Bridging virtual and real fit – the importance of real fit testing

BEAM 2026

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What are we trying to solve?

- How to make sure more products fit more people….
- Specifically….How to create fit data resources that can be used to predict fit for new or existing products and train, with or without the help of AI, our virtual models.

What are the challenges?

- Fit is subjective
  - Comfort and personal preference (subject reports)
  - Investigators opinions
    - Design team vs pattern team vs marketing vs merchants
    - If it is slightly unstable but very comfortable is that a pass?
    - If it is slightly uncomfortable but very stable is that a pass?
- Fit definition is difficult to define and changes
  - Different products,
  - Different purpose,
  - Consumer feedback etc
- There is no standard for fit scoring

What are the ideas about solving?

- Develop a Concept of Fit (CoF)
  - Concept of Fit (CoF) for individual studies
  - Concept of Fit for comparing between studies → standard way of developing a CoF
- Way to record the different CoFs to allows comparison
- Standardizing the measuring and scoring (5-point scale etc.)

What is the CoF

- A description of how the product should fit, what constitutes a good fit versus poor fit, and methods for assessing or measuring it.
- This is formal document that states what constitutes a fit or not fit - example →

COF →

When the waistline and/or the hip on the pant is deemed extremely too tight or extremely too loose – fail

translated to a question in the fit questionnaire

Questionnaire

The subject experiences no tightness across the thighs when stepping up on a 20cm high box

5-point scale

Waist circumference

- -2 (Extremely too tight)
- -1 (Slightly too tight)
- 0 (Perfect)
- +1 (Slightly too loose)
- +2 (Extremely too loose)

The waistline at the back would have no bunching or horizontal wrinkling

Add pictures

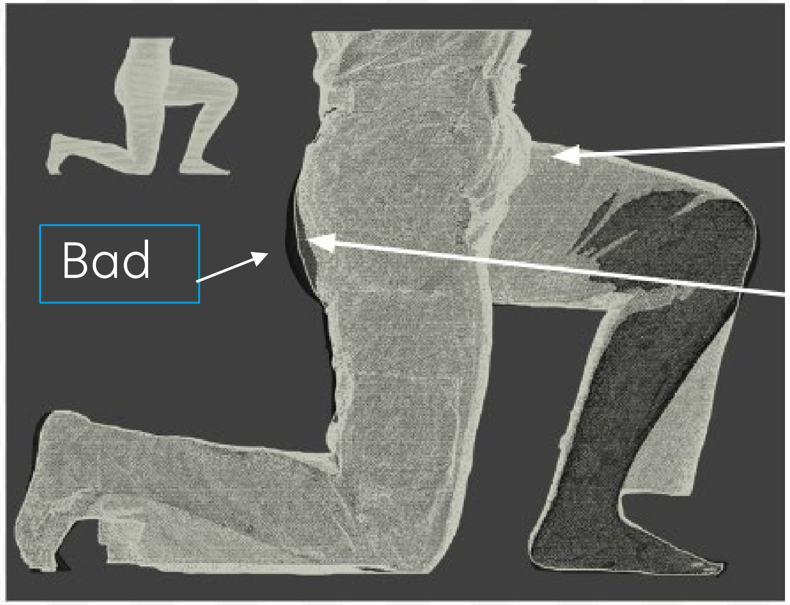
	1	2	3	4	5	
Extreme bunching	○	○	○	○	○	No bunching

DOCUMENTED, AGREED, and SIGNED off on

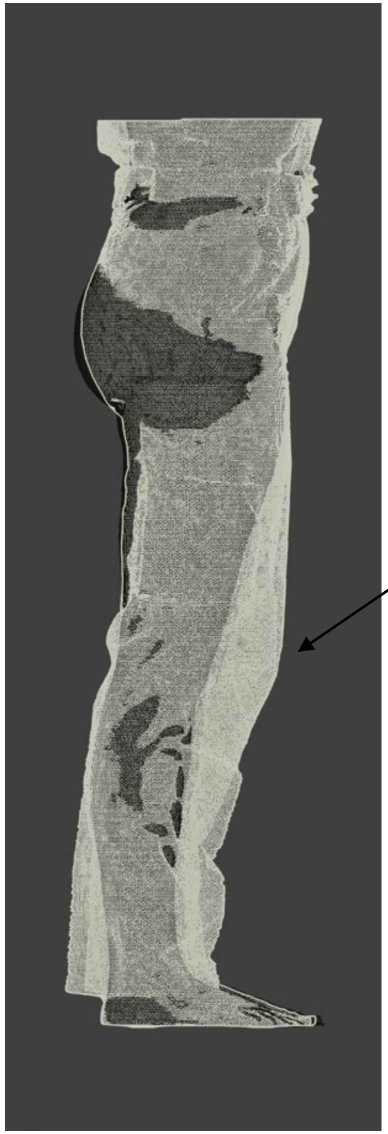
ANTHROTECH

CoF – pilot test example

Use scanning (the real person), if possible, to visualize and understand individualized fit problems



- Reaching agreement on PASS or FAIL
- Tradeoff between sizes
- Systematic fit issue



This detail is not existing in VM – compression, Crotch occlusion Posture

Visualize, documents pass/ fails

Robinette, K.M., Veitch, D., Alemany, S., & Bredenkamp, K. (2024). Product Fit and Sizing: Sustainable Product Evaluation, Engineering, and Design (1st ed.). CRC Press. https://doi.org/10.1201/9781003397533 Chapter 5 Mass produced apparel p 255

Needs for future virtual/AI models

Today's Virtual model cannot tell us

- True location on the body
- True interaction with the body
- True interaction with other components and environments
- Comfort and Stability
  - Tightness /looseness
  - Heat level
  - Pressure spots
- Personal preference
- Body product performance

<u>GOAL: get the model to replicate the factors observed in the real world, with particular focus on CoF fit criteria</u>

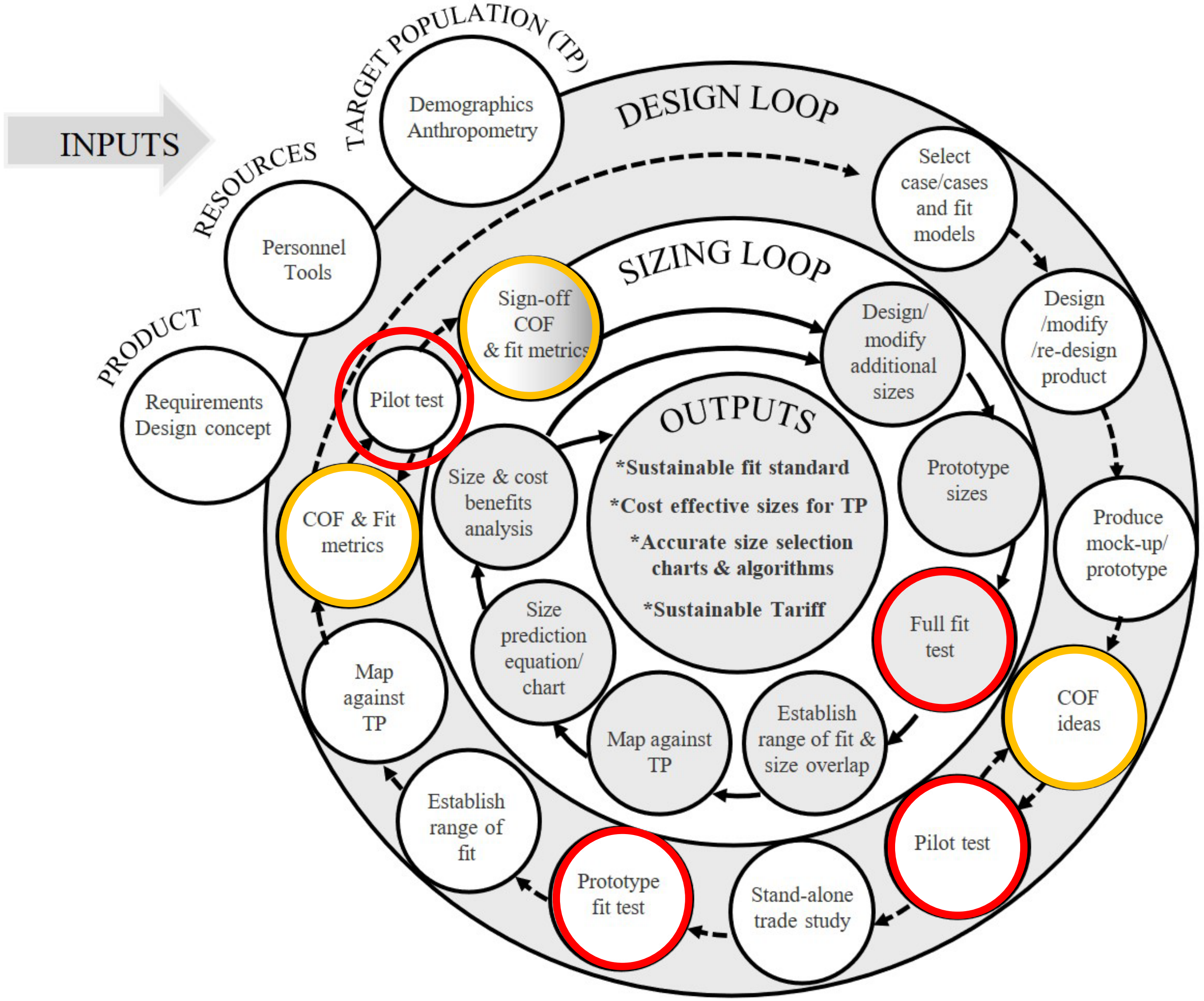
Fit & Performance Data Need for Training models

- Product specific data when properly fit for:
  - Product location
  - Product interaction with the body
  - Product interaction with other components or environment
  - Comfort and stability
  - Personal preferences
  - Performance
- Product specific data when NOT fit or when fit is borderline

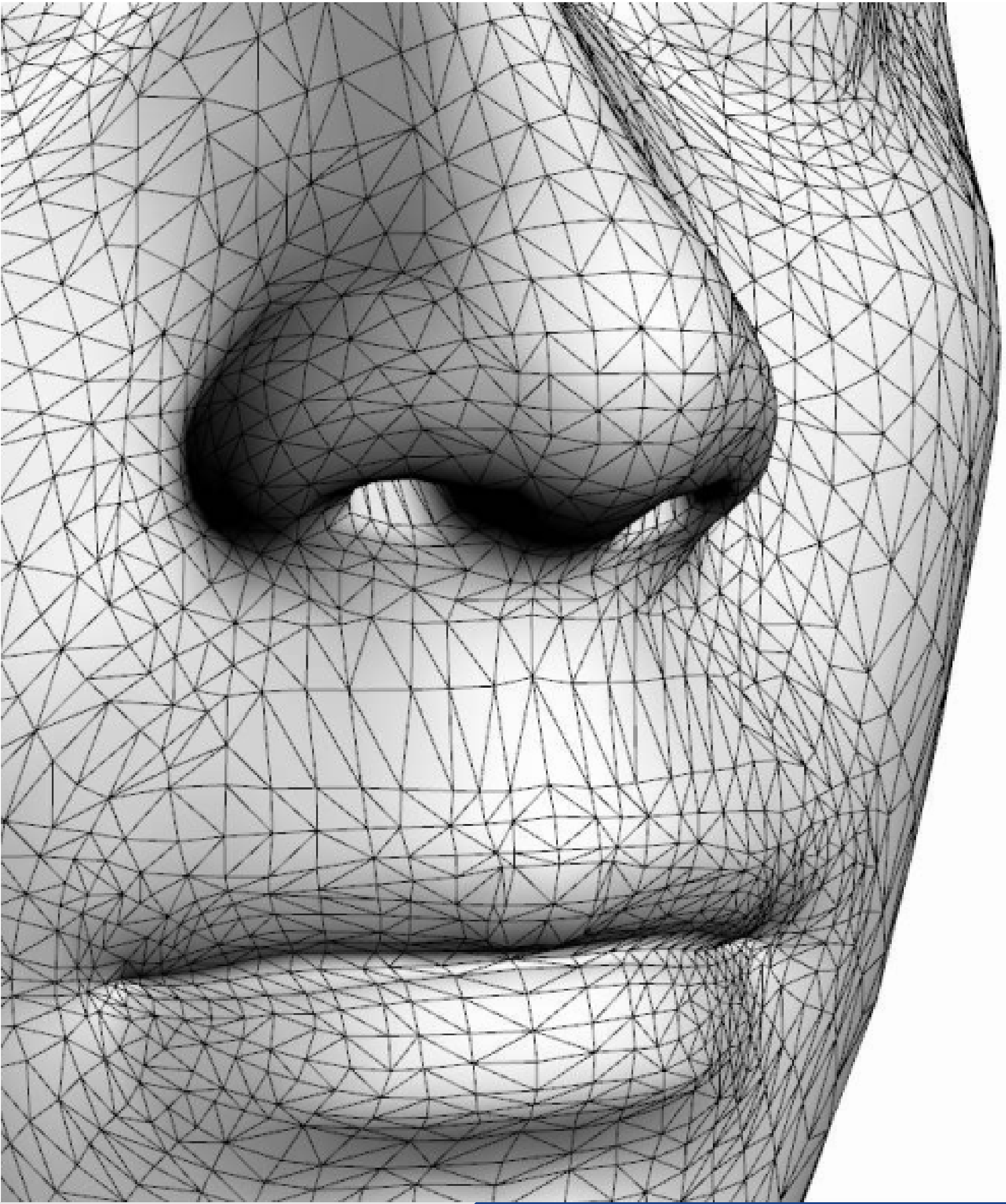
Aesthetic vs Technical Fit

- Industry is dividing ‘fit’ into at least 2 parts:
  A: Aesthetic fit e.g. pocket placement, collar width etc
  B: Technical fit e.g. body compression, movement, comfort, performance/functionality, personal preference, integration of components, safety, sleeve balance, performance of stretch fabrics, etc
- Todays virtual models are very useful for Aesthetic fit but for Technical fit there is still room for improvement
- The Reality Gap: When a new capability is not "true-to-life" enough to predict real-world fit issues.
- To achieve technical fit we need real-people fit data – can’t train without data set
  - REAL PEOPLE in THE PRODUCT is GROUND TRUTH

SUSTAINABLE PRODUCT EVALUATION, ENGINEERING & DESIGN (SPEED) PROCESS



One of the most important components is CoF
Can't have a reliable and repeatable fit test without a good CoF



ANTHROTECH

All measurements have measurement uncertainty and fit measurement must necessarily have some random error caused by the subjectiveness. However, if we can add some consistency and standardization to how we gather, record, and save fit data, that will help reduce the uncertainty and improve our fit knowledge and predictions.

Understanding Who We Fit and Who We Don’t Fit

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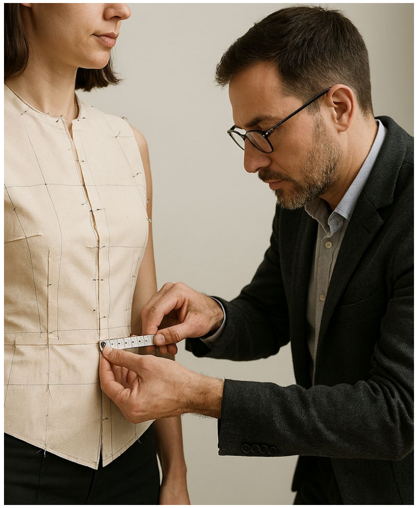
Overview

- How fit is achieved today
  - What is working
  - What could be improved

- Need/Benefits of fit testing with real people
- How do we capture the information for future use



AI Generated Images

Most manufacturers don’t know who they fit

Two typical Women’s size charts*

All dimensions are in inches.									
Size	2	4	6	8	10	12	14	16	18
Bust	33	34	35	36	37	38.5	40	41.5	43.5
Waist	26	27	28	29	30	31.5	33	34.5	36.5
Hips	36	37	38	39	40	41.5	43	44.5	46.5

	XS	**S**		**M**		**L**		**XL**		**XXL**
	2	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**
Chest	32.5	33.5	34.5	35.5	36.5	38	39.5	41	43	45.5-47.5
Waist	25	26	27	28	29	30.5	32	33.5	35.5	38-40
Hips	35	36	37	38	39	40.5	42	43.5	45.5	48-50

28 in = 711 mm
38 in = 965 mm

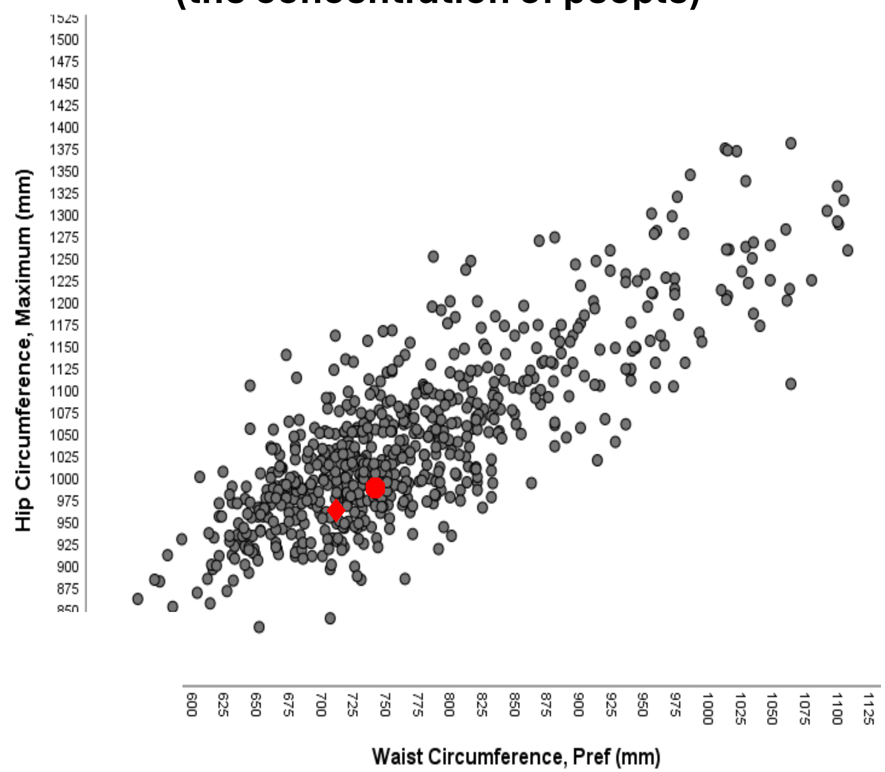
29 in = 737 mm
39 in = 991 mm

Fit their fit model but who else do they fit?

- **How big is the fit range?**
- **What shape is the fit range?**
- **Where is the fit range located?**

They probably did not look at this.

They are missing the Sweetspot (the concentration of people)

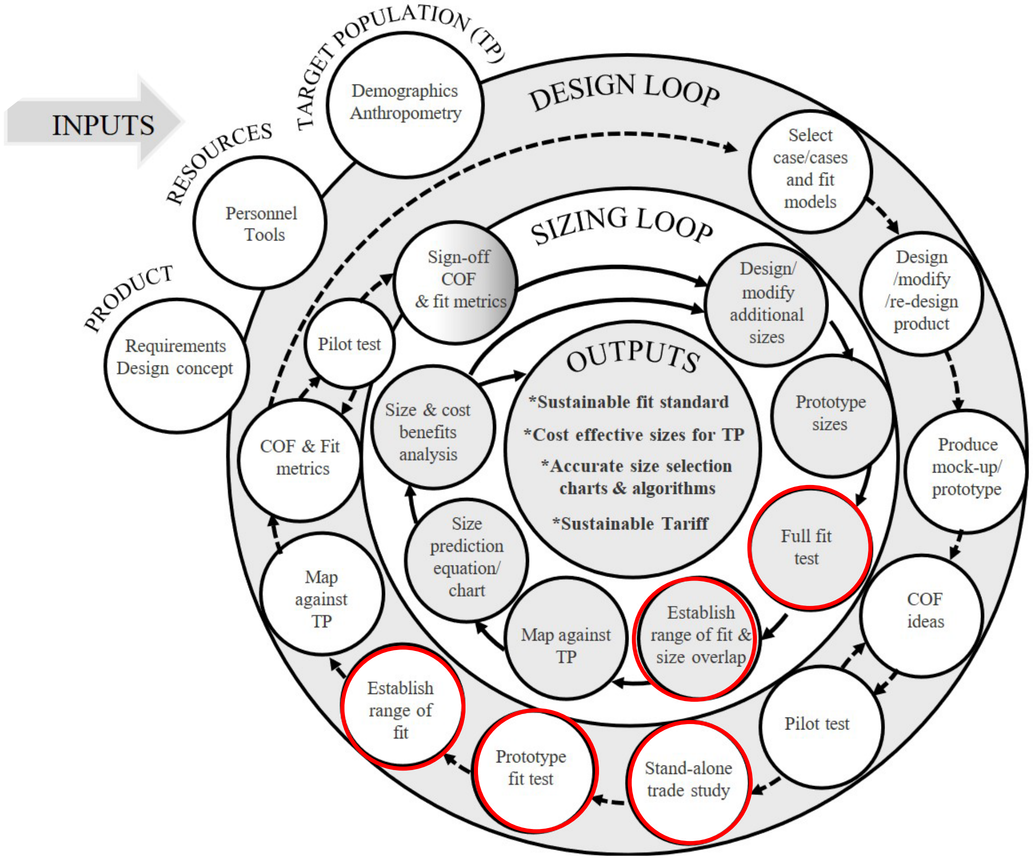


* An actual charts downloaded from two different retailer’s websites in Nov. 2024.

What Is Range-of-Fit and How Do We Find It?

- Range-of-Fit (ROF) is the location and range of fit in a single size
- Requires well-defined Concept-of-Fit (COF)
  - Document
    - What is a pass versus a failure
    - How to measure it
  - Stakeholders Agree
- Requires Fit Assessment
  - Real people with prior similar products
  - Real people with mockups/prototypes
  - Sufficient sample to determine when it stops fitting

Fit Assessment in the SPEED Process



- We establish ROF through fit testing in both Design & Sizing Loops.
- Can standards for fit data collection help us create fit knowledge?

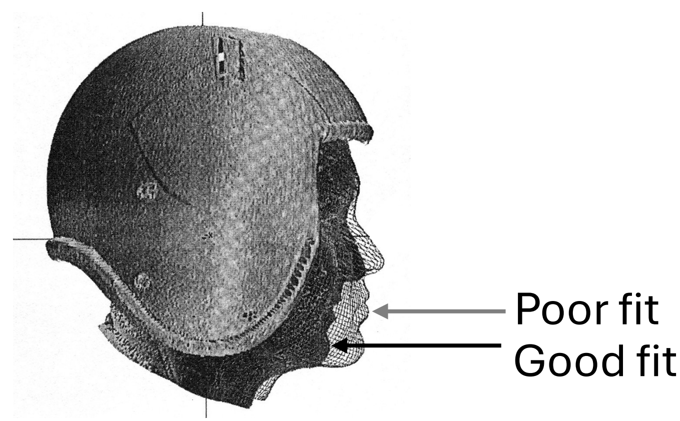
Fit Assessment Needs for finding ROF

Basic Fit Audit

- Approved and tested COF
- Sufficient sample of people to find ROF
  - Some pass and some fail
- At least one size of product
- Measurements of people
- Fit Scores

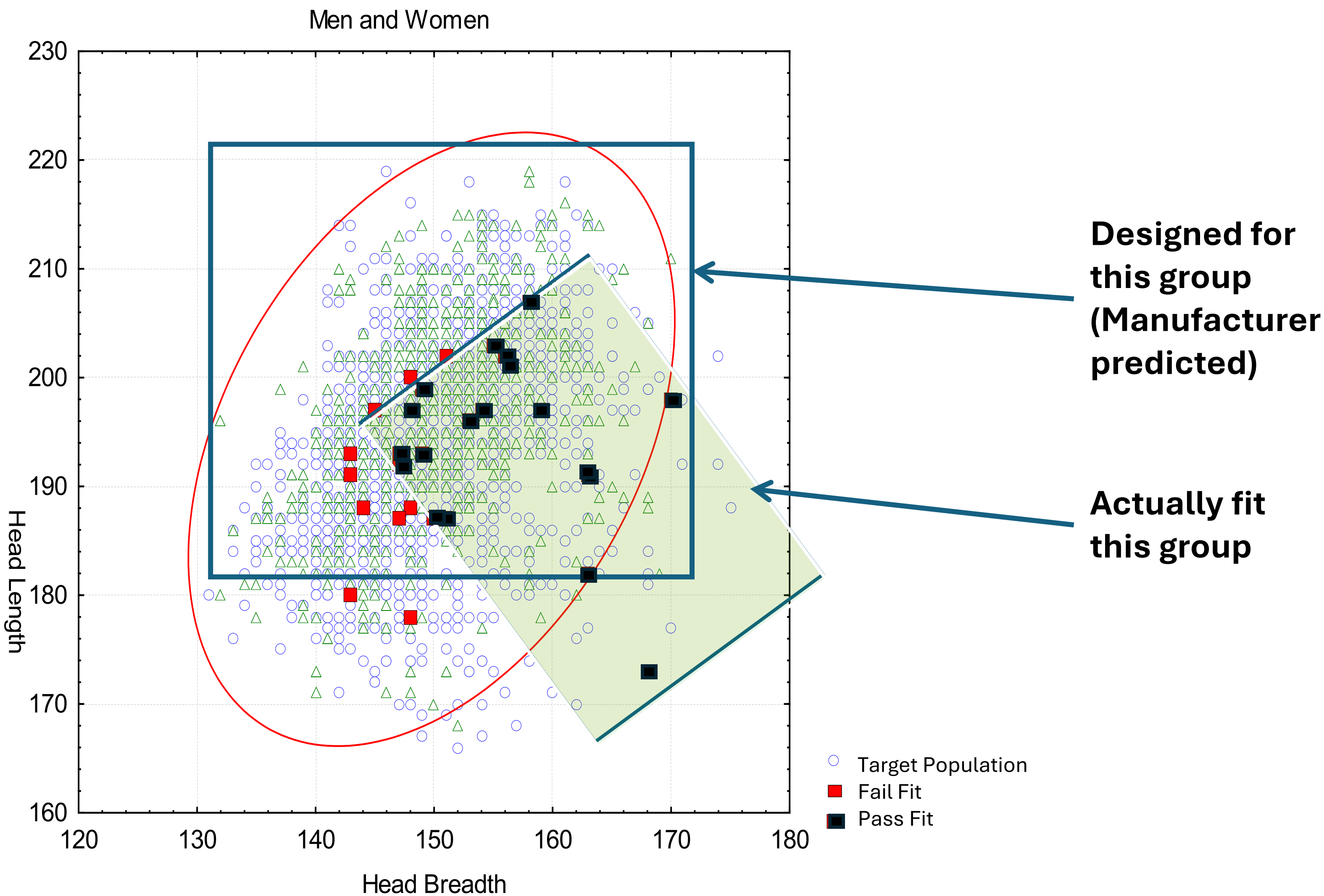
For Product Improvement*

- Documented COF
- Measurements of product
- Description of product/specifications
- Measurement of location of product on people



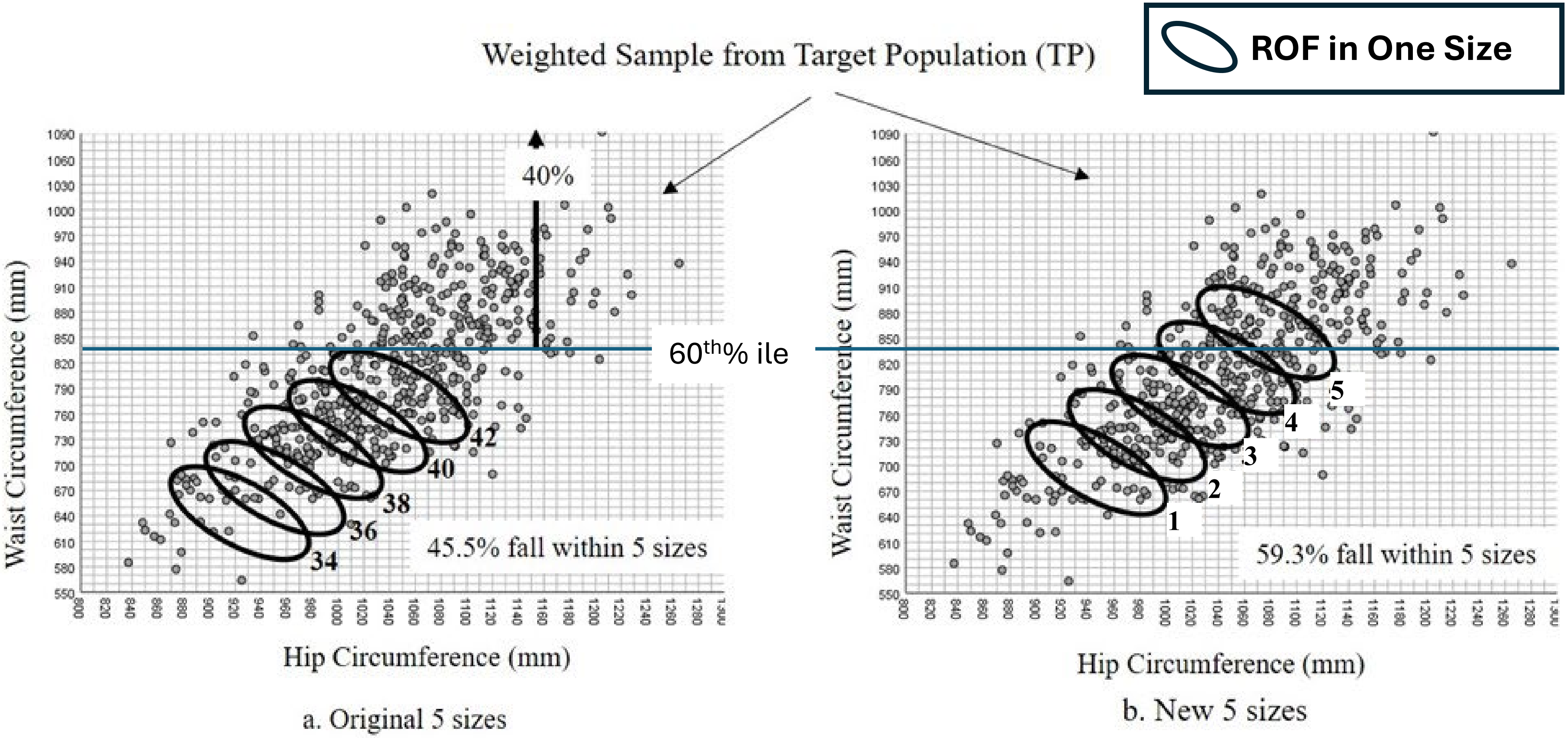
*And For Fit and Sizing Teaching Resource (FAST)

Fit Audit with Real People: Design Loop



From Robinette and Harrison 2005

Fit Audit with Real People: Sizing Loop



- Optimized & **standardize** base size and grade
- Create company/organization fit standard for product lines:
  - Sizing quality control
  - Reduce time to market
  - Continuity of product line sizing
  - User understanding of sizing

Other Benefits of Fit Assessment

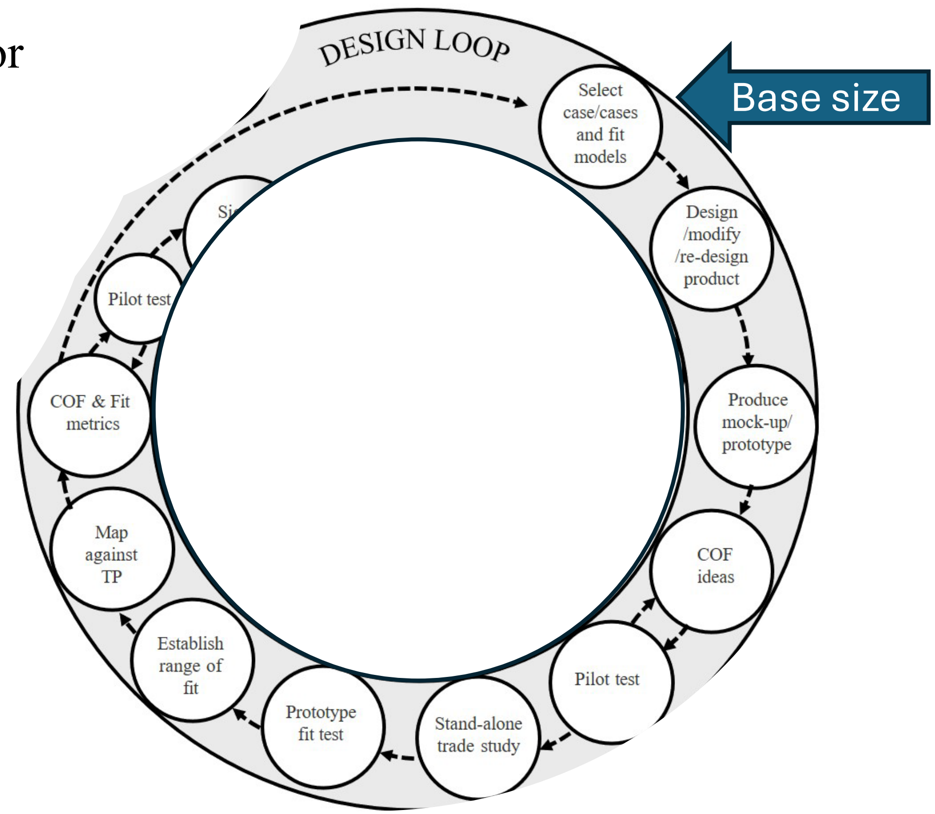
- Validated fit range
- Optimize size assortment
  - Remove unnecessary sizes (reduce waste)
  - Reduce size overlap (save money)
  - Evaluate cost vs benefit of adding sizes
  - Adapt to new populations
  - Best tariff estimates
- Effective fit prediction
  - Determine best fit predictor variables
  - Use to get the right size to the customer
- Increased sales
- Higher profits
- Safer products
- More satisfied customers
- Improved reputation

New Product with No Precedents/Prototypes

Case: a single individual in one of 3 forms:
1) a list of measurements of an individual,
2) a 3-D (or 4-D) model of an individual, or
3) the actual individual (fit model)

Base Size Case Selection *

1. Select 2 or 3 key (or control) variables
2. Select the key variable sizes for our desired case size
3. Find and select candidates near this size
4. Examine them for other measurements and attributes
5. Choose the best from the candidates

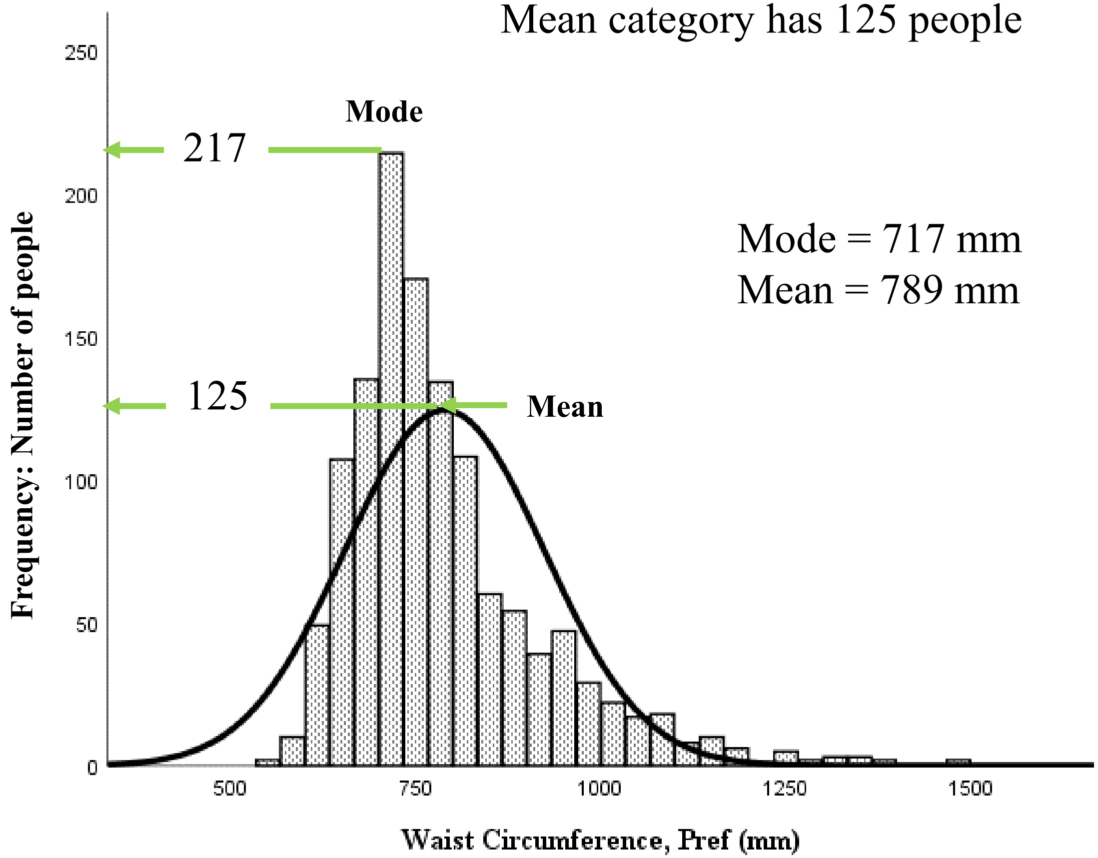


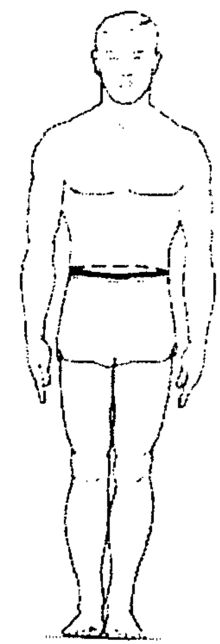
* Base size might change after fit testing validation

Select a case or fit model where people are concentrated

Raw data is best

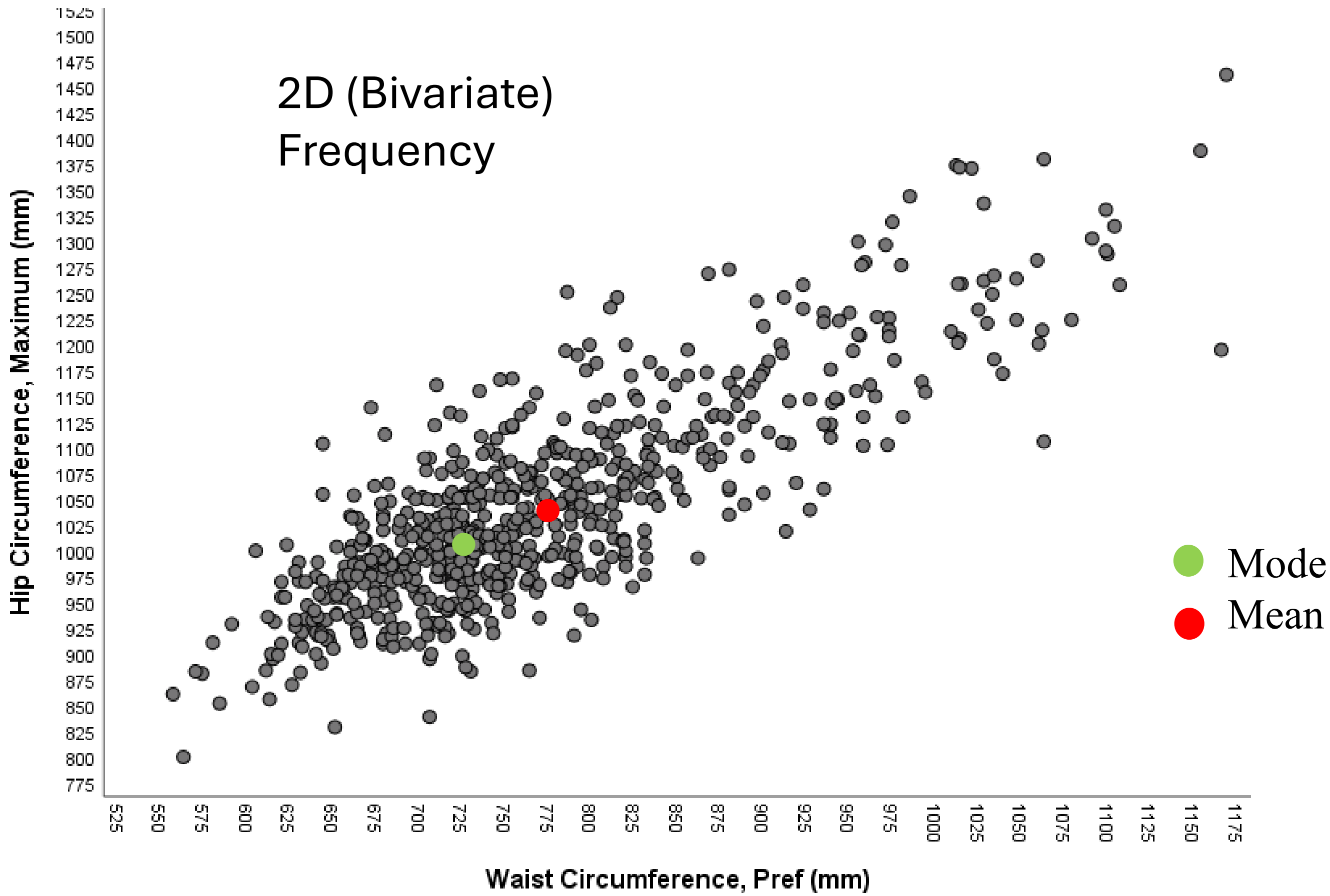
Mode category has 217 people
Mean category has 125 people





Sizes should be located where we will capture the most people

Mode can be the best starting point

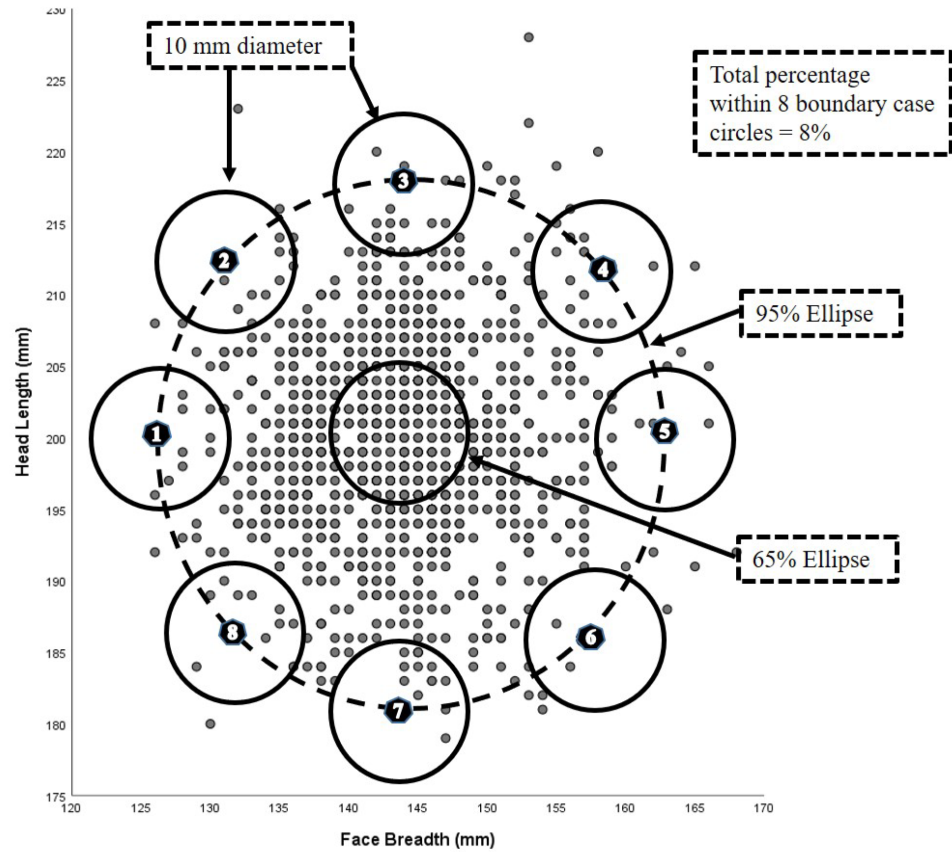


- Mode is the value that occurs most frequently
- For design it is the Sweetspot
- If we create our first mock-ups/prototypes for testing here we can be sure to fit a lot of people

Boundary sizes versus middle size

- Boundary cases can be helpful to visualize or test the range of fit
- Boundary can be useful for distributing subjects for fit testing
  - Random sample will tend toward middle
  - Move to boundary to find the “no-fit zone”
- Boundary **sizes** are usually **not** cost effective
  - Fit all 8 boundary sizes and only accommodate 8%
  - Middle size fits 65% in one size

True ROF is 10 mm



* From Robinette et al 2025

New Product Key Variable Selection†

Considerations
- Most Important variables
- Correlated with other important variables
- Not correlated with each other

Strong correlation

Weak or no correlation

†After fit testing we can use data to tell us which are best

	IPD	Head Bdth.	Head Circ.	Head Len.	Bitragion Bdth.	Face Bdth.	Face Len.	Sellion-Supramenton
IPD	1	.201**	.234**	.125**	.226**	.301**	.133**	.237**
Head Bdth.	.201**	1	0.479**	.005	.666**	.708**	.108**	-.004
Head Circ.	.234**	.479**	1	.788**	.435**	.455**	.349**	.167**
Head Len.	.125**	.005	.788**	1	.072*	.063*	.338**	.186**
Bitragion Bdth.	.226**	.666**	.435**	.072*	1	.778**	.144**	-.023
Face Bdth.	.301**	.708**	.455**	.063*	.778**	1	.183**	.032
Face Len.	.133**	.108**	.349**	.338**	.144**	.183**	1	.718**
Sellion-Supramenton Len.	.237**	-.004	.167**	.186**	-.023	.032	.718**	1

* Significant at the 0.05 level (2 tailed) ** Significant at the 0.01 level (2 tailed)

Principal Component Analysis (PCA) with 1D Measurements*

- Multivariate method to:
  - Understand correlations amongst a given set of variables
  - Guide the selection of key variables
- Creates combination variables called components
  - Number of components = number of input variables
  - Each component is a linear combination of **all** input variables
  - Components are uncorrelated (independent)

Coefficients for first 3 out of 8 components
Varimax rotation

Component Coefficient Matrix			
	Component		
	1	2	3
IPD (mm)	.134	.217	-.100
Head Breadth (mm)	.338	-.036	-.050
Head Circumference (mm)	.058	-.080	.492
Head Length (mm)	-.150	-.080	.618
Bitragion Breadth (mm)	.342	-.034	-.040
Face Breadth (mm)	.353	.014	-070
Face Length (mm)	-.025	.477	.007
Sellion Supramenton (mm)	-.054	.570	-.131

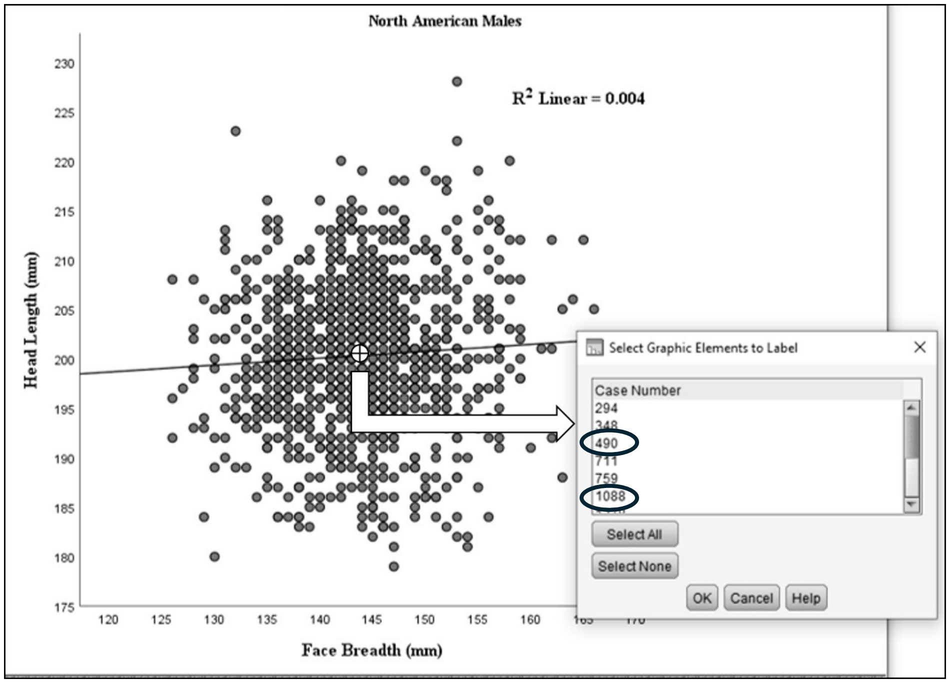
PCA Limitations & Pitfalls

- To recreate each component must have values for all measurements
  - Not practical for sizing or size selection
  - Most important measurement is only partially represented by first components
- First components are **not** the most important variables
  - The greatest variability can be error: components may not be important
  - Importance is product dependent
  - Components are dependent on the selection of input variables
  - If unimportant variables are input, unimportant variables are output

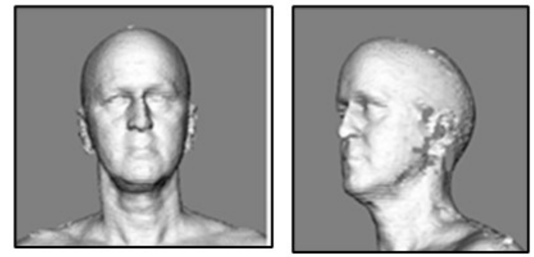
Hudson et al., (2006) further note, "… since all of the dimensions put into the analysis are given equal weight, *accommodation based on the components will include some of the variability of the possibly less important dimensions at the expense of the more important ones*."

For products worn on the body
Select cases where people are concentrated

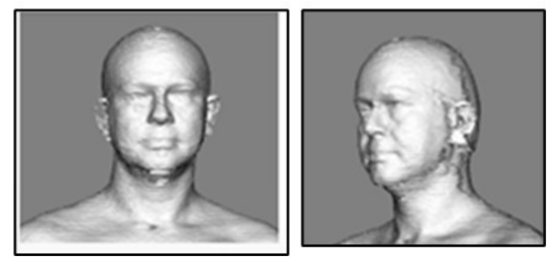
Two dimensions: Face Breadth x Head Length



Case Number 490



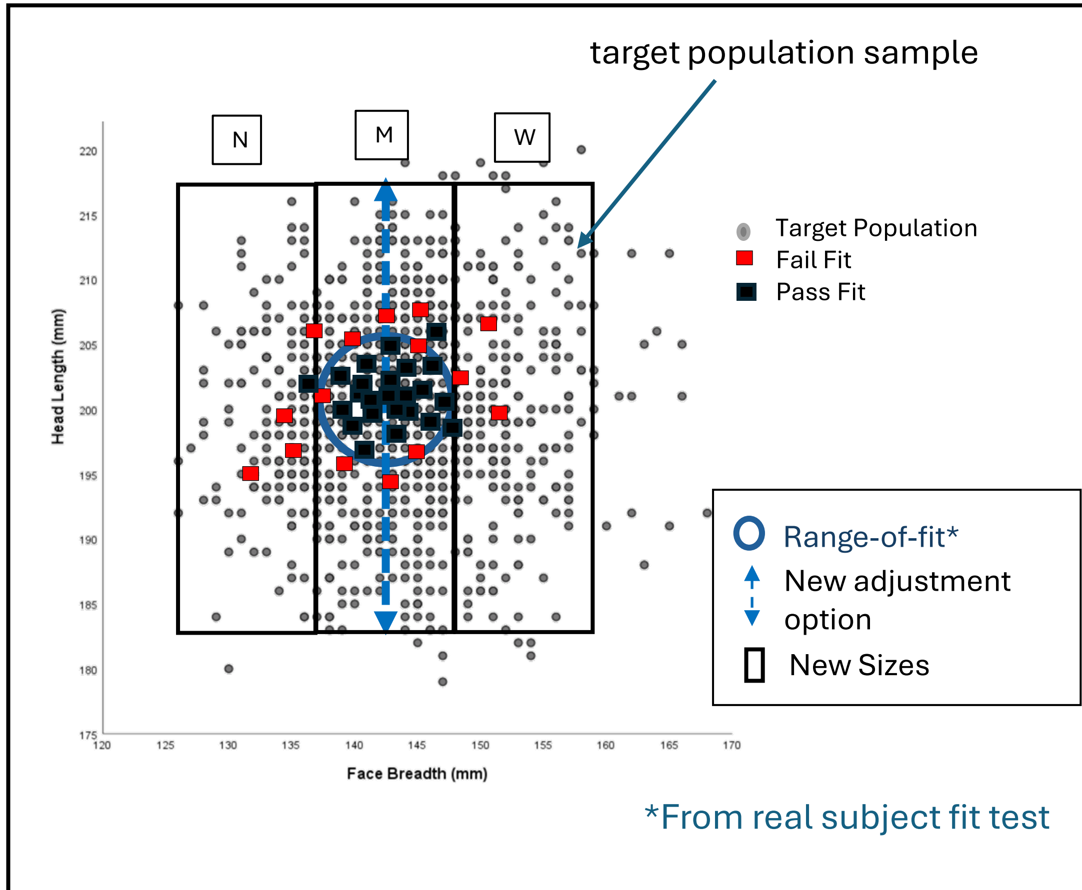
Case Number 1088



Case No.	IPD	Head Circ.	Head Breadth	Head Length	Bitragion Breadth	Face Length	Face Breadth	Sellion-Supramenton
490	65	575	158	200	149	119	143	101
1088	70.1	582	158	200	151	124	143	96

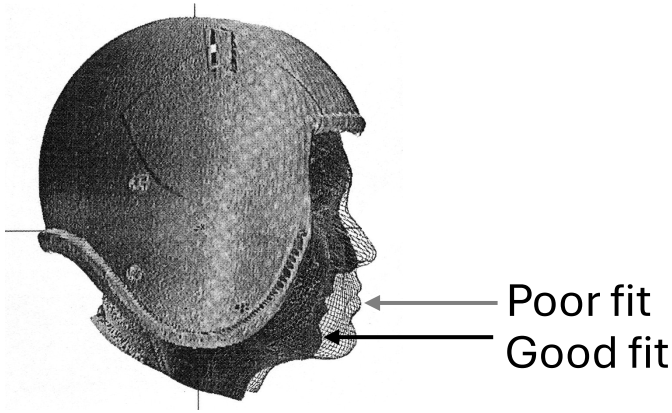
Range-of-Fit for Informed Design & Sizing Decisions

- Map range-of-fit against TP
- Decide sizes/adjustability
- Next steps depend on outcome
  - Move to sizing loop
  - Add sizes as needed & test
  - Adjust product & re-test



Fit Database Needs for Improving Future Fit Prediction

- COF documentation
- Standardized fit scoring
- Product properties & specification
- Product purpose
- Product location on body
  - When it fits
  - When it doesn't
- Raw data
  - Anthropometry
  - Fit scores
  - Product dimensions



Today's Process can Improve Tomorrow's Process With Standardization

- We have the ability to achieve good fit
- Today validated and effective fit requires fit measurement on real people
- Limitations:
  - We are not saving our fit data
  - We do not have fit measurement standards
- With fit standards & databases might train virtual/AI Models
- Can we do it?

References

Daniels, G.S.. 1952. The Average Man. TN-WCRD 53-7. (AD 10 203) Wright Air Development Center, Wright-Patterson Air Force Base, OH

Hudson, J. A., Zehner, G. F., Parakkat, J., & Choi, H. J. (2006). A Methodology for Evaluating Advanced Operator Workstation Accommodation (Technical Report AFRL-HE-WP-TR-2007-0016). Air Force Research Laboratory, Human Effectiveness Directorate.

Harrison, C. A. and Robinette K.M. (2005) Principles of fit to optimize helmet sizing, Proceedings of the NATO Research Technology Organization's Human Factors & Medicine Panel Symposium on Strategies to Maintain Combat Readiness During Extended Deployments: A Human Systems Approach, Prague, Czech Republic, 3-5 October, 2005, pp.

Robinette, K. M., Veitch, D., Alemany, S., and Bredenkamp, K. (2025) *Product Fit and Sizing: Sustainable Product Evaluation, Engineering, and Design*, CRC Press, ISBN 9781032491189

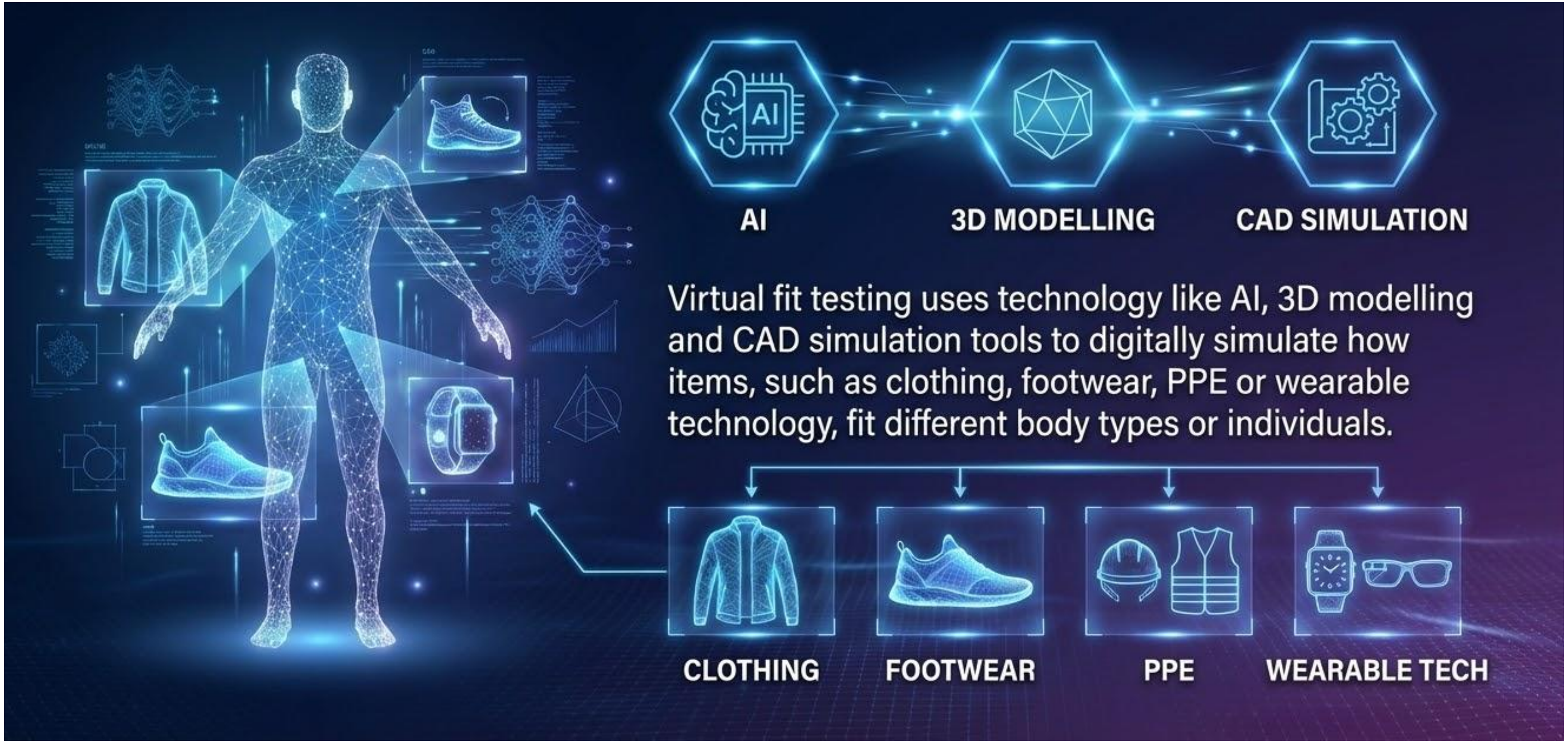
Virtual Fit Testing

Transforming how products are designed, validated, and sold

The 2nd Biomechanical Engineering and Anthropometry Meeting (BEAM)
March 24 – 26, 2026

Karen Bredenkamp, Magic Leap

What is virtual fit testing?



Examples of virtual fit testing tools

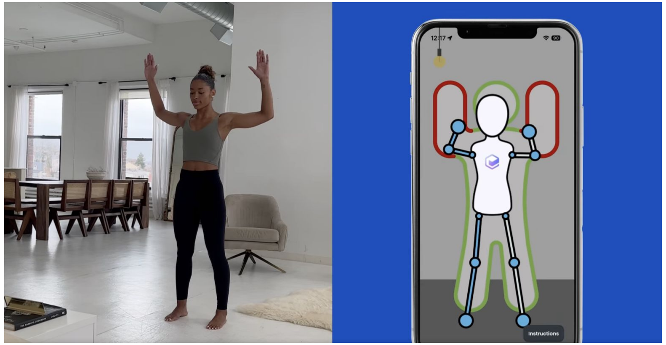
- Product design tools
  - Workstation design
  - Apparel
  - Footwear
  - Wearable technology
  - PPE
- Online shopping tools
  - Eyewear
  - Apparel
  - Footwear

Examples: Online fitting/shopping tools

3DLOOK

Warby Parker

Verifyt.app



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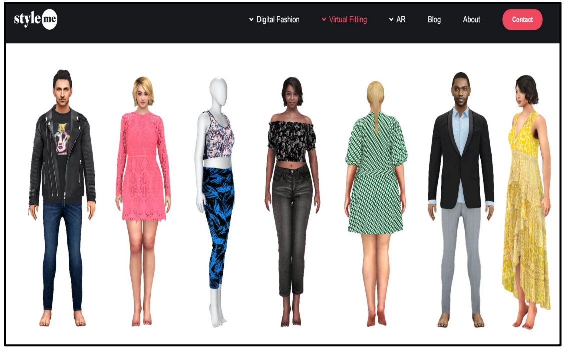

Examples: Product design tools

clo

browzwear

Add occupant space/ergonomics virtual simulation

What is the current school of thought on virtual fit testing?

Especially among engineers and management

"Virtual fit testing is transforming how products are designed, validated, and delivered by enabling accurate evaluation of fit, comfort, and performance long before physical prototypes exist. By using digital human models and simulation, organizations can rapidly assess how apparel, wearables, protective gear, and equipment interact with the human body across diverse body types and use cases. This reduces costly rework, shortens development cycles, and minimizes reliance on time-consuming physical trials, while improving safety and user satisfaction. Beyond efficiency, virtual fit testing drives better outcomes by uncovering ergonomic risks early, supporting inclusive design, and enabling data-driven decisions that lead to higher-performing, better-fitting products. As products become more integrated with the human body, virtual fit testing is essential for scaling innovation with confidence, speed, and precision."

- ChatGPT

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- ChatGPT

Benefits of virtual fit testing in wearable product design

1. **Supports attaining designs that are closer to the final shape and size as starting point of fit iteration**
   a. Complicated designs, such as technology products, has high value in a close-to-final size, shape and form factor early in development timeline

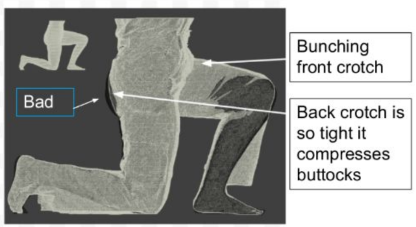
2. **Allows for longer design time, shorter testing cycles**
   a. Technology products require designs by multidisciplinary teams, needing longer design lead times and multiple team design decisions eg. ID, mechanical components, electrical components, durability and manufacturability

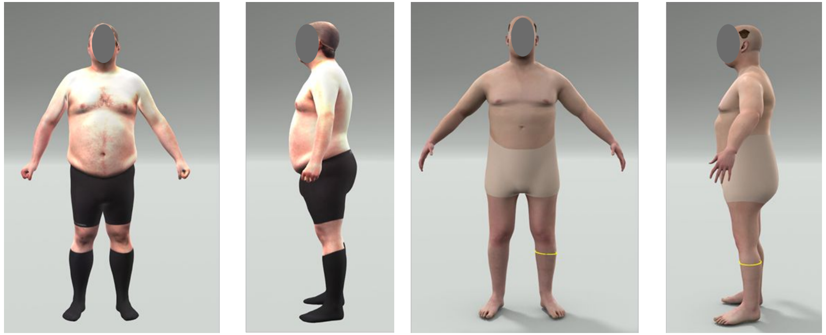
3. **Leads to less empirical (real user) fit testing cycles**
   a. Especially beneficial for products with costly and long production lead times that are restricted in the amount of empirical fit testing cycles eg. shoes, body armour, helmets, technology products

4. **Virtual try-on supports better shopping experiences and decisions, and therefore better customer satisfaction and lower return rate**

Risks of virtual fit testing?

- **Virtual models often <u>lack sufficient representation</u> of humans, such as for :**
  - Comfort ratings and acceptance
  - Soft tissue deformation
  - Product wear position preferences
  - Change in body shape due to postures (ie designing high heel footwear)
  - Representation of areas often occluded in scans such as crotch and armpit





3D scanned
High shape & posture accuracy

Parametric model
Low shape & posture accuracy

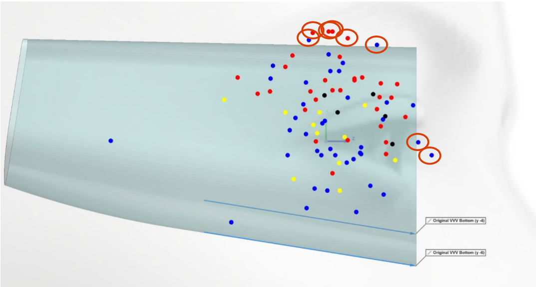
MOVE 4D

browzwear

Risks of virtual fit testing? (cont…)

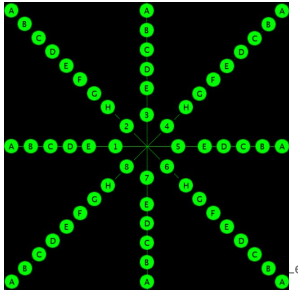
- **Virtual fit testing often not <u>accurate performance prediction</u>**
  - **Theoretical performance predictions** are usually used during virtual fit testing, however these regularly **lack sound empirical validation**
    - Even when empirically validated, discrepancies between predicted and actual still exists
  - Examples include:
    - Slippage
    - Virtual or real world field of view
    - Audio performance or sound localization
    - Particle protection or mask seal
    - Body movement
    - Material stretch

Visual registration prediction



HOWEVER

Empirical % virtual display visible = 100%

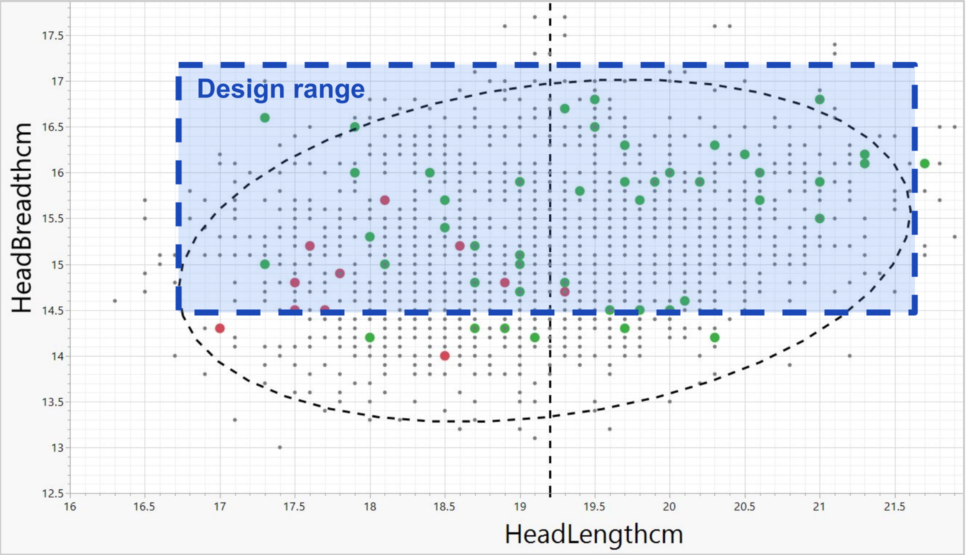


Example: Fit failures of glasses designed using virtual fit simulation

- Glasses designed using virtual fit simulation
- Prototypes were manufactured and fitted on a sample of 57 participants
  - Good representation of head size confirmed before testing
- Slippage evaluated by:
  - Executing a series of body movements → representative of body movements expected in identified use cases
  - Natural use over 4h of wear

- ***Results:***

  Slippage = 9/49 (**18.4%**) slippage **FAIL**



Example: Fit failures of glasses designed using fit simulation (continued…)

- Glasses designs modification recommendation:
    - Keep the temple force the same, but increase the temple arm curve → pulling it in

Example: Fit failures of glasses designed using fit simulation (continued...)

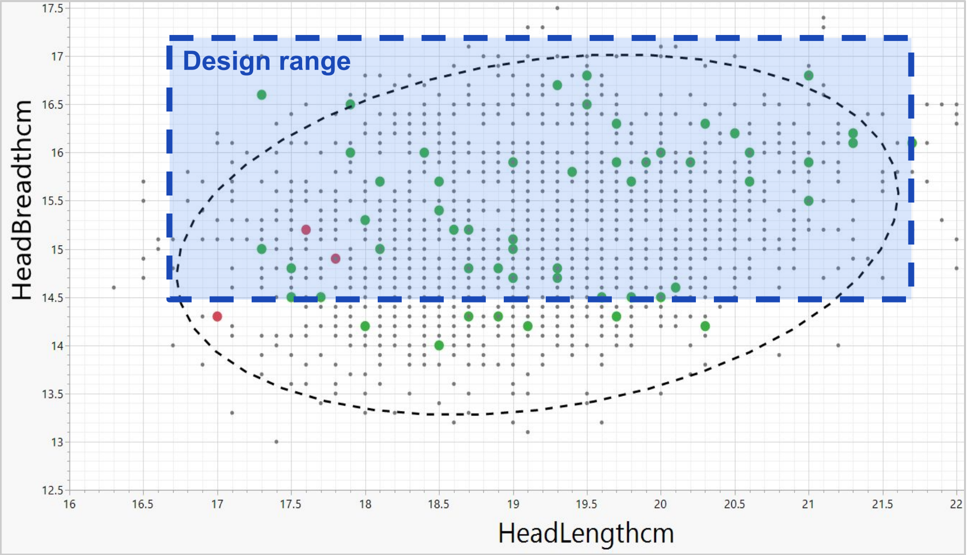
- Proposed modification implemented to temple arms
- Glasses were prototyped
- Same slippage protocol repeated

- ***Results:***

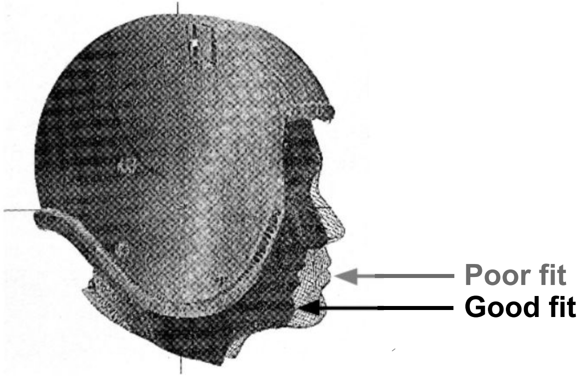
Slippage reduced

11/57 (**19.3%**) slippage **FAIL**

2/49 (**4.1%**) slippage **FAIL**



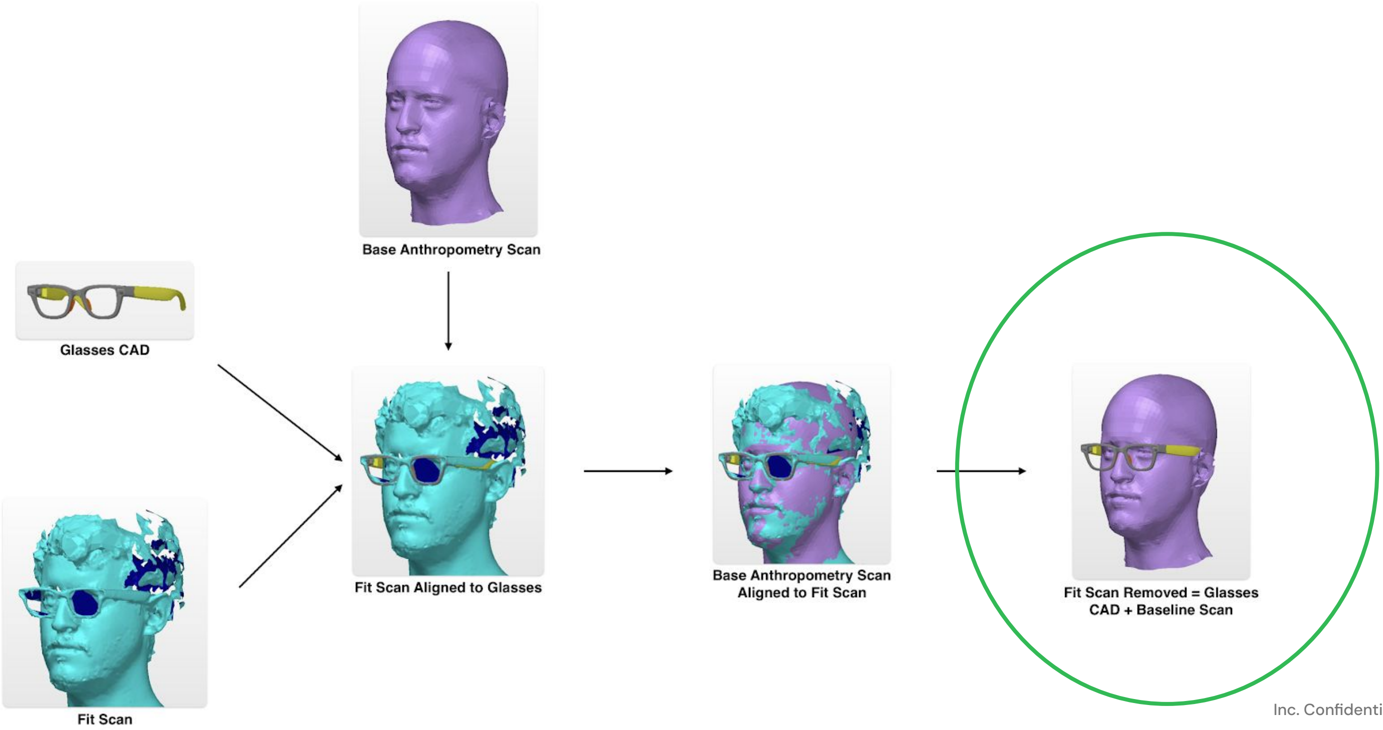
Risks of virtual fit testing? (cont…)



- **Virtual fit testing models often lack robust empirical validation – especially if it "looks" good**
  - Often, time pressures force team to move forward with no to minimal empirical validation – accepting the model could be good enough with validation testing on very few (1–5) participants

Example: Validation of glasses virtual fit simulator

MANUAL ALIGNMENT OF FIT SCAN



Future needs & must haves for reliable virtual fit testing

Sharing of information

- Comprehensive validation of virtual fit testing tools to quantify deviation from actual fit
- Continuous improvement of fit testing tools to improve deviations between virtual and actual fit
- Continuous improvement of virtual models to represent the human better

- Standardized empirical fit testing data <u>per product type and purpose</u>
  - Documented, Standardized Concept-of-fit (COF) metrics
  - Standardized empirical fit testing protocols
  - Empirical fit testing results databases
- Virtual fit testing validation standards / guidelines
- Guidelines on allowable virtual vs empirical fit testing deviations

FINAL POSITION:
Real fit testing a necessity in future designs

VIRTUAL FIT VALIDATION

- Early virtual fit tool development
  - Small scale validation (n=5-10)
  - Early validation to confirm fit rules / simulation algorithms

- Virtual fit tool accuracy confirmation & calibration
  - Larger scale, representative of TP (n=30-65)
  - Confirm tool accuracy across varying body shapes and sizes

PRODUCT DESIGN VALIDATION

- Understanding fit metrics and Piloting COF
  - Before fit testing
  - Thorough understanding of fit and fit metrics are required in order to develop sound COF
  - Confirms fit testing rules, procedures and acceptance criteria

- Early design fit confirmation
  - Small scale validation (n=5-15)
  - Early design validation to confirm fit (could include subset of COF per test)
  - Could be several iterations per design

- Design fit verification
  - Larger scale, representative of TP (n=40-100)
  - Confirm fit across all COF metrics
  - Depending on success of fit, design could require several iterations (Fit simulation could reduce number of iterations)

Thank you

BEAM

The 2nd Biomechanical Engineering and Anthropometry Meeting (BEAM)

Towards Fit Intelligence: Standards, Fit Databases, and AI for Product Design

Dr. Sandra Alemany
Applied R&D Director

INSTITUTO DE BIOMECÁNICA DE VALENCIA

Towards Fit Intelligence

The problem of fit prediction

Introduction

Today fit cannot be predicted in reliable way it must be tested

- **The Current Bottleneck:** Achieving the good fit currently relies on high levels of professional expertise and multiple physical iterations.

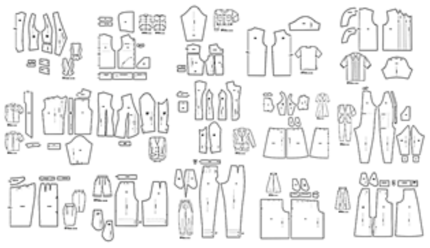
- **The Complexity Barrier:** Traditional scientific methods have struggled to predict fit because it is a multi-zone interaction influenced by:
  - **Material properties** and product geometry.
  - **Dynamic fit:** How the product behaves during activity/movement.
  - **Anthropometric diversity:** The vast range of human shapes and proportions.
  - **Performance** specs: safety vs comfort vs performance.

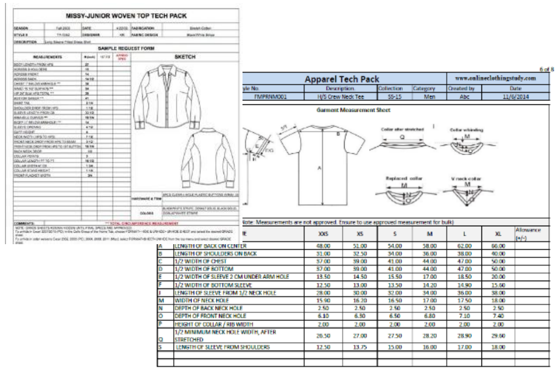
Towards Fit Intelligence

The current design process

Introduction

Iterative Loop



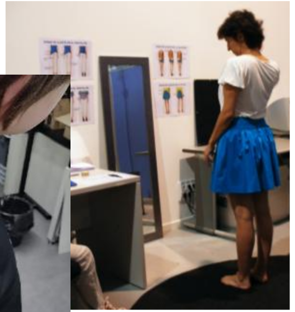


Database of patterns and spec. sheets

Source:https://www.uphance.com/blog/fashion-prototyping/

Source: https://cadfashionstudio.com/the-importance-of-prototyping-in-fashion/

Manufacturing physical prototypes

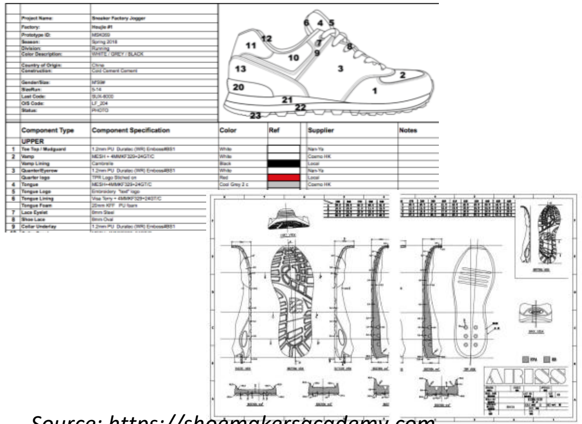


Fit Assessment

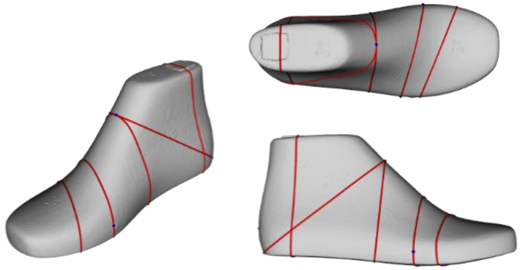
Mannequins

Live fit models

The current design process



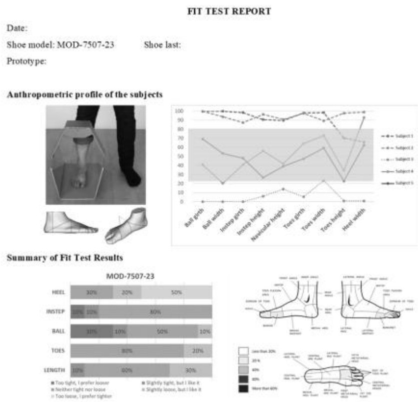
Source: https://shoemakersacademy.com



Database of shoe lasts and spec. sheets

Source: https://www.tecnicadelcalzado.com/

Manufacturing physical prototypes



Fit Assessment

Live fit models

Towards Fit Intelligence

Standards & databases

The Goal

Research has focused on:

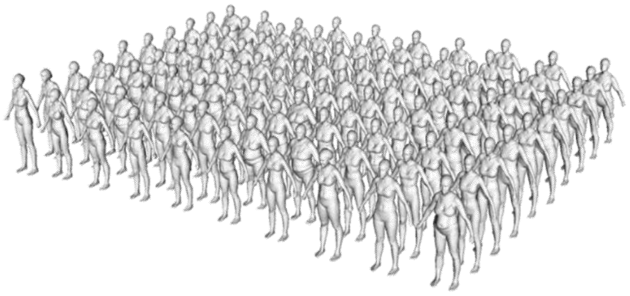
- Anthropometric measurement protocols.
- Population datasets.
- Anthropometric measurements & shape descriptors.

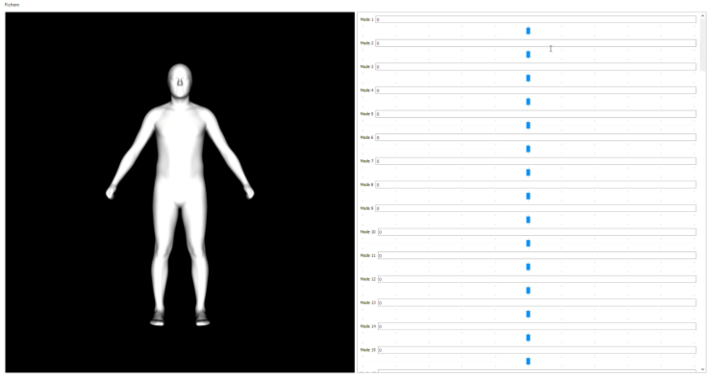
However:

- Fit databases remain scarce.
- Heterogeneous definitions and CoF.
- Heterogeneous scoring scales.
- Limited reuse potential.

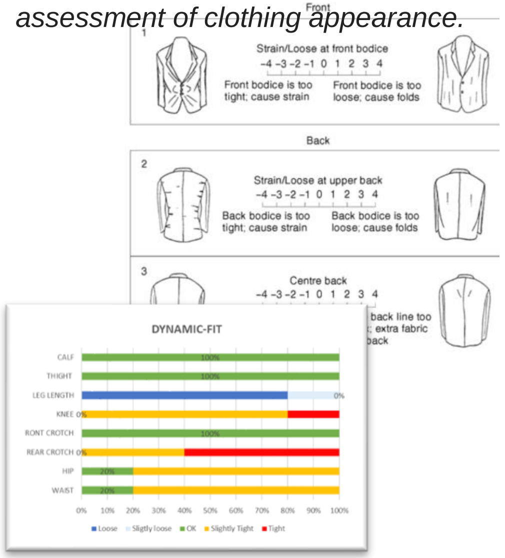
The limitations:

- Systematic fit improvement.
- Validation of virtual fitting.
- AI-based design support.





Fan, J. (2004). *Subjective assessment of clothing appearance.*



Fit Evaluation Scales (FES)

Origin	FES	Ranking/Points System	Remarks
Petrova and Ashdown (2012)	4-point scale	Rank 1 = best fit Rank 4 = worst fit	Overall fit in bust-waist-hip area was checked by 3 judges.
Bye and McKinny (2010)	5-point scale	Score 1 = unacceptable fit Score 2 = poor fit Score 3 = acceptable fit Score 4 = good fit Score 5 = excellent fit	Pant fit based on 17 criteria and dress fit based on 24 criteria were checked by 6 judges
Song and Ashdown (2010)	5-point scale	Score 3 = good fit	Jacket fit at 18 critical body locations was judged by 3 judges
Ashdown and O'Connell (2006)	4-point scale	No scoring system, rather descriptive options	Jacket fit at 13 specific areas and an overall fit assessment was done by 9 judges
Nam et al. (2005)	5-point scale	Score 5 = strongly agree Score 1 = strongly disagree	Fit of cooling vest at 36 torso areas checked by 3 judges
Ashdown et al. (2004)	3-point scale	Score 1 = acceptable Score 0 = marginal Score −1 = unacceptable	3 judges evaluated pant fit using 15 criteria
Shen and Huck (1993)	9-point scale	Score 0 = best fit Other scores range from −4 to +4	25 fit criteria of female bodice were checked by 3 judges

Sayem, A. S. M. (2023). Clothing fit evaluation: from physical to virtual. *Digital fashion innovations*, 17-38.

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Towards Fit Intelligence

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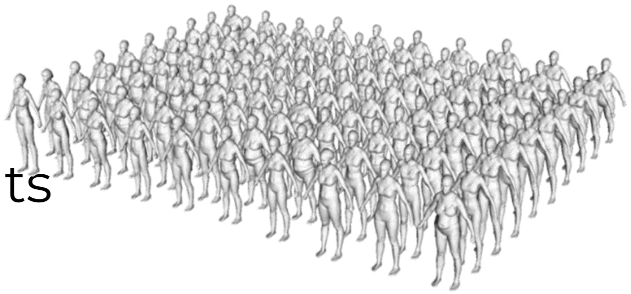

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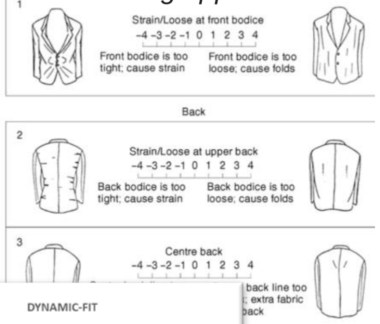

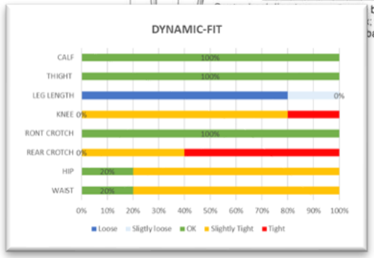

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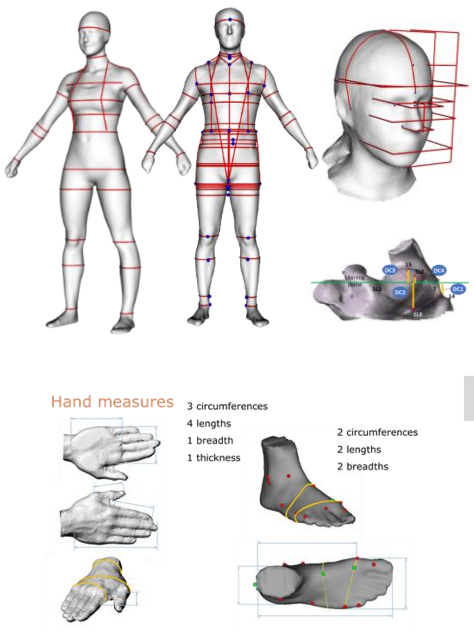
Towards Fit Intelligence

Data involved in fit interaction

Fit factors

USER

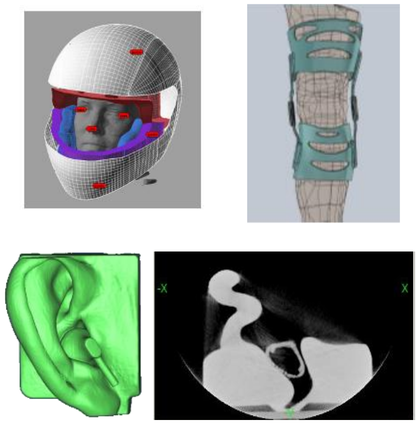


Anthropometry

and

Personal fit preferences

FIT



FIT ZONES

CoF
Fit scores / zones

PRODUCT

Geometry, material and sizes

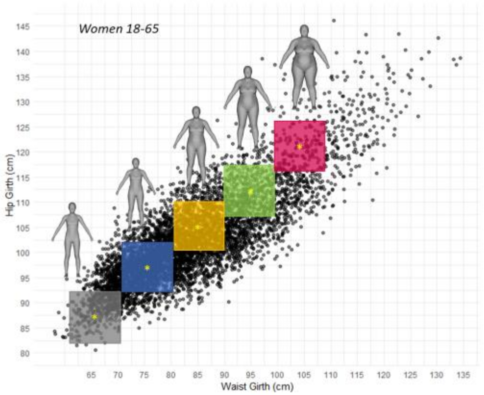
Towards Fit Intelligence

Anthropometric descriptors

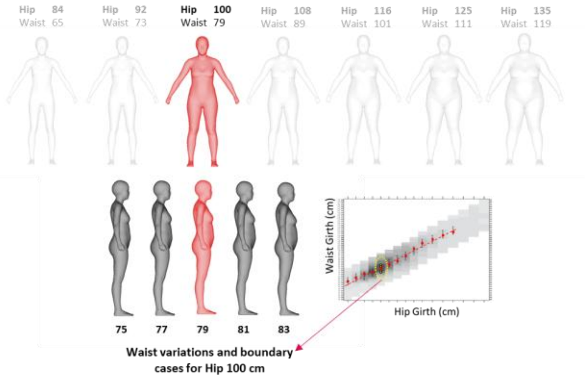
USER

Target Population

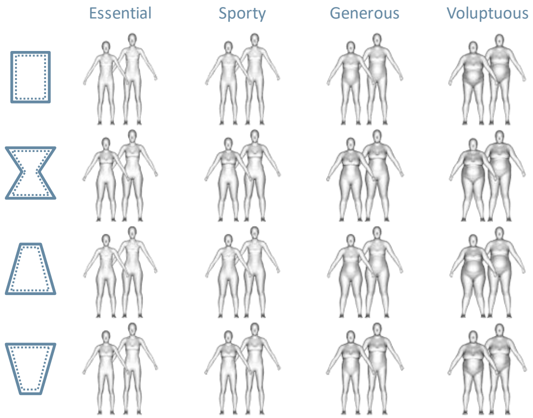
Ideal Bodies



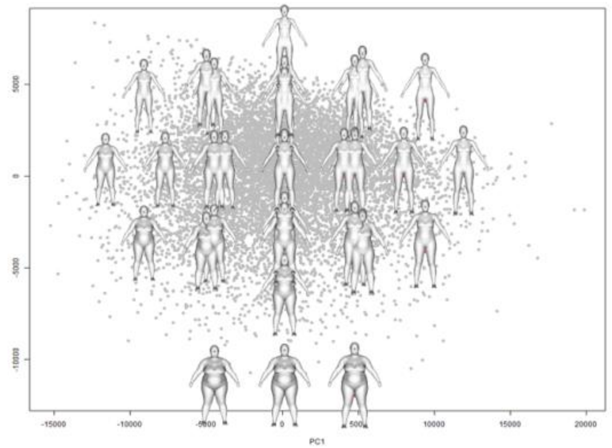
+ Boundary cases



Morphotypes



Mapping

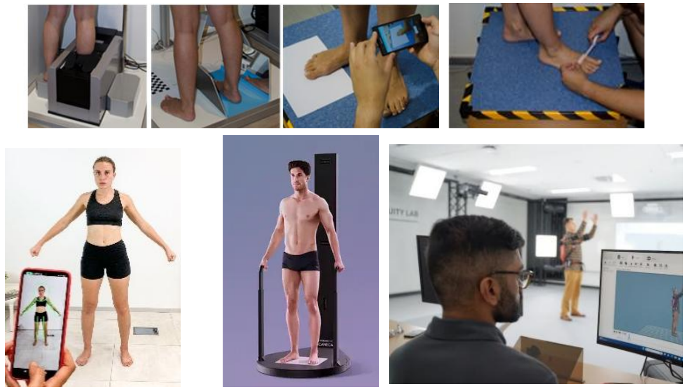


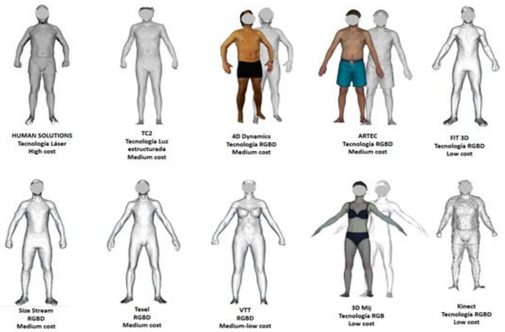
Towards Fit Intelligence

Anthropometric descriptors

USER

Diversity of measuring devices and protocols





Diversity of digital tape algorithms

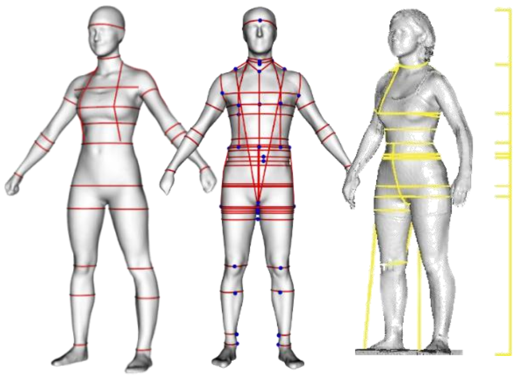
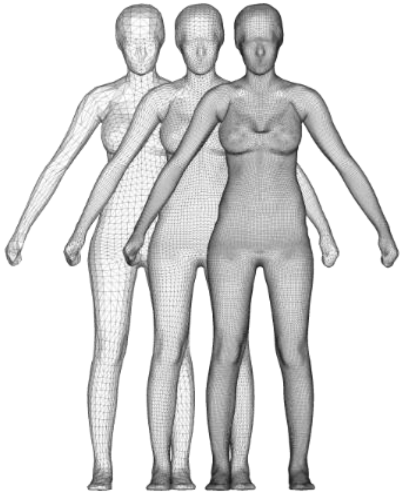


TABLE 11 **Mean signed difference (bias), in mm, for each measuring station in Phase 2**

Measuring station	Neck girth	Back neck point to waist	Upper arm girth (right)	Back neck point to wrist (right)	Across back shoulder width	Bust girth	Waist girth	Hip girth	Thigh girth (right)	Total crotch length	Inside leg height
Expert measurer 1	-1.9	2.6	-9.7	22.1	9.0	-1.2	-12.0	1.3	1.4	4.8	3.0
Expert measurer 5	-6.6	-21.5	3.0	-14.4	7.6	-5.0	1.5	-12.8	5.1	13.0	12.2
PortalMX	-1.0	-31.1	5.8	-15.2	15.7	-3.3	-5.4	10.5	-1.6	27.4	19.2
MOVE4D	1.0	3.1	2.1	-21.9	-15.8	16.6	13.6	6.6	3.8	-2.5	-14.9
SS@Home	-4.7	20.0	2.2	5.0	-30.6	-3.8	47.3	7.8	-15.8	-8.8	-12.0
3DLOOK	-2.3	28.0	-12.5	-3.1	-3.9	-6.8	-32.6	-8.2	7.5	10.4	2.3
eM+	7.3	0.5	1.5	21.8	23.1	-16.3	-29.2	-11.2	-2.4	-43.5	-1.9
3Davatar body	8.2	-1.4	7.3	6.0	-5.5	19.8	17.0	6.0	1.9	-1.1	-7.8
All expert	-4.2	-9.4	-3.3	3.8	8.3	-3.1	-5.3	-5.8	3.3	8.9	7.6
All digital	1.4	3.1	1.1	-1.3	-2.8	1.0	1.8	1.9	-1.1	-3.0	-2.5
Grand means	363.9	428.9	320.0	787.6	422.9	999.9	880.6	1044.1	608.7	769.5	750.2

Ballester, A., et al.. (2022). Comparative analysis of anthropometric methods: past, present, and future. IEEE 3D Body Processing Group.

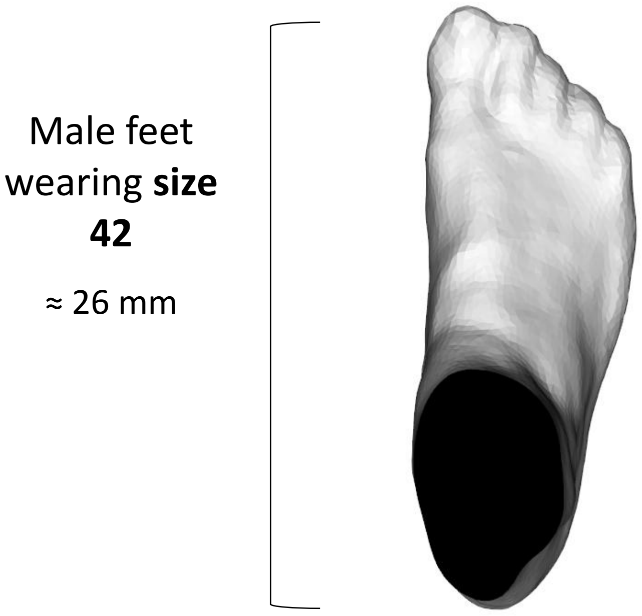
Diversity of template topology & PCA

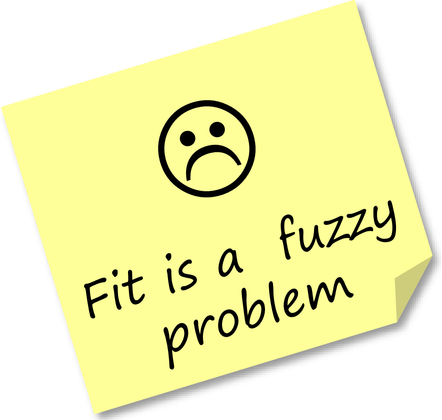


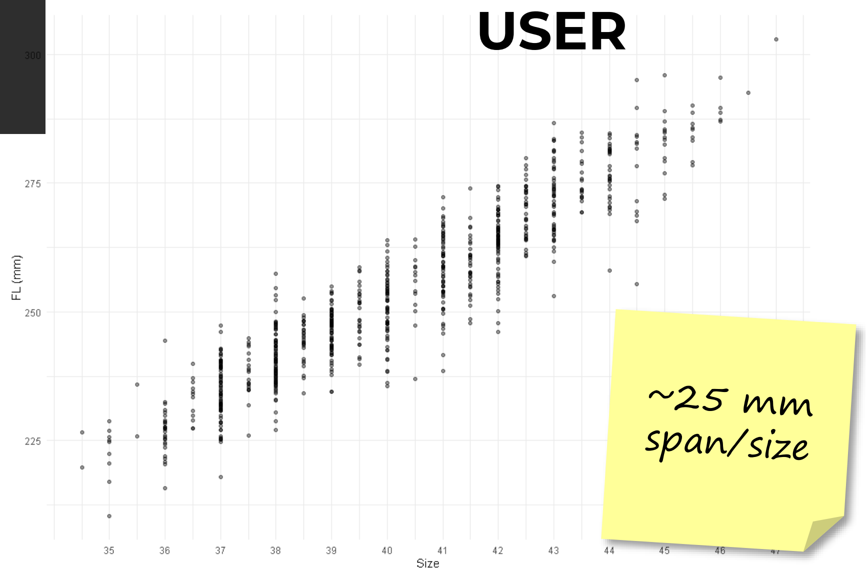
Towards Fit Intelligence

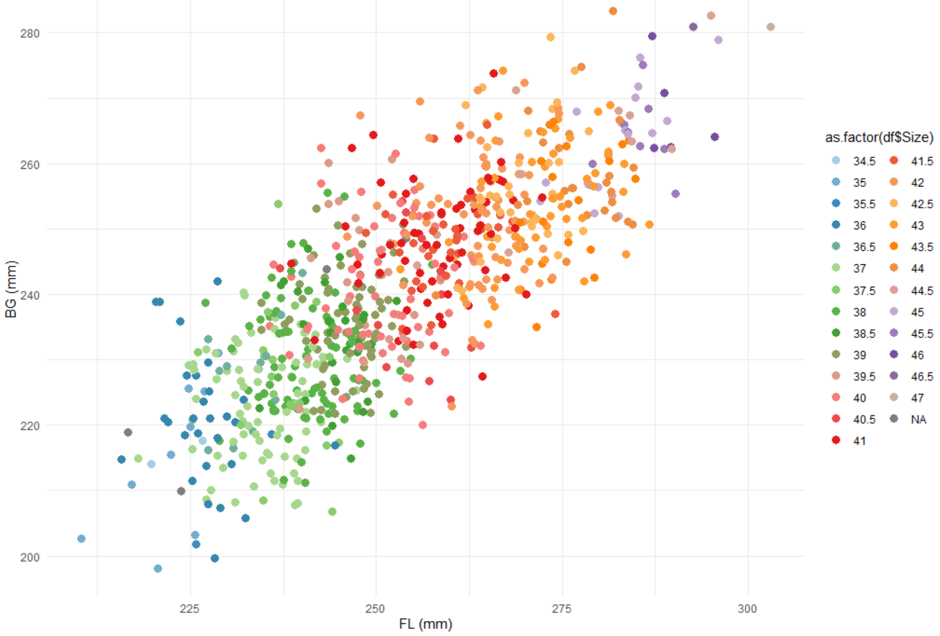
Personal preferences

Personal preferences in footwear sizing might reach up to 2,5 cm > 3 EU Sizes.







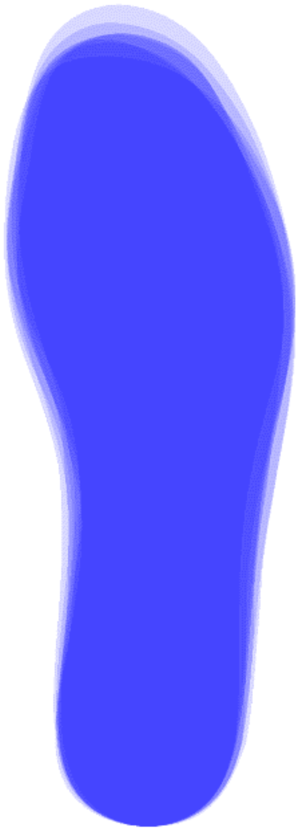


Towards Fit Intelligence

Product Design inconsistency

PRODUCT

LL differences of
2 cm ≈ 3 EU sizes!!



Treads of
8 shoe lasts labelled as
size 38

Foot metrics

FL	272
TP	226
TG	245
TH	27
TW	109
P1M	201
P5M	175
BP	188
BG	262
BH	44
MBH	33
LBH	23
BW	110
IG	266
IH	74
IW	95
NP	102
NH	47
IHG	369
HW	70

M1	59,55
M2	-8,041
M3	0,002
M4	-2,865
M5	-1,172
M6	1,016
M7	-0,204
M8	-1,866
M9	0,204
M10	0,997

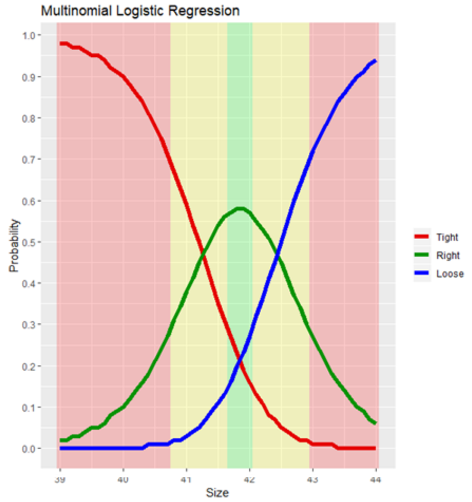
Set of lasts

F-41130
F-45598
F-U48654
F-U7640
F-U7641
M-U3192
M-U5009
M-U6552
M-U7640
M-U7641
M-U7679
U-U3338
U-U7616-4

Sizes

Last Size	Tight	Right	Loose
39	1,00	0,00	0,00
40	1,00	0,00	0,00
41	0,97	0,03	0,00
42	0,87	0,13	0,00
43	0,53	0,43	0,04
44*	0,13	0,58	0,30
45	0,01	0,26	0,73
46	0,00	0,06	0,94
47	0,00	0,01	0,99
48	0,00	0,00	1,00

Fit probabilities



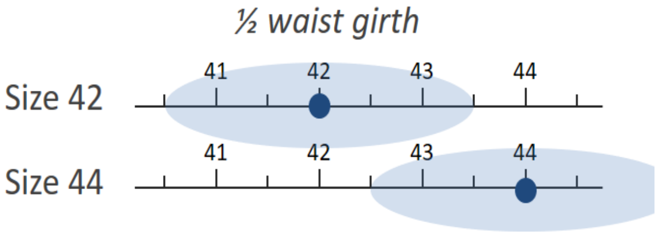
Fit Probabilities
for $Last_i$ x $Size_j$

Product design inconsistencies require specific FIT prediction models

Towards Fit Intelligence

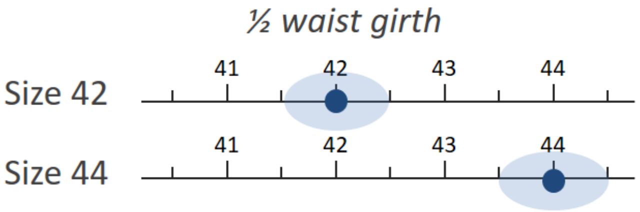
Manufacturing inconsistency

PRODUCT



☹ **Relaxed quality control (±1.5 cm)**

Uncertain real FIT

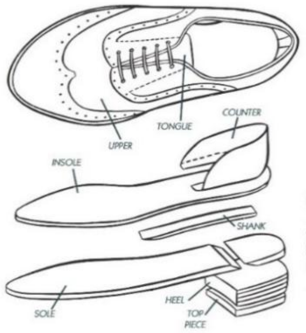


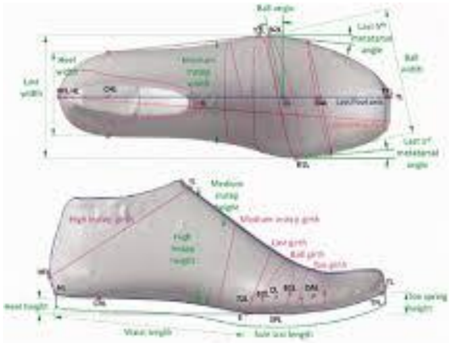
☺ **Strict quality control (±0.5 cm)**

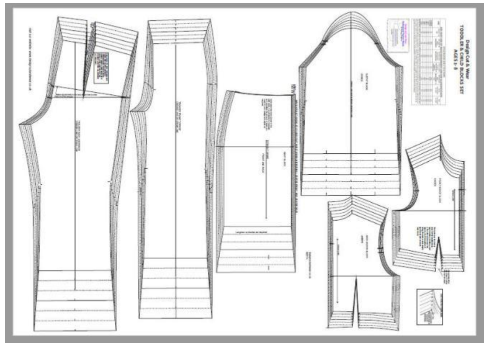
Product metadata

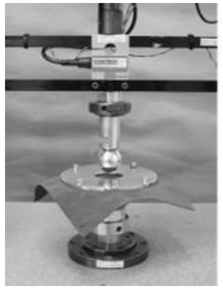
PRODUCT

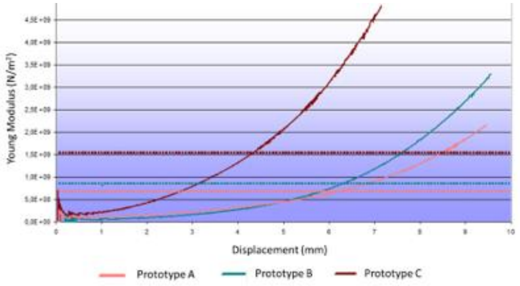
- **Product Anatomy:** Main components affecting fit.
- **Material properties.**
- Main **geometry**: Key dimensions.
- Number of **sizes** and grading rules.











Towards Fit Intelligence

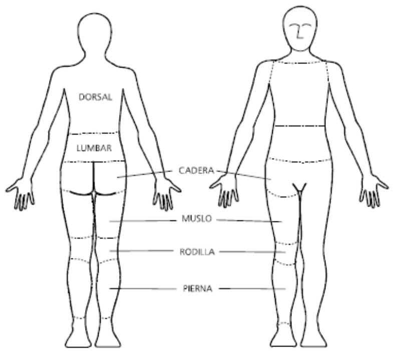
FIT Descriptors

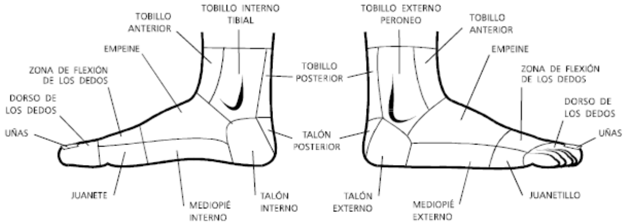
Fit data collection protocols

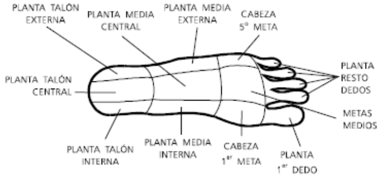
Fit ontology

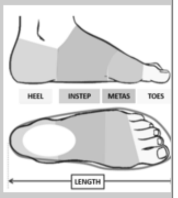
- Anatomical zones.
- Standardizable CoF.
- Scoring scale.
- Additional functional aspects: movement restriction, slippage, etc.

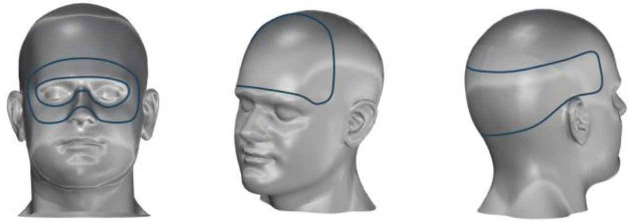
- Use conditions of the fit test:
    - static
    - dynamic
    - extreme postures
    - Instant vs long term fit







	Fit Perception (subject answer)					How it is preferred (subject answer)			Fit Areas
Length	Very short	Short	Ok	Large	Very large	Shorter	As is	Larger	
Heel	Very tight	Tight	Ok	Loose	Very Loose	Narrower	As is	Wider	
Instep	Very tight	Tight	Ok	Loose	Very Loose	Narrower	As is	Wider	
Ball	Very tight	Tight	Ok	Loose	Very Loose	Narrower	As is	Wider	
Toes	Very tight	Tight	Ok	Loose	Very Loose	Narrower	As is	Wider	
General	Very tight	Tight	Ok	Loose	Very Loose	Narrower	As is	Wider	



consistent fit annotations

BEAM

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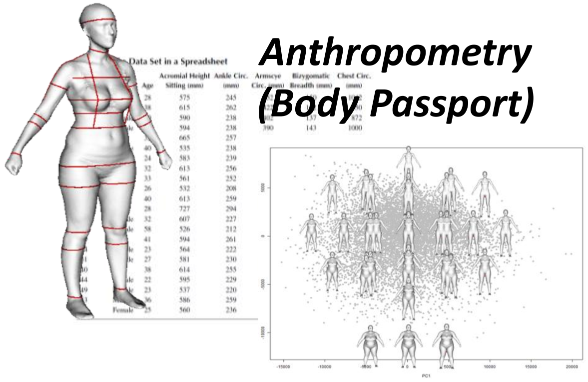
Fit framework

Design proces

Anthropometry (Body Passport)

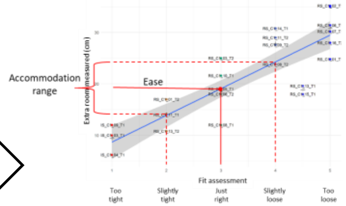


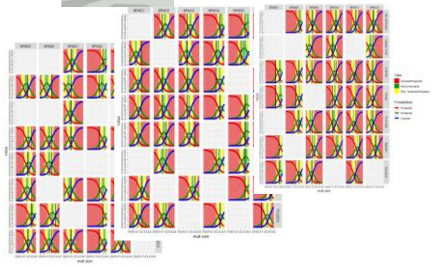
Annotations: Corresponding Fit rating

Product & Specs (Product Passport)

Paired Database
Products, Fit Ratings and 3D Bodies

AI Fit Prediction Models





Learnings & AI Fit tools

- **Body-Specific Fit Guidance:** Identify which bodies each pattern fits best (and worst).
- **Pattern Optimization:** Discover systematic issues across sizes or styles.
- **Ease & Grading Rules:** Derive data-driven rules for ease distribution and size grading.
- **Generative Design Inputs:** Use fit annotations to guide automated pattern generation.
- **Training virtual models:** To improve virtual simulations.

Benefits

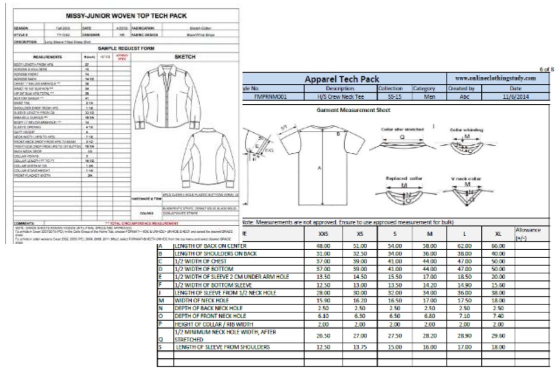
1. ***Reduced Design Loop*** → *Pattern design first-time right.*
2. ***Better inclusivity*** → *Covering grater body diversity.*
3. ***Reduced return rates*** → *Fit & Labelling consistency.*
4. ***Preparing the future*** → *Made-to-order (customization).*

Towards Fit Intelligence

The current design process

Save fit test in a standard way!!!!!

Iterative Loop



Database of patterns and spec. sheets

Source:https://www.uphance.com/blog/fashion-prototyping/

Source: https://cadfashionstudio.com/the-importance-of-prototyping-in-fashion/

Manufacturing physical prototypes

Fit Assessment

Thanks!

Time for Q&A

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The Instituto de Biomecánica (IBV) has been recognized as a **CERVERA Center of Excellence** for the development of the **COMANDO** (CER-20251029), **TACTIX** (CER-20251027) and **GUARDIANES** (CER-20251017) projects, financed by the Ministerio de Ciencia, Innovación y Universidades through the Centro para el Desarrollo Tecnológico y la Innovación E.P.E. (CDTI).

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