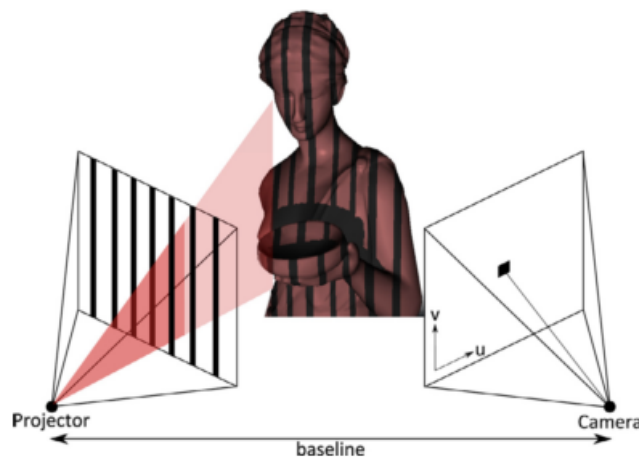


Figure 1.6 : Principle of structured light systems (Sarbolandi, Lefloch, & Kolb, 2015).

The introduction of Kinect camera in 2010, which is an add-on for Microsoft game console X-box, was a ground breaking innovation for 3D body scanning technologies which actually is a developed version of structure light system scanners (Tong et al., 2012). Kinect uses near-infrared light as the light source which is not visible to human eye, whereas the sensors that the device is equipped with, can detect the infra-red light. Instead of stripe grids, Kinect uses a grid of dots. In addition to surface counterering, device is competent to capture the color of the scan surface (Sarbolandi et al., 2015). After Microsoft introduced Kinect in 2010, other companies also developed in-depth cameras working according to the same principle. Most of the hand-hold scanners currently available use infra-red light to capture the 3D shapes of the objects (Alexandrea, 2018). These type of scanners provide easy access as the equipment required for scanning is mobile and inexpensive, however, their resolution is not as good as a laser line scanning (Daanen & Ter Haar, 2013).

For apparel applications, pioneers of 3D body scanning technology directed their attention to structure light system since the competition in the market has considerably challenged by the debut of Kinect type cameras. For instance, Styku, one of the sector leaders, uses a single Kinect camera for scanning (Styku, 2016). Many of the 3D scanner companies revised their products by adding in-depth cameras, and most of the contemporary 3D scanners are based on structure light system (Daanen & Ter Haar, 2013), (Gill, 2015) .

3D scanning technology is developing with an incredible pace. Apple introduced its mobile phone iPhone X in November 2017, and this phone actually has an in-depth sensor working according to the same principles as Kinect and the other in-depth sensors. With iPhone X, it is now possible to get a very detailed scan of a human face in seconds (Miller, 2017) and probably in near future it will be possible to get a very detailed body scan with a mobile phone.

1.3.6 Garment simulation for fit assessment

Virtual fitting is a notion that emanated from the literature of 3D garment simulation researches. However, there is no official description for virtual fitting. Magnenat-Thalmann (2010), one of the pioneers of 3D garment simulation studies, has used virtual fitting as the forced assembly of the 2D fabric patterns along the side seams in

a virtual context and fabrics' deformation according to the shape of the virtual model (Magenat-Thalmann, 2010).

In the past decade, as commercial 3D garment simulation software became more accessible, the evaluation of virtual garment fit has been investigated by scholars. In literature, virtual garment fit assessment is classified according to the method used for the process. These methods can be either objective such as quantitatively measuring/calculating the strain on the garment (tension maps) or the distance/area/volume between body and virtual garment, or subjective as visually analyzing a virtually dressed body model (Loker et al., 2008).

1.3.6.1 Objective fit evaluation of a garment simulation

Measuring distance/area/volume between the virtual model and the garment

The linear distances between the 3D scanned body model and the virtual cloth is a quantifiable data. Two-dimensional and three-dimensional data such as circumference slices, surface areas, and volumes between the body scan and the cloth can be used to provide comprehensive and objective analyses of the garment fit (Song & Ashdown, 2010).

Initial attempts to objectively evaluate virtual fit is attributed to Loker, Ashdown and Schoenfelder (Loker, Ashdown, & Schoenfelder, 2005). In their study, they offered an improved sizing system by using the information gathered from 3D body scan data (Loker et al., 2005). According to their objective, they scanned female subjects with pants and measured the volume and the area between body and the virtual pants (Figure 1.7). They also evaluated the virtual fit visually. Therefore, their study is actually a combination of objective and subjective virtual fit evaluation (Loker et al., 2005).

Lee *et.al.* adopted a similar approach (Lee, Nam, Cui, Choi, & Choi, 2007). In their research they produced two different garments and they assigned three female participants. Each participant tried the garment on and they got scanned with the garment. At the same time, researchers created virtual garment on the scanned body model by using a simulation software. Finally, vacant space areas, the areas between body scan and the garment at cross-sections, are obtained for certain body locations such as waist, hips etc. by using some special software. Eventually the calculated vacant spaces of real garments and the virtual garments were used to statistically compare the similarity of the fits (Lee et al., 2007).

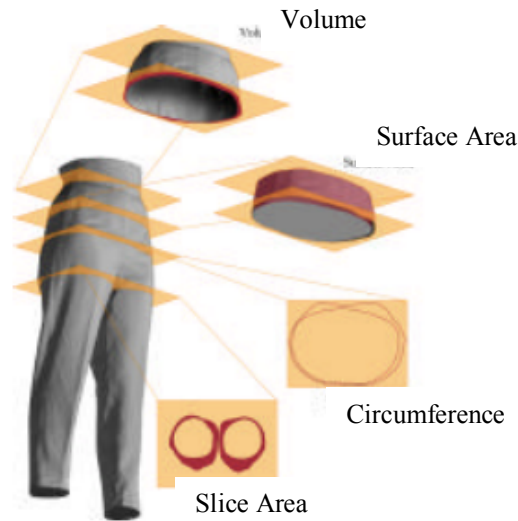


Figure 1.7 : Objective measuring procedure for fit evaluation (Loker et al., 2005).

Vacant space area is used by some researchers to develop a *fit index* (F) (Equation 1.1) which is expected to help garment fit evaluations (Xu & Zhong, 2003). Lin and Wang (2016) took the fit index as a ground and suggested *fit index relation* ($F_{relation}$) (Equation 1.2) which is a measurable parameter to compare real fit to virtual fit (Lin & Wang, 2016).

$$F = \frac{A_{garment} - A_{body}}{A_{body}} \quad (1.1)$$

F : fit index, $A_{garment} - A_{body}$: the area between the body and the garment, A_{body} : total body area.

$$F_{relation} = \frac{F_{virtual} - F_{real}}{F_{real}} \quad (1.2)$$

$F_{relation}$: fit index percentage for real fit and virtual fit, $F_{virtual}$: fit index of garment simulation, F_{real} : fit index of real garment.

Distance, area and volume between body model and the virtual garment are used to develop methods for production of customized garments with a better fit as well. Apeagyei and Otieno (2007) first tested the usability of a 3D simulation software for mass customization (Apeagyei & Otieno, 2007). The virtual ease values (the cross-sectional distance between virtual model and virtual garment) at hips, waist and bust

were used to assess the fit of a skirt and a jacket simulation visually (Apeageyi & Otieno, 2007). In 2010, Wang and his peers developed a method to involve customers to the production cycle for a customized garment (Wang, Lu, Chen, Geng, & Deng, 2010). In their method, customers were allowed to tweak style curves and cross-sectional distances between the garment and the model on the 3D simulation software (Wang et al., 2010).

Measuring stretch on the virtual fabric

With the developments in 3D garment simulation technology, commercial software are now able to display the tension values on the virtual fabrics (Gill, 2015). Some researchers thought to use these tension values for assessment of garment fit (Liu et al., 2017).

Earlier works of using tension maps for garment fitting dates back to 2000's. Kim and Park (2007) engaged 3D body scans to develop basic garment patterns (Kim & Park, 2007). In their study, they used the strain reduction method to optimize the distance between the basic garment patterns and the body in a virtual context. Initially, they created 3D garments on the scanned bodies and determined the placement of the darts on 3D form, after, they projected the patterns on 2D plane. During this projection a certain amount of strain has occurred as the 3D pattern is forced to deform to a 2D plane. The optimum level of strain guided the researchers to determine ideal basic patterns of skirt and bodice (Kim & Park, 2007). In 2011, Istook also benefited the stretch values displayed by the simulation software to compare the garment fit on two different body models (Istook, 2011). In Istook's study (2011), one of the body model was obtained by 3D body scanning the subject and the other one was created by inserting the measured body measurements of the subject to the simulation software. However, even though she utilized the stretch maps displayed by the software, she had visually assessed the stretch maps for comparison (Istook, 2011). Ancutiene and Sinkevičiute (2011) also measured strain and ease values of tight fitting dresses on a virtual model created by a 3D garment simulation software (Ancutiene & Sinkevičiute, 2011). The researchers aimed to explore the impact of fabrics mechanical properties on garment fit in virtual environment. Thus, they simulated ten dresses on the same model by inserting the mechanical properties of ten different fabrics and eventually compared the ease and strain values of each simulation (Ancutiene & Sinkevičiute, 2011). Figure 1.8 shows dress simulations and the ease values in Ancutiene and

Sinkevičiute's work that was obtained by using mechanical properties of alternative fabrics.

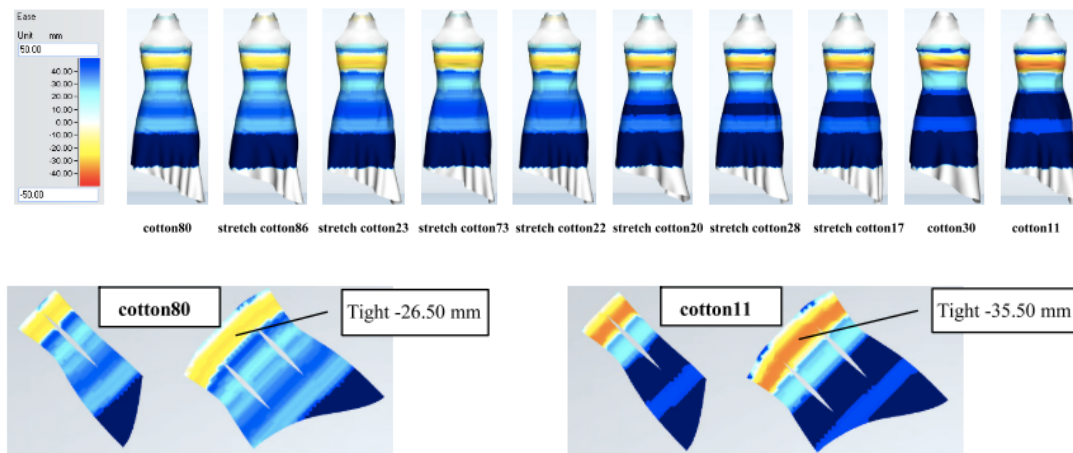


Figure 1.8 : Ease values measured by a simulation software according to alternative fabric properties (Ancutiene & Sinkevičiute, 2011).

Sayem and Bednall (2017) used Optitex's 3D garment simulation software to create basic bodice patterns and to simulate the garment on a virtual model (Sayem & Bednall, 2017). They graded the bust measurement of bodice and obtained thirteen virtual garments which varied by 1 cm at bust. Finally, they calculated the average tension, stretch and collision pressure values of each garment to interpret their correlation with the alteration of the pattern measurement at bust. They suggested that the correlation between the real ease and tension values obtained from simulations might be used to predict a good fit (Sayem & Bednall, 2017). Sayem and Bednall's (2017) suggestion was experimented by Liu and her colleagues (Liu et al., 2017). For their experiment, they selected nine females that represent the average female figures and sizes in China. Each participant was asked to select and try-on eight pants among seventy-two pants and decide if the pants they have tried are a good fit or a bad fit. At the same time, researchers created the 3D garment simulation of the pants on parametric body models in Clo 3D™ and measured the virtual pressure on each simulation. Finally, they used machine learning to predict the fit evaluation of women by using the virtual pressure data (Liu et al., 2017).

Some researchers utilized garment simulation and virtual fit to design special garments for disabled. For instance, Jin (2016) developed a shirt for a wheelchair tennis player (Jin, 2016). For the product development, tennis player was 3D body scanned in various postures and the shirt was simulated on his body scans by using a 3D

garment simulation software. Eventually, Jin (2016) determined optimum ease values of the shirt according to the tension values displayed by the software (Jin, 2016).

Combining motion capture systems with 3D garment simulation software allowed researchers to explore virtual garment fit during motion. Mert and her colleagues (2018) simulated a top and a sweatpants on a walking model (Mert et al., 2018). In their study they displayed tension maps of the virtual garments for thirteen snapshots and compared the distances between the model and the garment for actual and virtual cases. Consequently, they analyzed the differences statistically (Mert et al., 2018).

Some researchers use visual interpretation of tension maps displayed by 3D garment simulation software to understand virtual garment fit (Power, 2013), (Lee, Hwang, & Baytar, 2018). For instance, Lee, Hwang and Baytar (2018) incorporated 3D garment fitting technology to develop better fitting garments for older women (Lee et al., 2018). They drafted virtual patterns on 3D body models and obtained 2D patterns by flattening method. Eventually they evaluated the fitness of developed patterns on virtual models by visually exploring tension maps displayed by the 3D garment simulation software (Lee et al., 2018).

1.3.6.2 Subjective fit evaluation of a garment simulation

Subjective analysis of the virtual garment fit is a common research approach since the beginning of the garment simulation studies. Some researchers actually propose that garment fit and drape are aesthetic concepts that depend on people's preferences, hence, they should be evaluated by people (Brand, 1964). Another asset of subjective evaluation is that people can identify and process complicated stimuli such as complex forms of pattern recognitions where objective measurements are insufficient (Leibowitz & Post, 1982). Many researchers have followed Brands's approach (Brand, 1964) and explored virtual garment fit by visual assessment. For instance, in 2012, Jevsnik and her colleagues used visual fit assessment to compare the real fit and virtual fit of a jacket (Jevsnik et al., 2012). In their study, a group of clothing and textiles experts evaluated the pictures of jackets on a real person and also on the virtual models of this person. The evaluation was done for different zones (sleeves, bust, bottom edge etc.) of the jacket on a three-point scale, namely; insufficient, appropriate, good. The total scores given by the judges were used to compare the jacket fits for real and virtual environment (Jevsnik et al., 2012). In a similar study, a six-piece A-line skirt was

produced and tried on by a fifty-five years old female subject. The subject was 3D scanned and virtual fit of the garment were created in Optitex on the 3D scanned model and the parametric model of the subject and the real fit images and virtual fit images were visually assessed by the researchers (Buyukaslan et al., 2015). Ancutiene and her colleagues (2014) also employed an expert panel to evaluate virtual garment fit of dresses created by a 3D garment simulation software. In their study, twenty experts from textile industry viewed simulations of six dresses from front, back, armhole, bust and side. Figure 1.9 shows the simulation pictures of these six dresses. The expert panel ranked each image from 1 to 6 (1: best and 6: worst). Finally, researchers analyzed the ranking results to draw out a conclusion (Ancutiene, Strazdiene, & Lekeckas, 2014).

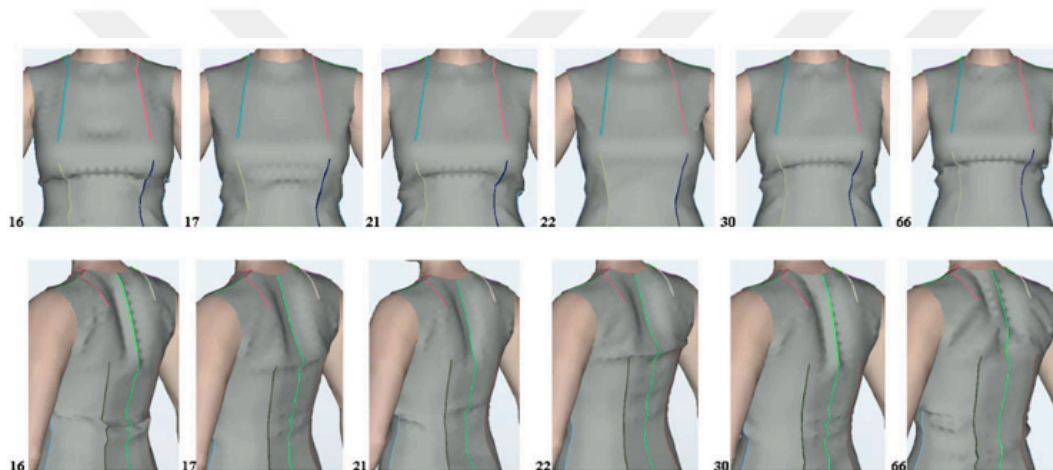


Figure 1.9 : Fit evaluation of six different dresses created by using alternative fabric properties (Ancutiene et al., 2014).

On the other hand, Hong et. al. (2018) explored the 3D to 2D design systems for customized bodice pattern for scoliosis patients (Hong, Bruniaux, Zeng, Curteza, & Liu, 2018). For this purpose, they 3D scanned twenty patients and developed basic bodice patterns on their 3D scanned body models. The evaluation of the fitting of the bodice patterns on 3D models were performed by fashion experts. According to the virtual garment fit evaluation protocol, each fashion expert viewed the virtual bodice on the 3D scanned model and evaluated fit for certain body parts such as bust etc. The evaluation was done on a Likert scale according to tightness and length appropriateness (short/long and tight/fit) (Hong et al., 2018). Kim and LaBat's (2013) study is one of the studies that has been referred often by researchers working on subjective fit evaluation of virtual garments (Kim & LaBat, 2013a). Their study is

particularly different than other studies in two means. Many of the studies about 3D garment simulation software focus on product development aspect of virtual prototyping. Hence, they rely on expert evaluation of virtual garments. Whereas, Kim and LaBat's (2013) study focuses on an online shopping scenario and employs users for fit evaluation of virtual garments (Kim & LaBat, 2013a). In their study, they 3D body scanned thirty-seven female participants at different sizes (2 to 20). Afterwards, researchers simulated a pair of pants on each participant's 3D scanned body model. The virtual pants sizes varied between 2 to 20 to match participants' sizes. Each participant viewed and selected the best fitting size on their own 3D scanned model and evaluated the virtual fit of that pants for thirteen fit locations on a 7-point Likert scale. Finally, participants are asked to try-on the real pants (the same size that the participant has selected during virtual garment) and evaluate the real fit of the same pants (Kim & LaBat, 2013a). Figure 1.10 shows the virtual fit of the pants created by using the 3D body scan of one of the subjects, and next to the virtual images, real pictures of the same subject wearing the actual pants are given.



Figure 1.10 : Virtual fit images of a pants created by using 3D body scan image of a subject, and pictures of the real pants fitted by the same subject (Kim & LaBat, 2013a).



2. METHODOLOGY

2.1 Theoretical Model

As explained in theoretical background, garment fit satisfaction in real environment depends on two main factors: internal and external factors (Figure 1.2). Internal factors mainly depend on the wearer, and the external factors depend on the time and the society (LaBat & DeLong, 1990). In this dissertation, exploring the impact of all internal factors affecting consumers' fit satisfaction was embraced as the research approach. External factors were excluded due to culture, society and time dependence. The essential internal factors were identified in DeLong and LaBat's study (1990) as body satisfaction and physical dimensions; and physical dimensions were described as the dimensional relationship between the body and the garment (Figure 1.2). To explore and test the factors affecting the real and virtual garment fit satisfactions of consumers, body satisfaction and physical dimensions titles were broken down into their components. The garment component is expanded by adding the design elements that form a garment. (Figure 2.1). A garment is composed of four design elements: silhouette, line, color and texture (Ellinwood, 2011). Texture of a fashion garment is often defined by its material and in most cases this material is the fabric (Ellinwood, 2011). After all, fabrics are identified by their tactile and physical properties since these properties are essential to define aesthetic and comfort features of a garment (Bassett & Postle, 1990). Hand properties such as fabric softness or stiffness are sensory and subjective features, whereas mechanical properties such as compression and bending rigidity are measurable and objective. Therefore, mechanical properties are often used instead of fabrics' tactile properties (Behery, 2005). For instance, stiffness of a fabric is attributed to its bending property while softness is attributed to its compression (Ozcelik, Supuren, Gulumser, & Tarakcioglu, 2008). Figure 2.1 is the extended model offered to display the factors affecting consumers' garment fit satisfactions.

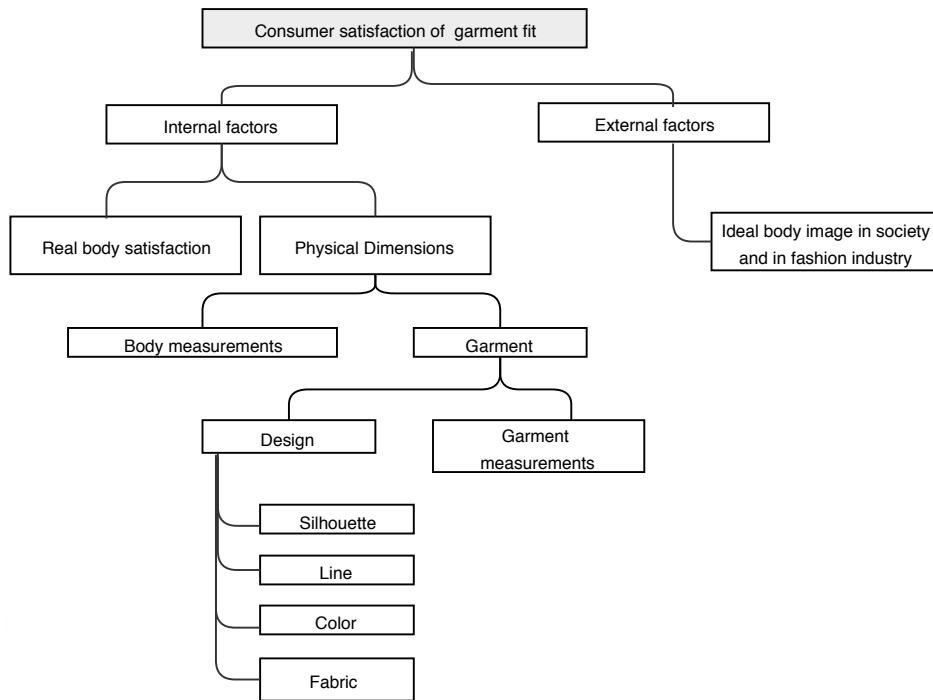


Figure 2.1 : Extended model offered for the factors affecting consumers' garment fit satisfactions (derived from LaBat and DeLong (1990)'s study).

This model (Figure 2.1) explains the garment fit satisfaction of real garments. However, with the advances in garment simulation technologies, it is necessary to divert this model to a virtual context. Because, in near future, virtual try-on technology would be used for online shopping, and consumers' virtual garment fit satisfactions would become conclusive for their purchase decisions.

Figure 2.2 shows the suggested factors that would affect consumers' virtual garment fit satisfactions. This model is derived from the factors that affect consumers' actual fit satisfactions.

During a virtual try-on experience, subjects are exposed to a visual stimulus which is the 3D image of a virtual garment on their own avatar. This avatar can be either a parametric body model created by plugging in the body measurements of the subject, or a body model obtained by 3D scanning the subject. For this dissertation, avatars were created by scanning the subjects by 3D body scanner in order to achieve their most realistic body models. Virtual try-on diverges from the real try-on by the existence of the interaction of the subjects with novel technologies such as 3D body scanners and virtual try-on. Thus, impacts of these novel technologies on consumers' virtual fit satisfactions were included in the research model (Figure 2.2).

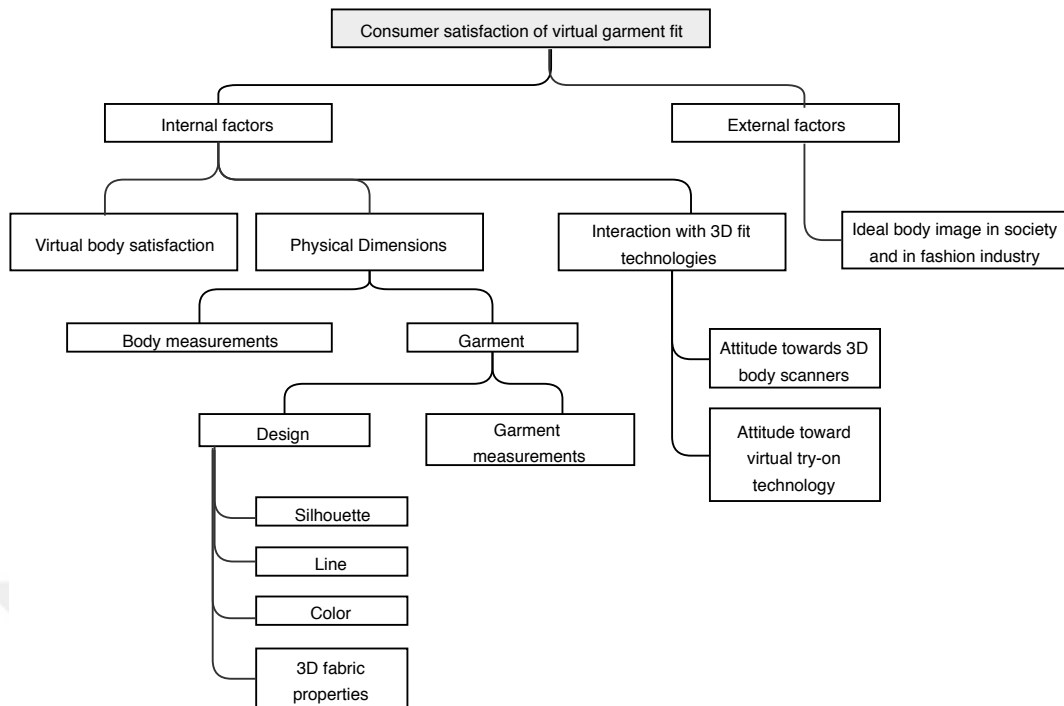


Figure 2.2 : Theoretical model to explore the factors affecting consumers' virtual garment fit satisfactions.

Body satisfaction affects real garment fit satisfaction of individuals (LaBat & DeLong, 1990). During virtual try-on, subjects are exposed to their own 3D body scan images. Hence, for the virtual try-on, body satisfaction factor was replaced with virtual body satisfaction (Figure 2.2). Moreover, during virtual try-on, subjects are not able to touch or see the real fabric, but instead of it, they interact with fabric's simulation which is created by using its 3D fabric properties. 3D fabric properties are actually derived from the measured fabric properties (i.e. bending rigidity, weight etc.), however, they are not the same due to the unit conversions and software limitations. Finally, body measurements were another factor in the model (Figure 2.2) that was expected to impact consumers' virtual fit satisfactions.

2.2 Experimental Design

While designing the experiments, the objectives of this study were reviewed, and each stage of the experiments were optimized to embrace the research objectives. The research model was explored in two phases as given in Figure 2.3 to investigate the research objectives. According to this schema, in the first phase of the study, correlations between some of the independent variables (body measurements, virtual body satisfaction, 3D fabric properties and interacting with 3D fit technologies) and

their impact on consumers' virtual garment fit satisfactions were explored. In the second phase of the study, consumers' virtual fit satisfactions were used as input parameter with other parameters (body measurements, body satisfaction and fabric properties) to predict consumers' real fit satisfactions.

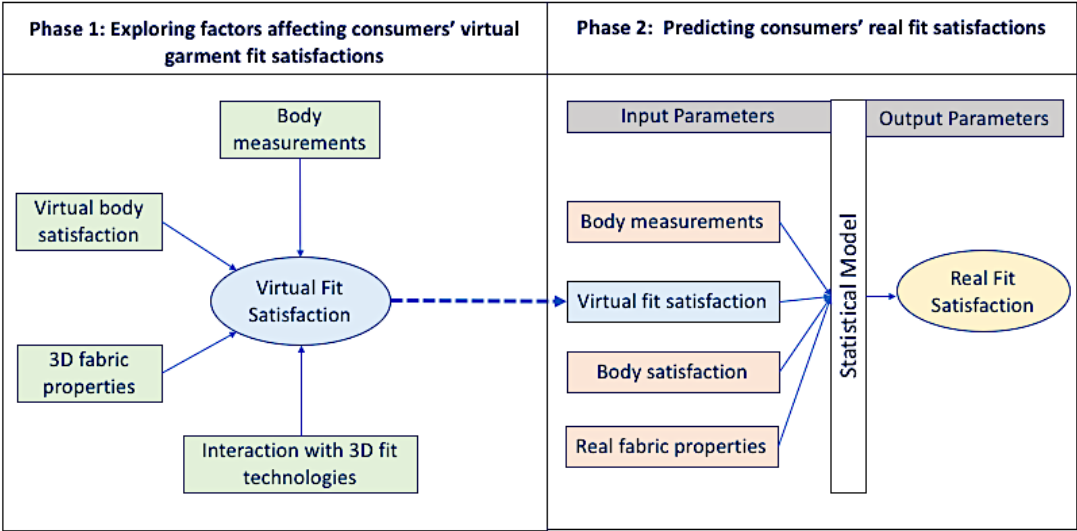


Figure 2.3 : Research model.

2.2.1 Target group

First of all, increasing garment fit satisfaction of consumers was a motive and the target group was selected by keeping this motive in mind. According to Shin (2013), there isn't any significant difference between male and female consumers' overall garment fit satisfactions. Since a significant difference of garment fit satisfaction due to gender wasn't detected, the size of the apparel market for each gender was considered. According to statistics, women are more likely to purchase an apparel item online when compared to men (Statista, 2016). Therefore, women were determined as the target gender of this study. Moreover, age range was determined to be between 18 to 35, because statistics show that this age group is more likely to purchase an apparel product online (Statista, 2017a). Another criterium was the body measurements of the subjects. Medium (M) size was determined as the sample size since it is usually used as a base size by the companies and many apparel brands work with medium size fit models for fit sessions (Armstrong, 2010). To determine the body measurements of a medium size, ASTM D5585 - 11e1 standards were used (ASTM International, 2011). As a result, the target group was determined as females between 18 to 35 years old with a waist girth between 25-28 inches and a hip girth between 36-39 inches.

2.2.2 Garment Samples

2.2.2.1 Designing the garments

Various studies show that women are less satisfied with their lower body parts, hence they are less satisfied with the fit of lower body garments (LaBat & DeLong, 1990), (Song & Ashdown, 2013). Therefore, a lower body garment was considered as the garment type. To be able to test the impact of fabric properties only, the test garments were designed to have the same silhouette, line and the color, but different fabrics.

Drape and the aesthetic fit aspect of the test garments

Drape is one of the significant problems of 3D garment simulation software (Pandurangan, Eischen, Kenkare, & Lamar, 2008). As mentioned by Lim and Istook (2011), the garment simulation has to mirror the actual garment in terms of fabric drape (Lim & Istook, 2011). Drape is very important for the aesthetic appearance of the fabrics (Jiang, Cui, & Hu, 2012), and it affects the aesthetic fit evaluations of the consumers (Kadolph, Langford, Hollen, & Saddler, 1993). Therefore, reflecting drape properties of a garment during its simulation is critical.

The drape feature of a fabric might be observed best on a loose fitting garment as it doesn't cling on the wearer (Pandurangan et al., 2008). Various scholars have preferred either flare or circular skirts to study the effect of fabric drape on garment fit evaluation (Kenkare, 2005), (Thi et al., 2010), (Wu, Mok, Kwok, Fan, & Xin, 2011), (Jevšnik, Kalaoğlu, Eryuruk, & Stjepanovic, 2015).

Consumers evaluate garment fit according to multidimensional aspects: functional, aesthetic and socio-psychological (Tselepis & Klerk, 2004). A garment should have enough room for movement and this aspect of the garment defines its *functional fit*. However, consumers have other expectations from garments such as flattering the body and hanging well (Tselepis & Klerk, 2004). These aspects of a garment define its *aesthetic fit*, and it is closely related to its intrinsic factors. Intrinsic factors such as fabric, style, design and construction could affect the aesthetic fit of a garment (Tselepis & Klerk, 2004). Fabric is one of the most important intrinsic factors and it may affect the aesthetic appearance of the garment as well as the physical comfort (Kadolph et al., 1993). Hanging of a fabric, in other words drape of a fabric, contributes to the aesthetic fit of a garment and garments made from alternative fabrics

may vary drastically in terms of aesthetic fit (Tselepis & Klerk, 2004), (Thi et al., 2010).

In this study, alternative fabrics were studied in order to see their impact on garment fit. While doing this, the impact of fabric drape on aesthetic fit was the focal point. Therefore, the garment design was determined to stress its drape attribute. The other intrinsic factors (style, design and construction) were kept identical for all of the test samples. Consequently, to highlight the function of drape on aesthetic fit satisfaction, a circular skirt style was appropriate.

Reference garment design

In order to understand the impact of fabric on aesthetic fit, the intrinsic impact of design and style should be minimized. Therefore, the selected design should be accepted and liked by majority of the population, otherwise a particular disliking of the design could dominate the aesthetic fit, and fabric impact may be hindered.

Details of the design were determined by a market research. A web search of the word, circular skirt, was conducted through Amazon.com, which is the biggest online retailer in U.S. (Gensler, 2017). The search brought more than six hundred results, and most of these results were skater skirts. Skater skirt is the name used to define the shorter length circle skirts (Koester & Bryant, 1991). On the other hand, according to the best seller skirt style list of Amazon.com, the skater skirt was the #1 on the list (Figure 2.4).

The details of the skater skirt and its sketch that was used as the reference design is given in Figure 2.5. According to the technical pack of the skirt on the website, the length of the skirt was 45 cm, and the waist circumference was 72 cm. The length of the skirt is a part of its design function. Skater skirts are often preferred by younger costumers (Schuessler, 2015), and since the target age of this study was young female between 18 to 35 years old, it was appropriate for the purpose of this study.

By considering all design criteria mentioned above, a skater skirt with 45 cm length, 72 cm waist was selected as the sample design.

Amazon Best Sellers

Our most popular products based on sales. Updated hourly.

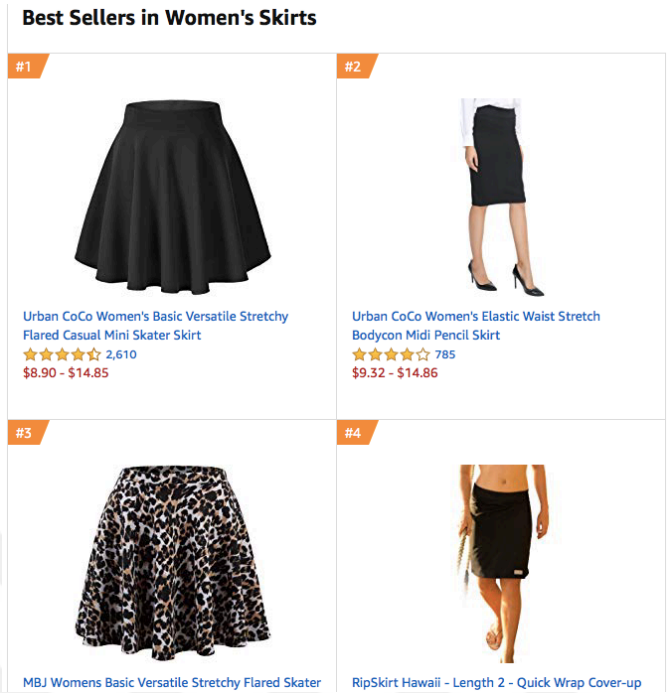


Figure 2.4 : Best seller skirt styles on Amazon.com (Amazon.com, 2017).



Figure 2.5 : Inspiration picture and its sketch.

2.2.2.2 Fabric selection

After deciding the garment style, the fabrics that will be used for this study was determined. Knitted fabrics are often used for snugging garments (i.e. socks and tights) or sportswear and casual wear (i.e. sweatshirts and t-shirts), on the other hand, woven fabrics are often used for pants, shirts, skirts and outwear garments (Hu, 2004). Since a skirt style was selected for this study, woven fabrics were a better alternative.

Simulations of similar fabrics

Fabrics with similar fabric properties display very similar drape simulations (Buyukaslan, Kalaoglu, & Jevsnik, 2017), (Buyukaslan, Jevsnik, & Kalaoglu, 2018).

Buyukaslan et al. (2017) measured the mechanical properties of five woven fabrics by SiroFAST and created their drape simulations by O/Dev on a virtual disc. At the same time, real drape behaviors of these fabrics were observed on a real disc.

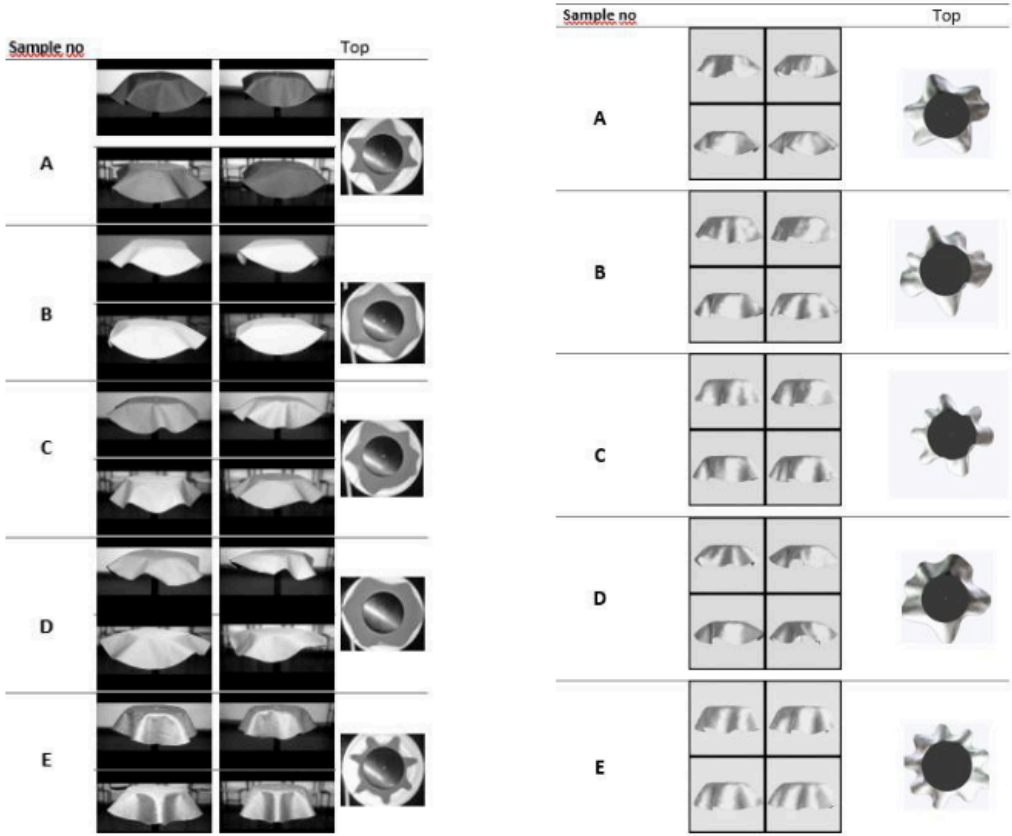


Figure 2.6 : Visual comparison of the real and virtual drape of five woven fabrics (Buyukaslan, Kalaoglu, & Jevsnik, 2017).

Twenty-seven human subjects were asked to match the simulations with the real drape pictures (Figure 2.6). This study showed that the simulations of fabrics with similar drape properties were distinguished hardly by the subjects. Subjects could only distinguish the simulations of fabrics which have relatively different drape properties. In other words, human eye is not very sensitive to slight drape changes (Buyukaslan, Kalaoglu, & Jevsnik, 2017). Therefore, the fabrics of this study were selected in order to show distinctive drape properties. Among other mechanical properties of fabrics, bending rigidity has the highest correlation with drape properties (Frydrych, Dziworska, & Cieslinska, 2000). However, while providing the fabrics, it wasn't convenient to seek fabrics according to their bending rigidities as many of the fabric suppliers didn't have information about bending rigidity of their fabrics. On the other hand, drape properties of fabrics are highly correlated to their weights as well (Frydrych

et al., 2000), and it is much more practical to seek fabrics from suppliers according to their weights.

As a result, fourteen fabrics with a wide weight range were collected from two different fabric manufacturers. Properties of the test fabrics are given in Table 2.1.

Table 2.1 : Properties of the collected fabrics.

#	Fabric Code	Weight (g/m ²)	Thickness (mm)	Composition*	Weave
1	Fabric 2	111	0.10	100% Cotton	Plain
2	Fabric 22	143	0.20	100 % Wool	Plain
3	Fabric 5	193	0.22	98/2 %, Co/Ea	Twill
4	Fabric 6	224	0.31	98/2 %, Co/Ea	Twill
5	Fabric 1	258	0.44	68/28/4 % Co/PES/Ea	Twill
6	Fabric 13	291	0.48	98/2 %, Co/Ea	Twill
7	Fabric 16	291	0.56	98/2 %, Co/Ea	Twill
8	Fabric 7	300	0.78	95/5 %, Co/Ea	Plain
9	Fabric 9	325	0.57	96/4%, Co/Ea	Plain
10	Fabric 8	337	0.64	96/4%, Co/Ea	Twill
11	Fabric 21	344	1.27	100% Wool	Plain
12	Fabric 20	354	1.09	100% Wool	Plain
13	Fabric 14	359	0.66	95/5 %, Co/Ea	Twill
14	Fabric 15	385	0.62	96/4%, Co/Ea	Twill

*Co: Cotton, Ea: Elastane, PES: Polyester

2.2.2.3 Making the garments

A professional seamstress was assigned to tailor the test garments. The measurements given in Table 2.2 were followed to prepare the patterns of the skirts.

Table 2.2 : Measurements of the garment samples

Feature	Measurement (cm)
Waist band width	2
Waist circumference	72
Skirt length at the side seam	43
Skirt length at the center front	42
Skirt length at the center back	42

Patterns were created digitally by using O/Dev Pattern Design Suite (PDS) (Figure 2.7). The same patterns were used for the production of all test skirts. All skirt samples had a black invisible zipper (18 cm) at the left side seam for easy donning on and off. For the production of the skirts, same type of interfacing and thread were used. All the skirt samples had the identical details (measurements and trims) except for their fabrics.

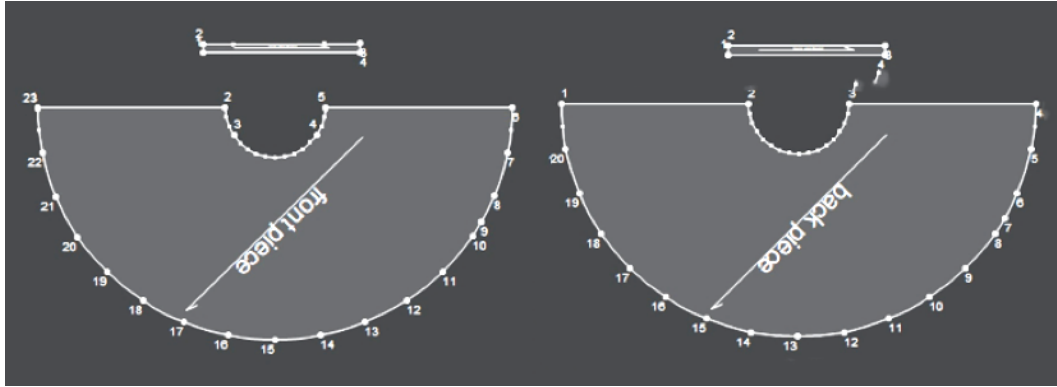


Figure 2.7 : 2D patterns of the garment samples.

2.2.3 Experiments

Experiments are organized as fabric experiments and garment fit experiments. Figure 2.8 shows the schema of fabric experiments and garment fit experiments conducted in this study. As illustrated in Figure 2.8, first of all properties of the test fabrics were measured and later garment fit experiments were conducted.

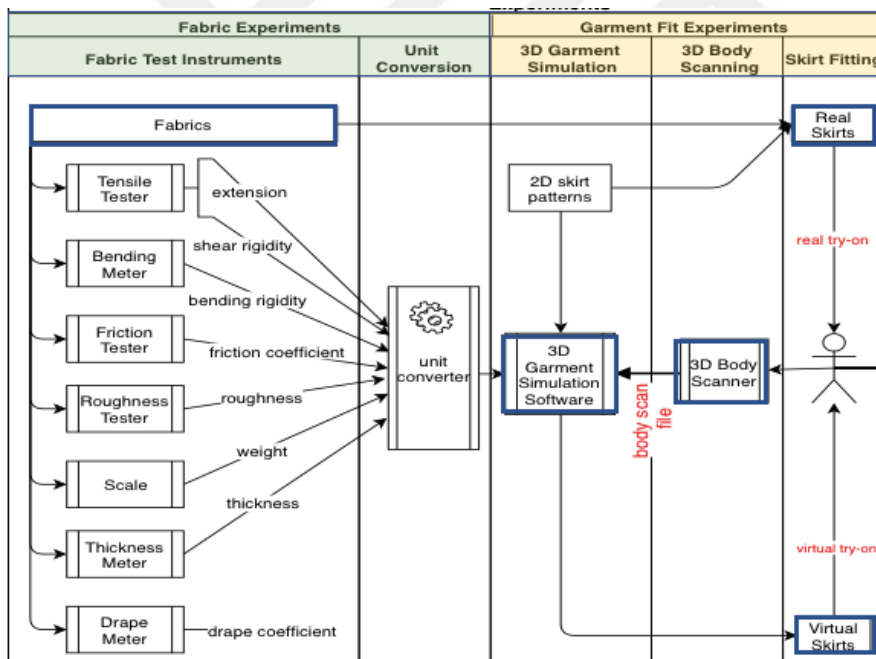


Figure 2.8 : Fabric experiments and garment fit experiments schema.

2.2.3.1 Fabric experiments

Measuring mechanical properties of fabrics

Fabrics' mechanical properties were measured to create realistic garment simulations and exploring the impact of mechanical properties on garment fit in virtual and real environment. As stated in the literature part, fabrics' mechanical properties are often

measured with SiroFAST or KES-FB instruments. However, alternative instruments were used for this study instead of KES-FB and SiroFAST due to accessibility. A further study was established to compare the garment simulations created by using traditional testing equipment versus using KES-FB or SiroFAST (Buyukaslan, Baytar, & Kalaoglu, 2018). According to the results of this study, no significant differences were found between garment simulations created by traditional, KES-FB and SiroFAST equipment, and it was concluded that traditional test equipment would be adequate to create garment simulations (Buyukaslan, Baytar, et al., 2018).

Working principles of SiroFAST instrument were considered and reproduced by traditional test equipment. Because KES-FB instruments are more complicated when compared to SiroFAST instruments, it would be more difficult to implement KES-FB tests. However, SiroFAST tests can be implemented by using traditional fabric test equipment (Frydrych et al., 2000). Therefore, mechanical properties of fabrics were measured by using traditional textile testing equipment.

Measuring extension

A tensile testing machine (James Heal-Titan), was used to measure extension of fabrics. Three fabric samples were cut at 15 x 5 cm sizes for warp and weft directions each, and samples were conditioned before conducting the tests. The load cell used for the experiments was 120 N, the distance between the clamps were 10 cm, and the pulling speed was 50 mm/min.

During the tests, fabric samples were slowly pulled until the force on the fabrics reached up to 120 N. When 120 N was reached, clamps released the samples and the jaws returned back to their former positions. Meantime, extensions of the fabrics were measured according to the displacement of jaws, and stress/strain diagrams were plotted by the computer attached to the tensile tester. It is possible to determine the extension values of the samples under any stress value from x-y coordinates of the stress/strain diagrams. O/Dev software requires the stretch values of warp and weft yarns under 100 gf/cm (Kuijpers, 2017). Therefore, the extension values under 100 gf/cm were recorded. This value is obtained by recording the extension value at 500 gf (=5N) (100 gf/cm x width of the fabric sample) on the stress-strain diagram (Frydrych et al., 2000). An example of a stress-strain diagram obtained from one of the test fabrics is given in Figure 2.9.

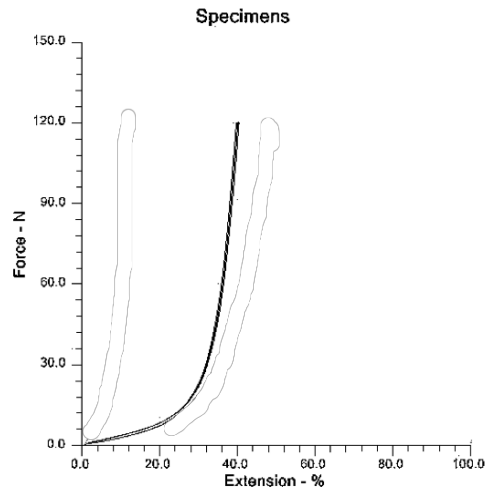


Figure 2.9 : Stress-strain diagram of Fabric 16 (weft direction).

Measuring shear rigidity

In this study, a tensile testing machine (James Heal-Titan), was used to measure extension of fabrics in bias direction, and the extension was used to calculate shear rigidity. Three fabric samples were cut bias in 15 cm x 5 cm sizes and conditioned before conducting the tests. The load cell used for the experiments was 120 N, the distance between the clamps were 10 cm, and the pulling speed was 50 mm/min

Shear rigidity values were derived from fabrics' bias extensions. The same testing method explained for extension measuring was applied. Bias cut fabric samples were pulled until the force on the fabrics reach upto 120 N. To calculate shear rigidity, SiroFAST-3 testing method was referred. In SiroFAST-3 system, bias cut fabric samples' extension values at 5 gf/cm are used to calculate their shear rigidities. To implement the same method, fabrics' bias extensions at 5 gf/cm were recorded. This value was obtained by recording the extension values at 25 gf (=0.25 N) (5 gf/cm x width of the fabric sample) on the stress-strain diagram which is obtained from Titan tensile tester (Frydrych et al., 2000). An illustration of the testing procedure is given in Figure 2.10.

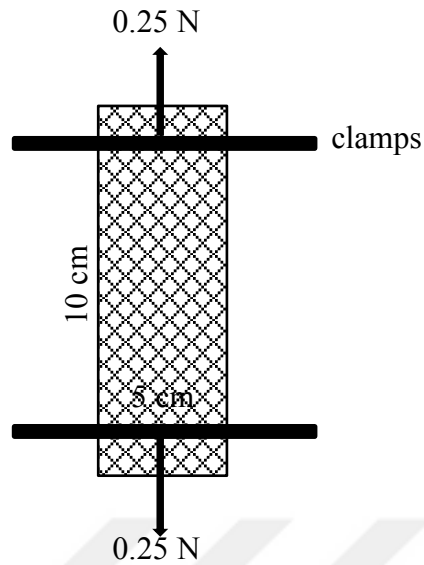


Figure 2.10 : Shear testing of the fabric samples.

Finally, measured extensions were used to calculate shear rigidities of the fabrics according to the equation 2.1 (CSIRO, 1990), (Wang et al., 2008), (De Boos & Tester, 1994).

$$G = \frac{123}{E5} \quad (2.1)$$

G : shear rigidity (gf/cm or N/m), $E5$: bias extension of the sample (%).

Measuring bending rigidity

Shirley fabric stiffness tester was used to measure bending lengths of the fabrics. For the fabric stiffness testing with Shirley tester, three fabric samples in warp and weft directions each (at total six samples) were cut at 15 cm x 2.5 cm sizes, and they were conditioned before conducting the tests. Studies show that there is a significant difference between bending lengths on the face and back sides of a fabric due to the fabric finish and the weave (Peirce, 1930). Accordingly, bending length of each fabric sample was measured two times for the face and two times for the back, and the average of them were recorded as the average bending length. Finally, these bending lengths were used to measure the bending rigidities of fabrics as described in BSI3356:1990 (British Standard Institution, 1990) by using the Equation 2.2.

$$B = W \times l^3 \times 9.81 \times 10^{-6} \quad (2.2)$$

B: bending rigidity (μNm), W : area density of the fabric (g/m^2), l : bending length (mm)

Measuring surface properties of fabrics

Surface friction

Static and dynamic friction of the face and the back of the fabrics were measured with MXD-02 Coefficient of Friction Tester (Labthink Company, 2017). The ASTM D1894 Standards (ASTM, 2008) were applied during friction testing. It is possible to measure friction in many different ways (i.e. fabric-fabric friction, fabric-metal friction, fabric-felt friction). For this study, fabric-felt friction was considered. Fabric pulling speed was 100 mm/min.

Surface roughness

Compact Surface Measuring Instrument, SurfCom 130A (Zeiss Company, 2016), was used to measure surface roughness. ISO 4287-1997 standards (International Organization for Standardization, 1997) were followed during testing. The probe speed was 5 cm/min and the evaluation range was 5 cm.

The measurements were conducted separately for the back and front of the fabrics since surface properties of the fabrics are often different on the face and the back (Peirce, 1930). Similarly, fabrics' surface properties vary for warp and weft directions. The surface roughness for the face of the fabrics were measured by taking the means of roughness's values measured for warp and weft directions, and the surface roughness's for the back of the fabrics were measured per se.

Measuring drape properties of fabrics

A Cusick drapemeter was used to test fabric drape due to its well-acceptance and accessibility (Chu, Cummings, & Teixeira, 1950), (Cusick, 1965), (Cusick, 1968). BS 5058:1974 standards were implemented to test the drape (BS 5058:1973, 1974). One sample, at a size of 36 diameter, was prepared for each fabric and placed on the Cusick drape meter. A camera was centrally mounted over the Cusick drape meter to capture the drape images. A sample of captured drape image is given in Figure 2.11.

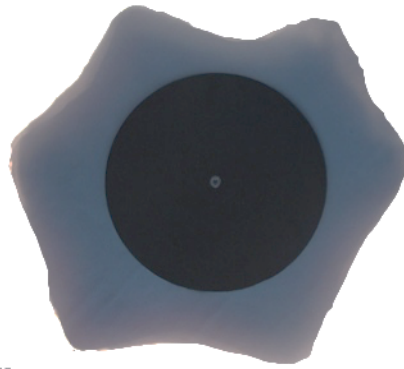


Figure 2.11 : Drape image on Cusick drape meter.

The tests were performed three times for the face and three times for the back of the fabric samples and *drape coefficient (DC)* of each fabric was calculated by taking the average of drape coefficients measured at the back and face of the corresponding fabric. To calculate DC of the fabrics, image analysis technique was used (Vangheluwe & Kiekens, 1993), (Robson & Long, 2000). Drape images of fabrics were transferred to the computer and opened with an open-access image analysis program, ImageJ (Schneider, Rasband, & Eliceiri, 2012). This program can measure distances between points, areas of the surfaces, and volumes of the objects from the captured images. To do that, it is necessary to introduce a known measurement to the program, which was the diameter of the Cusick disc (18 cm) in this case. The drape areas of each sample were measured by using ImageJ program and the measured values were used to calculate the drape coefficients of the samples according to the Equation 2.3 (Cusick, 1968).

$$DC = \frac{\text{Drape area-plate area}}{\text{Fabric area-plate area}} \quad (2.3)$$

2.2.3.2 Fabric clustering

Although fourteen fabrics were provided from suppliers, each participant tried on four different skirts due to two reasons. First reason was the experiment time. If subjects were to try-on fourteen skirts, and evaluate their real and virtual fit, they would have committed almost a whole day for the experiment which wouldn't be feasible. The other reason was the efficiency and reliability. A long experiment would have been overwhelming for the subjects resulting in slack answers to fit questions. Eventually,

trying-on four skirts during the garment fit experiments was found reasonable in terms of experiment time and experiment reliability.

The skirts for try-on were determined by clustering skirts according to their fabric properties and each subject was asked to try-on one of the skirts from each cluster. Hierarchical clustering analysis (HCA) by using the Ward criterion with a pre-defined cluster number (four) was applied to the Euclidean distance matrix by using R software (Boehmke, 2018). At each step the pair of clusters with minimum between-cluster distance are merged, generating clusters that were more equal in size.

2.2.4 Garment fit experiments

2.2.4.1 Preparing for virtual fit

There are alternative software to create garment simulations and these software were summarized in literature part. In this study, two of these commercial software were considered: O/Dev by Optitex and V-Stitcher by Browzwear. However, only O/Dev software was used for garment fit experiments due to various reasons listed below. Although V-Stitcher was not used for fit experiments, virtual simulations created by using the same 3D fabric properties in V-Stitcher were reported in the Appendix B.

Optitex's 2D/3D CAD system (O/Dev™) was selected because of its widely acceptance in fashion and apparel industry. Adidas, GAP, Under Armor, Target and Roberto Cavalli and Li&Fung are some costumers that use O/Dev for their product development (Optitex, 2018). O/Dev is also used by various fashion schools (Parsons School of Design, London College of Fashion and Cornell University). In addition to the penetration superiority, Lim (2009) observed that Optitex 3D CAD system gave more similar simulations to the real garment when compared to V-stitcher for instance (Lim, 2009). However, the simulation technologies are constantly developing, and companies are improving their algorithms by incorporating more of the fabrics mechanics. Therefore, for this study a pre-test was conducted by using O/Dev and V-Stitcher.

Pre-tests with O/Dev

To create virtual garments; 2D skirt patterns (Figure 2.7) were used and virtual stitches were defined between pattern pieces.

Selection of simulation properties in O/Dev

O/Dev simulation software enables users to change the simulation properties. The simulation properties window with its default settings are given in Figure 2.12.

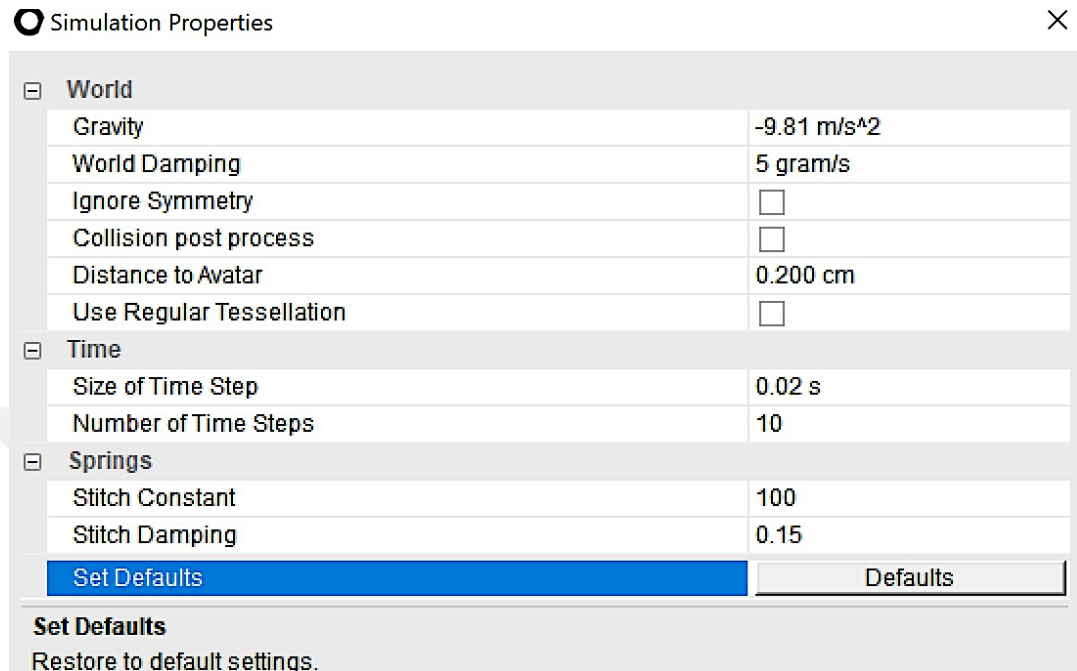


Figure 2.12 : O/Dev simulation properties window.

Simulation properties were systematically changed to explore their influence on simulation quality. For this purpose, the circular skirt developed for this study was simulated on the default model, Eva, with alternative simulation properties. The fabric properties were kept the same and only simulation properties have been altered for each simulation. The simulation properties that were inserted to find the optimum simulation for this research are given in Table 2.3.

Unit conversion of the fabric properties for O/Dev

O/Dev enables users to enter/change the fabric properties to create more accurate simulations. For this study, measured fabric properties were plugged into the software for this objective. However, the units of the fabric properties required by the software were different than the units measured by either KES-FB, SiroFAST or the test instruments used for this study. Hence, measured fabric properties were converted with the *Fabric Converter* program as in earlier researches (Lim & Istook, 2011), (Yan, 2011). This converter is actually designed to convert either KES-FB or SiroFAST measured fabric properties. FAST conversion window of the Fabric Converter (see Figure 2.13) was used for this study since the test methods used in this study were

implemented from SiroFAST system, and therefore the units of measured fabric properties were compatible with FAST units, but incompatible with KES units.

Table 2.3 : Alternative simulation properties applied in O/Dev for pre-testing.

Feature	Default	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8
Ignore symmetry	No	Yes	No	Yes	No	No	No	No	No
Collision post process	No	No	Yes	Yes	No	Yes	No	No	Yes
Distance to avatar	0.2	0.2	0.2	0.2	0.2	0.2	0.1	2	0.2
Use regular tessellation	No	No	No	No	No	No	No	No	No
Size of time steps	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01
Number of time steps	10	10	10	10	20	20	10	10	20

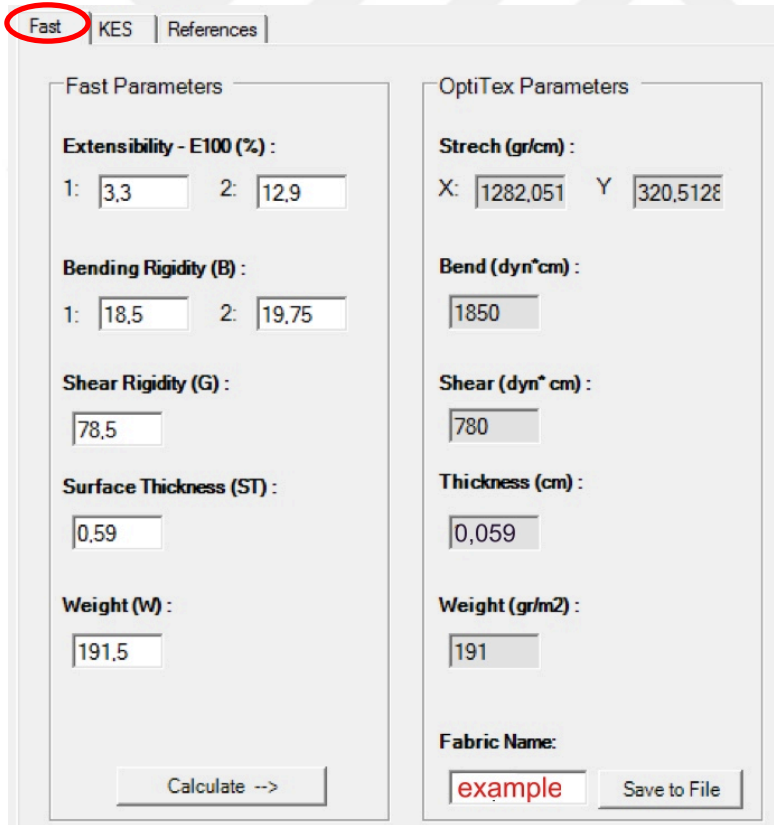


Figure 2.13 : FAST conversion interface of Fabric Converter for O/Dev.

While conducting the unit conversions, several issues about Fabric Converter were noticed. The first issue was the stretch property. Stretch values of fabrics should be

denoted by percentage (%) since it is the extension percentage of the fabric at a certain tension (Kaynak, 2017). However, in the Fabric Converter it has a unit of g/cm, and it is ambiguous how SiroFAST extensibility (or elongation) values are converted. Moreover, bending rigidities measured by SiroFAST have μNm units (see Table 1.1), whereas, the required bending rigidity units in O/Dev software is $\text{dyne}\cdot\text{cm}$. For the unit conversion, Fabric Converter multiplies bending rigidities measured by SiroFAST by 100, however it should be multiplied by 10 as $1 \mu\text{Nm}$ is equal to $10 \text{dyne}\cdot\text{cm}$. This issue was communicated with Optitex Company, however, a clarification couldn't be compromised. Due to the ambiguity of units and unit conversions, Fabric Converter was used as is by taking the previous studies as a reference (Lim & Istook, 2011), (Yan, 2011).

Creating virtual fabrics by O/Dev

First of all, fabrics' surfaces were scanned by a flatbed scanner and exported to O/Dev to use as the texture for simulations. Afterwards, converted properties of experiment fabrics were entered to the fabric editor window (Figure 2.14) in O/Dev. However, while creating virtual fabrics, further issues were encountered. Software doesn't allow users to enter any fabric thickness value smaller than 0.05 cm. When any thickness smaller than 0.05 is inserted, the software automatically changes it to 0.05. Therefore, the thickness values lower than 0.05 were automatically changed to 0.05 cm by the software. Second of all, the fabric scans were opened in O/Dev to give texture to virtual fabrics. However, the fabric textures were not very visible when displayed on the software due to their dark colors (see Appendix A). Therefore, for the fabric displays, 90 percent grey color from software's color palette was selected for all skirt simulations. Finally, friction value required by O/Dev was ambiguous. As explained detailed in methodology part, there are various friction coefficients. It can be either static or dynamic friction. Besides, fabrics' friction properties vary for face and back of the fabric as well as warp and weft directions. To determine which friction value should be assigned, a document provided by Optitex company was used as reference (Optitex, 2016). Even though, the ambiguity of the required friction value remained, dynamic friction coefficient of the back of the fabric in warp direction was determined to be used for this study.

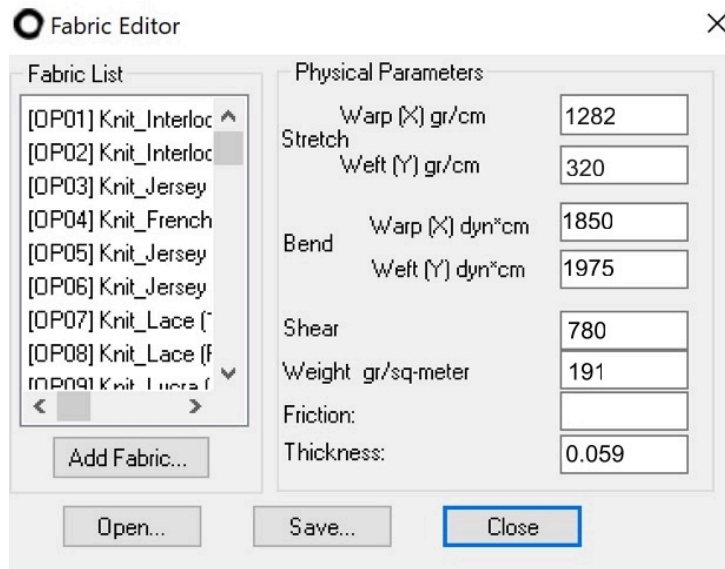


Figure 2.14 : Fabric editor interface to create virtual fabrics in O/Dev.

2.2.4.2 Data collection

A questionnaire was developed in an online survey software, Qualtrics, to measure the variables to understand the research questions of this study. The survey questions were all measured with 7-point Likert scales.

The questionnaire was consisted of seven parts. Figure 2.15 illustrates the questionnaire parts.

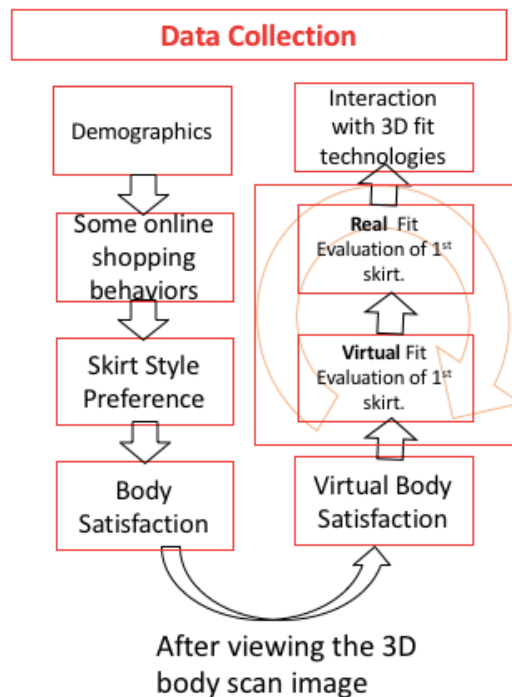


Figure 2.15 : Data collection during garment fit experiments.

First part of the questionnaire included demographic questions (age, education level, ethnicity and fashion knowledge).

Second part of the questionnaire was designed to measure online shopping behaviors of subjects such as online shopping frequency and RTW garment satisfaction for various garment types such as skirts, t-shirts, jeans.

Third part was designed to understand subjects' skirt style preferences. For this purpose, three types of skirts (pencil skirt, circular skirt and A-line skirt) were demonstrated to subjects and they were asked to answer three questions (if they had liked the silhouette, overall fit of the skirt and their purchase intention) for each skirt style. Subjects' liking of the color of the skirt was also measured by showing a black circular skirt image on the computer screen and asking subjects to rate their liking of the skirt color.

Fourth part of the questionnaire was a body satisfaction scale. There are several scales in the literature used to measure body satisfaction levels of subjects (Secord & Jourard, 1953), (Rosen & Ross, 1968), (Mahoney & Finch, 1976), (LaBat & DeLong, 1990). In this study, the body satisfaction scale used by Shin and Baytar was adopted (Shin & Baytar, 2013). This scale measured the body satisfaction level of subjects for twenty-one items on a 7-point Likert scale. In the fifth part, virtual body satisfactions of subjects were measured by using the same scale only after showing their 3D body scan images.

Sixth section of the questionnaire was designed to measure garment fit satisfaction of the subjects. Therefore, subjects were asked to evaluate the fit of the real and virtual garments on four different areas (waistline, abdomen level, hip level and hem level) for three different views (front, back and side). Subjects evaluated the virtual fit first, and later, they evaluated the real fit of the skirt. Below guide (Figure 2.16) was used to help participants to clearly interpret the fit locations. The questionnaire that was used during the experiments for fit evaluation is given in Figure 2.17.

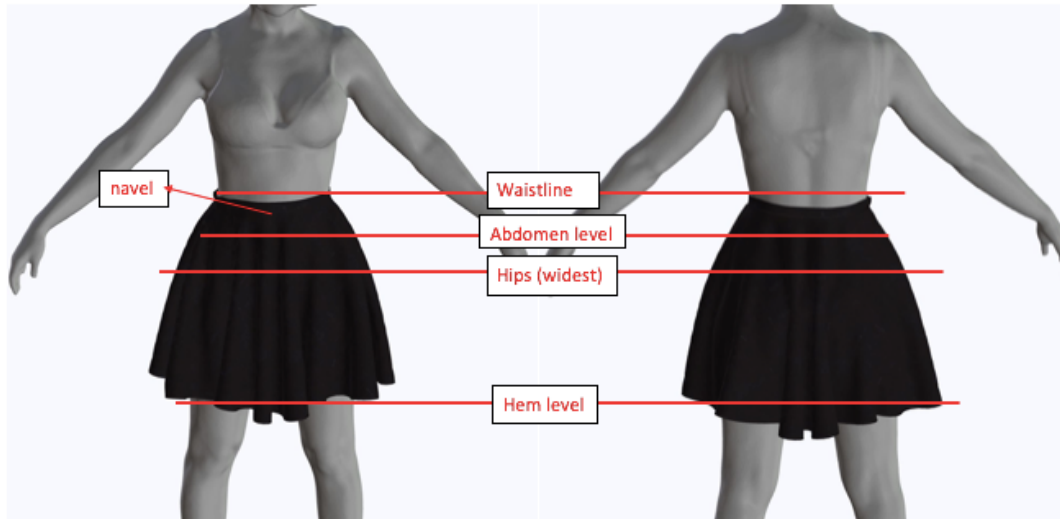


Figure 2.16 : Garment fit evaluation guideline.

Please rate your fit satisfaction of the skirt for each body part from 1 to 7 (Enter a number in below boxes)

1= extremely dissatisfied
2= dissatisfied
3= somewhat dissatisfied
4= neither dissatisfied nor satisfied
5= somewhat satisfied
6= satisfied
7= extremely satisfied

	front view	back view	side view
waistline	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
abdomen level	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
hips level	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
hem	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Figure 2.17 : Skirt fit evaluation scale.

The seventh and the final section of the questionnaire was designed to measure subjects' interactions with 3D fit technologies (3D body scanning technology and virtual try-on technology). The questions to measure interactions with 3D body scanning was derived from Loker and her colleagues' study (Loker, Cowie, Ashdown, & Lewis, 2004). In Loker et.al.' s study, participants' were asked five questions about 3D scanning process: comfort with scanning process, comfort with viewing the scan file, comfort with showing the scan file to families and friends, willingness to pay for the 3D body scan, and willingness to be 3D scanned again. From this questions, only three of them (comfort with scanning process, comfort with viewing the scan file and willingness to be scanned again) were used. On the other hand, participants' acceptance of virtual try-on experience was measured by a five items scale which was

derived from Kim and LaBat's study (Kim & LaBat, 2013b). This scale consisted of questions to understand if subjects had enough information to evaluate the garment fit, satisfied with the virtual model for evaluating the garment fit, whether they were likely to use virtual try-on technology in the future and use virtual model for apparel online shopping purposes, and finally, if they would pay more to use a virtual model to get garments that actually fit.

2.2.4.3 Garment fitting

The protocol used during the experiments is given in Figure 2.18. Each subject tried on four different skirts. As illustrated in Figure 2.18, subjects were first scanned with a 3D body scanner and their scans were used for 3D garment simulations of the skirts. The skirts that the subject would try-on were pre-determined by the researcher. The pre-determination was done according to the results of fabric clustering. Researcher gave one of the skirts from each cluster to ensure that subjects try-on at least one of the skirts from each cluster.

Before subjects try on each skirt, they saw its virtual counterpart on their own body model on a computer screen and evaluated its virtual fit first. After virtual fit evaluation, they tried on the actual skirt and evaluated the real fit of the skirt. This procedure was repeated for four different skirts.

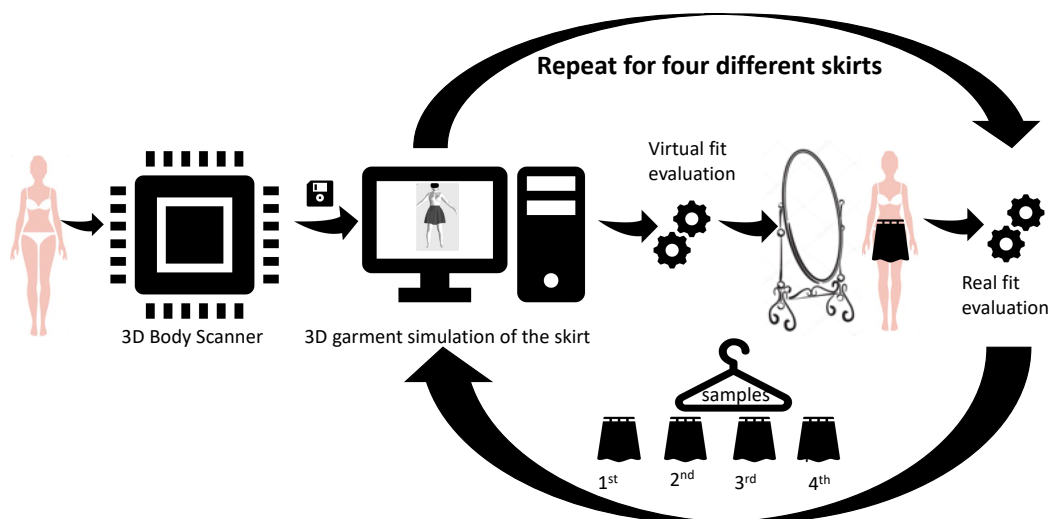


Figure 2.18 : Protocol of garment fit experiments.

3D body scanning the subjects

For garment fit experiments, each subject was asked to come to the 3D BodyScan Lab at an appointed time. When subjects arrived the lab, first of all, their waist and hips measurements were taken by a measuring tape to verify that subject was within the limits of recruiting criteria. Suitable subjects were scanned with their underwear in standing position.

A laser light 3D body scanner (Human Solutions Vitus XXL) in the BodyScan Lab at Cornell University was used for the experiments. This scanner has eight cameras and captures approximately three hundred thousand points at a single scan to ensure an a hundred percent identical scan of the body (3D BodyScan Lab, 2018). However, it does not capture colored scans and the captured body scans were in grey scale.

Processing the 3D body scan image

The 3D body scanner software (ScanWorX) allows users to reconstruct the scan surface to achieve more realistic body images. Scan surfaces were reconstructed by using human standard posture selection and saved as STL (binary) files. Afterwards, STL body scan files were smoothed and scaled to fifty percent by GeoMagic™ software to achieve the final look given in Figure 2.19. These body scan images were saved in obj. format to open easily in 3D garment simulation software.

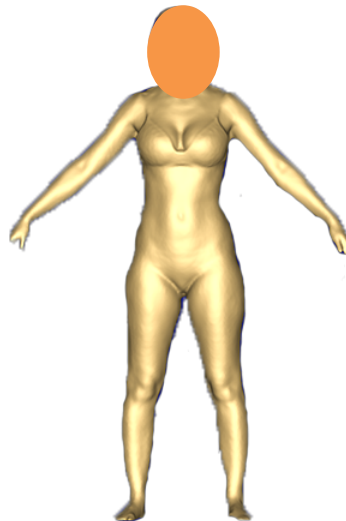


Figure 2.19 : Processed 3D body scan image.

Virtual try-on

3D body scan images of the subjects (Figure 2.19) were opened in the simulation software, and skirt patterns were placed on the subject's virtual model. Created virtual fabrics were called for each simulation. For instance, if the virtual try-on of Skirt 2 would be examined, 3D fabric properties of Fabric 2 was called in the software to create its virtual correspondent. Finally, the simulations were shown to the subjects on the computer screen. Researcher rotated, zoomed in/ out for subjects to see the virtual skirts from all perspectives. Researcher also set the rotate function to continuously rotate the simulation. In Figure 2.20, snapshots of the simulations on a subject from several views were given for readers' interpretation of the process.

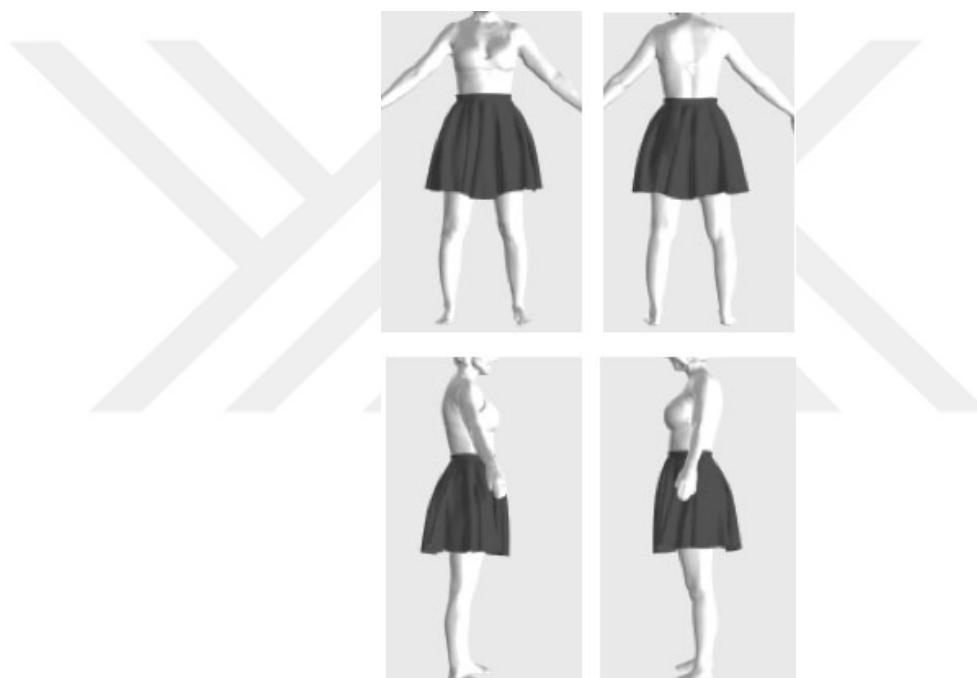


Figure 2.20 : Snapshots of a virtual try-on on a subject.

Real try-on

After each virtual try-on, subjects were asked to try-on the actual skirt in a dressing room. Subjects could keep their own upper garment, or if they required, a tank top was provided. Subjects were provided a mirror to look at the fit of the skirt.

2.2.4.4 Post-experimental processes

Obtaining body measurements of subjects

Body measurements of subjects were extracted from their 3D body scan images. 3D body scanner software (ScanWorX) allows users to collect anybody measurement by

taking vertices or measuring distances on the body surface. For this study, lower body measurements were defined to be prominent since the garment type adopted for this study was a skirt. Accordingly, seven body measurements were considered for this study. These measurements are given in Table 2.4.

Table 2.4 : Body measurements used for the study.

Feature	Measurement
Vertical	Overall height, waist height, hip height
Horizontal	Waist girth, belly circumference, hip girth, thigh girth

Analyzing the data

The data were collected from Qualtrics in xsl. file format and restructured for convenience of analysis. The statistical analysis was conducted by using IBM SPSS Version 25 (IBM Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp).

The statistical methods used for this study were descriptive, Pearson’s correlation tests, paired t-tests, one-way ANOVA, Post Hoc tests, multilevel linear regression models and cross validations.

3. RESULTS

3.1 Fabric Experiments

3.1.1 Fabric properties

Fabrics' properties measured by test instruments are given in Table 3.1. To create virtual fabrics, fabric units were converted as described in methodology part. The 3D fabric properties that were used for fabric simulations are given in Table 3.2.

3.1.2 Fabric clustering

Fourteen fabric samples were clustered according to their fabric properties, and skirts for try-on were determined according to the results of this clustering. Four clusters were extracted by hierarchical cluster analysis (HCA).

Principal components analysis (PCA) was used to visualize the clustering of the skirts. According to PCA plot (Figure 3.1): Fabric 2, 22 and 5 clustered together (cross symbol); Fabric 1, 6, 13 and 16 clustered together (circle symbol); Fabric 8, 9, 14 and 15 clustered together (triangle symbol); and finally, Fabric 7, 20 and 21 clustered together (x symbol).

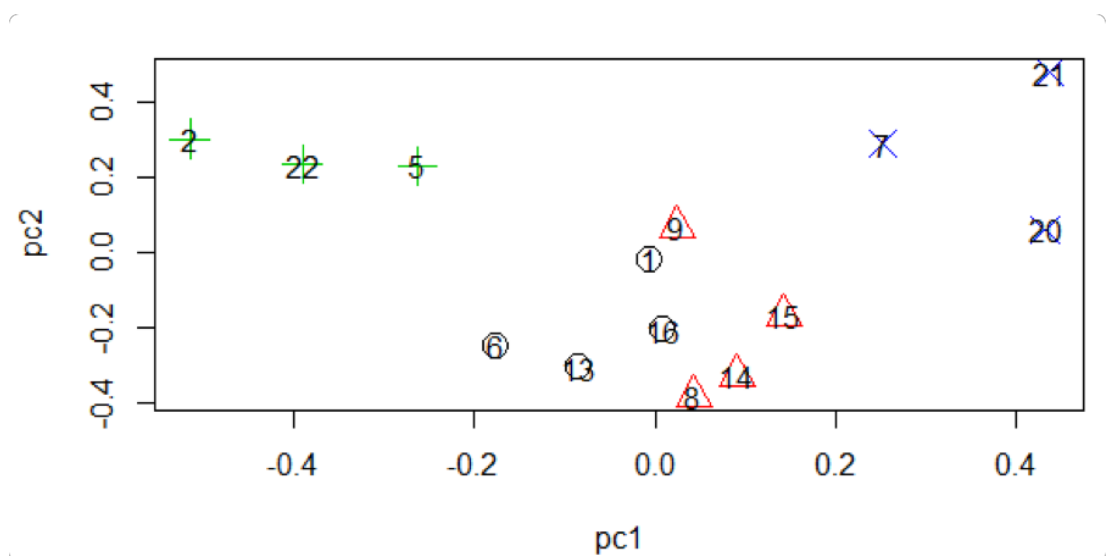


Figure 3.1 : PCA plot of fabrics according to their properties.

After clustering the fabrics objectively, some of the fabrics in each cluster were eliminated. The reason of this elimination was the fabric likeness. Some of the fabrics were subjectively very similar to another fabric in the same cluster. Since the skirts' fits were designed to be done subjectively by human; feel and vision of the fabrics for subjects were considered to be important. Accordingly, two textile experts evaluated the hand properties of fabrics subjectively and eliminated the fabrics which were very similar to another fabric in the same cluster. Fabric 5 was eliminated from the 1st cluster; Fabric 13 and Fabric 16 were eliminated from the 2nd cluster; Fabric 14 and Fabric 9 were eliminated from the 3rd cluster, and finally Fabric 7 and Fabric 20 were eliminated from the 4th cluster.



Table 3.1 : Fabric Properties

#	Fabric Code	Weight (g/m ²)	Thickness (mm)	Drape Coefficient	Elongation (%) (at 500 grf)		Shear Rigidity (N/m)	Bending Rigidity (μNm)		Surface Roughness(μm)		Surface Friction	
					Warp	Weft		Warp	Weft	Face	Back	Face	Back
1	Fabric 2	111	0.10	0.344	3.329	9.410	43.195	1.069	0.584	10.055	10.635	0.713	0.623
2	Fabric 22	143	0.20	0.420	13.222	13.143	18.102	0.890	0.940	11.755	11.125	0.634	0.702
3	Fabric 5	193	0.22	0.443	3.245	11.035	144.478	2.585	1.125	14.330	8.400	0.790	0.811
4	Fabric 6	224	0.31	0.774	2.997	13.434	206.486	7.603	2.683	12.380	12.874	0.870	0.934
5	Fabric 1	258	0.44	0.673	3.142	19.004	122.673	7.324	3.976	17.085	12.200	0.650	0.914
6	Fabric 13	291	0.48	0.731	2.894	11.873	154.982	10.187	5.702	10.175	8.885	0.933	1.018
7	Fabric 16	291	0.56	0.726	3.188	7.711	208.649	12.391	5.830	13.325	12.090	0.961	0.950
8	Fabric 7	300	0.78	0.526	1.054	13.217	119.807	6.011	4.736	22.240	12.160	1.211	0.842
9	Fabric 9	325	0.57	0.484	2.952	20.491	141.761	6.854	2.068	13.770	12.687	0.855	1.044
10	Fabric 8	337	0.64	0.774	1.615	24.007	231.261	23.126	6.802	10.380	10.635	0.895	1.026
11	Fabric 21	344	1.27	0.350	2.826	4.349	121.906	8.395	2.922	21.455	20.285	0.919	0.996
12	Fabric 20	354	1.09	0.667	5.558	7.783	45.270	4.782	3.097	21.140	20.186	1.069	1.064
13	Fabric 14	359	0.66	0.733	2.432	19.783	195.552	15.731	4.239	11.340	13.285	0.827	0.886
14	Fabric 15	385	0.62	0.632	2.538	26.022	142.198	15.707	7.589	13.725	12.975	0.694	0.905

Table 3.2 : 3D fabric properties for simulations.

#	Fabric Code	Weight (g/m ²)	Thickness (cm)	Stretch (g/cm)		Shear (gf/cm)	Bend (dyne*cm)		Surface Friction
				Warp	Weft		Warp	Weft	
1	Fabric 2	111	0,050*	1155	408	43	107	58	0.6
2	Fabric 22	143	0,050*	290	292	18	89	94	0.7
3	Fabric 5	193	0,050*	1185	348	144	259	112	0.8
4	Fabric 6	224	0,050*	4669	1286	206	760	268	0.9
5	Fabric 1	258	0,050*	1224	202	123	732	398	0.9
6	Fabric 13	291	0,050*	1330	325	155	1019	570	1.0
7	Fabric 16	291	0,056	1209	498	209	1239	583	0.9
8	Fabric 7	300	0,078	3649	291	120	601	474	0.8
9	Fabric 9	325	0,057	1303	187	142	685	207	1.0
10	Fabric 8	337	0,064	2374	160	231	2313	680	1.0
11	Fabric 21	344	1,027	1359	884	122	840	292	1.0
12	Fabric 20	354	1,009	688	494	45	478	310	1.1
13	Fabric 14	359	0,066	1435	208	196	1578	460	0.9
14	Fabric 15	385	0,062	1514	147	142	1571	759	0.9

3.2 Skirt Samples

After clustering the fourteen fabrics and eliminating some of them, seven skirts were used for the garment fit experiments. The skirts used for the garment fit experiments are given in Table 3.3. The skirt codes were determined according to their fabric codes. Finally, each subject tried-on one of the skirts from each cluster.

Table 3.3 : Skirts used for garment fit experiments.

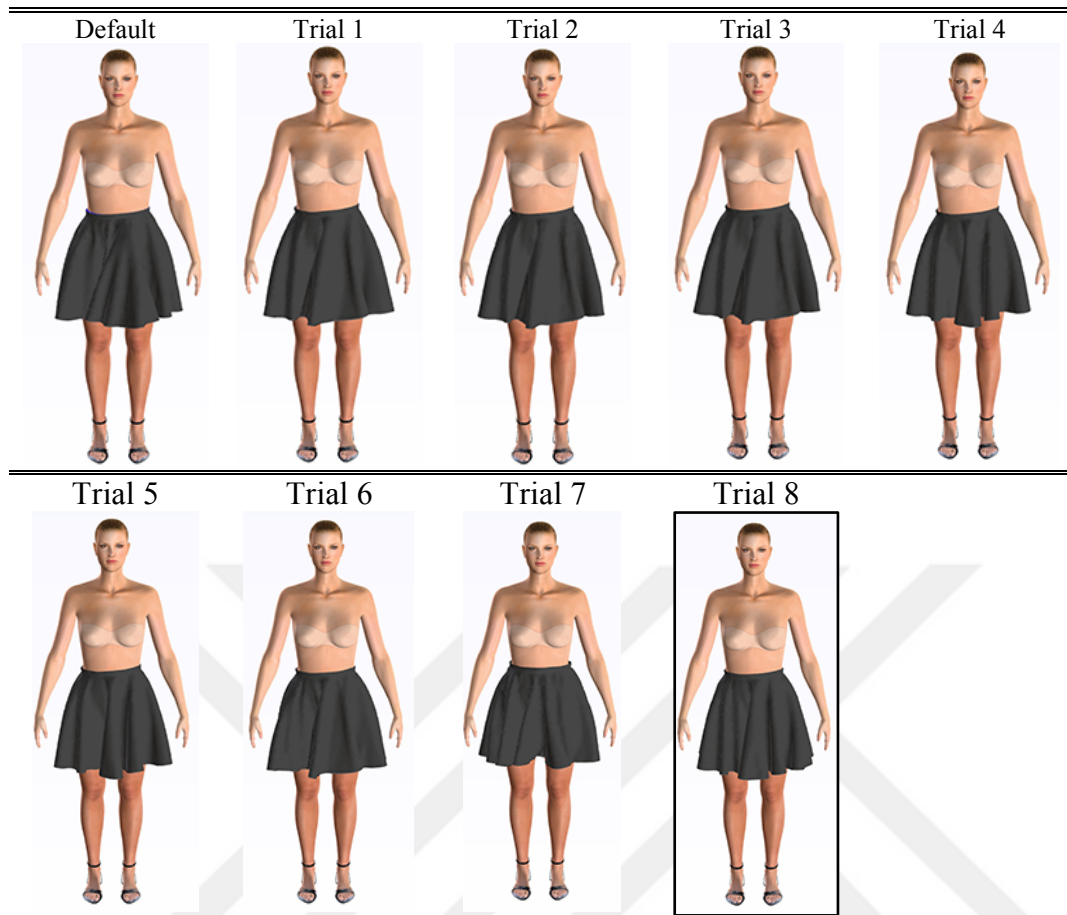
Cluster	Skirt Code
1	Skirt 2 and Skirt 22
2	Skirt 1 and Skirt 6
3	Skirt 8 and Skirt 15
4	Skirt 21

Simulation properties of virtual skirts

As mentioned in methodology, alternative simulation properties were suggested (Table 2.3) and tested on default avatar (Eva) to find the optimum simulation properties for creating the virtual skirts. Obtained virtual skirts according to the entered simulation properties are given in Table 3.4.

According to the virtual skirt images in Table 3.4, the skirt folds on Trial 1-4 were still looking dynamic, hence it was concluded that the default number of time steps should be increased to allow enough time for simulation to be completed. The software instructions suggest that selecting collision post process gives more accurate simulation, however, it requires smaller size of time steps. Thus, it was concluded to select collision post process option, decrease the size of time steps to 0.01 and increase the number of time steps to 20. The simulation obtained according to these setting are marked in Table 3.4.

Table 3.4 : Virtual skirts with alternative simulation properties.



Real and virtual skirts on a dress form

The pictures of real skirt samples that were used for garment fit experiments are given in Table 3.5 (left column) on a dress form for presentation purpose. On the other hand, the same dress form was scanned by the 3D body scanner and the scan image was used in O/Dev as the model for the skirt simulations. Simulations of each skirt on the dress form are given in Figure 3.5 (right column). These simulations were created by using the 3D fabric properties given in Table 3.2.

Table 3.5 : Images of real and virtual skirt samples.

Skirt Code	Real Skirt	Virtual Skirt
Skirt 2	 A photograph of a black, flared, knee-length skirt with a gathered waistband, displayed on a light-colored mannequin torso.	 A 3D digital rendering of the same black, flared, knee-length skirt with a gathered waistband, displayed on a dark gray virtual mannequin torso.
Skirt 22	 A photograph of a black, flared, knee-length skirt with a gathered waistband, displayed on a light-colored mannequin torso.	 A 3D digital rendering of the same black, flared, knee-length skirt with a gathered waistband, displayed on a dark gray virtual mannequin torso.
Skirt 1	 A photograph of a black, flared, knee-length skirt with a gathered waistband, displayed on a light-colored mannequin torso.	 A 3D digital rendering of the same black, flared, knee-length skirt with a gathered waistband, displayed on a dark gray virtual mannequin torso.

Table 3.5(continued) : Images of real and virtual skirt samples.

Skirt Code	Real Skirt	Virtual Skirt
Skirt 6		
Skirt 8		
Skirt 15		

Table 3.5(continued) : Images of real and virtual skirt samples.

Skirt Code	Real Skirt	Virtual Skirt
Skirt 21		

3.3 Garment Fit Experiments

Garment fit experiments were conducted in the 3D BodyScan Lab in Fiber Science and Apparel Design Department at Cornell University between April -June 2018. The study was first approved by Institutional Review Board of Cornell University (Appendix C).

For recruiting subjects, e-mails and flyers were used. Subjects e-mailed the researcher to set an appointment for the experiment. Each experiment took approximately sixty minutes and participants were awarded \$15 at the end of the study.

Subjects were 3D body scanned first and answered some questions. Try-on session started afterwards. Each subject was given one skirt from each skirt cluster (Table 3.3). As there were four clusters and seven skirts, each subject tried-on different skirts from each cluster. Figure 3.2 illustrates how the samples were distributed to subjects. For instance, P1 wore Skirt 2, Skirt 1, Skirt 8 and Skirt 21; and P2 wore Skirt 22, Skirt 6, Skirt 15 and Skirt 21. Each skirt was distributed among clusters to be worn at similar number of times. In Cluster 1: skirt 2 was worn 22 times and Skirt 22 was worn 23 times; in Cluster 2: Skirt 1 was worn 23 times and Skirt 6 was worn 22 times; in Cluster 3: Skirt 8 was worn 24 times and Skirt 15 was worn 21 times; and finally in Cluster 4: Skirt 21 was worn by all subjects, so 45 times since it is the only skirt in this cluster.

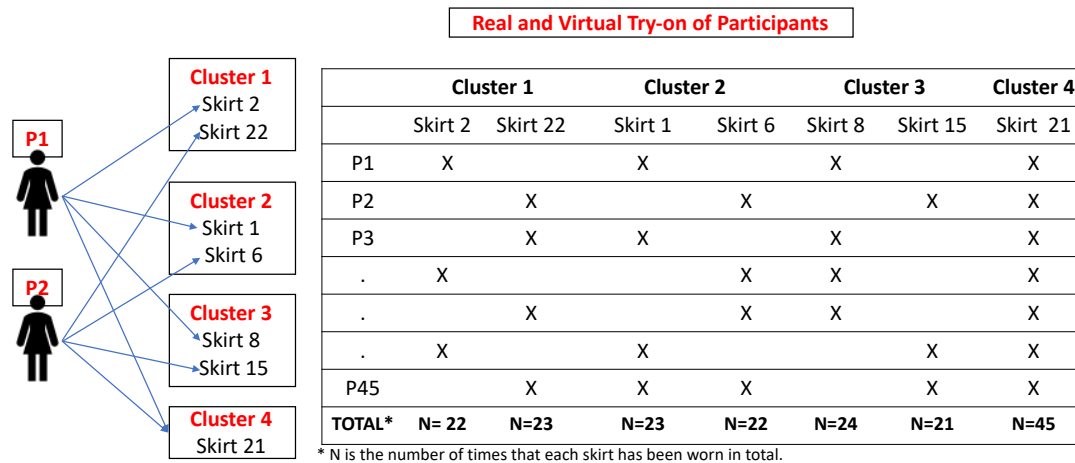


Figure 3.2 : Distribution of skirt samples between subjects.

3.3.1 Demographics

Forty-seven participants attended to the experiments, however after an initial examination of the data, two participants were dismissed due to unreliability and inconsistency of their answers. Eventually, forty-five participants' data were used and analyzed.

Participants' age varied between 18 to 35, and 71 percent of the participants were younger than 25 years old. Overall, calculated mean of participants' age was 23.6 with a standard deviation of 4.75. Fifty-six percent of the participants were European/European American, 33 percent were Asian/Asian American, 7 percent were Hispanic, 2 percent were Middle Eastern/North African, and 2 percent were African American. Majority of the participants were undergraduate students (44 percent), and the rest of them were either graduate students or participants with a graduate degree. Seventy three percent of the participants stated that they haven't had any classes about textiles or fashion, whereas 27 percent said that they attended at least to one class about textiles or fashion.

3.3.2 Online shopping frequencies

Participants' online apparel shopping frequencies were measured for various garment types with a 7-point Likert scale (1: never, 7: always). Online shopping frequencies of participants for different garments are given in Table 3.6. According to this table, sweatshirts were the most purchased item online while trousers were the least purchased item. Online shopping frequencies for all items were below 4: sometimes.

Table 3.6 : Participants' online shopping frequencies for various garment types.

Item	N	Min	Max	Mean	Std. Dev.
Sweatshirts	45	1	7	3.67	1.462
T-shirt	45	1	7	3.56	1.531
Skirts	45	1	6	3.33	1.365
Blouses	45	1	6	3.33	1.261
Jeans	45	1	7	3.20	1.817
Hoodies	45	1	7	3.04	1.678
Trousers	45	1	6	2.62	1.435

The results of participants' online shopping frequencies for skirt item is given in Table 3.7. According to the Table 3.7, there were five subjects that never purchase a skirt item online. Only eight of the participants mentioned that they frequently or usually buy skirts online. On the other hand, the majority of the participants (n=25) stated that they occasionally or sometimes purchase skirts online. This result showed that sample group was adequate for the purpose of the skirt fit study.

Table 3.7 : Participants' online shopping frequencies for skirts.

	Frequency	Percent	Cumulative Percent
Never	5	11.1	11.1
Rarely	7	15.6	26.7
Occasionally	12	26.7	53.3
Sometimes	13	28.9	82.2
Frequently	5	11.1	93.3
Usually	3	6.7	100.0
Total	45	100.0	

In addition to descriptive statistics, paired sample t- tests were conducted to figure out if participants' shopping frequencies for skirts have varied significantly for any of the items. The analysis showed that participants' shopping frequency for skirts was not very much different than the shopping frequencies of other items. Participants' online shopping frequency for skirts (M=3.33, SD=1.37) was only significantly higher than the shopping frequency for trousers (M=2.62, SD=1.46), $t(45)= 2.90$, $p < .05$, $r = 0.31$).

3.3.3 Fit satisfactions for RTW garments

Participants' general fit satisfactions with multiple RTW garments were measured with a 7 -point Likert scale (1: extremely dissatisfied, 7: extremely satisfied). The results are given in Table 3.8. According to the Table 3.8, participants were most satisfied with the fit of RTW t-shirts and least satisfied with the fit of RTW trousers.

Participants' average satisfactions varied between somewhat satisfied (5) and satisfied (6) for upper body garments (T-shirts, sweaters, cardigans and blouses), whereas participants' satisfactions with lower body garments were less.

Table 3.8 : Participants' RTW garment fit satisfactions for various apparel items.

Item	N	Min	Max	Mean	Std. Dev.
T-shirts	45	3	7	5.53	1.036
Sweaters	45	2	7	5.36	1.151
Cardigans	45	3	7	5.24	1.090
Blouses	45	2	7	5.22	1.106
Skirts	45	1	6	4.51	1.254
Jeans	45	2	7	3.96	1.580
Trousers	45	2	7	3.91	1.505

Participants' RTW garment fit satisfactions for skirt item is given in Table 3.9. According to this table, most of the participants were somewhat satisfied with the fit of RTW skirts, and a significant percent of the participants (more than thirty-five percent) were either neutral or dissatisfied at a certain extend.

Table 3.9 : Participants' RTW skirts fit satisfactions.

	Frequency	Percent	Cumulative Percent
Extremely dissatisfied	1	2.2	2.2
Dissatisfied	2	4.4	6.7
Somewhat dissatisfied	8	17.8	24.4
Neither satisfied nor dissatisfied	5	11.1	35.6
Somewhat satisfied	20	44.4	80.0
Satisfied	9	20.0	100.0
Total	45	100.0	

Later, paired sample t- tests were conducted to figure if participants' RTW skirts fit satisfactions were significantly different than any of the other items. The paired t-test results are reported in Table 3.10. Table 3.10 shows that, participants' fit satisfaction for RTW skirts was significantly lower than their fit satisfactions for T-shirts, blouses , sweaters and cardigans. Whereas, participants' fit satisfaction for RTW skirts was significantly higher than jeans and trousers.

Table 3.10 : Paired t-test between participants' RTW skirts fit satisfactions and other garment types.

Pair	Mean Diff.	Std. Dev.	Std.Err. Mean	Lower	Upper	t	df	Sig. (2-tailed)
Skirts - T-shirts	-1.022	1.644	.245	-1.516	-.528	-4.170	44	.000
Skirts - Blouses	-.711	1.456	.217	-1.148	-.274	-3.277	44	.002
Skirts - Sweaters	-.844	1.651	.246	-1.340	-.348	-3.431	44	.001
Skirts - Cardigans	-.733	1.558	.232	-1.201	-.265	-3.158	44	.003
Skirts - Jeans	.556	1.589	.237	.078	1.033	2.345	44	.024
Skirts - Trousers	.600	1.498	.223	.150	1.050	2.686	44	.010

3.3.4 Skirt style preferences

Participants answered three questions about their skirt style preferences. These questions were designed to understand to what extent participants like the silhouette, overall fit and color of the three different skirt styles (A-line, pencil and circular) on a 7-point Likert scale (1: dislike a great deal, 7: like a great deal). In addition, one question was asked to understand participants' purchase intention for the corresponding skirt style. Factor analysis showed that participants' silhouette and overall fit liking were loaded on the same factor, however color and purchase intention questions were irrelevant. Therefore, purchase intention and color liking questions were not included in data analysis. Skirt style preferences of participants in Table 3.11 were calculated by taking the average of the scores for the silhouette and overall fit questions for the corresponding skirt style. According to Table 3.11, the most preferred skirt style were pencil skirt style and the least preferred style was A-line skirt.

Table 3.11 : Participants' preferences for different skirt styles.

Item	N	Min.	Max.	Mean	Std. Dev.
Pencil skirt	45	2.00	7.00	5.63	1.184
Circular skirt	45	2.00	7.00	5.23	1.237
A-line skirt	45	1.00	7.00	4.18	1.624

The results of participants' preference frequencies for circular skirt style are given individually in Table 3.12 in order to interpret how participants liked the skirt style that was used for this study. Table 3.12 shows that, only few participants (n=2) disliked the circular skirt style to different extends while three of the participants neither like nor dislike the style. Majority of the participants (n=40) liked the circular skirt style to different extends.

Table 3.12 : Participants' preference frequencies for circular skirt style.

	Frequency	Percent	Cumulative Percent
Dislike a moderate amount	1	2.2	2.2
Dislike a little	1	2.2	4.4
Neither like nor dislike	3	6.7	11.1
Like a little	5	11.1	22.2
Like a moderate amount	21	46.7	68.9
Like a great deal	14	31.1	100.0
Total	45	100.0	

Paired sample t-tests were conducted to figure if participants' circular skirt preferences were significantly different than the other skirt styles. Table 3.13 points that, participants preferred circular skirts significantly more than the A-line skirts and less than the pencil skirts.

Table 3.13 : Paired t-test between participants' circular skirt preferences and other skirt styles.

Pair	Mean Diff.	Std. Dev.	Std.Err. Mean	Lower	Upper	t	df	Sig. (2- tailed)
Circular - Pencil	-.400	1.691	.252	-.908	.108	-1.587	44	.120
Circular - A-line	1.056	2.185	.326	.399	1.712	3.240	44	.002

3.3.5 Body measurements

During participant recruitment, subjects with 25-28 inches waist girth, and 35-38 inches hip girth were sought. However, some participants were not within the required limits (See Table 3.14 for waist and hips girths of participants). Especially hip measurements of some participants were higher than the required measurements. As the skirt style is a circular style and has some design ease at hips area, the participants with slightly larger hips and waist were allowed to participate in the experiment if they could easily don-on and off the skirt and zip it up. Participants with significantly different body measurements than the recruiting criteria were excluded.

Table 3.14 : Body measurements of participants.

Item	N	Min.	Max.	Mean	Std. Dev.
Weight*	45	105	154	130.73	12.689
Body height	45	59.85	70.03	64.69	2.495
Waist height	44	36.75	44.65	40.78	1.857
Hip girth	45	33.99	43.87	38.19	1.964
Belly circ.	44	27.89	37.10	31.64	2.148
Waist girth	45	24.56	30.88	28.02	1.616
Thigh girth	45	19.62	27.22	23.66	1.602

Weight-height scatter diagram of participants is given in Figure 3.3 for interpreting the average body mass index (BMI) of participants. BMI is the measure of body fat based on height and weight. According to Figure 3.3, body height /weight diagram, all of the participants had similar BMI and none of the participants had exceptional BMI, which confirms the appropriateness of sample group for trying on a M size garment.

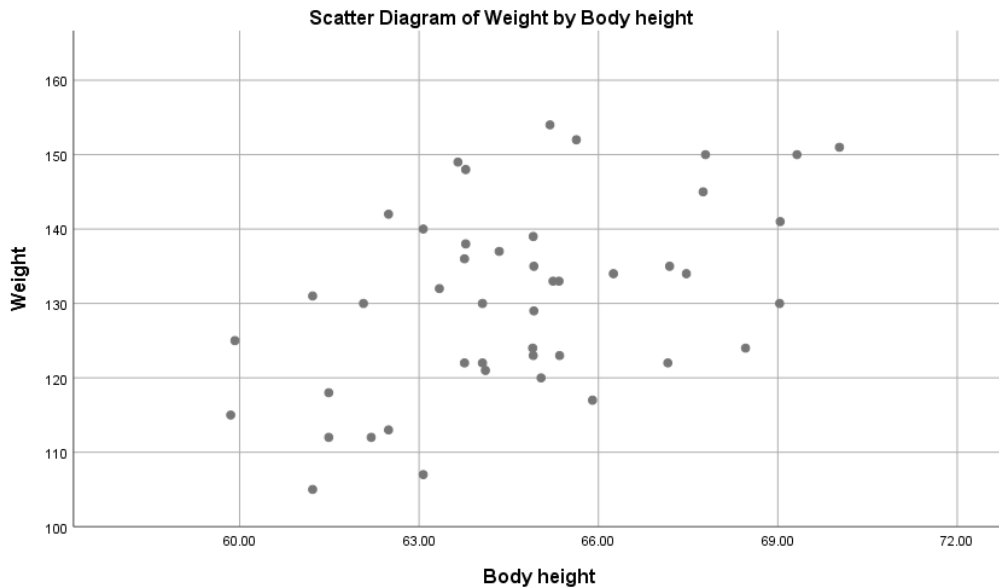


Figure 3.3 : Scatter diagram of participants' weight by their body height.

3.3.6 Body satisfactions

Body satisfactions of participants were measured on a 7-point Likert scale (1: extremely dissatisfied, 7: extremely satisfied). Means of real and virtual body satisfactions of participants for corresponding body parts are given in Table 3.15. According to the real and virtual body satisfactions, participants were most satisfied with their wrists. For the real body satisfaction, thighs were the least satisfied body part. Whereas, for the virtual case, abdomen was the least satisfied body part.

Participants' virtual body satisfactions were often lower than their actual body satisfactions.

Table 3.15 : Real and virtual fit satisfactions of participants.

Item	Real		Virtual	
	Mean	Std.D.	Mean	Std.D.
wrist	6.00	.826	5.87	.968
neck	5.80	1.160	5.62	1.154
height	5.49	1.236	5.50	1.355
shoulder width	5.38	1.370	5.51	1.308
ankle	5.27	1.452	5.36	1.480
back	5.22	1.312	4.96	1.595
feet	5.20	1.325	5.36	1.313
knees	5.11	1.247	5.32	1.290
appearance	5.07	1.232	4.40	1.615
arms	5.02	1.305	5.13	1.471
bust	4.87	1.546	5.00	1.665
posture	4.84	1.224	5.07	1.698
profile	4.84	1.205	4.64	1.708
waist	4.82	1.353	4.18	1.542
legs	4.82	1.556	4.55	1.677
torso	4.80	1.272	4.42	1.672
body build	4.73	1.355	4.00	1.784
buttocks	4.60	1.558	4.45	1.663
weight	4.33	1.462	3.80	1.812
hips	4.33	1.314	4.00	1.624
abdomen	4.29	1.325	3.53	1.471
thighs	4.27	1.558	3.91	1.668

Principle Component analysis (PCA) of body satisfaction scale

Using overall body satisfactions of participants are more convenient than using body satisfaction for single body parts. Therefore, principle component analysis (PCA) with Oblimin rotation was conducted to reduce dimensions of the body satisfaction scale. According to the analysis; appearance, profile, back, torso and body build items were removed after several PCAs due to their low communalities and loading on several factors at a time. After removing these items, a final PCA was conducted with the rest of the items. According to the results, five factors with Eigen values higher than 1 were extracted as given in Table 3.16. These factors explained 71.67 percent of the total variance. The KMO and Bartlett's test result was significant and high enough (KMO= .73, $p < 0.01$). Finally, Cronbach's alphas were calculated to test reliability of each scale. Cronbach's alpha of factor 4 was relatively low (.581). The items loaded

on Factor 4 were bust, height and posture. Since these items were not essential for the purpose of the skirt fit study, a further PCA was not conducted.

Table 3.16 : PCA of body satisfaction scale.

	Component*				
	1: around hips	2: upper body	3: lower body	4: stance	5: around waist
hips	.811				
buttocks	.688				
thighs	.611				
weight	.538				
neck		.688			
shoulder w.		.800			
arms		.671			
wrist		.800			
legs			-.670		
knees			-.908		
ankle			-.919		
feet			-.725		
bust				.747	
height				.765	
posture				.587	
waist					.780
abdomen					.884
Cronbach's alpha	.850	.770	.864	.581	.850

*After extraction of appearance, profile, back, torso and body build items.

As shown in Table 3.16; hips, buttocks, thighs and weight items loaded on factor 1, hence factor 1 was named as: satisfaction around hips. Neck, shoulder width, arms and wrist satisfactions loaded on factor 2, hence factor 2 was named: upper body satisfaction. Legs, knees, ankle and feet items loaded on factor 3, hence factor 3 was named as lower body satisfaction. Bust, height and posture loaded on factor 4, hence factor 4 was named as stance satisfaction. Finally, waist and abdomen items loaded on factor 5, hence factor 5 was named as satisfaction around waist.

Body satisfactions for specific areas

As mentioned earlier, the reason of reducing the dimension of body satisfaction scale was the convenience of using overall body satisfactions instead of single body parts. After reducing dimensions of the scale into five factors, participants' body satisfactions for each factor were calculated separately. For instance, lower body satisfaction level of each participant was calculated by taking the mean of their body satisfactions for each item that had loaded on this factor; in this case legs, knees, ankles and feet satisfactions (see Table 3.16). Each participants' upper body, lower body, around waist, around hips and stance satisfactions were calculated one by one according to the explained procedure.

In addition to real body satisfaction, the same procedure was applied to virtual body satisfactions in order to calculate participants' virtual body satisfactions for each factor.

A further descriptive statistics was conducted to interpret the data. Mean of the real and virtual body satisfactions of all participants for each factor were calculated individually. Table 3.17 shows the mean real and virtual body satisfactions of participants for each body area. Participants had the highest satisfaction with their upper bodies for virtual and real cases. Participants' virtual body satisfactions for waist and hips area were lower than their actual satisfactions. Participants lowest body satisfaction for real case was with their hips area, whereas, the lowest satisfaction for virtual case was with the waist area.

Table 3.17 : Real and virtual body satisfactions of participants for specific body areas.

	Real		Virtual	
	Mean	Std.D.	Mean	Std.D.
Upper body	5.55	.916	5.53	1.041
Lower body	5.10	1.180	5.10	1.180
Stance	5.07	.991	5.17	1.162
Around waist	4.56	1.249	3.86	1.397
Around hips	4.38	1.226	4.02	1.256

Later, paired sample t-tests were conducted to figure whether participants' real fit satisfactions were significantly different than their virtual body satisfactions for specific body areas. The results are given in Table 3.18.

Table 3.18 : Paired t-test between participants' real and virtual body satisfactions for specific body parts.

Pair (RBS-VBS)	Mean Diff.* (d)	Std. Dev.	Std.Err. Mean	Lower	Upper	t	df	Sig. (2-tailed)
Around hips	.349	1.188	.181	-.017	.714	1.926	42	.061
Upper body	.0167	.747	.111	-.208	.241	.150	44	.882
Stance	-.129	.857	.129	-.3898	.132	-.996	43	.325
Around waist	.700	1.125	.168	.362	1.038	4.174	44	.000

*d= Mean RBS - Mean of VBS

Table 3.18 shows that, participants' virtual body satisfactions for waist area was significantly lower than their real body satisfactions for the same area. On the other hand, virtual body satisfactions and real body satisfactions at other areas were not significantly different.

3.3.7 Interaction with 3D fit technologies

3.3.7.1 3D body scanning

Participants were asked three questions in this section. Each question was measured on a 7-point Likert scale. The results are given in Table 3.19.

Table 3.19 : Participants' interaction with 3D body scanning.

Item	N	Min.	Max.	Mean	Std. Dev.
Comfort with 3D body scanning	45	5	7	6.58	.543
Comfort with viewing the 3D scan image	45	2	7	5.67	1.477
Willingness to be scanned again	45	4	7	6.24	.957

According to the Table 3.19, 60 percent of the participants were extremely comfortable with 3D body scanning process, 38 percent were comfortable, and 2 percent were somewhat comfortable, none of the participants were uncomfortable with the scanning process. On the other hand, 38 percent of the participants were extremely comfortable to view their 3D scan image, 29 percent were comfortable, 13 percent were somewhat comfortable, 4 percent were neither, 13 percent were somewhat uncomfortable and 2 percent were uncomfortable. Finally, 89 percent of the participants were willing to be scanned in the future while 11 percent were neutral. None of the participants had negative approach to be 3D scanned again in the future.

Principle Component Analysis of 3D body scanning questions

A PCA with Oblique rotation was conducted further to determine if there were any underlying factors of these three questions. A single factor with Eigen value 1.963 explained the 65 percent of the total variance. However, KMO and Bartlett's test result was quite low (KMO measure = .59) and comfort with scanning process item had a low communality (.38). The reliability of the scale was assessed according to calculated Cronbach's alpha (.70). Even though, $\alpha = .70$ is referred to be adequate in many sources (Field, 2013), due to its low communality, comfort with 3D body scanning variable was excluded. Eventually, a new variable, attitude towards 3D body scanning was calculated for each participant by taking the mean of the other two items (willingness to be scanned again and comfort with viewing the 3D scan image).

3.3.7.2 Virtual try-on technology

Participants' acceptance of virtual try-on technology was measured with a five items scale (Kim & LaBat, 2013b). The scale measured participants' agreements for each item on a 7-point scale (1: strongly disagree, 7: strongly agree). Calculated means for each item is given in Table 3.20.

Table 3.20 : Participants' acceptance of virtual try-on.

Item	N	Min.	Max.	Mean	Std. Dev.
Use virtual try-on for online shopping	45	2	7	5.29	1.424
Use virt. try-on in the future for fit evaluation	45	1	7	5.16	1.623
Satisfaction with using virtual try-on for fit evaluation	45	1	7	4.56	1.778
Visual information obtained from simulation	45	1	7	4.27	1.643
Willingness to pay for virtual try-on tech.	45	1	7	3.82	1.696

Eighty percent of the participants were positive (above 4) to use virtual try-on technology for online apparel shopping. Seventy-three percent of participants were eager to use virtual try-on technology in the future to evaluate garment fit. Sixty-two percent of participants were satisfied with using virtual try-on for fit evaluation in different respects, while 33 percent of the participants were not satisfied (below 4) and 5 percent were neither satisfied nor dissatisfied. Fifty-one percent of the participants were positive for the visual information gathered by the virtual try-on technology,

whereas, 42 percent of the participants were negative. Finally, only 24 percent of the participants were willing to pay extra money for virtual try-on technology, more than half of the participants mentioned that they wouldn't pay extra for virtual try-on technology.

Principle Component Analysis of acceptance of virtual try-on technology scale

A PCA with Oblique rotation was conducted to determine the factors of the scale. A single factor with Eigen value 3.83 was extracted and it explained 77 percent of the total variance which is fairly good (Field, 2013). KMO value was .78 and communalities were high for each item (higher than .60). Factor loadings of each item were higher than .80 except willingness to pay extra (.77). Finally, the Cronbach's alpha value was calculated as 0.92 which confirms that the scale was good to measure the construct (Field, 2013). Eventually, a new variable, *acceptance of virtual try-on*, was calculated for each participant by taking the mean of their answers to these five questions.

3.3.8 Skirt fit satisfactions

3.3.8.1 Descriptives

Skirt fit satisfactions of participants were measured on a 7-point Likert scale for four fit locations (waistline, abdomen level, hips level and hem level) at three different views (front, back and sides of the skirts). Thus, each participant had twelve fit evaluations (four fit locations at three views) for each skirt as described in methodology (Figure 2.17). Each participant's fit satisfactions for each location were measured by taking the mean of participant's fit evaluations for front, back and side of the skirt at corresponding location, and overall fit satisfaction of each participant for the corresponding skirt was measured by calculating the mean of her fit satisfaction at waist, abdomen, hips and hem. This procedure was followed for real skirts and virtual skirts. For instance; participant-1 (P1)'s fit satisfaction of a real skirt is given in Figure 3.4. According to the evaluations in Figure 3.4, P1's RFS for waistline was calculated by taking the mean of evaluations at front, back and side view. Accordingly, P1's RFS at waistline was 5.33. Similarly, P1's RFSs for abdomen level, hips level and hem level were 4.33, 6 and 4.67; respectively. On the other hand, overall RFS of P1 for this skirt was calculated by taking the mean of twelve evaluations. In Figure 3.4, P1's overall RFS for this skirt was 5.08.

Please rate your fit satisfaction of the skirt for each body part from 1 to 7 (Enter a number in below boxes)

1= extremely dissatisfied
2= dissatisfied
3= somewhat dissatisfied
4= neither dissatisfied nor satisfied
5= somewhat satisfied
6= satisfied
7= extremely satisfied

	front view	back view	side view
waistline	5	6	5
abdomen level	4	5	4
hips level	6	6	6
hem	4	5	5

Figure 3.4 : P1’s fit evaluations for a skirt sample.

Table 3.21 shows participants’ overall fit satisfactions for each skirt in real and virtual context. Participants’ fit satisfaction results are reported for specific fit areas (i.e. waist, abdomen level, hips level, hem level) and for overall. According to Table 3.21, participants had the maximum fit satisfaction for Skirt 2 and the minimum satisfaction for Skirt 15. Their overall fit satisfactions with skirts varied between M=5.33 and M=3.94. On the other hand, for the virtual case, participants were most satisfied with the Skirt 6 and least satisfied with the Skirt 2. However, participants’ fit satisfactions varied between M=4.83 and M=4.43 for the virtual case. The lowest virtual fit satisfaction with Skirt 2 was particularly due to low satisfaction scores for the hemline. For most of the skirts (Skirt 2, Skirt 22, Skirt 6, Skirt 8 and Skirt 21), overall fit satisfaction scores for real cases were higher than the virtual cases. For the real fit, participants were mostly least satisfied with abdomen and waistlines of the skirts. However, for the virtual cases, it was not possible to observe such a trend.

Table 3.21 : Participants' average RFSs and VFSs for different skirts (overall and specific fit areas).

Skirt Cluster	Skirt Code	Item	RFS		VFS	
			Mean	Std.D.	Mean	Std.D.
1	Skirt 2	waist	4.88	1.873	4.71	1.261
		abdomen	5.29	1.183	4.52	1.116
		hips	5.35	1.232	4.30	1.399
		hem	5.79	.894	4.23	1.561
		Overall	5.33	1.119	4.44	1.110
1	Skirt 22	waist	5.00	1.570	4.90	1.253
		abdomen	5.26	1.146	4.75	1.120
		hips	5.39	1.254	4.71	1.220
		hem	5.39	1.336	4.93	1.263
		Overall	5.26	1.150	4.82	1.023
2	Skirt 1	waist	4.57	1.591	5.13	1.192
		abdomen	4.28	1.653	4.71	1.574
		hips	4.70	1.414	4.51	1.470
		hem	4.80	1.388	4.64	1.708
		Overall	4.58	1.249	4.75	1.216
2	Skirt 6	waist	5.12	1.503	4.83	1.320
		abdomen	4.77	1.370	4.62	1.335
		hips	5.06	1.528	4.56	1.572
		hem	5.62	1.218	5.29	1.502
		Overall	5.14	1.171	4.83	1.168
3	Skirt 8	waist	5.01	1.749	4.61	1.371
		abdomen	4.42	1.781	4.40	1.373
		hips	4.58	1.628	4.82	1.322
		hem	5.101.652	5.14	1.304	
		Overall	4.78	1.505	4.74	1.174
3	Skirt 15	waist	4.40	1.649	4.65	1.356
		abdomen	3.65	1.319	4.54	1.077
		hips	3.76	1.257	4.68	.840
		hem	3.95	1.42	4.65	1.344
		Overall	3.94	1.161	4.63	.897
4	Skirt 21	waist	4.96	1.488	4.63	1.393
		abdomen	4.96	1.160	4.53	1.111
		hips	5.13	1.274	4.72	1.265
		hem	5.21	1.258	4.79	1.360
		Overall	5.06	1.178	4.67	1.080

Histogram of overall RFS and VFS for each skirt is given in below Figure 3.5 for visualization and easier interpretation. Figure 3.5 clearly shows that participants' real fit satisfactions varied considerably among the skirts while virtual fit satisfaction scores were relatively close to each other (M=4.82 for Skirt 2 and Skirt 21, and M=4.83 for Skirt 6). The highest discrepancy for participants' virtual and real fit satisfaction scores were observed for Skirt 2. Participants were most satisfied with Skirt 2 for real case and least satisfied with the same skirt for virtual case.

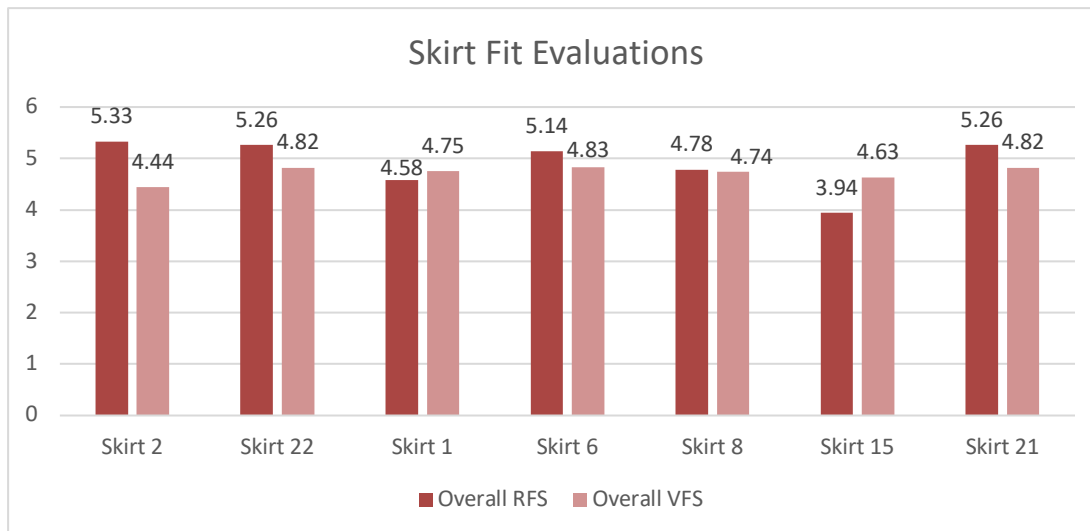


Figure 3.5 : Participants’ overall RFSs and overall VFSs for different skirts.

3.3.8.2 One-way ANOVA

One-way ANOVA between participants’ RFSs for the test skirts

In this study, seven skirts made from different fabrics were used for fitting tests. To understand if participants’ overall RFSs were significantly different between these test skirts, a one-way ANOVA was conducted. According to the one-way ANOVA, *there was a significant difference between overall RFSs of different skirts*, ANOVA ($F(6,173) = 3.515, p = .003$).

A further Post-Hoc analysis was carried out to figure which skirt/skirts was different in terms of overall RFSs. Since each skirt was worn for different number of times, for instance Skirt 21 was worn by 45 participants while Skirt 2 was worn by 23 participants, Hochberg Post-Hoc test was appropriate for this study (Field, 2013). According to Post-Hoc analysis, participants’ overall RFSs for Skirt 15 ($M= 3.94, SD:1.161$) were statistically different than Skirt 2 ($M= 5.33, SD= 1.119, p=0.006$), Skirt 6 ($M=5.14, SD=1.171, p=0.031$), Skirt 21 ($M=5.26, SD=1.149, p=0.013$) and Skirt 22 ($M=5.26, SD=1.149, p=0.009$)

One-way ANOVA between participants’ VFSs for the test skirts

To understand if participants’ overall VFSs were significantly different between virtual skirts, a one-way ANOVA was conducted. According to the one-way ANOVA, *there was no significant difference between overall VFSs of different skirts*, ANOVA($F(6,173) = .333, p = 0.92$). Since no difference was determined, a further Post-Hoc analysis was not necessary.

3.3.8.3 Paired t-tests and Pearson's correlations between participants' RFSs and VFSs (regardless of the skirt codes)

In this study, seven different skirts were clustered in four groups, and each participant tried one of the skirt from each cluster resulting each participant to try-on four different skirts. Since each participant wore four different skirts, number of cases (N) were 180 (Number of participants=45, number of skirts that each participant wore=4; $45 \times 4 = 180$) which means that there were 180 RFS scores and 180 VFSs scores at total, and Pearsons' correlation analysis and paired t-test analysis were conducted among these 180 cases. So, in this section, participants' RFSs and VFSs correlation and mean difference analysis are conducted regardless of the differences among the skirts. As the only difference between the skirts is their fabrics, this section gives information how garment simulation was effective regardless of the fabric differences.

Pearson's' correlation

A Pearson's correlation test and paired t-test were conducted between overall RFSs and VFSs of participants regardless of skirt code. In addition to overall fit satisfactions, specific fit locations such as waist line, abdomen level were also paired.

According to Pearson's correlation analysis between overall RFSs and VFSs of participants, a significant correlation was spotted ($r = .63$, $N = 180$, $p < 0.01$). Moreover, Pearson's correlation analysis between RFSs and VFSs at abdomen was $r = .42$ ($N = 180$, $p < 0.01$); RFS and VFS at waist was $r = .48$ ($N = 180$, $p < 0.01$); RFS and VFS at hips was $r = .60$ ($N = 180$, $p < 0.01$); RFS and VFS at hem was $r = .65$ ($N = 180$, $p < 0.01$).

The correlation coefficient scatter diagram of overall RFS and VFS of participants is given in Figure 3.6. Figure 3.6 shows each participants' overall RFS and VFS for all of the skirts they had tried on. Hence, there are $N=180$ cases (dots) in the diagram. In this diagram, a positive linear correlation between overall RFSs and VFSs was observed. The correlation coefficient of this data $r = .63$ ($N=180$, $p < .01$) and calculated R^2 was 0.40. In other words this linear model explains the 40 percent of the variability of the participants' RFS around its mean and VFS is a good variable to relate to RFS (Field, 2013).

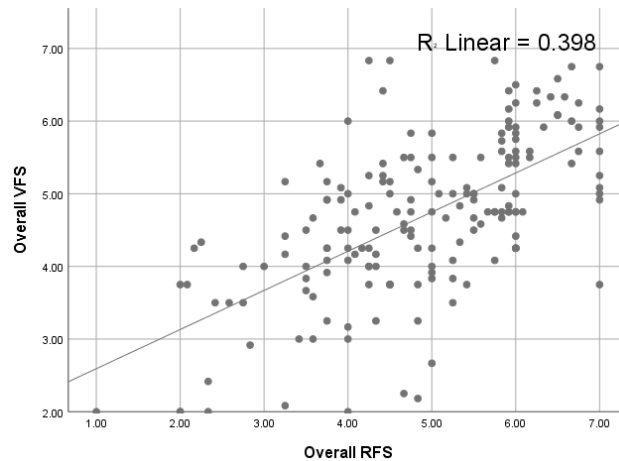


Figure 3.6 : Scatter diagram of overall VFSs and RFSs of participants (regardless of the skirt codes, N=180).

Paired t-tests

A paired t-test between overall RFSs and VFSs of participants was conducted to see if there was any significant difference between the means of these two groups. In addition, one by one paired t-tests were conducted for RFSs and VFSs at certain fit areas (i.e. waist, abdomen level) to see if there was any significant difference for RFSs and VFSs for any specific fit area. The paired t-test results between RFSs and VFSs of participants are given in Table 3.22. According to the Table 3.22, there was a significant difference between the overall RFSs and VFSs ($t(6, 179)=2.690$, $p< 0.01$). Participants' fit satisfactions for hips and hem area were significantly different in real case than the virtual case ($t(6, 179)=2.859$ and $t(6,179)=3.676$, respectively $p<0.01$), whereas, no significant differences were observed for abdomen and waist areas ($t(6,179)= 1.188$, $t(6,179)= .921$, respectively, $p>0.05$).

Table 3.22 : Paired t-tests between RFSs and VFSs of participants (regardless of the skirt codes).

Pair (RFS-VFS)	Mean Diff.* (d)	Std. Dev.	Std.Err. Mean	Lower	Upper	t	df	Sig. (2-tailed)
overall	.206	1.027	.0766	.055	.36	2.690	179	.004
waist	.104	1.600	.113	-.118	.326	.921	179	.179
abdomen	.128	1.443	.108	-.085	.340	1.188	179	.118
hips	.263	1.234	.0920	.081	.445	2.859	179	.003
hem	.328	1.196	.0892	.152	.504	3.676	179	.000

* d= Mean RFS - Mean of VFS

3.3.8.4 Paired t-tests and Pearson's correlations between participants' RFSs and VFSs (regarding the skirt codes)

In this section, the real and virtual fit satisfactions of participants were explored for each skirt individually. For instance, 22 of the participants wore Skirt 2 and evaluated its real and virtual fit (see Figure 3.2). Therefore, it was also critical to observe how real and virtual fit satisfactions were correlated and compared for individual skirts since the fabrics of each skirt were different than each other, and simulation software might be more sufficient to reflect drape properties of some fabrics better than the others. Therefore, RFS and VFS comparisons were also conducted within skirts by respecting their fabric differences.

Pearson's' correlations

Pearson's correlation tests were conducted between RFSs and VFSs of each skirt for each body area that have been evaluated and results are given in Table 3.23. According to the Table 3.23, the highest correlation between overall RFSs and VFSs was observed for Skirt 22 ($r = .84$, $N=23$, $p < .01$) and the lowest correlation was observed for Skirt 2 ($r = .42$, $N=22$, $p=0.05$). Although this two skirts were clustered in the same group according to their fabric properties, their overall RFSs and VFSs correlations were considerably different. Similar pattern was also observed for Skirt 8 and Skirt 15. The correlation between overall RFSs and VFSs for Skirt 8 ($r = .67$, $N=24$, $p < .01$) was considerably different than the Skirt 15 ($r = .52$, $N=21$, $p < .01$) which is in the same cluster (Cluster 3). Participants' RFSs and VFSs were correlated significantly for most of the skirts for specific fit locations too. The correlations between RFSs and VFSs at waist and abdomen were often lower than the correlations at other parts.

Table 3.23 : Pearson’s correlations between overall and specific RFSs and VFSs of participants (regarding skirt differences).

Skirt Cluster	Skirt Code	Item	N	Pearson’s Correlation	Sig. (2-tailed)
1	Skirt 2	waist	22	.09	.698
		abdomen	22	.37	.089
		hips	22	.48	.024
		hem	22	.66	.001
		Overall	22	.42	.052
1	Skirt 22	waist	23	.67	.000
		abdomen	23	.74	.000
		hips	23	.75	.000
		hem	23	.76	.000
		Overall	23	.84	.000
2	Skirt 1	waist	23	.55	.007
		abdomen	23	.45	.033
		hips	23	.56	.003
		hem	23	.85	.000
		Overall	23	.71	.00
2	Skirt 6	waist	22	.46	.022
		abdomen	22	.47	.021
		hips	22	.76	.006
		hem	22	.74	.000
		Overall	22	.75	.000
3	Skirt 8	waist	24	.59	.003
		abdomen	24	.37	.078
		hips	24	.54	.007
		hem	24	.77	.000
		Overall	24	.67	.000
3	Skirt 15	waist	21	.45	.023
		abdomen	21	.29	.199
		hips	21	.55	.010
		hem	21	.53	.013
		Overall	21	.52	.016
4	Skirt 21	waist	45	.56	.000
		abdomen	45	.49	.001
		hips	45	.79	.000
		hem	45	.69	.000
		Overall	45	.72	.000

Paired t-tests

Paired t-tests between RFSs and VFSs for each skirt were conducted individually to see if there was any significant difference between the means of the groups when fabric differences of the skirts were considered. In addition, one by one paired t-tests were conducted for RFSs and VFSs at certain fit areas (for instance, waist) to see if there was any significant difference for RFSs and VFSs of the skirt for any specific fit area, and the results are given in Table 3.24. According to the Table 3.24, significant differences between RFSs and VFSs were observed for Skirt 2, Skirt 22, Skirt 15 and

Skirt 21 ($p < .01$). Whereas, no significant difference was observed for Skirt 1, Skirt 6 and Skirt 8 ($p > .05$). The highest significant discrepancy between its overall RFS and VFS mean scores was observed for Skirt 2 ($d = .87$) and minimum was observed for Skirt 21 ($d = .40$). For particular fit locations, only RFSs and VFSs at waist showed no significant difference for each skirt ($p > .05$ in all cases). No particular pattern was observed for other fit locations.

Table 3.24 : Paired t-tests between RFS and VFS of participants (regarding skirt differences).

Skirt Code	Pair (RFS-VFS)	Mean Diff.* (d)	Std. Dev.	Std.Err. Mean	Lower	Upper	t	df	Sig. (2-tailed)
2	waist	.167	2.165	.461	-.793	1.126	.361	21	.722
	abd.	.773	1.291	.275	.201	1.345	2.808	21	.011
	hips	1.045	1.350	.288	.447	1.644	3.632	21	.002
	hem	1.561	1.179	.251	1.038	2.083	6.208	21	.000
	overall	.886	1.201	.256	.353	1.418	3.459	21	.002
22	waist	.101	1.148	.239	-.395	.598	.424	22	.676
	abd.	.507	.822	.171	.152	.863	2.960	22	.007
	hips	.681	.885	.184	.299	1.064	3.693	22	.001
	hem	.464	.903	.188	.073	.854	2.463	22	.022
	overall	.438	.626	.131	.168	.709	3.357	22	.003
1	waist	-.565	1.372	.286	-1.159	.028	-1.975	22	.061
	abd.	-.435	1.701	.355	-1.170	.301	-1.226	22	.233
	hips	.188	1.298	.271	-.373	.750	.696	22	.494
	hem	.159	.915	.191	-.236	.555	.836	22	.412
	overall	-.163	.938	.196	-.569	.243	-8.33	22	.414
6	waist	.288	1.441	.307	-.351	.927	.937	21	.359
	abd.	.152	1.368	.292	-.455	.758	.520	21	.609
	hips	.500	1.083	.231	.020	.980	2.166	21	.042
	hem	.333	1.018	.217	-.118	.785	1.535	21	.140
	overall	.318	.830	.177	-.050	.686	1.798	21	.087
8	waist	.403	1.464	.299	-.216	1.021	1.347	23	.191
	abd.	.014	1.806	.369	-.749	.776	.038	23	.970
	hips	-.236	1.443	.295	-.845	.373	-.802	23	.431
	hem	-.042	1.051	.215	-.485	.402	-.194	23	.848
	overall	.035	1.130	.231	-.442	.512	.151	23	.882
15	waist	-.254	1.531	.334	-.951	.443	-.760	20	.456
	abd.	-.889	1.439	.314	-1.544	-.234	-2.831	20	.010
	hips	-.921	1.064	.232	-1.405	-.436	-3.965	20	.001
	hem	-.698	1.341	.293	-1.309	-.088	-2.386	20	.027
	overall	-.690	1.036	.226	-1.162	-.219	-3.054	20	.006
21	waist	.333	1.358	.202	-.075	.741	1.647	44	.107
	abd.	.430	1.145	.171	.086	.774	2.517	44	.016
	hips	.407	.822	.123	.160	.654	3.323	44	.002
	hem	.415	1.035	.154	.104	.726	2.688	44	.010
	overall	.399	.845	.126	.145	.653	3.164	44	.003

* $d = \text{Mean RFS} - \text{Mean of VFS}$

3.4 Factors Affecting VFSs of Participants

3.4.1 3D fabric properties and VFS

Association between overall VFSs of participants and 3D fabrics' properties were explored by Pearson's correlation test, and results are given in Table 3.25.. According to the Table 3.25, *none of the 3D fabric properties (in Table 3.2) were significantly associated with overall VFSs of participants.*

Table 3.25 : Pearson's correlations between participants' overall VFSs and 3D fabric properties .

	Weight	T* (3D)	B_warp (3D)	B_weft (3D)	E-warp (3D)	E_weft (3D)	Fric. Coeff. (back)
Pears. Corr.	.011	-.016	.017	.013	.035	.018	.041
VFS Sig.(2-tailed)	.886	.835	.824	.858	.641	.810	.582
N	180	180	180	180	180	180	180

*T: thickness, B: bending rigidity, E: elongation are the 3D fabric properties in Table 3.2.

3.4.2 Interaction with 3D fit technologies and VFS

Association between overall VFSs of participants and their interaction with 3D virtual try-on and 3D body scanning were explored by Pearson's correlation tests, and results are given in Table 3.26. According to the Table 3.26, interaction with virtual try-on and 3D body scanning technologies were weakly correlated with participants' VFSs, $r = .24$, $N=180$, $p < .01$ and $r = .29$, $N=180$, $p < .01$, respectively.

Table 3.26 : Pearson's correlations between participants' overall VFSs, and interaction with virtual try-on and 3D body scanning.

		VFS	Virtual try-on	3D body scanning
VFS	Pearson Correlation	1	.239	.259
	Sig. (2-tailed)		.001	.000
	N	180	180	180
Virtual try-on	Pearson Correlation	.239	1	.292
	Sig. (2-tailed)	.001		.000
	N	180	180	180
3D body scanning	Pearson Correlation	.259	.292	1
	Sig. (2-tailed)	.000	.000	
	N	180	180	180

3.4.3 Body measurements and VFS

Association between overall VFSs of participants and their body measurements were explored by Pearson's correlation test, and results are given in Table 3.27. According

to the Table 3.27, all of the body measurements were significantly correlated to overall VFSs of participants except body height and waist height. Table 3.27 shows a negative correlation between VFSs of participants and their weight, waist girth, belly circumference and thigh girth. The highest negative correlation between VFS and body measurements was observed for belly circumference ($r = -.34$, $N=180$, $p < .01$).

Table 3.27 : Pearson’s correlations between participants’ overall VFSs and body measurements.

	Weight	Body height	Waist girth	Belly circ.	Hip girth	Thigh girth	Waist height
Pearson Corr.	-.225	.007	-.282	-.343	-.294	-.291	.059
VFS Sig.(2-tailed)	.002	.924	.000	.000	.000	.000	.447
N	180	180	180	180	180	180	168

3.4.4 Virtual body satisfaction and VFS

Association between overall VFSs of participants and their virtual body satisfactions (VBSs) were explored by Pearson’s correlation test and results are given in Table 3.28. According to the Table 3.28, participants’ VBSs were positively correlated to their VFSs. The strongest correlation was between VBS around hips ($r = .50$, $N= 180$, $p < 0.01$) and the lowest correlation was with the upper body ($r = .22$, $N=180$, $p < 0.01$).

Table 3.28 : Pearson’s correlations between VFSs and participants’ virtual body satisfactions (VBSs).

	VBS around hips	VBS around waist	VBS of lower body	VBS upper body	VBS of stance	Overall VBS
Pearson Corr.	.501	.287	.387	.219	.465	.447
VFS Sig. (2-tailed)	.000	.000	.000	.003	.000	.000
N	180	180	180	180	180	180

3.4.5 Other factors

In this study, participants’ preference of the circular skirt style, RTW garment satisfactions of the skirts, online shopping frequencies of the skirts were also measured. The correlations between these measured properties and overall VFSs of participants were also tested. Table 3.29 shows a significant correlation between VFSs of participants and their preference for the circular skirt style ($r = .33$, $N=180$, $p < .01$), and RTW fit satisfactions for the skirts ($r = .25$, $N=180$, $p < .01$). However no significant correlation was observed between participants’ VFSs and their online shopping frequencies for the skirts.

Table 3.29 : Pearson’s’ correlations between VFS and other factors.

		Online Shop. Frequency (skirts)	RTW fit satisfact. (skirts)	Preference for the circular skirt	VFS
VFS	Pearson C.	-.029	.250	.329	1
	Sig. (2-tailed)	.696	.001	.000	
	N	180	180	180	180
Online Shop. Freq.(skirts)	Pearson C.	1	.243	-.162	-.029
	Sig.(2-tailed)		.001	.030	.696
	N	180	180	180	180
RTW fit satisfaction (skirts)	Pearson C.	.243	1	-.262	.250
	Sig.(2-tailed)	.001		.000	.001
	N	180	180	180	180
Preference for the circular skirt	Pearson C.	-.162	-.262	1	.329
	Sig.(2-tailed)	.030	.000		.000
	N	180	180	180	180

Figure 3.7 is illustrated according to the Pearson’s correlation values obtained from Table 25 to Table 29. The correlation between each item and measured virtual fit satisfactions are given on the arrows.

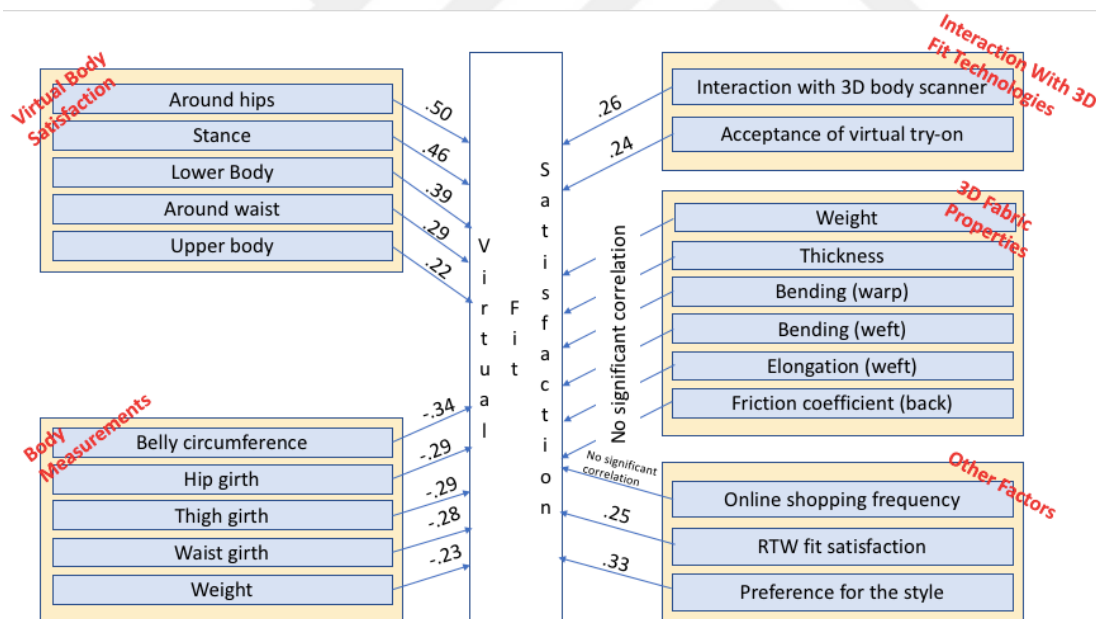


Figure 3.7 : Pearson’s correlations for factors affecting virtual fit satisfactions (Summary from Table 25-29).

3.5 Predicting Participants’ Real Fit Satisfactions (RFSs)

3.5.1 Building the statistical model

As illustrated in the Figure 3.2, each participant wore different skirts than each other. Hence a simple linear regression analysis was not appropriate for this study (Field,

2013). According to the research design, different skirts were distributed between participants. Therefore, a multilevel linear regression model (MLM) where skirts constitute the first level, and participants constitute the second level was appropriate for the nature of the collected data. According to the research model (Figure 2.3): VFS, body measurements (weight, height, waist height, belly circumference, waist girth, hip girth, thigh girth); real body satisfactions (upper body, lower body, area around hips, area around waist, stance); actual fabric properties (W, T, B_{warp}, B_{weft}, E_{warp}, E_{weft}, G, friction coefficient_(back), friction coefficient_(face), surface roughness, DC) were used as fixed factors and participant code was used as a random factor to predict the RFSs of the participants. Finally, RFS was the dependent factor in the statistics model.

An initial MLM was conducted by using all parameters. After the first analysis, SPSS automatically excluded some of the fabric properties (W, T, G, surface roughness, friction coefficient_(back), DC) due to redundancy. When variables are highly correlated this occurs as a common issue, and it is necessary to exclude highly correlated variables to prevent multicollinearity (Field, 2013). Finally, a MLM with maximum likelihood method was established. Results of the analysis is given in Table 3.30 and Table 3.31.

Table 3.30 shows the effects of each independent variable on the RFSs of participants, and Table 3.31 shows the strength (β coefficients) of each independent variable to impact dependent variable which was RFSs of participants in this case.

Table 3.30 : Type III test of fixed effects (all data).

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	50.480	1.046	.311
Weight	1	38.138	.359	.553
Body height	1	37.755	3.867	.057
Waist girth	1	37.972	.000	1.000
Belly circumference	1	37.571	3.086	.087
Hip girth	1	37.417	.928	.342
Thigh girth	1	38.201	.009	.926
Waist height	1	37.666	6.928	.012
RBS at waist area	1	37.769	.071	.791
RBS at hips area	1	39.131	1.573	.217
RBS at lower body	1	38.783	2.205	.146
RBS at upper body	1	38.899	.699	.408
RBS of stance	1	40.154	.015	.902
B_warp	1	154.152	3.643	.058
B_weft	1	155.263	13.328	.000
E_warp	1	164.068	.098	.755
E_weft	1	149.735	.401	.528
Friction coeff. (Face)	1	160.285	.454	.502
VFS	1	80.722	55.005	.000

*Dependent variable: Real fit satisfaction (RFS)

Table 3.31 : Estimates of fixed effects (all data).

Items	Estimate	Std. Error	df	t	Sig.	Lower Bound	Upper Bound
Intercept	4.887	4.780	50.48	1.023	0.311	-4.711	14.485
Weight	-0.011	0.018	38.138	-0.599	0.553	-0.048	0.026
Body height	-0.158	0.080	37.755	-1.966	0.057	-0.321	0.005
Waist girth	0.000	0.117	37.972	0	1	-0.237	0.237
Belly circumference	-0.143	0.082	37.571	-1.757	0.087	-0.309	0.022
Hip girth	0.093	0.096	37.417	0.963	0.342	-0.102	0.288
Thigh girth	-0.009	0.093	38.201	-0.093	0.926	-0.198	0.180
<i>Waist height</i>	0.275	0.104	37.666	2.632	0.012	0.063	0.486
RBS at waist area	0.019	0.072	37.769	0.267	0.791	-0.126	0.165
RBS at hips area	0.108	0.086	39.131	1.254	0.217	-0.066	0.283
RBS at lower body	0.119	0.080	38.783	1.485	0.146	-0.043	0.281
RBS at upper body	-0.074	0.089	38.899	-0.836	0.408	-0.255	0.106
RBS of stance	0.010	0.084	40.154	0.123	0.902	-0.159	0.180
B_warp	0.095	0.050	154.15	1.909	0.058	-0.003	0.194
<i>B_weft</i>	-0.369	0.101	155.26	-3.651	0.000	-0.569	-0.169
E_warp	-0.008	0.025	164.07	-0.313	0.755	-0.058	0.042
E_weft	-0.018	0.028	149.74	-0.633	0.528	-0.073	0.038
Friction coeff. (Face)	-1.262	1.873	160.29	-0.674	0.502	-4.960	2.437
<i>VFS</i>	0.543	0.073	80.722	7.417	0.000	0.397	0.688

*Dependent variable: Real fit satisfaction (RFS)

According to Table 3.31, participants' VFSs significantly predicted their RFSs, $F(1, 80.722) = 55.005, p < .01, \beta = 0.543$. Among the body measurements, only waist height was found significant to predict participants' RFSs, $F(1, 37.666) = 6.928, p < .05, \beta = 0.275$.

On the other hand, participants' RBSs for specific areas were not significant to predict their RFSs. However, another MLM was established by using the overall RBS instead of specific areas (all other variables were kept the same). Overall RBS of each participant was calculated by taking their mean RBSs for specific areas. In that particular analysis, participants' overall RBSs were found significant to predict their RFSs, $F(1, 41.578) = 5.710, p < .05, \beta = .235$. Finally, among other fabric properties, only B_{weft} significantly predicted the RFSs of participants, $F(1, 155.263) = 13.328, p < .01, \beta = -.369$. Other fabric properties were not significant.

Participants' RFSs were predicted by using the developed MLM. The prediction scores were automatically generated by the SPSS. SPSS uses the estimates of fixed effects (Table 3.31) to predict the dependent variable. The beta coefficients of each independent variable are the numbers below the estimates column. SPSS predicted RFS scores for each case according to the β coefficients and intercept given in Table 3.31. The scatter diagram of predicted RFSs and measured RFSs is shown in Figure 3.8. This result shows a significant positive association between the predicted RFSs which were obtained from the developed MLM, and the measured RFSs which were obtained from the experiments. Finally, Pearson's correlation between participants' *predicted RFSs* and *actually measured RFSs* were tested, and the results showed a high correlation between predicted and measured RFSs of participants ($r = .775, N = 180, p < .01$).

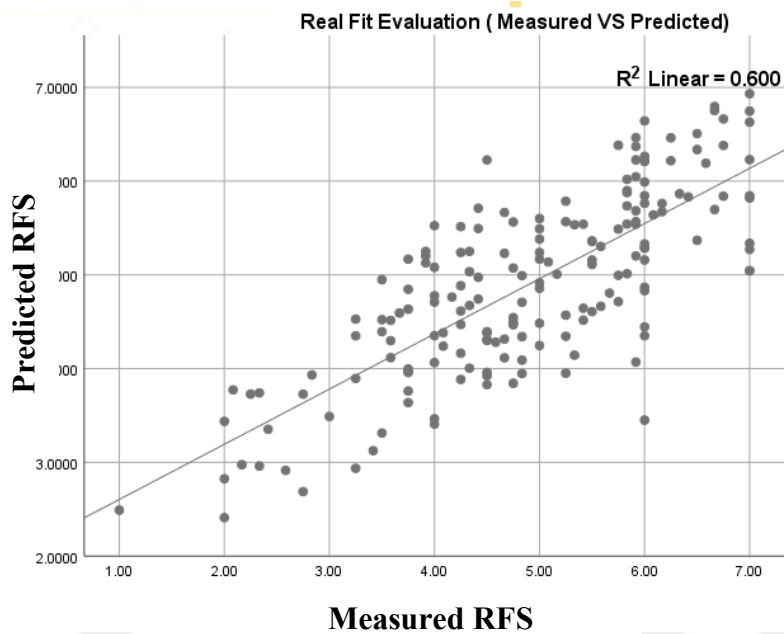


Figure 3.8 : Pearson’s correlation between measured and predicted RFSs (all data, N=180).

3.5.2 Validity of the developed model

Cross-validation is a method to evaluate predictive models by partitioning the original sample into a training set to train the model, and a test set to evaluate it (Refaeilzadeh, Tang, & Lui, 2018) . To evaluate the developed predictive model of this study, data set was randomly partitioned 20/80 percent (20 percent to be used as the test data, and 80 percent to be used for the training data). Eighty percent of the data which were randomly selected were used to train MLM. For training: VFS, body measurements (weight, height, waist height, belly circumference, waist girth, hip girth, thigh girth); real body satisfaction for specific areas (upper body, lower body, area around hips, area around waist, stance); actual fabric properties (W , T , B_{warp} , B_{weft} , E_{warp} , E_{weft} , G , friction coefficient_(back), friction coefficient_(face), surface roughness, DC) were used as fixed factors and participant code was used as a random factor to predict the RFSs of the participants. Finally, RFS was the dependent factor. The results of this analysis are given in Table 3.32.

Table 3.32 : Estimates of fixed effects (training data: Eighty percent of the total data).

Items	Estimate	Std. Error	df	t	Sig.	Lower Bound	Upper Bound
Intercept	5.124	5.059	54.860	1.013	.316	-5.014	15.263
Weight	-.014	.019	41.998	-.713	.480	-.052	.025
Body height	-.095	.084	40.246	-1.122	.269	-.265	.076
Waist girth	-.010	.125	42.489	-.081	.935	-.261	.241
Belly circumference	-.108	.089	44.063	-1.221	.229	-.288	.071
Hip girth	.030	.101	38.981	.300	.766	-.174	.235
Thigh girth	.056	.103	47.971	.545	.588	-.152	.264
Waist height	.192	.108	37.408	1.781	.083	-.026	.409
RBS at waist area	.105	.076	39.121	1.382	.175	-.049	.259
RBS at hips area	.028	.092	41.871	.301	.765	-.157	.212
RBS at lower body	.117	.082	37.561	1.430	.161	-.049	.283
RBS at upper body	-.010	.093	40.854	-.102	.920	-.198	.179
RBS of stance	-.012	.093	50.242	-.124	.902	-.199	.176
B_warp	.098	.055	123.788	1.786	.076	-.011	.207
B_weft	-.381	.114	131.055	-3.343	.001	-.607	-.156
E_warp	-.031	.029	137.366	-1.087	.279	-.088	.026
E_weft	-.022	.031	121.275	-.713	.477	-.083	.039
Friction coeff. (Face)	-2.076	2.053	129.558	-1.011	.314	-6.137	1.985
VFS	.550	.078	88.720	7.021	.000	.394	.705

*Dependent variable: Real fit satisfaction (RFS)

According to the Table 3.32, a regression equation to predict participants' RFSs were generated. The general linear regression equation is given in Equation 3.1. According to this equation, dependent variable (Y_i) is the RFS, β_0 is the intercept (5.124), β_i are the numbers under estimate column, and X_i , independent variables are the items under the first column (i.e. weight, RBS at hips area etc.).

$$Y_i = \beta_0 + \beta_1 X_i + \varepsilon_i \quad (3.1)$$

Y_i : Dependent variable, β_0 : intercept, β_1 : Coefficient (estimate), X_i : Independent variable, ε_i : random error term.

Afterwards, this regression equation was used to calculate predicted RFSs of the test data (Twenty percent of the data that was partitioned at the beginning). The results showed that predicted and measured RFSs of the test data were highly correlated ($r = .83$, $N=32$, $p < 0.01$) as given in Table 3.33 and illustrated in Figure 3.9. According to the Figure 3.9, this mixed linear model explains the 69 percent of the variability of the participants' measured RFSs around its mean.

Table 3.33 : Pearson’s correlation between predicted RFSs and measured RFSs (test data).

		Measured RFS
Predicted RFS	Pearson Correlation	.828
	Sig. (2-tailed)	.000
	N	32

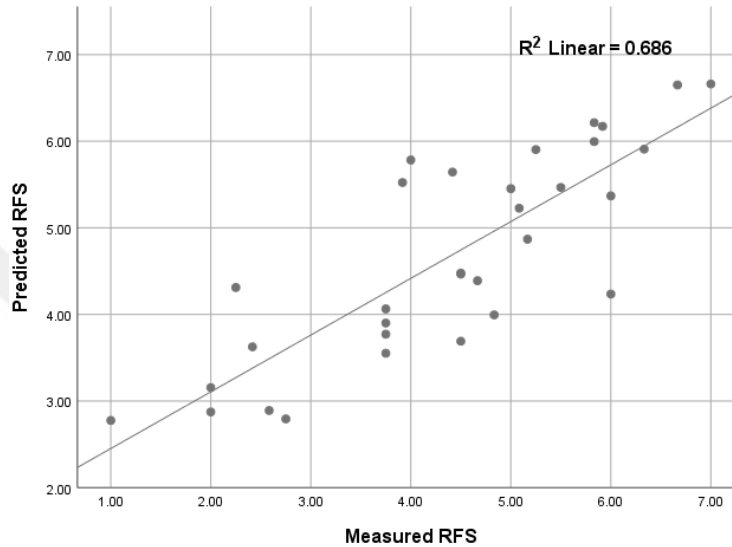


Figure 3.9 : Scatter diagram of measured and predicted RFSs (test data, N=32).

Moreover, paired t-test between measured RFSs and predicted RFSs of the test data was conducted to see if there was any significant different between their mean values, and the results are given in Table 3.34. According to the Table 3.34, *there was no significant difference between measured RFSs and predicted RFSs of the test data ($t(1, 31) = -1.885, p = 0.073$).*

Table 3.34 : Paired t-test between measured RFSs and predicted RFSs of test data.

Pair	Mean Diff.	Std. Dev.	Std.Err Mean	Lower	Upper	t	df	Sig. (2-tailed)
Measured RFSs- Predicted VFSSs	-.278	.847	.150	-.583	.028	-1.855	31	.073

4. DISCUSSION AND CONCLUSION

Discussion and conclusion part was organized according to the research objectives.

4.1 Objective One: Exploring Factors' Affecting Consumers' Virtual Fit Satisfaction

One of the objectives of this study was to explore factors' affecting consumers' virtual fit satisfactions. For this purpose, a circular skirt was selected and fit experiments were conducted with circular skirts made from various fabrics. The offered independent variables that may be correlated to consumers' virtual fit satisfactions were consumers' body measurements, virtual body satisfactions, 3D fabric properties and consumers' interaction with 3D fit technologies. According to the results in the Table 3.28, the highest correlations were found between VFSs and VBSs. Especially participants' VBSs around hips was correlated fairly good to their VFSs ($r = .50$, $N=180$, $p < .01$). This result could be interpreted as; while trying to understand virtual fit satisfaction of consumers, virtual body satisfaction should be considered. In this study, virtual body satisfaction for hips area stand out due to the garment type selected for the study. However, for other garment types, virtual body satisfactions for different body areas might be more significant.

In this study, real and virtual body satisfactions were measured separately. Because in a virtual fit context, consumers are exposed to their virtual bodies. Since in this study, factors effecting the virtual fit satisfactions of the consumers were examined, virtual body satisfactions were offered as a factor instead of real body satisfactions. The discrepancy between measured real and virtual body satisfactions of participants confirms this suggestion. According to the paired t-test analysis between RBSs and VBSs (Table 3.18), participants' body satisfactions around hips area and waist area dropped significantly after seeing their own 3D body scan images ($t(1,42) = 1.926$, $p < .05$) and $t(1,42) = 4.174$, $p < .01$, respectively). An interesting result was that participants' RBSs were lowest for the hips area but after seeing their 3D scan images,

the lowest VBSs were recorded for the waist area (Table 3.17). These results can also be interpreted as participants' body satisfactions for their waist area (waist and abdomen) dropped considerably after viewing their 3D body scans. A recent study about the body satisfaction change after exposure to 3D body scan found that subjects became negative about their heights, buttocks and hips whereas, they were neutral for their waist and stomach (Park, 2018). The findings of this dissertation also confirm that participants' body satisfactions for hips area dropped after seeing their 3D scans, however in contrast with Park's study, participants were not neutral for their waist and stomach (or abdomen). On the contrary, the most significant body satisfaction drop after exposure to 3D scan image was observed for waist area.

On the other hand, VFSs of participants were weakly correlated to their body measurements (Table 3.27). The body measurements considered in this study was weight, height, waist height, belly circumference, waist girth, hips girths and thigh girth due to the selected garment type. The highest correlation was observed between participants' belly circumference and VFSs ($r = .34$, $N=180$, $p < .01$). It should be noted that participants also had a low virtual body satisfaction for their abdomen area (Table 3.15). This may be interpreted as participants were more vulnerable for their abdomen appearance, and for a virtual try-on case they often evaluate the fit according to this area.

Moreover, correlation between participants' VFSs and their interaction with 3D fit technologies and 3D fabric properties were also observed (Table 3.26). However, according to the results, only a little correlation between consumers interaction with 3D fit technologies and their virtual fit satisfactions were recorded. The results show that if participants have positive interaction with 3D body scanning process and virtual try-on technology they tend to be satisfied with the virtual fit satisfaction of the garments as well. However, it should be noted that the correlations were weak ($r = .26$ and $r = .24$, $N=180$ respectively) and further studies are needed to confirm this finding.

Finally, no significant correlation was found between the 3D fabric properties and participants' VFSs (Table 3.25). 3D fabric properties (elongation, bending, shear, friction, thickness, weight) of seven different fabrics were considered for this study, however for none of these properties a significant correlation was found. This may be due to two reasons: It may be either due to the fabrics selected for this study or due to

the simulation software. In an ideal case, it is expected that participants' virtual fit satisfactions vary according to the changing 3D fabric properties.

It should be also recalled that simulation software didn't allow to insert any fabric thickness values lower than 0.05 cm, and any thickness value lower than 0.05 cm was automatically changed to 0.05 cm by the program. Therefore, even if some fabrics had different thickness values than each other, their 3D fabric properties were same and were 0.05 cm. Moreover, it was also ambiguous how the extension values were converted in the Fabric Editor of the software.

4.2 Objective Two: Comparing Consumers' Virtual and Real Fit Satisfactions

According to the RFS results (Table 3.21), participants were generally less satisfied with the skirt fit at abdomen and hips areas when compared to the fit at waist and hem areas. Similarly, participants' VFSs at abdomen and hips areas were lower than their VFSs at waist and hem areas. Even though, participants' fit satisfactions were different for actual and virtual skirts, simulations were good to show poorly fitting areas which are in this case, the hips and abdomen areas.

Moreover, a Pearson's correlation test was conducted to detect the association between participants' real fit and virtual fit satisfactions regardless of their fabric differences. According to the results (Figure 3.6), a strong correlation between overall RFSs and overall VFSs were found ($r = .63$, $N=180$, $p < 0.01$). This is an indicator to confirm that participants' VFS is a good predictor to estimate their RFSs. In addition to overall fit satisfactions, the correlations between participants' real and virtual fit satisfactions for specific body areas (waist, abdomen, hips and hem) were also explored. According to the results, correlations between participants' RFSs and VFSs at hips ($r = .60$, $N=180$, $p < 0.01$) and hem level ($r = .65$, $N=180$, $p < 0.01$) were stronger when compared to their correlations at waist ($r = .48$, $N=180$, $p < 0.01$) and abdomen areas ($r = .42$, $N=180$, $p < 0.01$).

It should be noted that Pearson's correlation analysis tells about the relationships between the variables and how strong these relationships are. However, it doesn't tell if there is a statistical difference between groups. Therefore, paired t-tests between real and virtual fit satisfactions were established to determine if these two groups were

significantly different (Field, 2013). According to the results (Table 3.21), participants' overall VFSs were significantly lower than their overall RFSs ($t(179)=2.690$, $d= -.206$, $p=0.004$). On the other hand, paired t-tests, between participants' RFSs and VFSs at different areas of the skirts (Table 3.22) showed that there were no significant differences between participants' RFSs and VFSs for waist and abdomen areas, whereas there were significant differences between participants' RFSs and VFSs for hips and hem areas. Ultimately, even though participants overall VFSs and RFSs were correlated as well as their specific fit satisfactions for certain areas, there were significant differences among them.

4.3 Objective Three: Understanding How Different Fabrics, Affect Consumers' Garment Fit Satisfactions in Real and Virtual Environment

Seven skirts with same measurements, same silhouette and color were used as fit samples. The only difference between the skirts were their fabrics. One-way ANOVA results showed that participants' fit satisfactions for actual skirts varied considerably due to their alternating fabrics, ($F(6,173) = 3.515$, $p = .003$) and there were no significant difference between the fit satisfactions for virtual skirts, ($F(6,173) = .333$, $p = 0.92$). For instance, as illustrated in Figure 3.5, participants' overall RFSs for Skirt 2 and Skirt 8 was $M=5.33$ and $M=3.94$ on a 7-point scale. On the other hand, VFSs varied only slightly (VFSs of Skirt 2 and Skirt 8 was $M=4.44$ and $M=4.74$, respectively). This can be interpreted as participants were not very sensitive to simulation alterations as much as they were sensitive to their actual counterparts.

Since the skirts were exactly same except their fabrics, the variation of the correlations could be interpreted to be related to their fabric differences. This may lead to an interpretation that simulation software may be more successful to reflect some fabrics' simulations rather than others. According to the Pearson's correlation tests (Table 3.23), participants' RFSs and VFSs were correlated at different respects for each skirt. The highest correlation between participants' overall RFSs and VFSs was recorded for Skirt 22 ($r= .84$, $N= 23$, $p< 0.01$), and the lowest correlation was recorded for Skirt 2 ($r= .42$, $N=23$, $p<0.05$). Moreover, paired t-tests between overall RFSs and VFSs with respect to the fabric differences (Table 3.24) showed that participants' overall RFSs and VFSs were significantly different only for some of the skirts' (Skirt 2, Skirt 22,

Skirt 21 and Skirt 15). For the rest of the skirts (Skirt 1, 6 and 8), no significant differences were observed. This result can be interpreted as virtual try-on was more successful for some of the skirts than the others. Since the only difference between the skirts is their fabrics, another way to put it out is to say that virtual try-on was more successful to simulate some of the fabrics when compared to some others. To understand the reason of this distinction, fabric properties were inspected carefully. According to the MLM analysis (Table 3.30 and Table 3.31) , among other fabric properties, only bending rigidity in weft direction was significantly correlated to participants' RFSs. As given in fabric properties table (Table 3.1); Fabric 2, 22, and 21 have the lowest bending rigidities in weft directions (0.58, 0.94 and 2.92 microNm, respectively) where Fabric 15 has the highest bending rigidity (7.59 microNm). According to these results, it may be possible to say that simulations were successful for the fabrics that have moderate bending rigidities (between 3 and 7 microNm) in their weft directions, and less successful for the fabrics with extreme bending rigidities (smaller than 3 microNm and bigger than 7 microNm).

Fabrics' bending rigidities are highly correlated with their drape properties (Frydrych et al., 2000), Fabrics with lower bending rigidities often drape better on 3D surfaces since they are keen to fold, bend and drape more than stiff fabrics (Kenkare & May-Plumlee, 2005). Skirt 2, 22 and 21 were more drapery than other skirts, and Skirt 15 was the least drapery. This conclusion was drawn from fabrics' bending rigidities (Table 3.1) and skirts' visual drape behaviors (Table 3.5). Since significant differences between participants' RFSs and VFSs for Skirt 2, 22, 21 and 15 were detected, it may be possible to say that 3D garment simulation is more successful in terms of garment fit evaluation for fabrics with moderate draping behaviors, and less successful for highly or poorly draping fabrics.

Finally, paired t-test analysis between participants' RFSs and VFSs with respect to fabric differences and fit areas (Table 3.24) pointed that participants' fit satisfactions for waist area didn't show any significant different for the virtual and real skirts and showed significant difference only for some of the skirts at abdomen area. This result may be interpreted as regardless of the fabric type, simulation software is good to give reliable information about the fit at the waist area. However, participants' RFSs and VFSs for hips and hem area were significantly different for all of the skirts.

4.4 Objective Four: Predicting Consumers' Real Garment Fit Satisfaction by Employing a Statistical Model

Predicting real fit satisfactions of subjects was the ultimate goal of this study. The factors that affect real fit satisfactions of consumers (LaBat & DeLong, 1990) were utilized to predict their real fit satisfaction. However, virtual fit satisfactions of subjects were also added to the research model (Figure 2.3). Consequently, real fit satisfactions of participants were tried to be predicted by using their body measurements, body satisfactions and virtual fit satisfactions in addition to fabric properties. A multilevel linear model (MLM) was adopted for the research purpose. The MLM results (Table 3.31) showed that virtual fit satisfaction was the strongest predictor of the real fit satisfaction ($F(1, 80.722) = 55.005, p < .01, \beta = 0.543$). In addition to VFS, bending rigidity in weft direction was also found to be significant to predict RFS. This result matches to earlier literature that seeks to understand the relationship between fabrics' mechanical properties and garments' fit (Postle et al., 1983). Bending rigidity is a substantial property for fabrics and it affects garments' drape properties (Postle, 1999). Drape is essential especially for the skirt type that is used in this study. Circular skirts are often made from drapery fabrics to ensure a smooth flow and eye-pleasing softer folds. Alike, in this study it is possible to see that skirts made from drapery fabrics had received higher garment fit satisfactions than the less drapery skirts (Table 3.21). On the other hand, drape coefficients of fabrics might be expected to be a variable to predict participants' RFSs as well. However, in this study, it is not the case. The fabrics' drape properties cannot be only explained by drape coefficients, because fabrics with very different drape properties may have same drape coefficient (Kenkare & May-Plumlee, 2005). Therefore, bending rigidity is often a more reliable parameter to predict drape properties of a fabric rather than its drape coefficient (Frydrych et al., 2000). This assumption was confirmed in this study.

Furthermore, among seven different body measurements, only waist height was found significant to predict participants' RFSs. The results show that there is a positive correlation between waist height and RFS (Table 3.31). When waist height is higher the RFS is higher. This might be due to the length of the skirt. The skirt is relatively a short skirt type. For the participants with lower waist line, skirt may feel a bit longer

than it actually should be. Therefore, they may think the skirt is too long for them and they may conclude that the style doesn't fit them well.

On the other hand, waist and body height of participants were not significantly correlated with their VFSs (Table 3.27), whereas, for RFS waist height was significant (Table 3.30). This might be interpreted as the focal point has changed when participants were evaluating the real and virtual skirts. In other word, participants were maybe less concerned with the length of the skirts while assessing the garment fit in virtual context, and when they actually wore the skirts their emphasis shifted to the length of the skirt. This is actually compatible with the studies investigating garment fit from consumers' perspective. For instance, Shin and Damhorst study (2018) confirms that consumers essentially pay attention to the tightness/looseness or length of the garments while assessing its actual fit (Shin & Damhorst, 2018).

Finally, RFSs of participants were predicted by the developed multilevel linear model. Participants' measured and predicted real fit satisfactions were analyzed by Pearson's correlation test at the first place. Pearson's correlation test showed that the correlation between participants predicted RFSs and measured RFSs were significantly high ($r = .775$, $N = 180$, $p < .01$, $R^2 = 0.600$). This result shows that a multilevel linear model was a useful statistical tool to predict RFSs of subjects when VFSs, body measurements, body satisfactions and fabric properties are used as predictors.

To test the validity and reliability of this developed prediction model, a cross-validation test was conducted. Experiment data ($N = 180$) was partitioned as test and training data ($N = 32$: test data, $N = 148$: training data). An MLM with same predictors (body measurements, body satisfactions, fabric properties and virtual fit satisfactions) was applied to training data. Eventually, the β coefficients generated by MLM for each predictor was used to develop a regression equation to predict real fit satisfactions of participants. This equation was used to generate predictions of real fit satisfactions of test data. To do that, predictor values of test data were plugged in to the equation and real fit satisfaction predictions were calculated. Finally, a Pearson's correlation test was conducted between the measured and predicted fit satisfactions of participant (Table 3.33). The correlation was significant, and it was remarkably high ($r = .83$, $N = 32$, $p < .01$). However, even if the correlations are high, mean values of two groups might be significantly different. Therefore, a paired t-test between predicted and

measured real fit satisfaction values for the test data was observed (Table 3.34). According to the paired t-test results there were no significant difference between these two groups ($t(1, 31) = -1.885, p=0.073$). This result confirms that a statistical model was successfully developed to predict real fit satisfactions of consumers by using their virtual fit satisfactions as well as consumers' body measurements, body satisfactions and fabric properties of the product.

4.5 Conclusion

This doctoral study focused on women's real and virtual garment fit satisfactions. Consumers' real fit satisfaction (RFS) and factors effecting it have been explored in literature, however, virtual garment fit satisfaction (VFS) is relatively a new notion. With the recent developments in 3D body scanning technologies; using virtual try-on for online apparel shopping is no more a dream. When this scenario actualizes, consumers' purchase decisions would depend on their VFSs. Therefore, to understand the factors affecting consumers' VFS are as critical as their actual satisfaction. In this study, consumers' virtual body satisfactions (VBSs), body measurements, interaction with 3D fit technologies (3D body scanning and virtual try-on), were measured and their correlation to consumers' VFSs were calculated. In addition to these consumer dependent factors, fabric dependent factors (3D fabric properties) and their correlation to consumers' VFSs have been investigated. According to the results, consumers' VBSs are correlated to their VFSs. For this dissertation a circular skirt sample was studied, hence the highest correlation between VBSs and VFSs was found for the VBS around hips area and the lowest correlation was found for the VBS of upper body. Aside VBS, body measurements of consumers were also correlated with their VFSs. Only waist height and overall height were not found significantly correlated. On the other hand, consumers' interaction with 3D body scanning and their acceptance of virtual try-on technology were weakly correlated with their VFSs.

In this study, participants' real and virtual fit satisfactions for seven different fabrics were examined. Real fabric properties were measured, and their units were converted by a "Fabric Converter" to plug into the simulation software. The simulations were generated according to these 3D fabric properties. According to the study results, none of the 3D fabric properties inserted to the software were correlated to participants'

VFSs. This could be interpreted as the 3D garment simulation was not sufficient enough to reflect fabric properties yet. Moreover, this study showed that unit conversion of 3D fabric simulation software is ambiguous and needs to be improved and clarified. In addition to this, the software used in this study restricts fabric thickness value with a maximum of 0.05 cm. However, a considerable amount of fabric used in fashion are thinner than 0.05 cm. This thickness obstacle of the software may be the reason of the insufficient reflection of fabric properties to the simulations.

The main purpose of this dissertation was to predict consumers' RFSs. To achieve this goal, some predictor variables were determined (real body satisfaction, body measurements, virtual fit satisfaction and fabric properties). By using these predictor variables, a multilevel linear regression model was developed to predict RFSs of participants attending to the study experiments. Eighty percent of the collected data were used to train the model, and 20 percent were used to test the model. According to the results of the test data, predicted RFSs were strongly correlated to actually measured RFSs, and according to paired t-test results there were no significant difference between these two groups.

This study showed that it is possible to predict consumers' garment fit satisfactions by using suitable variables. For skirts, lower body related measurements and body satisfactions are prominent for the fit satisfactions and it was confirmed by this study. As anticipated, for other types of garments (i.e. blouses), essential parameters to predict fit satisfaction should be different than the parameters used in this study. However, this study showed that virtual garment fit satisfaction was the best variable to predict real fit satisfaction and it was followed by body satisfaction and body measurements at the related area.

Implications

This study is expected to have a potential industrial implication. When inexpensive and easy-use 3D body scanners spread, consumers will be able to 3D scan themselves at their home at no or minimum cost. Then, according to anticipations, they will be able to log in to the web site of an apparel company, upload their 3D body to the server of the company, select a garment from the virtual racks and virtually try it on. According to the results of this study, consumer's virtual fit satisfaction will depend on some of her body measurements, virtual body satisfaction, interaction with 3D fit

technologies, silhouette likeness and online shopping behaviors. If the company has a data pool with specific information about its customers, then by using the suggested factors, it would be easier to offer the correct product to the customer. Moreover, as long as customer evaluates her VFS of the product and shares it with the apparel company online, her approximate RFS may be predicted by the apparel company. This would help the customer whether to purchase the product, and ultimately help the apparel company to reduce return costs.

Research limitations

It should be also noted that this study had some restrictions. In this study, a particular skirt was selected to be used during experiments. However, fashion industry offers a variety of product types and hundreds of style variations. Thus, for different product types and altering styles, the variables offered in this dissertation should be altered and used. For instance, the body measurements considered in this study were waist and body height, waist girth, hip girth and thigh girth, belly circumference and weight due to the product type studied. However, the body measurements that are significant for a blouse fit will be probably different. Similarly, virtual body satisfaction around hips had the highest correlation with virtual fit satisfaction in the skirt case. Whereas, for a blouse case, upper body satisfaction is anticipated have the highest correlation. Therefore, for further studies, it is suggested that various product types and variety of styles are explored in terms of virtual and real garment fit satisfaction.

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APPENDICES

APPENDIX A: Fabric surface scans.

APPENDIX B: Skirt simulations created by V-Stitcher.

APPENDIX C: Notice of expedited approval from Institutional Review Board for Human Participants

APPENDIX D: Research survey





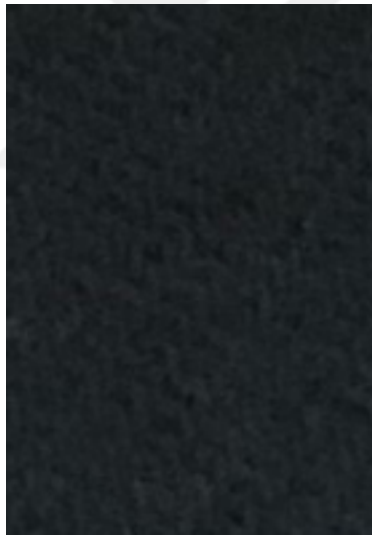
APPENDIX A



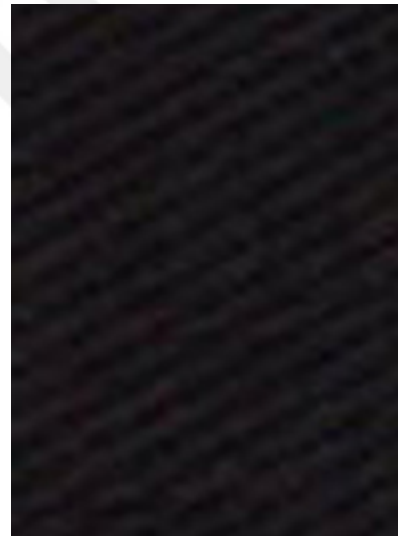
(Fabric 2)



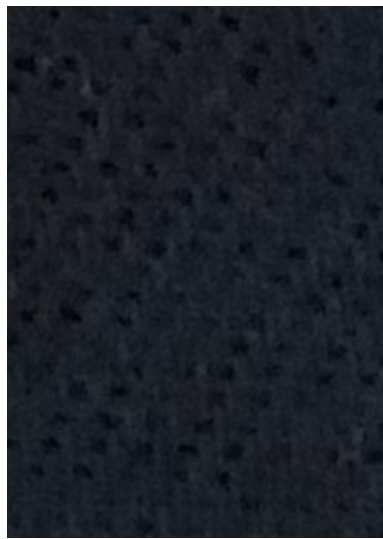
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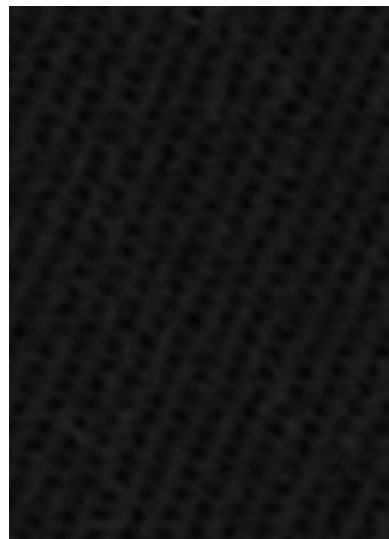
(Fabric 1)



(Fabric 6)



(Fabric 8)



(Fabric 15)


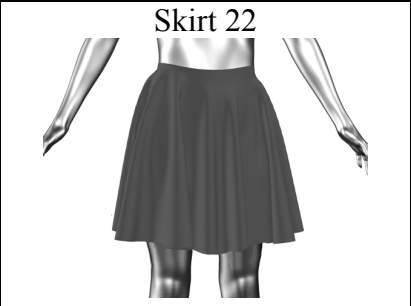
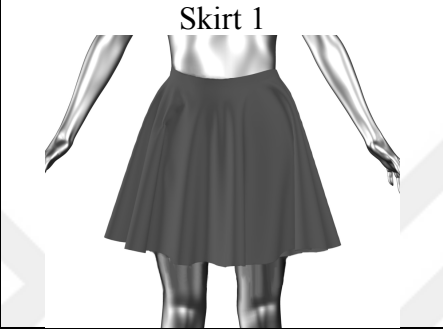
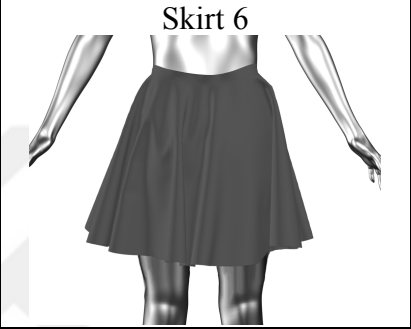

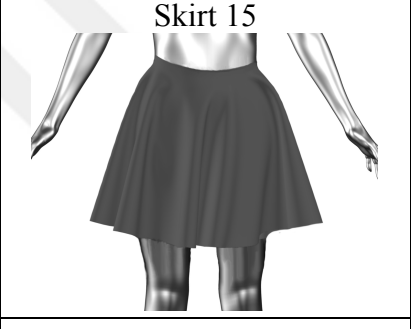



Fabric 21

Figure A.1 : : Surface scans of fabrics.

APPENDIX B

Table A.1 : Skirt simulations created by V-Stitcher.

Cluster 1	<p>Skirt 2</p> 	<p>Skirt 22</p> 
Cluster 2	<p>Skirt 1</p> 	<p>Skirt 6</p> 
Cluster 3	<p>Skirt 8</p> 	<p>Skirt 15</p> 
Cluster 4	<p>Skirt 21</p> 	

APPENDIX C



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Institutional Review Board for Human Participants

NOTICE OF EXPEDITED APPROVAL

To: Evrim Buyukaslan
From: Carol Devine, IRB Chairperson *Carol M. Devine*
Protocol ID#: 1712007670
Protocol Title: Evaluating fabrics' mechanical properties for garment fit satisfaction in real and virtual environment
Approval Date: January 17, 2018
Expiration Date: January 16, 2019

Cornell University's Institutional Review Board for Human Participants (IRB) has reviewed and approved the inclusion of human participants in the research activities described in the protocol referenced above. This approval shall remain in effect until **January 16, 2019**.

The following personnel are approved to perform research activities on this protocol:

- Evrim Buyukaslan
- Fatma Baytar
- Fatma Baytar

This approval by the IRB means that human participants can be included in this research. However, there may be additional university and local policies that apply before research activities can begin under this protocol. It is the investigator's responsibility to ensure these requirements are also met.

Please note the following important conditions of approval for this study:

1. All consent forms, records of study participation, and other consent materials **must** be held by the investigator for **five years** after the close of the study.
2. Investigators must submit to the IRB any **proposed amendment** to the study protocol, consent forms, interviews, recruiting strategies, and other materials. Investigators may not use these materials with human participants until receipt of written IRB approval for the amendment. For information about study amendment procedures and access to the Amendments application form, please refer to the IRB website: <http://www.irb.cornell.edu/forms>.

Figure A.2 : Notice of expedited approval from Institutional Review Board for Human Participants

APPENDIX D

Qualtrics Survey Software

11/27/18, 12:31 PM

Demographic questions- (age, ethnicity, education)

Thank you for agreeing to take part in this study.

Please enter the code number that the researcher gave you.

What is your age?

Please specify your ethnicity.

- European American/ European
- Asian American/ Asian
- African American/ African
- Hispanic/Latino
- Native American
- Middle Eastern/ North African
- Alaskan Native
- Native Hawaiian / Pacific Islander
- Other

Figure A.3 : Survey

Please select the option best describes your educational status.

- High school graduate
- Undergrad student
- Bachelor's degree
- Master's student
- Master's degree
- Doctorate student
- Doctorate degree
- Other

Did you take any courses related to textiles, fashion, or apparel ?

- Yes
- No

Body Satisfaction Scale

In the following scale, there are some items. Please rate your satisfaction level of your own body for each item.




	1- Extremely dissatisfied 	2- Dissatisfied	3- Somehow dissatisfied	4-Neither satisfied nor dissatisfied 	5- Somehow satisfied	6- Satisfied	7- Extremely satisfied 
Neck	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Bust	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Torso	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Shoulder width	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Arms	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Figure A.3 (continued): Survey




Wrist	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
	1- Extremely dissatisfied 	2- Dissatisfied	3- Somehow dissatisfied	4-Neither satisfied nor dissatisfied 	5- Somehow satisfied	6- Satisfied	7- Extremely satisfied 
Waist	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Abdomen	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Back	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Hip	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Buttocks	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Thigh	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
	1- Extremely dissatisfied 	2- Dissatisfied	3- Somehow dissatisfied	4-Neither satisfied nor dissatisfied 	5- Somehow satisfied	6- Satisfied	7- Extremely satisfied 
Legs	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Knees	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Ankle	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Feet	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Height	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Weight	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
	1- Extremely dissatisfied 	2- Dissatisfied	3- Somehow dissatisfied	4-Neither satisfied nor dissatisfied 	5- Somehow satisfied	6- Satisfied	7- Extremely satisfied 
Profile	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Posture	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Figure A.3 (continued): Survey

Body Build	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Appearance	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Online Shopping Behavior

Overall, how would you rate your satisfaction with the fit of ready-to-wear garments listed below?

	1- Extremely dissatisfied 	2- Dissatisfied	3- Somehow dissatisfied	4-Neither dissatisfied or satisfied 	5- Somehow satisfied	6- Satisfied	7- Extremely satisfied 
T-shirts	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Shirts	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Sweaters	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Cardigans	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Skirts	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Jeans	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Trousers	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

How often do you buy the garments listed below online?

	Never	Rarely	Occasionally	Sometimes	Frequently	Usually	Every time
Blouses	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
T-shirts	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Sweaters	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Hoodies	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Figure A.3 (continued): Survey

Skirts	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Jeans	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Trousers	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Fashion Taste

Please look at the pencil skirt image and answer the questions. Assume that the skirt is within your preferred price range.






	1-Strongly disagree 	2-Disagree	3-Somewhat disagree	4-Neither agree nor disagree 	5-Somewhat agree	6-Agree	7-Strongly agree 
I liked the silhouette of the skirt	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I liked the color of the skirt	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I liked the overall fit of the skirt	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I would purchase this skirt if I have seen this	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Figure A.3 (continued): Survey

picture online

Please look at the full skirt image and answer the questions. Assume that the skirt is within your preferred price range





	1-strongly disagree 	2-Disagree	3-Somewhat disagree	4-Neither agree nor disagree 	5-Somewhat agree	6-Agree	7-Strongly agree 
I liked the silhouette of the skirt	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I liked the color of the skirt	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I liked the overall fit of the skirt	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I would purchase this skirt if I have seen this picture online	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Please look at the A-line skirt image and answer the questions. Assume that the skirt is within your preferred price range.

Figure A.3 (continued): Survey



	1-Strongly disagree 	2-Disagree	3-Somewhat disagree	4-Neither agree nor disagree 	5-Somewhat agree	6-Agree	7-Strongly agree 
I liked the silhouette of the skirt	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I liked the color of the skirt	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I liked the overall fit of the skirt	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I would purchase this skirt if I have seen this picture online	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Thank you. We are done with the first part of the study!

Now, please tell the researcher that you are ready to see your 3D body scan.

Please click "Next" AFTER researcher shows you the body scan image of yours!




Virtual body satisfaction scale

Please look at your 3D Body Scan and rate your body satisfaction now.

Figure A.3 (continued): Survey

	1- Extremely dissatisfied 	2- Dissatisfied	3- Somehow dissatisfied	4-Neither satisfied nor dissatisfied 	5- Somehow satisfied	6-Satisfied	7- Extremely satisfied 
Neck	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Bust	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Torso	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Shoulder width	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Arms	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Wrist	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
	1- Extremely dissatisfied 	2- Dissatisfied	3- Somehow dissatisfied	4-Neither satisfied nor dissatisfied 	5- Somehow satisfied	6-Satisfied	7- Extremely satisfied 
Waist	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Abdomen	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Back	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Hip	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Buttocks	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Thigh	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
	1- Extremely dissatisfied 	2- Dissatisfied	3- Somehow dissatisfied	4-Neither satisfied nor dissatisfied 	5- Somehow satisfied	6-Satisfied	7- Extremely satisfied 
Legs	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Knees	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Figure A.3 (continued): Survey

Ankle	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Feet	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Height	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Weight	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
	1- Extremely dissatisfied 	2- Dissatisfied	3- Somewhat dissatisfied	4-Neither satisfied nor dissatisfied 	5- Somewhat satisfied	6-Satisfied	7- Extremely satisfied 
Profile	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Posture	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Body Build	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Appearance	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

3D Body Scanning Experience

Please select the most suitable statement for your scanning experience.

	Strongly disagree 	Disagree	Somewhat disagree	Neither agree nor disagree 	Somewhat agree	Agree	Strongly agree 
I was comfortable with the scanning process.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I am comfortable to view my body scan.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I would have 3D scanning again.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Figure A.3 (continued): Survey

Thank you.

Now you will start to evaluate skirt fits.

Please tell the researcher that you are ready so she can show you the skirt images on your own body scan!

Skirt 1 Virtual Fit (Optitex)

Please look at the virtual skirt that the researcher showed you and rate your fit satisfaction of the virtual skirt for each body part from 1 to 7 (Enter a number in below boxes).

- 1= extremely dissatisfied
- 2= dissatisfied
- 3= somewhat dissatisfied
- 4= neither dissatisfied nor satisfied
- 5= somewhat satisfied
- 6= satisfied
- 7= extremely satisfied

	front view	back view	side view
waistline	<input type="text"/>	<input type="text"/>	<input type="text"/>
abdomen level	<input type="text"/>	<input type="text"/>	<input type="text"/>
hips level	<input type="text"/>	<input type="text"/>	<input type="text"/>
hem	<input type="text"/>	<input type="text"/>	<input type="text"/>

Thank you! Now please tell the researcher that you completed questions and ready to put on the skirt sample. Please hit the next button after you put on the skirt.

Skirt 1 Real Fit

Figure A.3 (continued): Survey

WELCOME BACK!

Please answer the questions below about the fit of the skirt you are wearing.

Please rate your fit satisfaction of the skirt for each body part from 1 to 7 (Enter a number in below boxes)

- 1= extremely dissatisfied
- 2= dissatisfied
- 3= somewhat dissatisfied
- 4= neither dissatisfied nor satisfied
- 5= somewhat satisfied
- 6= satisfied
- 7= extremely satisfied

	front view	back view	side view
waistline	<input type="text"/>	<input type="text"/>	<input type="text"/>
abdomen level	<input type="text"/>	<input type="text"/>	<input type="text"/>
hips level	<input type="text"/>	<input type="text"/>	<input type="text"/>
hem	<input type="text"/>	<input type="text"/>	<input type="text"/>




Thank you!

Please tell the researcher that you are done with the questions so that she can show you the virtual image of another skirt.

3 D Virtual try-on experience

Please select the most suitable statement for your virtual try-on experience.

Figure A.3 (continued): Survey

	Strongly disagree 	Disagree	Somewhat disagree	Neither agree nor disagree 	Somewhat agree	Agree	Strongly agree 
Virtual models gave me enough visual information to evaluate skirt fits as the actual fits.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I am satisfied using a virtual model for evaluating skirt fit.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I would use a virtual model for evaluating apparel fit in the future.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I would use a virtual model for apparel online shopping.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I am willing to pay more to use a virtual model to get skirts that fit.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

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Figure A.3 : Survey

CURRICULUM VITAE



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- 2017-2018 US Cornell University, Visiting scholar at Fiber Science and Apparel Design.
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- 2010-2012 Istanbul, HTL Fashion, Merchandiser
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PUBLICATIONS, PRESENTATIONS AND PATENTS ON THE THESIS:

- **Buyukaslan E.,** Jevsni S., Kalaoglu F. (2018). Comparative analysis of drape characteristics of actually and virtually draped fabrics, *International Journal of Clothing Science and Technology*, 30(3), 286-301.
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