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Development of Requirements for a Web-Based Anthropometry Tool

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DEVELOPMENT OF REQUIREMENTS FOR A WEB-BASED ANTHROPOMETRY TOOL

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As represented by

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Abstract

A planning effort was carried out for the development of a suite of web-based anthropometric software tools and associate databases based on the Canadian Forces Anthropometric Survey (CFAS) 2012 data for use in Canadian Armed Forces acquisition processes. Three parallel streams were followed in carrying out this objective:

1. Undertook a review of potential requirements for a web-based anthropometry tool. Essential and desired requirements were identified, ranked and prioritized.
2. Identified requirements for the underlying database.
3. Identified a notional software distribution model.

Based on this effort, an initial strawman for a Statement of Requirements (SOR) for a suite of web-based anthropometric software tools was developed and a notional software architecture is proposed.

Executive Summary

Development of Requirements for a Web-based Anthropometry Tool

Edward T. Nakaza, Caitlin Yee, Human*Systems*® Incorporated; DRDC Toronto
DRDC-RDDC-2018-C001; Defence R&D Canada – Toronto; March, 2017.

Background

To effectively exploit the data that was collected for the Canadian Forces Anthropometric Survey (CFAS) 2012, Department of National Defence stakeholders identified a requirement for a web-based tool that would allow all stakeholders involved in capability development to accurately, independently, and correctly apply CF anthropometric data.

Objective

The aim of this effort was to carry out initial planning for the development of a suite of web-based anthropometric software tools and associate databases, based on the CFAS 2012 data for use in Canadian Armed Forces acquisition processes.

Method

A systematic approach was followed in order to develop a suite of web-based anthropometric software tools and associate databases based on the CFAS 2012. Three parallel streams were followed in carrying out this objective:

1. Undertook a review of potential requirements for a web-based anthropometry tool. Essential and desired requirements were identified, ranked and prioritized.
    - Conducted a technology review and trade study of the CFAS Explorer 2012 software, 3D shape analyzer tools, and Commercial-Off-The-Shelf (COTS) web-based tools. This review focused on the capability and functionality of software tools.
    - Conducted review of past efforts looking at potential requirements for a web-based anthropometry tool. This review was based on the 2012 Comprehensive Ergonomic Tools and Techniques (CETTs) and 2015 Soldier System Effectiveness (SoSE) Architecture Framework (AF) stakeholder meetings, and in discussion with the Technical Task Authority (TTA).
    - Based on the above two tasks, a mind map of potential capability and functionality requirements for a web-based anthropometry tool was developed.
    - The mind map of potential capability and functionality requirements were subsequently reviewed and validated by the Task Authority (TA) and TTA and gaps in information were identified. These requirements were next categorically organized to create a multi-voiced decision model.
    - A facilitated multi-voiced group discussion and validation effort was conducted with stakeholders
2. Identified requirements for the underlying database.

- In consultation with the TTA, preliminary requirements for the underlying database were identified during this task.

3. Identified a notional software distribution model.
    - A generic software distribution model was developed as part of this task. Hosting of the software tool was not evaluated, however, possible options include DWAN, DRENET or commercial host.

Results

Based on this effort, an initial strawman for a Statement of Requirements (SOR) for a suite of web-based anthropometric software tools was developed and a notional software architecture was proposed.

Conclusion

Throughout this project, stakeholders affirmed the importance, utility, and need for a 1D and 3D web-based anthropometry tool. It was therefore recommended that the SOR strawman, developed during this project phase be used in a subsequent phase, following an iterative software development process. This development cycle should begin with the conceptualization and system design of the web-based anthropometry tool, storyboarding the software tool sets/applications, and coding/programing the software. While requirements validations, integration assessments, trade-off analysis and usability evaluations with users be conducted throughout the evaluation process.

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Acknowledgements

The authors would like to extend their immeasurable gratitude to the numerous stakeholders and individuals who have contributed their knowledge, expertise and time over the past several years to help us get to this point. And in helping to pave the future path, to creating and implementing a web-based anthropometric tool, to benefit everyone within the Canadian Armed Forces.

2. Background

To effectively exploit the data that was collected for the 2012 anthropometric survey of the Canadian Forces (CF), Department of National Defence (DND) stakeholders identified a requirement for a web-based tool that would allow all stakeholders involved in capability development to accurately, independently, and correctly apply CF anthropometric data (Nakaza, 2012).

In support of this need, three focus groups were held with key stakeholders to define requirements for a web-based anthropometry tool. The first two stakeholder meetings were held in 2012 as part of the Comprehensive Ergonomics Tools and Techniques (CETTs) project, while the third meeting was held in 2015 as part of the Soldier System Effectiveness Architecture Framework (SoSE AF) development project.

During the 2012 effort *"a trade study was initially conducted on the current state of the art in applied anthropometric tools. Potential content for a web-based applied anthropometry tool was prototyped using Microsoft PowerPoint and packaged into a storyboard presentation based on two case studies. Using this storyboard, two focus groups were held with DND Stakeholders to discuss roles and responsibilities, past and current projects, and related stakeholder needs, requirements, and functionality that need to be reflected in a web-based tool. Finally, the user interface for a web-based tool was briefly examined"* (Nakaza, 2012). The 2015 stakeholder meeting further developed these requirements for a web-based anthropometry tool. A list of the attendees for these focus group meetings and a summary of key requirements for a web-based anthropometry tool are presented in Annex B: Web-based anthropometry tool – summary of key stakeholder requirements (2012 and 2015).

As per the Statement of Work (SOW), the aim of this tasking was to now carry out initial planning for the development of a suite of web-based anthropometric software tools and associate databases, based on the Canadian Forces Anthropometric Survey (CFAS) 2012 data, for use in Canadian Armed Forces acquisition processes. Three parallel streams were followed in carrying out this objective:

1. Undertook a review of potential requirements for a web-based anthropometry tool. Essential and desired requirements were identified, ranked and prioritized.
2. Identified requirements for the underlying database.
3. Identified a notional software distribution model.

The following report discusses this effort in more detail.

3. Methods

A systematic approach was followed in order to develop a suite of web-based anthropometric software tools and associate databases, based on the CFAS 2012. Three parallel streams were followed in carrying out this objective. Figure 1 depicts this project approach.

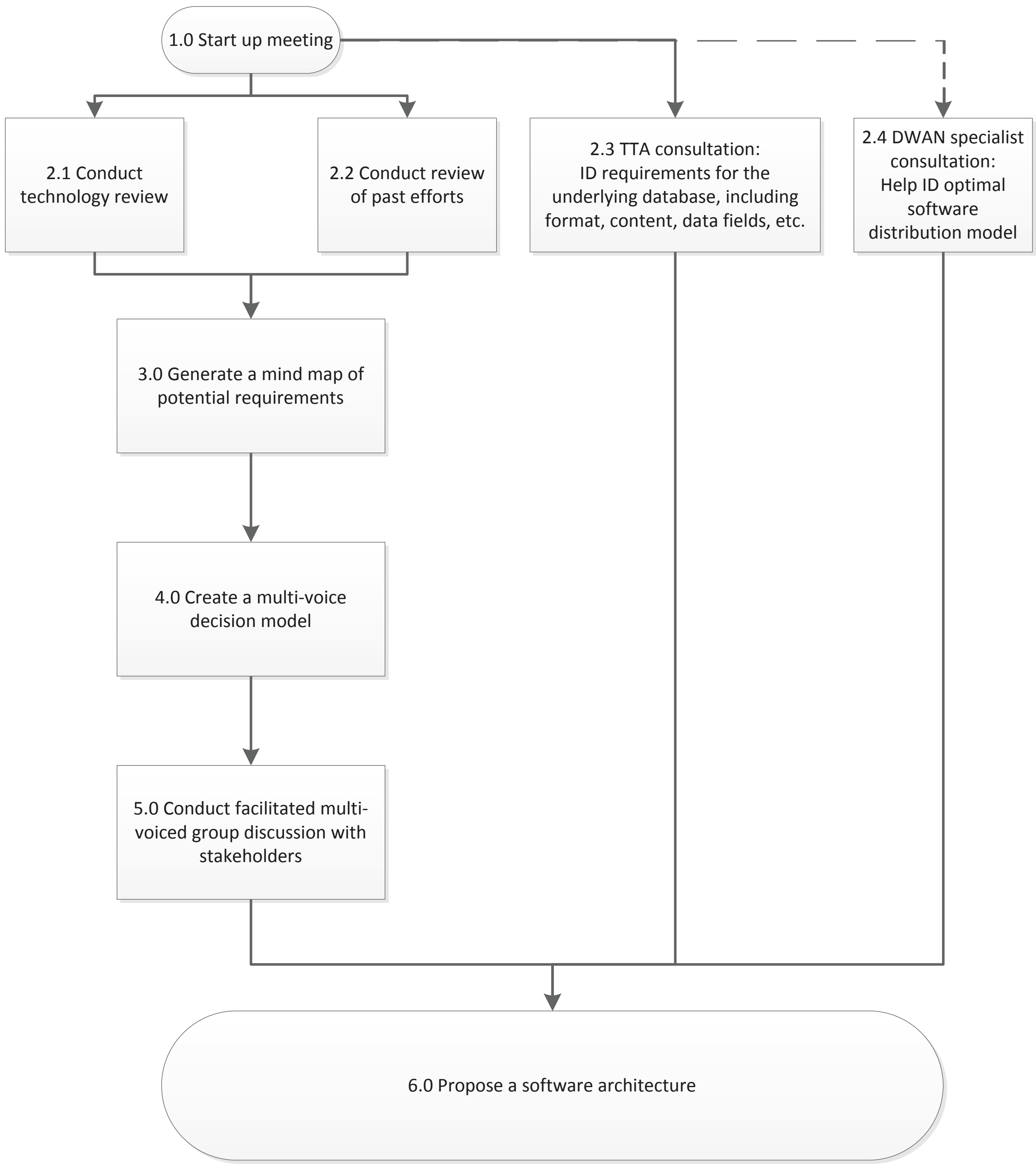


Figure 1: Systematic project approach (function flow diagram)

The following section provides a brief overview of each of these tasks.

3.1 Start-up meeting (Task 1.0)

A start-up meeting was undertaken with the Task Technical Authority (TTA) to discuss the project scope and intent, review past efforts, and to discuss the project process.

3.2 Conduct technology review (Task 2.1)

A technology review and trade study of the CFAS Explorer 2012 software, 3D shape analyzer tools, and Commercial-Off-The-Shelf (COTS) web-based tools was undertaken. This review focused on the capability and functionality of software tools.

3.3 Conduct review of past efforts (Task 2.2)

A review of potential requirements for a web-based anthropometry tool was undertaken, based on the 2012 CETTs and 2015 SoSE AF stakeholder meetings, and in discussion with the TTA.

3.4 TTA consultation (Task 2.3)

In consultation with the TTA, preliminary requirements for the underlying database were identified during this task.

3.5 DWAN specialist consultation (Task 2.4)

Due to time limitations and lack of availability, a DWAN specialist was consulted during this task to help identify a notional software distribution model for the anthropometry tool. This task, as well as investigating other distribution options (e.g. DRENET, commercial server) will be investigated at a later date.

3.6 Generate a mind map of potential requirements (Task 3.0)

Based on Task 2.1 (Section 3.2) and 2.2 (Section 3.3) above, a mind map of potential capability and functionality requirements for a web-based anthropometry tool was developed.

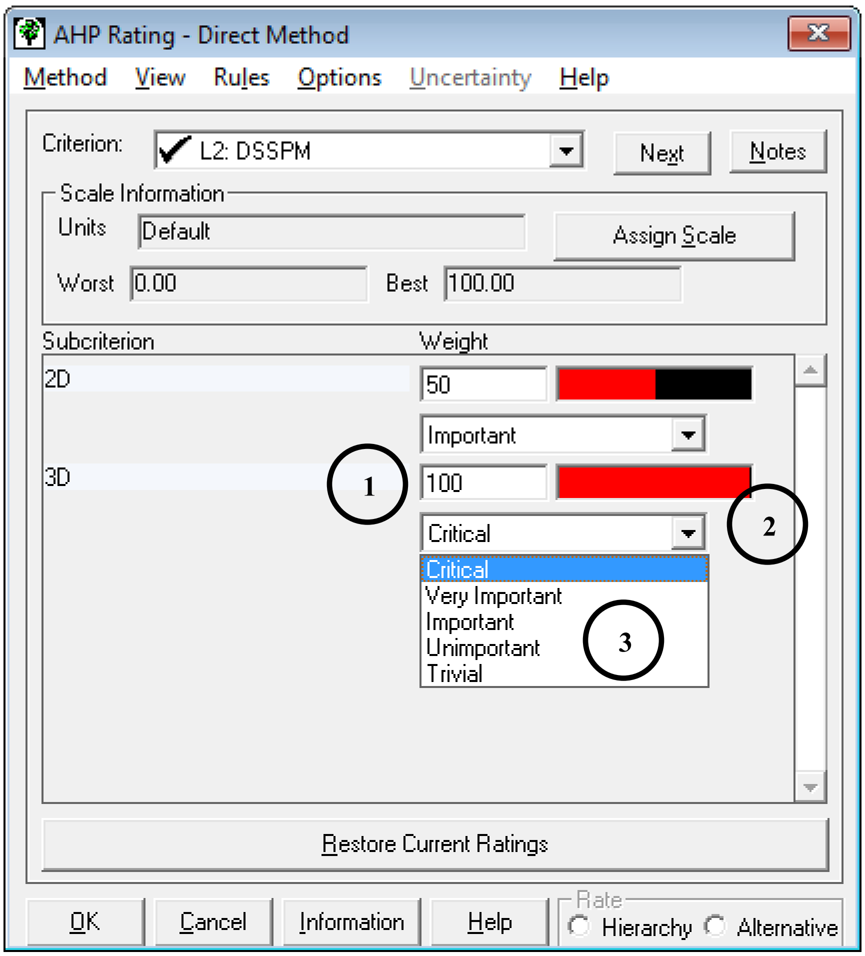
3.7 Create a multi-voice decision model based on above task (Task 4.0)

Following the completion of Task 3.0 (Section 3.6), the mind map of potential capability and functionality requirements were reviewed and validated by the Task Authority (TA) and TTA and any gaps in information were identified. These requirements were next categorically organized to create a multi-voiced decision model.

3.8 Conduct facilitated multi-voiced group discussion with stakeholders (Task 5.0)

The multi-voiced decision model, as developed in Task 4.0 (Section 3.7), was subsequently used by the TA and TTA to rate the measures of importance for these desired requirements, utilizing the Criterium Decision Plus (CDP version 4.0, InfoHarvest Inc., Seattle, WA) software – Analytic Hierarchy Process (AHP). Using weights, the relative importance of each sub-criterion with respect to the other sub-criteria of a given parent criterion was undertaken, taking a top down approach.

These preferences were then multiplied down the structure of the hierarchy resulting in a score of relative importance. Three types of psychometric rating scales were used during this exercise; Numerical (i.e., score out of 100), Graphical (i.e., adjust a horizontal bar on the graphical view to show graphically how a criterion rates), and Verbal (five-point scale of importance ranging from Critical to Trivial). This criterion rating window is shown in Figure 2.



Numerical (i.e., score out of 100) (no. 1), Graphical (i.e., adjust a horizontal bar on the graphical view to show graphically how a criterion rates) (no. 2), and Verbal (five-point scale of importance ranging from Critical to Trivial) (no. 3)

Figure 2: CDP software criterion rating window

A facilitated focus group discussion was subsequently conducted to validate the prioritization of requirements for a web-based anthropometric tool, as well as to identify missing capability and functionality requirements. This stakeholder meeting was held on 15 February 2017 at the National Printing Bureau (NPB) – ADM(PA) conference room alpha, in Gatineau, Quebec. Stakeholder participants are listed in Table 1.

Table 1: Anthropometry tool stakeholder prioritization meeting

Stakeholder	Organization
Major Mark Rutley (TA)	ADM(Mat) Director Soldier Systems Program Management (DSSPM) 10 (Integrated Soldier System Project – ISSP) - Human Factors Support Cell (Bioscience Officer)
Allan Keefe (TTA)	DRDC-Toronto - Defence Scientist
James Kuang	ADM(Mat) DSSPM 10 (ISSP) - Life Cycle Materiel Manager (LCMM) - Anthropometry – BoSS
Jean-Christophe St-Maur	Director Land Requirements (DLR) 5 – HSI specialist (Bioscience Officer)
Patricia Brown	ADM(Mat) DSSPM 3 (Operational Equipment)
Captain Christopher Bryan	Directorate Technical Airworthiness and Engineering Support (DTAES)
Carol Cracknell	ADM(Mat) DSSPM 2 (Clothing) - Design and development

4. Results

Results of the systematic approach, that was followed to develop a suite of web-based anthropometric software tools and associate databases based on the CFAS 2012, are presented in the following section.

4.1 Start-up meeting (Task 1.0)

During the start-up meeting the proposed project process was discussed with the TTA, several minor changes were made, and understanding of the project scope, and expected deliverables were clarified. A software demonstration of the 3D Shape Analyzer tool was also provided by the TTA. The demonstration included exploring the shape database, and the ability to hold Body Mass Index (BMI) constant, while investigating Principal Components Analysis (PCA)1 and PCA(1+n). A preliminary technology review of the capability and functionality of the CFAS 2012 Explorer, and COTS anthropometry based tools was also presented to the TTA. This technology review is discussed in more detail in Section 4.2 below. Initial discussion into the identification of requirements for the underlying database was also undertaken. This is discussed in more detail in Section 4.4.

4.2 Conduct technology review (Task 2.1)

A technology review and trade study, focussing on the capability and functionality of web-based anthropometric software tools was undertaken. The prototype Microsoft-Access based CFAS Explorer one-dimensional (1D) tool and User Guide served as a starting point for this technology review, to determine the current capability and functionality afforded to the Canadian Armed Forces (CAF). This tool provided users with a capability to select, filter, plot and export CFAS data as well as perform basic analysis of the bivariate distribution of selected measures. Following this review, the world-wide-web was used to search for and identify COTS web-based anthropometry tools. The search criteria explored 1D/traditional data toolsets and three-dimensional (3D) toolsets separately. 1D/traditional data toolsets were the focus of early searches, since these were generally more fully developed. The focus of the review subsequently shifted towards 3D oriented standalone anthropometric tools, several of which were still under development. These 3D oriented tools were, included in this review to demonstrate the potential capability and functionality that could be incorporated into a web-based anthropometric tool.

Discussion with the TTA served as additional guidance for the technology review. Where possible, the software tools themselves were tested. User manuals, presentation slides, video tutorials, and research papers were also used to identify potentially useful features of the COTS tools and those that were under development. A list of these anthropometric software tools is presented below in section 4.2.1, and a summary of the capabilities and features explored during the technology review is presented in section 4.2.2. This information has also been incorporated into the summary of potential requirements for a web-based anthropometry tool, which is discussed in more detail in Section 4.6. Please refer to Annex A: Trade study of Commercial-Off-The-Shelf anthropometry based tools – presentation, for the complete technology review.

4.2.1 Review of anthropometric software tools

The following sources of information were used in undertaking this technology review.

Table 1: Anthropometric software tools

Source	Description	Hyperlink
MARC Tool [U.S. Army Research Laboratory Human Research and Engineering Directorate]	An app intended to provide a resource for accessing standardized body size data, guidance on applying the data, and tools that aid in collection and evaluation of such data as applied to the design of Army materiel ("Mobile Apps for Human System Integration").	YouTube Tutorial: https://www.youtube.com/watch?v=yewOFd8r6AA Portable Document Format (PDF): https://www.arl.army.mil/opencampus/sites/default/files/HS15.pdf
Open Design Lab [Pennsylvania State University]	Explore and download various anthropometric data for populations such as the U.S. Army or U.S. civilians. This program contains anthropometric data from the U.S. Army Anthropometry Survey (ANSUR) I, gross anthropometry measures of U.S. civilians from the National Health and Nutrition Examination Survey (NHANES), and Society of Automotive Engineers (SAE) Manikins. (Penn State Open Design Lab, 2014)	Web-Based Tool: http://openlab.psu.edu/
DINED [Delft University of Technology]	Compare anthropometric data from different studies, visualize the correlation between body dimensions, compare a person or persona to a population, and predict how far an individual can reach using this suite of tools (DINED Anthropometric Database).	Web-Based Tool: http://dined.io.tudelft.nl/en/how-it-works
Civilian American and European Surface Anthropometry Resource (CAESAR) Database [Shape Analysis Ltd.]	The CAESAR Database uses an integrated text and shape search engine. Search of similar body shapes can be constrained by demographic and/or traditional anthropometric data. The search engine can also manage 3D clothing files as well as 3D equipment.	PowerPoint Presentation: http://webapp1.dlib.indiana.edu/virtual_disk_library/index.cgi/3725325/FID3800/speakers/robinett.pdf
3D-Anthropometric Sizing Analysis System (ASAS) [Pohang University of Science and Technology & Ergonomic	A 3-dimensional sizing analysis system for head-related designs based on the CAESAR database (Lee et al., 2015).	YouTube Tutorial: https://www.youtube.com/watch?v=xZQUeWhfqXk Journal Article: http://journals.sagepub.com/doi/pdf/10.1177/1541931215591308

Design Technology Lab]		
EuroFit	A set of tools to facilitate the exploitation of 3D anthropometric data using an online platform and open framework (Alemany, 2014).	Website: http://www.eurofit-project.eu/cms/front_content.php?idcat=67&lang=1 Keynote Presentation: http://www.slideshare.net/AlfredoBallesterFern/20150602-cadans-seminar-v08slideshare04
Size North America – iSize [Human Solutions of North America, Inc.]	A web-based tool (iSize portal) with anthropometric data from the North American population, with the goal of helping develop products, marketing strategies, and overall business.	Website: http://www.sizenorthamerica.com/cms/front_content.php?idcat=59&lang=1 YouTube Tutorial: https://www.youtube.com/watch?v=1m0PhcFWiy4
BodyLabs Overview [Body Labs Inc.]	Pose, animate, measure, compare, analyze, average, predict, and design using 3D avatars. Easily add textures and integrate processed body models into animation, gaming or virtual reality applications.	Website : https://www.bodylabs.com/
DRessing Any Person (DRAPE) [Body Labs Inc.]	A system to digitally dress and animate synthetic bodies, in order to predict clothing deformation and facilitate clothing synthesis (Guan, Reiss, Hirshberg, Weiss, and Black, 2012).	Abstract: https://www.bodylabs.com/resources/white-papers/drape/
BodyLabs – Blue [Body Labs Inc.]	A program that predicts detailed body measurements based on height and weight, with the aim of helping users find better-fitting clothing. Users may measure and input 6 key body measurements to improve the accuracy of the predicted measures Pose, animate, measure, compare, analyze, average, predict, design. Easily add textures and integrate processed body models into animation, gaming or virtual reality applications. (Body Labs Inc., 2016).	YouTube Video: https://www.youtube.com/watch?v=33qBnhdWQ7w PDF: https://www.bodylabs.com/wp-content/uploads/2016/09/Body-Labs-Blue-Data-Sheet.pdf
Sensitive Couture	An interactive tool that allows “bidirectional editing between 2D patterns and 3D high-fidelity simulated drape forms” (Umetani, Kaufman, Igarashi, and Grinspun,	PDF: http://www.cs.columbia.edu/cg/SC/SC.pdf (Umetani, N., Kaufman, D. M., Igarishi, T., Grinspun, E. [PDF]. (n.d.). Sensitive Couture for Interactive Garment Modeling and Editing.)
University of Michigan Transportation Research Institute	3-dimensional parametric human models developed by combining skeleton geometry models and external surface models for individuals of varying age and size.	http://mreed.umtri.umich.edu/mreed/pubs/Reed_2013_3D_Anthropometry.pdf Journal Articles: http://www.jbiomech.com/article/S0021-

(UMTRI)		9290(16)30694-7/fulltext https://www.researchgate.net/publication/293489949_Development_and_Validation_of_a_High_Anatomical_Fidelity_FE_Model_for_the_Buttock_and_Thigh_of_a_Seated_Individual http://link.springer.com/article/10.1007/s10439-015-1307-6
3D Production Suite [EFI Optitex]	A fully integrated 2D/3D clothing pattern production suite. Allows users to build a library of custom 3D human models, and visualize changes in style, fit, colour, fabric, and design features.	YouTube Video: http://optitex.com/solutions/odev/3d-production-suite/
Total Human Model for Safety (THUMS) [JSOL Corporation]	Finite element human models including internal organ geometry, skeleton models, and muscle models designed for use in crash simulations (JSOL Corporation, 2017).	Website: http://lsdyna.jsol.co.jp/en/thums/index.html
Anthropometric Measurement Interface (AMI) [Delft University of Technology]	A database of anthropometric measurements that allows users to explore measurement techniques employed by various studies ("Anthropometric Measurement Interface Demonstration Guide").	PDF (user manual): http://wear2.io.tudelft.nl/files/manuals/AMI_Demo_Manual.pdf
Job Assessment Software System (JASS)	An app that allows users to identify the human aptitudes required for a certain job and the amount of aptitude that is required. Many subject matter experts (SME's) can rate the same job to increase accuracy ("Mobile Apps for Human System Integration"). *Note: This example, although not directly related to 1D/3D anthropometry, was included to demonstrate the potential incorporation of functional anthropometry (job selection criteria) into a web-based software tool.*	Youtube Tutorial: https://www.youtube.com/watch?v=CD0brhKKO88 PDF: https://www.arl.army.mil/opencampus/sites/default/files/HS15.pdf
CFAS 2012 Explorer [Defence Research and Development Canada (DRDC)]	A Microsoft-Access based data explorer tool that allows users to search the CFAS 2012 database using custom data queries based on key demographic criteria (Keefe, Angel, and Mangan, 2015). *Note that the CFAS 2012 Explorer tool is not a commercial off-the-shelf tool.*	User Manual: CFAS Explorer [User Manual]. (2013). Toronto, ON: Research Operations Group, DRDC - Toronto Research Centre. Final Report: http://pubs.drdc-rddc.gc.ca/BASIS/pcandid/www/engpub/DDW?W%3DSYSNUM=803174
3D Shape Analyzer	A tool that conducts multiple levels of principal components analysis (PCA)	As demonstrated by the TTA.

[National Research Council (NRC)]	on 3D scans from the CFAS 2012 database. *Note that the 3D Shape Analyzer is not a commercial off-the-shelf tool.*	

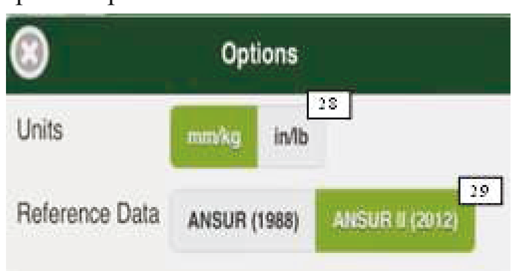
4.2.2 Summary of capabilities and features explored during the technology review

Key capabilities and features identified and explored during the technology review (Annex A) were categorized and summarized based on the results of the multi-voiced model. This information is categorized based on 1D and 3D toolset features and is included as part of the tables in Annex E: Preliminary SOR strawman for a web-based anthropometry tool (column for 'Concept Example'). For example the following section outlines some of these capabilities and features for 1D and 3D toolsets

4.2.2.1 Traditional (1D) toolsets

4.2.2.1.1 Unit conversion

- The Explore Anthropometry module of the MARC anthropometry resource, allows users to easily switch between metric and imperial measurement units, and between reference databases using the "options" panel.

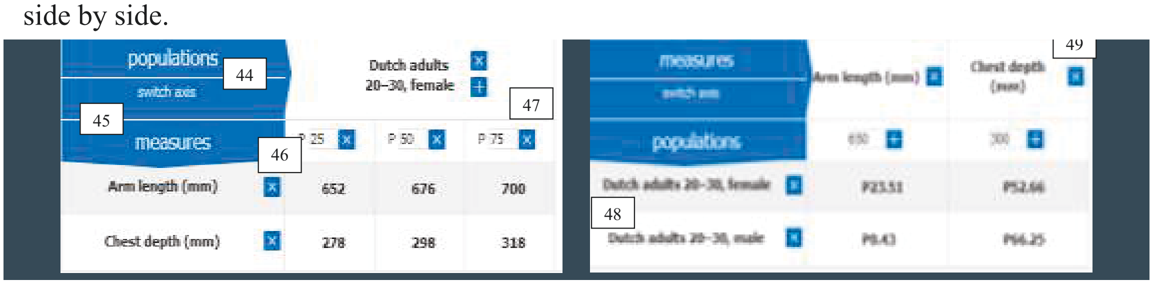


(Accessed from https://www.youtube.com/watch?v=yewOFd8r6AA, reprinted with permission from Chris Garneau, Army Research Labs)

Figure 3: MARC anthropometry resource

4.2.2.1.2 Visualization

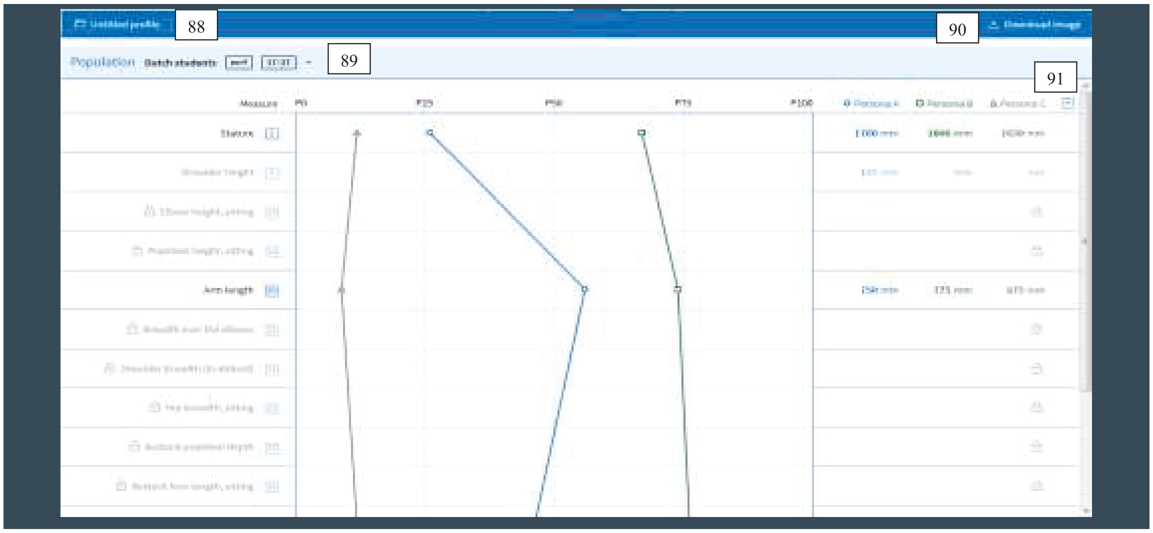
- The 1D Database Explorer by TU Delft, allows users to select and compare multiple data sets side by side.



(Accessed from http://dined.io.tudelft.nl, reprinted with permission from Johan Molenbroek TUDelft)

Figure 4: TUDelft database explorer

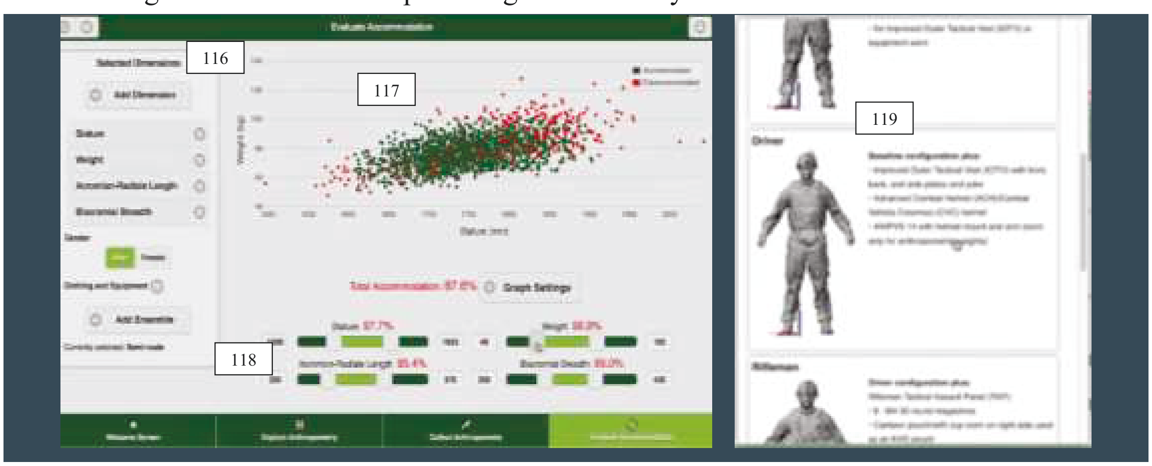
- With the Profiler tool by TU Delft, users can input anthropometric measurements and see a graphical representation of how those measurements compare to a selected data set.



(Accessed from http://dined.io.tudelft.nl, reprinted with permission from Johan Molenbroek TUDelft)

Figure 5: TUDelft profiler tool

- The MARC tool contains a library of clothing and equipment offsets for the US Army, which can be applied during accommodation analysis. Accommodated values are shown in black, while dis-accommodated values are red. By changing the equipment settings, users can see the change in accommodation percentage immediately.



(Accessed from https://www.youtube.com/watch?v=yewOFd8r6AA, reprinted with permission from Garneau, Army Research Labs)

Figure 6: MARC multivariate accommodation analysis

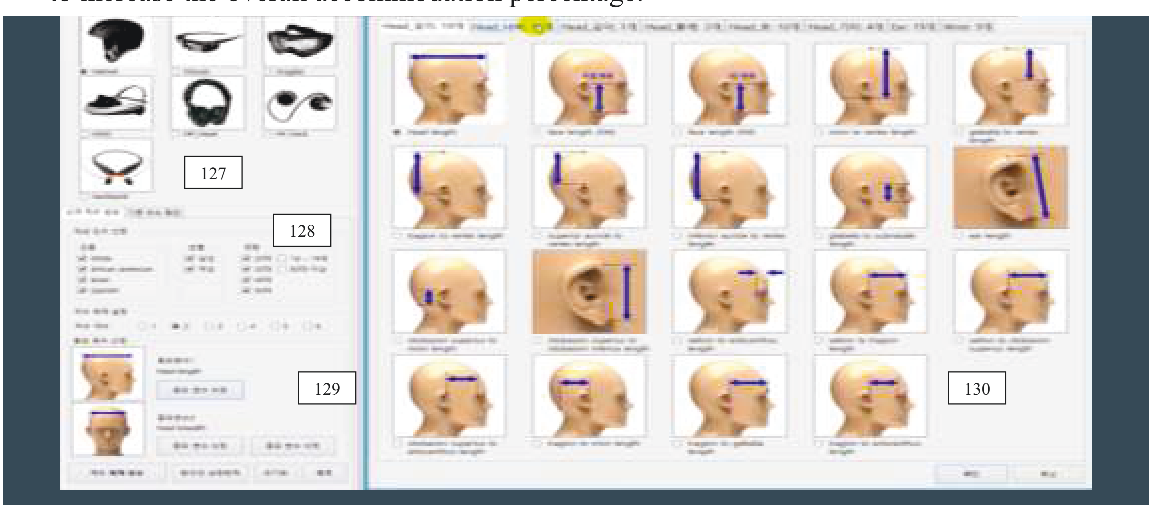
4.2.2.1.3 Accommodation

- The Multivariate Accommodation Calculator developed the Open Design Lab at Penn State, allows the user to evaluate accommodation percentage based on multiple anthropometric measurements.

(Accessed from http://openlab.psu.edu/, reprinted with permission from Parkinson, Penn State)

Figure 7: Penn State Open Design Lab data explorer

- 3D Anthropometric Sizing Analysis System by EDT Lab, generates recommended sizing categories based on user-selected populations and measurements (note: the tool is currently only populated by head forms). The sizing categories can then be manually adjusted in order to increase the overall accommodation percentage.

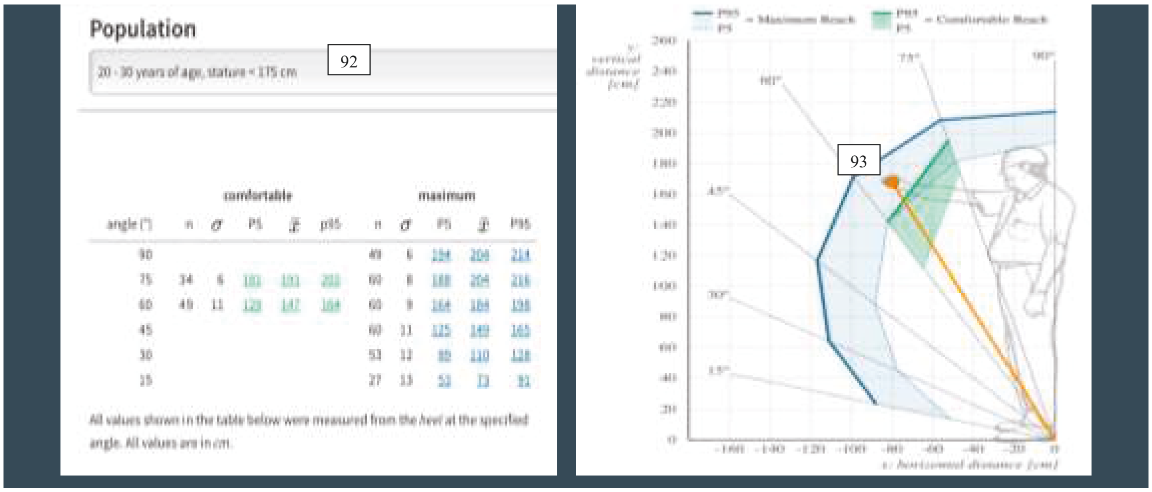


(Accessed from https://www.youtube.com/watch?v=xZQUeWhfqXk, reprinted with permission from Lee)

Figure 8: EDT Lab anthropometric sizing analysis system

4.2.2.1.4 Reach analysis

- TU Delft's 1-Dimensional Reach Envelopes, predict an individual's reach range based on age and height. This information is represented in a table as well as on an interactive diagram.

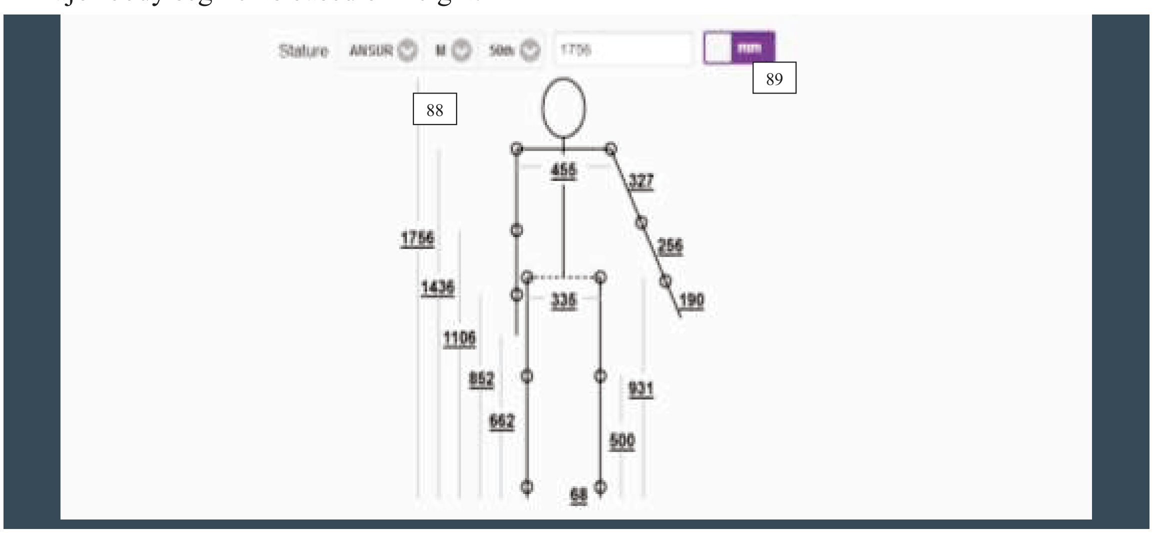


(Accessed from http://dined.io.tudelft.nl, reprinted with permission from Johan Molenbroek, TUDelft)

Figure 9: TUDelft reach envelope analysis

4.2.2.1.5 Proportionality constraints

- The Scaling Calculator developed by Penn State's Open Design Lab, predicts the length of major body segments based on height.

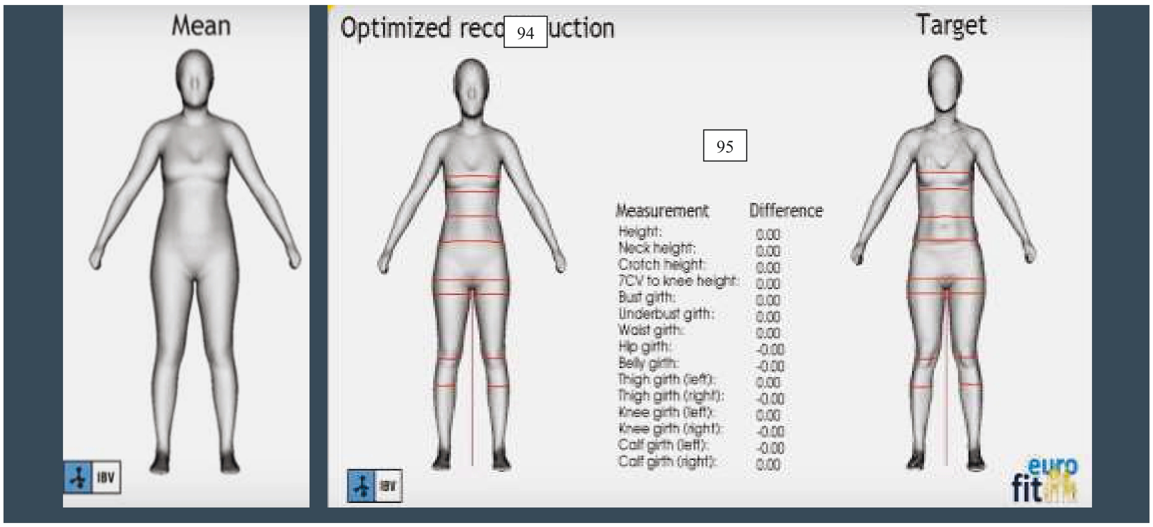


(Accessed from http://openlab.psu.edu/, reprinted with permission from Parkinson, Penn State)

Figure 10: Open Design Lab scaling calculator

4.2.2.1.6 3D reconstruction from 2D measurements

- The EuroFit project's 3D reconstruction tool, uses 2D anthropometric measurements to generate a 3D model of the individual.



(Accessed from http://www.slideshare.net/AlfredoBallesterFern/20150602-cadans-seminar-v08slideshare04, reprinted with permission from Ballester)

Figure 11: EuroFit 3D reconstruction from 2D manikin

- The Manikin Picker from Penn State Open Design Lab, contains a library of 3D manikins. Users specify anthropometric measurements and search for the manikins that most closely match their specifications. 2D measurement data for each manikin is also available to the user.

(Accessed from http://openlab.psu.edu/, reprinted with permission from Parkinson, Penn State.)

Figure 12: Open Design Lab manikin picker

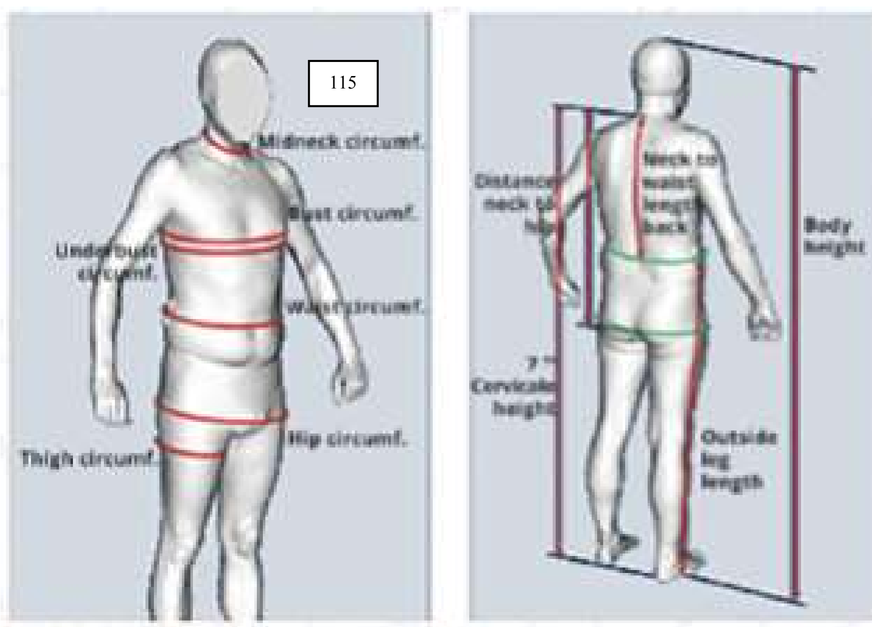
4.2.2.1.7 Functional anthropometry

- The Job Assessment Software System (JASS), allows users to specify skills requirements for certain tasks, and to associate those tasks with jobs. This capability could easily be adapted to anthropometric measurements or functional anthropometry for use in personnel selection or bid evaluation.

4.2.2.2 Three-dimension toolsets

4.2.2.2.1 Digital measurement

- The digital measuring tape by EuroFit, is able to extract 1D anthropometric measurements from high quality 3D scans. This allows the user to digitally calculate standard or custom body measurements.

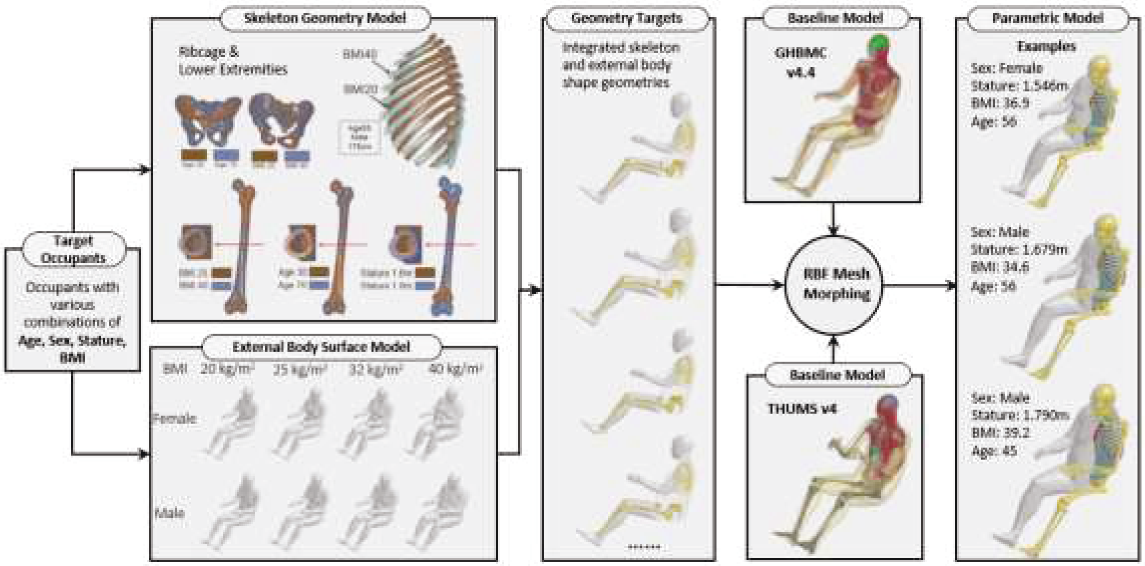


(Accessed from http://www.slideshare.net/AlfredoBallesterFern/20150602-cadans-seminar-v08slideshare04, reprinted with permission from Ballester)

Figure 13: EuroFit Project digital measuring tape

4.2.2.2.2 Internal organ shape analysis

- Parametric human models developed by the University of Michigan’s Transportation Research Institute (UMTRI), combine skeletal and external body surface models based on Computerized Tomography (CT) scans of hundreds of adults.



(Accessed from https://www-esv.nhtsa.dot.gov/Proceedings/25/25ESV-000314.pdf, reprinted with permission from Hu)

Figure 14: UMTRI parametric human models

- The location and composition of internal organs have been built into JSOL Corporation's Total Human Models for Safety.

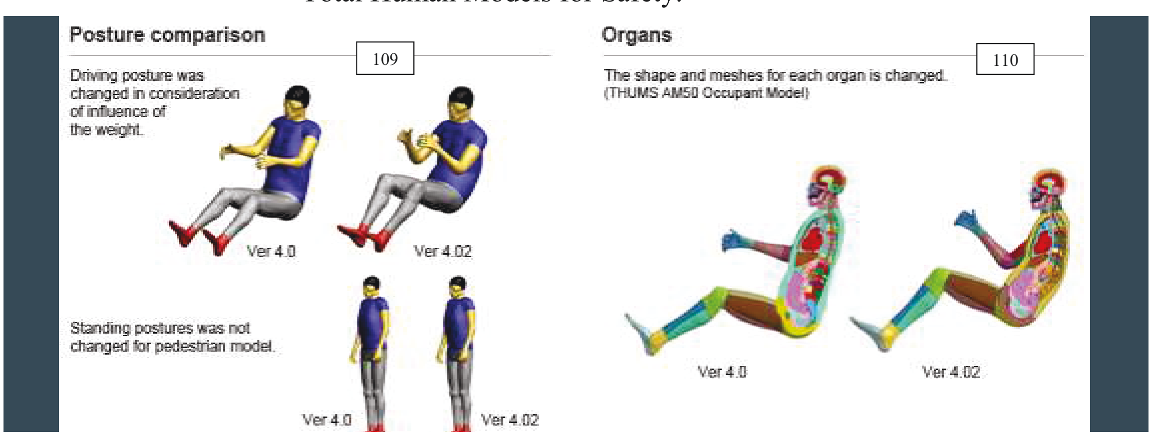
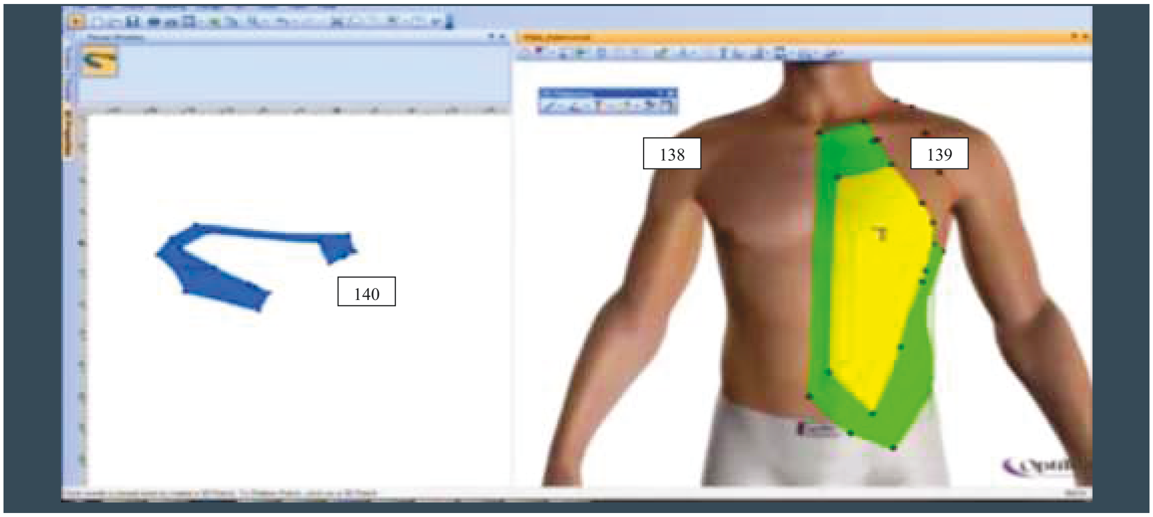


Figure 15: JSOL organ model

4.2.2.2.3 Clothing

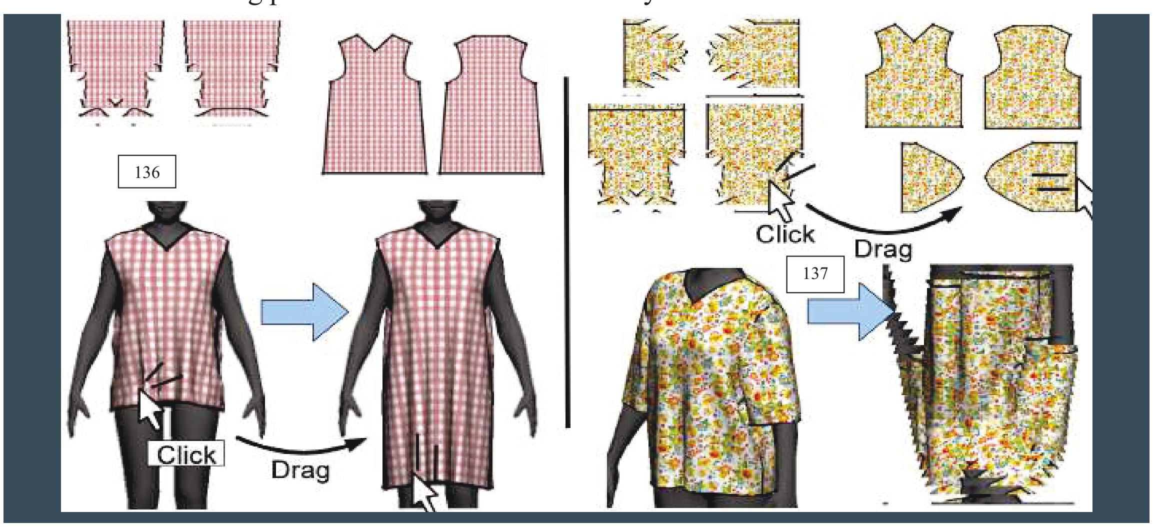
- The 3D production suite by Optitex, allows users to store a library of 3D manikins, on which articles of clothing can be created. The 2D clothing pattern is generated automatically, and users may make changes on either the 2D pattern or the 3D garment.



(Accessed from http://optitex.com/solutions/odev/3d-production-suite/, reprinted with permission from EFI Optitex)

Figure 16: Optitex clothing design

- Sensitive Couture allows users to virtually dress 3D manikins with digital garments. Changes to the 2D clothing pattern are reflected immediately on the 3D model.

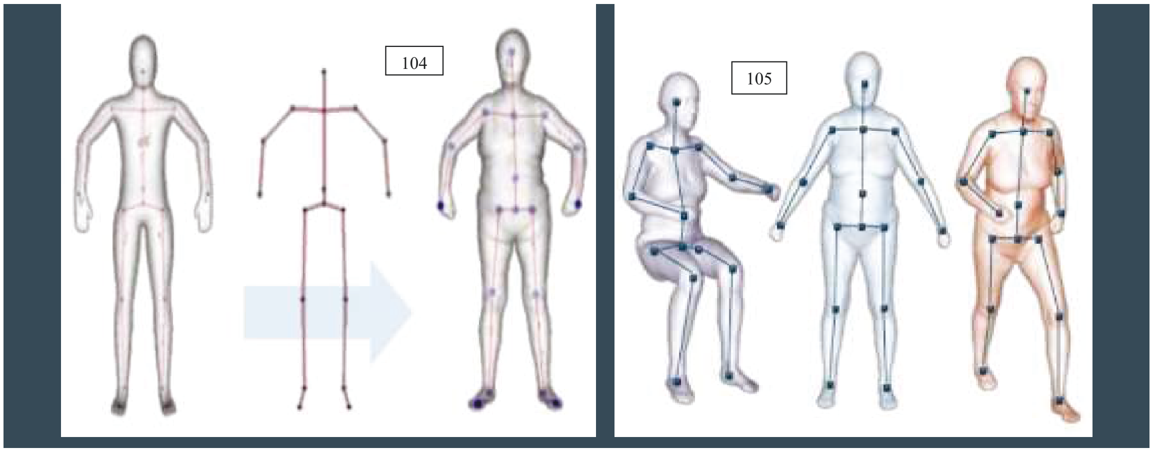


(Accessed from http://www.cs.columbia.edu/cg/SC/SC.pdf, reprinted with permission from Umetani)

Figure 17: Sensitive Couture 2D/3D clothing design

4.2.2.2.4 3D scan animation

- EuroFit's Skeleton Transfer feature scales and adjusts a skeleton template to fit a 3D scan, giving the user the ability to manipulate the posture of the scan.



(Accessed from http://www.slideshare.net/AlfredoBallesterFern/20150602-cadans-seminar-v08slideshare04, reprinted with permission from Ballester)

Figure 18: EuroFit skeleton transfer

- The DRAPE tool developed by BodyLabs allows users to dress and animate 3D manikins. This tool also incorporates fabric characteristics to predict how the manikins' clothing will deform as they perform different actions. More recently, these algorithms have been

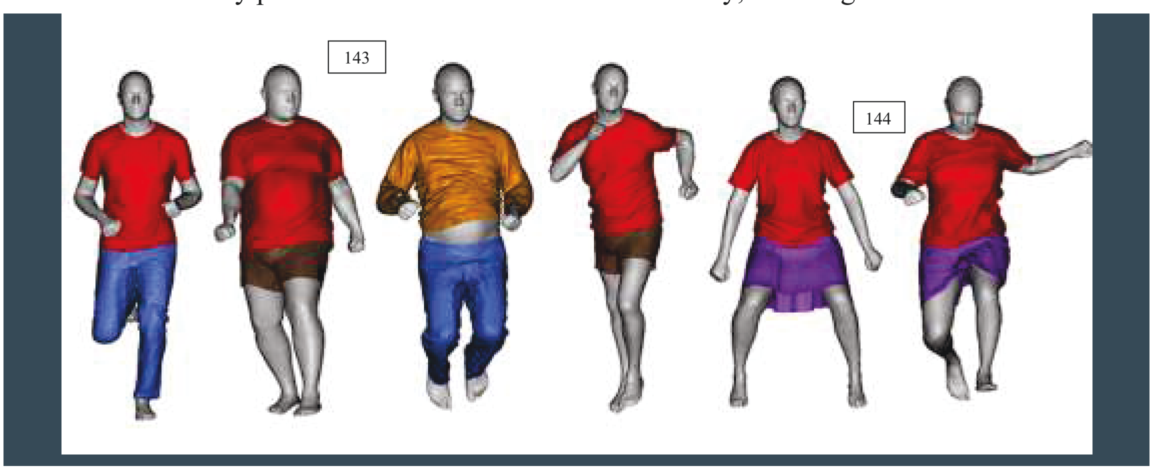


Figure 19: Body Labs clothing deformation

4.3 Conduct review of past efforts (Task 2.2)

A review of past efforts, which investigated DND stakeholder requirements for a web-based anthropometry tool, was undertaken. These requirements were initially derived from two stakeholder meetings held in 2012 as part of the Comprehensive Ergonomics Tools and Techniques (CETTs) project, and a third meeting held in 2015 as part of the Soldier System Effectiveness Architecture Framework (SoSE AF) development project. In total 25 individuals representing stakeholders from the Directorate Land Requirements (DLR), Directorate Technical Airworthiness and Engineering Support (DTAES), Directorate Soldier Systems Program Management (DSSPM), Director General Major Project Delivery (DGMPD), Project Management Office Canadian Surface Combatant (PMO CSC), PMO Joint Support Ship (JSS), and other organizations participated. This list is presented in the Table 2 below, and in Annex B: Web-based anthropometry tool – summary of key stakeholder requirements (2012 and 2015).

Table 2: 2012 and 2015 stakeholder meeting participants

2012 stakeholder meeting
Army DLR (x2)
ADM(Mat), DTAES (x2)
ADM(Mat) DSSPM (x3)
ADM(Mat) DGMPD(L&S) (x3)
ADM(Mat) PMO CSC (x1)
ADM(Mat) PMO JSS (x1)
Unknown affiliation (x4)
2015 stakeholder meeting
ADM(Mat) DSSPM 2 (x3)
ADM(Mat) DSSPM 9 – weapon systems (x1)
ADM(Mat) DSSPM 3 (x2)
ADM(Mat) DSSPM 10 (ISSP) (x3)

A review of information as identified and provided by the TTA was also conducted. These included several publications as well as a list of derived requirements.

Table 3: Review of capability and functionality based on information identified and provided by the TTA

Source	Description	Review of capability and functionality
CFAS Explorer – Users Guide (n.d.) (also discussed in Table 1)	A data visualization tool for exploring the anthropometric data collected during the 2012 Canadian Forces Anthropometric Survey	- Chart type: uni/bivariate graphs - Selecting and displaying data - Summarize, plot, export data - Graphing tools (e.g. ellipse, min/max, boundary) - Summary statistics - Reset form - Query parameters - Graphical User Interface (GUI) - Tool tip - Percentile information
Cheng & Robinette (2007)	To promote the use and sharing of anthropometric databases, the World Engineering Anthropometry Resources (WEAR) group discusses an XML schema and web services as an alternative method for networking databases,	- Database structure: coding
Edwards, Furnell, Coleman, & Davis (2014)	A preliminary anthropometry standard for Australian Defence Force Army equipment evaluation is described. This preliminary standard is based on the Australian Warfighter	- Summary statistics: uni/multivariate - Protective Equipment and Clothing Correction Factors - Guidance on the assessment of user fit, clearance, reach, vision and posture - Measurement guide

	Anthropometry Survey (AWAS)	- Boundary manikins - Body landmark definitions - Overlay of skeletal system on 3D manikin
Furnell, & Coleman (2016)	Paper discusses future trends in military anthropometry	- Boot strapping - Toolsets: UMTRI Child Body Shape Explorer
Keefe, Angel, & Mangan (2015)	Report summarizing the methodology and findings from the 2012 Canadian Forces Anthropometric Survey (CFAS)	- Database content - Survey methodology such as sampling strategy, selection of dimensions to measure, adherence to various standards (e.g., International Organization for Standardization (ISO)), database validation and verification - CFAS Explorer Tool - Body landmark definitions - Overlay of skeletal system on 3D manikin
Keefe, personal communication (27 January 2017)		<u>Base module</u> - Database - Population filter requirements - Analysis and presentation of data requirements - Input/output requirements - Technical specifications <u>PCA module</u> - Input - Output -Specification generation requirements - Bid evaluation requirements - General requirements Toolset capability and functionality [1D] - Visualization module - Accommodation module - Principal components calculator - Clothing tariffing tool - Encumbrance offsets - Boot strapping analysis [3D] - PCA analyser - Internal organ shape analyser - Shape viewer - Clothing module - Blending/retargeting - CAD library
Nakaza & Tack (2015)	A storyboard was created for a web-based applied anthropometry tool. Using this storyboard, two focus groups were held with DND Stakeholders to discuss roles and responsibilities, past and current projects, and related stakeholder	- Toolset capability and functionality are summarized in Annex B: Web-based anthropometry tool – summary of key stakeholder requirements (2012 and 2015)

	needs, requirements, and functionality that need to be reflected in a web-based tool.	
Shu, Xi, & Keefe (2015)	Data processing and analysis methodology of the 2012 CFAS 3D data set	- Geometry processing tools - Characterizing human shape based on raw 3D scan data - Data registration - Parameterization of 3D data models - Mesh model - Principal Components Analysis - Shape Analyzer

This information is included in the summary of potential requirements for a web-based anthropometry tool, which is discussed in more detail in Section 4.6

4.4 TTA consultation (Task 2.3)

As stated in Section 4.1 above, initial discussion into the identification of requirements for the underlying database was undertaken with the TTA. These requirements included aspects such as the database structure and database content. Based on this guidance, a more thorough review of requirements was undertaken. It was however emphasized by the TTA that under this contract, the main effort was to "establish requirements for an anthropometric tool based on user input. Database design and other programming elements would be decided at design time". The following, therefore presents a high level overview of recommended requirements for the underlying database structure and database content.

4.4.1 Database structure

The establishment of a common database structure makes it possible to incorporate data from multiple surveys, such as CFAS and ANSUR, into a single database. In addition to greatly increasing the pool of available data, this allows users to analyze anthropometric data from multiple databases together, or to examine the differences between populations.

ISO 15535:2006 – General Guidelines for Establishing Anthropometric Databases contains recommendations for the characteristics of the user population, sampling methods, measurement items, and statistics to be used when establishing an anthropometric database. *ISO 15535:2006* was revised and replaced with *ISO 15535:2012*, but unfortunately this standard could not be accessed in time to be incorporated into this document.

ISO and International Electrotechnical Commission (IEC) guidelines for the coding, and entry, and validation of data are described in Sections 4.4.1.1, 4.4.1.2, and 4.4.2.1 below. Information from other anthropometric databases and publications were then used to supplement ISO standards. The recommendations for data integration (Section 4.4.1.3) and security (Section 4.4.1.4) are based on techniques employed by similar anthropometric databases to combine multiple data sets.

4.4.1.1 Coding

ISO/IEC 8859 is a series of character encoding standards established jointly by the ISO and IEC. *ISO/IEC-1:1998* contains 191 graphic characters called "Latin alphabet no. 1", and is intended for data and text processing applications as well as information interchange. This is the standard referenced by *ISO 15535:2012*.

In addition, the World Engineering Anthropometry Resource (WEAR) recommends an open source, reusable, extensible, and vendor-independent data format that can also encode character sets beyond American Standard Code for Information Interchange (ASCII), in order to accommodate international databases (Cheng and Robinette, 2007).

4.4.1.2 Data Entry

ISO 15535:2006 Sections 6.2, 6.3, and 7.1 recommends the following format for data entry.

- Basic demographic information (refer to section 4.4.2.2) shall be recorded as Items 1 to 11.
- Anthropometric measurements from ISO 7250-1:2008 shall be recorded as Items 11 to 56.
- Additional body measurements not present in ISO 7250 shall be recorded as data Items 57 and higher, in alphabetical order.

Please refer to *ISO 15535:2012* for further information.

4.4.1.3 Data Integration

4.4.1.3.1 Database Screening

The 2012 CFAS adheres to the survey methodology described in *ISO 15535:2006* (Keefe et al., 2015). Prior to integrating data from external sources into the database, a set of inclusion criteria should be established. Refer to *ISO 15535:2012 – General Guidelines for the Establishment of Anthropometric Databases* for more information.

4.4.1.3.2 Data Input

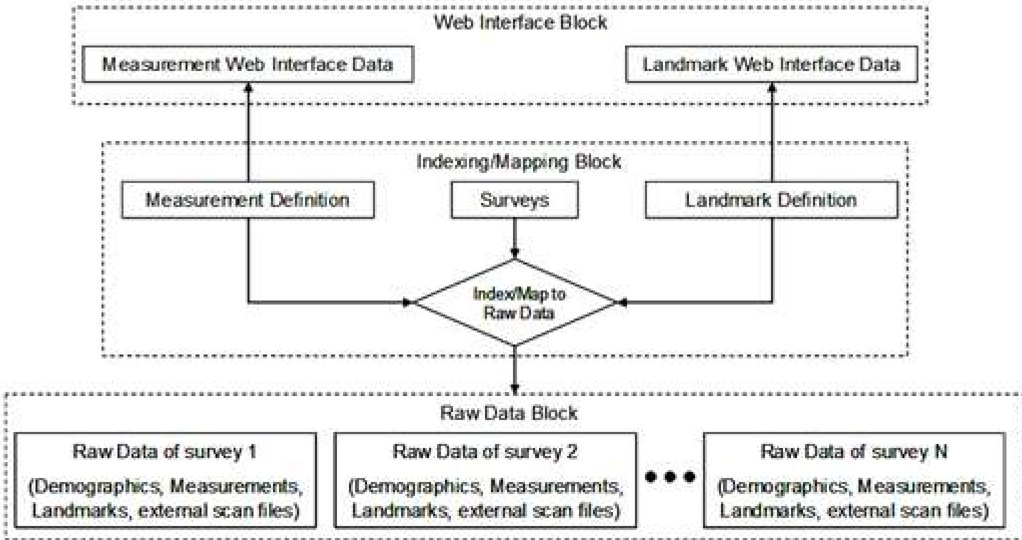
Researchers from the Committee on Data (CODATA) Anthropometry Task Group have examined several challenges associated with integrating data from multiple databases in a single software tool. Developers of the Collaborative Biomechanics Data Network use one of two data integration methods, depending on the contributor. Table 4 provides a summary of the data integration techniques used by the WEAR database and the Collaborative Biomechanics Data Network (CBDN).

Table 4: Comparison of data integration methods

Tight Integration	Linked Server	ETL and Data Warehouse	XML Schema (Loose Integration)
• Data is stored and maintained by the database keepers • Contributors are not required to commit time and resources to keeping the data up to date • Contributors have little autonomy over the data	• Straightforward architecture • Allows for queries, updates, commands, and transactions on distributed data sources • High level of integration requires a lot of maintenance and gives contributors less autonomy over their data • Requires direct access and a reliable network connection	• Not as intuitive to use • Load and rarely change data • Data must be checked before entering into database • Efficient for adding, updating, and storing data • Requires tight integration between databases – meaning less autonomy for contributors	• Contributors are responsible for maintenance of the data • Standardized template for data input • Allows contributors to maintain autonomy over their data • Text-based files are able to pass over firewalls • User authentication and authorization can be complicated • Facilitate database manipulation for distributed contributors

Note. Data integration methods are from Cheng and Robinette, 2007, and from Buhrman and Cheng, 2011.

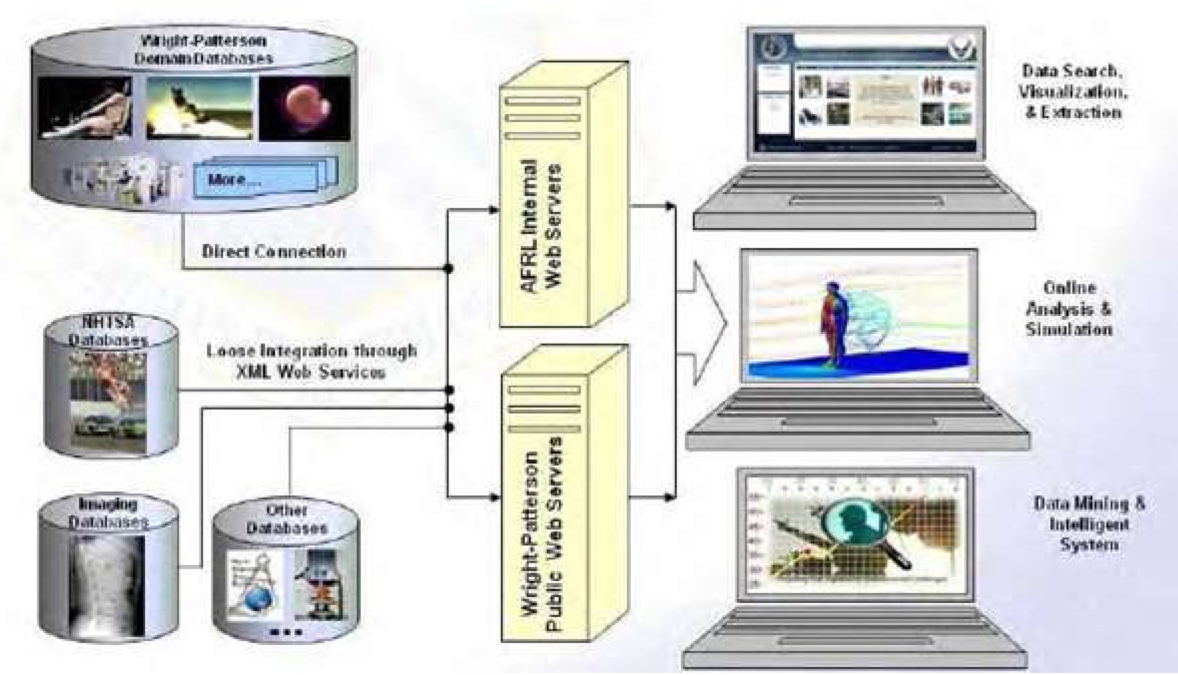
Based on an analysis of the short-term and long-term goals of the WEAR database, an extensible markup language (XML) web service was proposed as a short-term solution, while a hybrid web service/data mart model was proposed to satisfy WEAR’s long-term objectives (Cheng and Robinette, 2007).



ARIS database design. Adapted from "Development of the AFRL CAESAR Web User Interface" by H. Cheng, S. E. Mosher, M. S. Boehmer, and K. Robinette, 2007, retrieved from http://wear2.io.tudelft.nl/files/Banff08/Huaining.pdf.

Figure 20: ARIS database design

The CBDN, which was developed by the United States Air Force Research Laboratory (AFRL), allows contributors to decide between tight and loose integration of data. Data that is tightly integrated in the database is housed and maintained within the AFRL servers. Loosely integrated data is shared using XML web services that the contributor and CBDN agree to in advance. Figure 21 shows the structure of the CBDN using both types of integration.



Collaborative Biomechanics Database Network Structure. Adapted from “Collaborative Biomechanics Data Network (CBDN)” by J. Buhrman and H. Cheng, 2011.

Figure 21: CBDN Structure

4.4.1.4 Security

The need for distinct levels of access to the information in the database was conveyed by the TA and TTA due to the sensitive nature of some of the data collected during anthropometric surveys. A three-tiered login approach was proposed to suit the needs of the different database users.

For example, CAD files and 3D scan data where the participants’ features may be identified may fall under a different security classification than age, rank, and Military Occupational Structure Identification (MOSID). If anthropometric surveys conducted by other countries are included in this database, the contributing nations may have their own requirements regarding who should have access to their data. Further investigation into this area is needed.

The CBDN addressed this issue by creating two separate databases from the same pool of data. Both conduct authentication and authorization using ASP and .NET technology. The full database is stored in the Department of Defense internal server, which requires a DoD Common Access Card as well as a user login to access. Select information is stored in a second server that is accessible to the public and maintained by an engineering support contractor (Buhrman and Chang, 2011).

The newest version of the .NET framework, .NET Core, was released in late 2016 and is supported on Mac and Linux as well as Windows. More information on the .NET and .NET Core frameworks can be found at Microsoft’s ASP.NET website (https://www.asp.net/).

4.4.2 Database Content

Adherence to standard database content ensures that all of the information required for meaningful analysis of the data is available to users. Detailed participant background information, measurement techniques, anthropometric data, and clothing and equipment specifications are used to analyze data from a single data set.

Consistency in database content also makes it easier for users to combine or compare different data sets. In such cases additional information, such as North Atlantic Treaty Organization (NATO) military rank codes and international sizing rules, allow the user to identify equivalent sub-populations between countries.

ISO 15535:2006, ISO 7250-1:2008 Basic Human Body Measurements for Technological Design Part 1 – Body Measures Definitions and Landmarks, and *ISO 20685:2010 3-D Scanning Methodologies for Internationally Compatible Anthropometric Databases* were the main sources of information for the following recommendations. Information from other anthropometric databases and websites was then used to supplement ISO standards.

4.4.2.1 Statistical Processing

4.4.2.1.1 Missing or Invalid Data

Keefe et al. (2015) used the null value "9999" in place of missing or invalidated data, in accordance with *ISO 15535:2006* recommendations. *ISO 15535:2012* contains the most up to date standards for inputting missing or invalid data.

4.4.2.1.2 Validation of 1-Dimensional Anthropometric Data

The following data validation techniques were used by Keefe et al. (2015) during the 2012 CFAS:

- Potential outliers were identified using the Grubbs Test
- Suspected outliers were evaluated by comparing the measurement to participant's 3D scan
- In accordance with *ISO 15535:2006* guidelines, a relational measurement analysis was also conducted to identify anomalies in the data set, and in the case that the data value was not plausible, it was replaced with the null value.

Refer to Keefe et al. (2015) for a complete description of the validation methods employed in the 2012 CFAS. *ISO 15535:2012* contains the current ISO recommendations for validation of anthropometric data.

4.4.2.1.3 Validation of 3-Dimensional Scans and Scan-Extracted Data

ISO 20685:2010 Sections 5.2, 5.4, and 5.5 outline the recommended data validation steps to be taken before 3D scan data or scan-extracted data is entered into the database.

- The 3D scanning and data extraction methods should be the same hardware and software used to collect the ISO 7250 data
- Each subject shall be scanned and measured traditionally at least once by a trained expert
- Following data collection, the difference between the scan and the measured value shall be computed for each variable and subject
- If the 95% confidence interval for the mean of scan-minus-measure differences is within the acceptable range, the 3D data may be used in standards relying on ISO 7250 protocols

For more information please refer to *ISO 20685:2010*.

Table 5 contains the maximum allowable error between scan-extracted values and traditionally measured values in accordance with *ISO 20685:2010 Section 4.2*.

Table 5: Maximum allowable error between extracted values and traditionally measured values

Measurement Type	Maximum Mean Difference (mm)
Segment Lengths	5
Body Heights	4
Large Circumferences	9
Small Circumferences	4
Body Breadths	4
Body Depths	5
Head Dimensions (no hair)	1
Head Dimensions (with hair)	2
Hand Dimensions	1
Foot Dimensions	2

Note. Adapted from ISO 20685:2010 - 3-D Scanning Methodologies for Internationally Compatible Anthropometric Databases. Copyright 2010 by ISO.

4.4.2.2 Background Information

4.4.2.2.1 Research Documents

The background information and research that was used to design the anthropometric surveys could be of great value to users of the database. For example, the CBDN developed by the United States AFRL contains research documents associated with each of the contributing databases. These documents are tagged to certain populations, equipment, and techniques so that they are easy for the user to locate (Buhrman, Cheng, and Chaikin, 2011).

4.4.2.2.2 Participant Information

ISO 15535:2012 specifies a list of required and recommended background data to be included in the database.

The subject number, date of birth, gender, place of birth, and ethnicity were collected for each participant in the 2012 CFAS, in accordance with *ISO 15535:2006* recommendations.

Additional background information such as handedness, rank, MOSID, environmental affiliation, component, unit, and time of service may be useful when examining databases of military personnel. The complete participant demographics collected for the 2012 CFAS can be found in Annex D of the CFAS 2012 Final Report by Keefe et al. (2015).

ISO 3166 contains a complete list of internationally recognized letter and/or number codes that are used to identify countries and subdivisions. These codes are available for download in .xml, .csv, and .xls formats.

4.4.2.2.3 Military Ranks

Table 6 contains a list of Canadian Forces ranks and their corresponding NATO Codes in accordance with *Standardization Agreement (STANAG) 2116* as referenced in “Canadian Army Rank Insignia”, 2016. Ranks and NATO Codes for other NATO countries could be added to the database to allow for comparison of equivalent ranks between militaries.

Note that rank codes WO-1 – WO-5 only apply to Warrant Officers in the United States Armed Forces. Warrant Officers of the Canadian Armed Forces are assigned rank codes OR-7 – OR-9 ("Ranks and Insignia of NATO", 2017).

Table 6: Canadian Forces ranks and corresponding NATO codes

	Canadian Forces Rank		
NATO Code	**Army**	**Air Force**	**Navy**
OF-10	N/A	N/A	N/A
OF-9	General	General	Admiral
OF-8	Lieutenant-General	Lieutenant-General	Vice-Admiral
OF-7	Major-General	Major-General	Rear-Admiral
OF-6	Brigadier-General	Brigadier-General	Commodore
OF-5	Colonel	Colonel	Captain
OF-4	Lieutenant-Colonel	Lieutenant-Colonel	Commander
OF-3	Major	Major	Lieutenant-Commander
OF-2	Captain	Captain	Lieutenant
OF-1	Lieutenant	Lieutenant	Sub-Lieutenant
WO-5	N/A	N/A	N/A
WO-4	N/A	N/A	N/A
WO-3	N/A	N/A	N/A
WO-2	N/A	N/A	N/A
WO-1	N/A	N/A	N/A
OR-9	Chief Warrant Officer	Chief Warrant Officer	Chief Petty Officer 1st Class
OR-8	Master Warrant Officer	Master Warrant Officer	Chief Petty Officer 2nd Class
OR-7	Warrant Officer	Warrant Officer	Petty Officer 1st Class
OR-6	Sergeant	Sergeant	Petty Officer 2nd Class
OR-5	Master Corporal	Master Corporal	Master Seaman
OR-4	Corporal	Corporal	Leading Seaman
OR-3	Private (trained)	Aviator (trained)	Able Seaman
OR-2	Private (basic)	Aviator (basic)	Ordinary Seaman
OR-1	Private (recruit)	Aviator (recruit)	Ordinary Seaman (recruit)

Note. Data for Canadian Forces ranks and corresponding NATO codes is from "Canadian Army Rank Insignia" (n.d.).

4.4.2.3 Measurement Techniques

4.4.2.3.1 Body Measures Definitions

Refer to *ISO 7250-1:2008* for a list of ISO-defined body measures definitions. Where body measures definitions differ from ISO standards, detailed information about the anthropometric measurements should be provided.

The CFAS 2012 Final Report (Keefe et al., 2015) provides the definition, associated landmarks, procedure, instruments, and source of each anthropometric measurement used in the survey in Annex

G. Supplementary notes are included in order to help with replication of the measurements in future surveys.

ISO 8559-1:2017 contains standards for anthropometric definitions for body measurement including landmark points, lines, and planes, specifically for the designation of clothing sizes.

4.4.2.3.2 Manual Measurements

Keefe et al. (2015) discuss the maximum allowable observer error for each anthropometric measurement in the 2012 CFAS along with a brief explanation of how allowable error was determined.

Refer to *ISO 15535* for recommendations on the minimum instrument accuracy for anthropometric measurements.

Table 7 shows the information used to describe measurements in the Anthropometric Measurement Interface ("AMI Demonstration Guide"). This information is then used to distinguish different measurement methods, and allow the user to search the database for similar measurement methods across data sets.

Table 7: AMI measurement method details

Measurement Description	Body Posture	Instrument	Clothing
• Measured or derived • Measurement category (ex. Distance) • Distance type (ex. Line) • Related segment • Reference axis • Anatomical reference plane • Side of body modifier	• Main pose • Torso pose • Breath type • Leg pose • Foot pose • Arm pose • Hand pose • Head pose	• Category (ex. Caliper) • Firmly applied (yes or no) • Instrument details (ex. Spreading caliper) • Resolution • Unit of measure	• Part of body • Covering description

4.4.2.3.3 3D Measurements and Scans

ISO 20685:2010 Section 4.1 and 5.5 state that a validation study report should be conducted (see Section 4.4.2.1) and included in the anthropometric survey report with the following:

- Demography and anthropometry
- Scanning and measuring protocols, including scan garments, anthropometric landmarks, and body positions
- Name and references describing 3D system being validated
    - Hardware model number
    - Software version number
- Mean, standard deviation, and sample sizes for each body dimension as measured by scans and by hand

- Mean, standard deviation, sample sizes, and 95% confidence intervals for scan-minus-measure differences for each body dimension

Landmarks for 3D scans in the 2012 CFAS were conducted in accordance with *ISO 20685:2010* recommendations. Additional landmarks were used based on the needs of the 2012 CFAS. For a complete list of the definitions, sources, equipment, and methods associated with each of the CFAS landmarks, refer to Keefe et al. (2015).

4.4.2.4 Anthropometric Data

Table 8 includes a summary of *ISO 15535:2006, ISO 20685:2010,* and *ISO 7250-1:2008* recommendations for information that should be included in the database. Please refer to *ISO 15535:2012, ISO 20685:2010,* and *ISO 7250-1:2008* for more information.

Table 8: Anthropometry data

1D Measurement Data	3D Scan Data	
• Measurement descriptions (written and visual) • Raw individual anthropometry measurements • Clothing information	Landmarks: • Individual landmark data • Landmarking tools and methods	3D Scans: • Scanning tools and methods • Individual scans • Other scan postures/views available for selected individual

Note. Information for recommended anthropometry data is from ISO 15535:2006 – General Guidelines for Establishing Anthropometric Databases, ISO 20685:2010 - 3-D Scanning Methodologies for Internationally Compatible Anthropometric Databases, and ISO 7250-1:2008 – Basic Human Body Measurements for Technological Design.

4.4.2.5 Summary Statistics

The importance of providing summary statistics for the search-defined population was agreed upon by the TA, TTA, and stakeholders. The CFAS 2012 Explorer tool presents users with the percentile data, frequency, mean, standard deviation, standard error, skewness, kurtosis, coefficient of variance, normality, and Pearson's r coefficient based on the search criteria.

The ability to flag data that is not normally distributed, identify nearest neighbour cases based on input, and identify the number of inclusion/exclusion points also facilitates data analysis.

4.4.2.6 Clothing and Equipment Specifications

Descriptions and pictures of the measurement/scan clothing worn by participants during the 2012 CFAS are provided by Keefe et al. (2015).

The ability to compare existing sizing rules (e.g., NATO sizing), or specify new ones, would help with sizing and accommodation analysis of equipment from manufacturers around the world. Table 9 and Table 10 include NATO sizes for shirts and pants and their equivalent US and UK sizes ("NATO Sizes", 2017).

Table 9: NATO sizes for shirts and conversion to US and UK sizes

NATO Size	UK Chest Size	US Chest Size	Height
170-88	35-37"	35-37"	Short 170
170-96	38-40"	38-40"	Short 170
170-104	42-44"	40-42"	Short 170
170-112	44-46"	44"	Short 170
180-88	35-37"	35-37"	Regular 180
180-96	38-40"	38-40"	Regular 180
180-104	42-44"	40-42"	Regular 180
180-112	44-46"	44"	Regular 180
190-96	38-40"	38-40"	Long 190
190-104	42-44"	40-42"	Long 190
190-112	44-46"	44"	Long 190
190-120	48-50"	46-48"	Long 190

Note. Adapted from "NATO-Sizes" by RVOPS, n. d., Retrieved from http://www.rvops.co.uk/nato-sizes/ Copyright 2017 by RVOPS.co.uk

Table 10: NATO sizes for pants and conversion to US and UK sizes

NATO Size	Inseam Size	Waist Size	Seat Size
80-80-96	31-33"	32"	38"
80-84-100	31-33"	33.6"	40"
84-88-104	31-33"	35.2"	42"
80-92-108	31-33"	36"	44"
80-96-112	31-33"	38"	46"
85-80-96	33-36"	32"	38"
85-84-100	33-36"	33.6"	40"
85-88-104	33-36"	35.2"	42"
85-92-108	33-36"	36"	44"
85-96-112	33-36"	38"	45"
85-100-116	33-36"	40"	46.5"
85-104-120	33-36"	41.5"	48"

Note. Adapted from "NATO-Sizes" by RVOPS, n. d., Retrieved from http://www.rvops.co.uk/nato-sizes/ Copyright 2017 by RVOPS.co.uk

4.5 DWAN specialist consultation (Task 2.4)

This task was not undertaken and is included as a place holder.

4.6 Generate a mind map of potential requirements (Task 3.0)

The following section provides an initial summary of potential requirements for a web-based anthropometry tool, based on findings from Section 3.2, 3.3, 3.4 and 3.5 (TBC). This summary of potential requirements were derived from the 2012 and 2015 stakeholder meetings, as well as those requirements as identified and provided by the TTA. Furthermore, information as identified during the conduct of the technology review of COTS anthropometry tools (Section 4.2) are also incorporated.

The capability and functionality requirements were originally organized around the following six categories; Guiding requirements, Process requirements, Traditional data tool sets, 3D anthropometry tool sets, Database structure, and Information Technology (IT) requirements. This mind map is depicted in Figure 22.

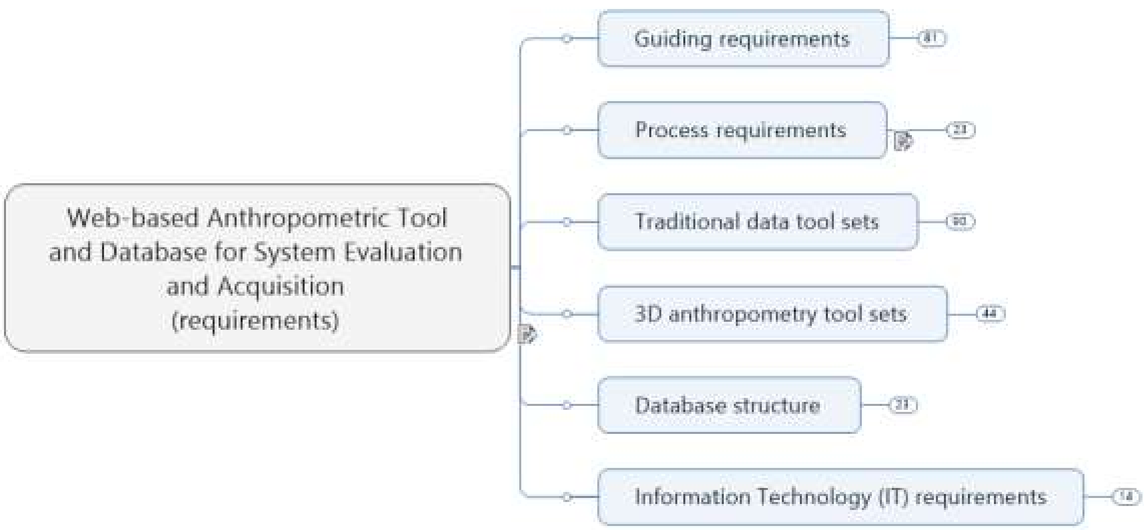


Figure 22: Mind map of potential requirements

Within each of the six categories, specific requirements were further defined in the mind map. For ease of reading, these requirements are presented in Table 11 through Table 16.

Table 11: Initial summary of potential requirements for a web-based anthropometry tool - guiding requirements

Category	Domain	Potential Requirement
Guiding requirements	Usability	• Data filtering ○ Gender ○ Age ○ Rank ○ MOSID ○ Component

		o Service o Language o Location o Ethnicity o Unit o Handedness o Corrective eyewear use • Permission based access o User authority o Checks and balances o Controlled access o Password • Language o Bilingual o Suitable for lay and experienced users • Receiving content information via mouse over and pop up dialogue boxes and bubbles • Interface should be able to continuously show the user which criteria have been selected • Users should also have the ability to modify those criteria and have the changes reflected in the data in real time • Ability to be able to save the defined parameters and to be able to lock those parameters
	Graphical User Interface (GUI)	• Simple • Intuitive • Icon driven • Follow best practices o Selection via single and double mouse clicks o Pull down menu o Radio buttons o Check boxes o Control buttons o Hyperlinks o Sliding tool bars o Clicking and dragging (ellipses, lines) o Mouse over o etc. • Graphics o Graphics, showing measurements and definitions should be included to aid the user in measurement selection
	Help	• Extensive set of guidance documents to aid in the correct use of tools • Inclusion of help files and tutorials • Garden path or case based example • Establish CAF standardized approach to anthropometric assessment • User feedback function o Report missing data

		o Provide feedback on the tool o Upload use cases o Request future studies o Wiki/blog based website (community of experts) • Reference documents o e.g., MIL STD 1472G, Scientific reports, ASTM 1166 • Glossary of terms • Visual + verbal definitions for landmarks

Table 12: Initial summary of potential requirements for a web-based anthropometry tool – process requirements

Category	Domain	Potential Requirement
Process requirements	Specification generation	• Specify sizes in seating systems, hatches, etc. for univariate and multivariate critical dimensions to ensure population accommodation • Specify sight lines, reach envelopes, and clearance to controls, equipment, control rooms or vehicles based on population data. • Ability to identify and specify optimal sizes in a bivariate (or multivariate) plot given garment or equipment critical dimensions. • Tariffing of personnel into a manufacturer's known garment or equipment size • Ability to identify the required range of adjustability to accommodate different dress states (e.g., for specifying things like load carriage or LPSVs worn over winter or summer dress with and without body armour). • Ability to identify required sight lines, reach envelopes, and clearance for both nude and clothed/equipped occupants. • Ability to "animate" an avatar via motion captured movements to explore fit and accommodation in a virtual dynamic world.
	Bid evaluation	• Ability to import 2D CAD drawings of designs to assess workspace envelopes for reach, sight lines, posture, clearance (e.g., head strikes), etc. • Ability to use anthropometric boundary manikins to evaluate proposed designs. • Ability to identify percentage of population accommodated / dis-accommodated based on critical dimensions. • Ability to output boundary manikin anthropometrics into a JACK or Santos Human • Ability to package, export and send out to contractors/bidders data generated from the web-based tool such as bivariate plots and charts, boundary manikins, data tables, diagrams, etc.
	Verifying and validating design changes	• Verify and validate design changes
	Scientific research	• Statistical analysis

Table 13: Initial summary of potential requirements for a web-based anthropometry tool – traditional data tool sets

Category	Domain	Potential Requirement
Traditional data tool sets	Visualization module	• Comparison of multiple datasets (e.g., LF97, ANSUR) • Incorporate scan extracted and predicted values • Select data based on demographic criterion(ia) • Provide ability to visualize uni and bivariate data • Histogram/scatter plot with confidence ellipses • Boundary cases for bivariate data • Combine multiple queries on one plot (e.g. male vs female) with separate summary statistics for each query. • Multivariate – indicate data points in and outside of ellipse or ellipsoid in different colours • Provide ability to visualize tri-variate data • Support the ability to "drill down" into specific sub-populations or even down to specific individuals from a more general overall presentation. • Summary statistics • Ability to generate user selected (e.g. 90%, 95%) accommodation ellipses (or ellipsoid in the case of multivariate data) • Adjustment to body measures based on clothing and equipment correction factors
	Accommodation Module	• Determine accommodation based on multiple anthropometric criteria • Possible approaches include nearest neighbour or stochastic evaluation • Evaluate adjustable design (e.g. adjustable seating/workstation) • Multiple regression analysis

	Principal Components Analysis (PCA) module/calculator	• Principal components based on user defined demographic and measurement criteria (i.e. PCA variables input from visualization module (max #))
		• Identify variables which are highly correlated and provide ability to deselect correlated variables
		• Can return specification of CAF determine standards (e.g. authorized set of manikins for bid evaluation)
		• Follows published approach (e.g. aCadre)
		• Up to 3 PC's and 27 manikins returned
		• Identifies redundant manikins
		• Summary statistics
		    ○ Provide Kaiser-Meyer Olkin measure of sampling adequacy and
		    ○ Bartlett test of sphericity
		    ○ Provide scree plot of PC's
		    ○ PCA based on covariance coefficient (TBC)
		    ○ Ability to export Eigen values, factor loading, factor coefficients and raw PCA scores based on # selected PC's (.csv file?)

		○ Boundary cases selected on user selected accommodation ellipse/ellipsoid ○ Reverse PCA – return anthropometric dimensions of each boundary/distributed case
	Clothing Tariffing tool	• Simple tariffs based on NATO sizing rules • Incorporate outputs from RTG-266 • New sizing rules may be based on analysis body shape data (e.g. incorporate preference or other body measurements) • Fit mapping tool • Grading tool • Sizing and tariffing box tool
	Clothing and Equipment Offsets/Correction Factors	• Based on future clothed and equipped anthropometric survey • Database of design offsets based on measured offsets for standard set of PPE • Ability to incorporate the envelope of the body from semi-nude, to clothed, to equipped. The user should have the ability to manipulate these outputs
	Boot strapping analysis	• Estimate requirements for multiple occupants
	2D CAD library of CAF platforms, vehicles, equipment etc.	• 2D CAD library of CAF platforms, vehicles, equipment etc.
	Proportionality constants calculator	• Calculate proportionality
	Manikin picker/ NRC predict body shape based on 2D anthropometric dimensions	• Pick/predict body shape based on 2D anthropometric dimensions
	Data output	• Ability to "lock" output data so that it cannot be tampered with • CSV files of univariate and multivariate data sets • Export plots/graphs • Table of boundary/distributed cases • 2D specifications of individuals, boundary and distributed cases • Manikin picker 3D CAD model

Table 14: Initial summary of potential requirements for a web-based anthropometry tool – 3D anthropometry tool sets

Category	Domain	Potential Requirement
3D anthropometry tool sets	Principal Components Analysis (PCA) Analyser	• Generate 3D shape manikins based on PCA for select demographics (e.g. sex, environment, pilots) • Extraction of body measures from PCA scans • PCA on segmentation of whole body model (e.g. torso or leg models) • Segmentation may be user defined in future (e.g. paint and apply template) • Future capability to model hand, foot or head scans • Identify critical PC's and dimensions for design • Explore range of body shapes based on defined constraint (e.g. all body shapes associated with 32" waist circumference) • Explore allometric scaling (how body scales from small to large) to aid in clothing/equipment sizing and design.
	Internal organ shape analyser	• Models of internal organs relative to external anthropometry to evaluate coverage or optimal placement of Personal Protective Equipment (PPE) across a wide range of shape and sizes, both sexes. • Models of skeletal system relative to external anthropometry
	Shape Viewer	• Tool to view shape library of raw scans. Select extremes or specific scans for design evaluation (e.g. real person close to PCA model?)
	Clothing module	• Virtual dressing – assess virtual garments based on clothing pattern, size and body shape • Heat map to show ease/fit • Models/visualizes draping
	Blending/Re-targeting	• Realistic animation of 3D scans to illustrate mobility or restriction due to clothing and equipment • Posing of scans for crew station design (includes equipped/clothed?). Predict fit, posture, sight lines, reach envelopes, and clearance. Determines posture for Digital Human Model (DHM) tools
	Clothing and Equipment Offsets/Correction Factors	• Based on future clothed and equipped anthropometric survey • Database of design offsets based on measured offsets for standard set of PPE • Ability to incorporate the envelope of the body from semi-nude, to clothed, to equipped. The user should have the ability to manipulate these outputs
	CAD library of CAF platforms, vehicles, equipment etc.	• CAD library of CAF platforms, vehicles, equipment etc.
	Data output	• Ability to "lock" output data so that it cannot be tampered with • 3D specifications of individuals, boundary and

		distributed cases • Export models (semi-nude/clothed/equipped))

Table 15: Initial summary of potential requirements for a web-based anthropometry tool – database structure

Category	Domain	Potential Requirement

Database structure	Data	Support inclusion of multiple datasets
		• Requirement
		  o Canadian Forces Anthropometric Survey (CFAS) 2012
		  o 1997 Anthropometric Survey of the Land Forces (LF97)
		• Desired
		  o U.S. Army Anthropometric Survey (ANSUR I) 1988
		  o U.S. Army Anthropometric Survey (ANSUR II) 2012
		  o U.S. Marine Corps Anthropometric Survey (MC-ANSUR) 2012
		  o Australian Warfighter Anthropometry Survey (AWAS) 2012
		  o National Health and Nutrition Examination Survey (NHANES)
		  o SAE international manikins
		  o The Technical Cooperation Program (TTCP)

	Structure	Refer to ISO *15535:2006 – General Guidelines for Establishing Anthropometric Databases (e.g., characteristics of the user population, sampling methods, measurement items, and statistics to be used when establishing an anthropometric database).
	Coding	Refer to ISO 15535:2012, ISO/IEC 8859, and ISO/IEC-1:1998 In addition, use an open source, reusable, extensible, and vendor-independent data format that can also encode character sets beyond ASCII, in order to accommodate international databases.
	Data entry	Refer to ISO *15535:2006 Sections 6.2, 6.3, and 7.1
	Database screening	Refer to ISO 15535:2012 – General Guidelines for the Establishment of Anthropometric Databases
	Data input	Refer to Table 4: Comparison of data integration methods

	Security	• Tiered login system
		  o B level with contact information for health services
		  o A level just information with sizing
		  o General - would never be able to see protected A or B
		• Controlled access
		  o Provide controlled access to the various tools/functions based on security clearance and user profile (similar to the CANadian Defence Information Database (CANDID) system, or SharePoint permissions)
		• Password
		  o Issue passwords with expiry dates to

		approved users requesting access to the web-based tool • Locked • Hidden
	Statistical processing - Missing or Invalid Data	Refer to ISO *15535:2006
	Statistical processing - Validation of 1-Dimensional Anthropometric Data	Refer to ISO *15535:2006
	Statistical processing - Validation of 3-Dimensional Scans and Scan-Extracted Data	Refer to ISO 20685:2010
	Research Documents	Include background information and research that was used to design the anthropometric surveys
	Participant Information	• Refer to ISO 15535:2012 for a list of required and recommended background data to be included in the database
		• Include additional background information such as handedness, rank, MOSID, environmental affiliation, component, unit, and time of service
		• Refer to ISO 3166 contains for a complete list of internationally recognized letter and/or number codes used to identify countries and subdivisions
	Body Measures Definitions	• Refer to ISO 7250-1:2008 for a list of ISO-defined body measures definitions • Refer to ISO 8559-1:2017 for anthropometric definitions for body measurement including landmark points, lines, and planes, specifically for the designation of clothing sizes.
	Other information to include	General • Measurement description (written and visual) • Individual landmark data • Landmarking tools and methods • Image of measurement • Clothing information • Any standards that reference measure (e.g. ISO, ANSUR I or II, International Society for the Advancement of Kinanthrop (ISAK)) • Link to survey final report 2D Measurement Data • Raw individual anthropometry measurements • Histogram (univariate) or scatterplot (bivariate) to represent data

		3D Scan Data • Identify if measure is scan extracted • Scanning tools and methods • Individual scans • Other scan postures/views available for selected individual • Clothing offsets • Nearest neighbour search

*ISO 15535:2006 has now been superseded by 15535:2012

Table 16: Initial summary of potential requirements for a web-based anthropometry tool – information technology requirements

Category	Domain	Potential Requirement
Information Technology (IT) requirements	Software architecture	• Commercial • Open source • Scalable
	Software distribution model	• Server-client via network/web • Stand-alone app
	Software hosting	• Personal Computer based • Client/server architecture
	Software updating and maintenance	

4.7 Create a multi-voice decision model based on above task (CDP manual pg. 136) (Task 4.0)

The review of the mind map of potential capability and functionality requirements by the TA and TTA resulted in several changes being made. Changes included renaming of categories (e.g., Traditional data tool sets → 1D anthropometry tool sets), inclusion of additional requirements (e.g., ability to specify custom sizing rules), and the reorganization of capability and functionality requirements within and between categories. A multi-voiced decision model, adopting the AHP – Direct Method within CDP4 software, was subsequently created focusing on the 1D and 3D anthropometry tool sets. A screen capture of this model is presented in Figure 23.

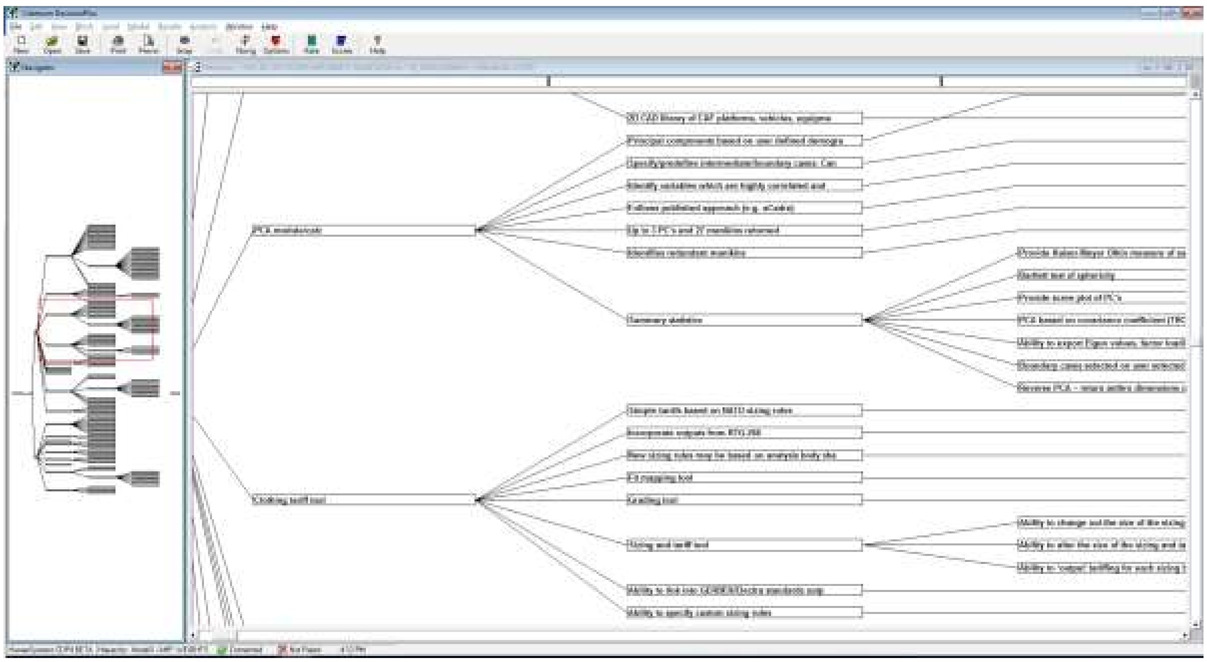


Figure 23: Screen capture of multi-voiced decision model

4.8 Conduct facilitated multi-voiced group discussion with stakeholders (Task 5.0)

The resulting ratings of the multi-voiced decision model for the measures of importance by the TA and TTA, for the capability and functionality requirements of the 1D and 3D anthropometry tool sets, were re-incorporated into the mind map. The verbal five-point scale of importance, utilized for the multi-voiced decision model, was converted to a corresponding scale of prioritization for this mind map. Where;

- Critical → Priority 1
- Very Important → Priority 2
- Important → Priority 3
- Unimportant → Priority 4
- Trivial → X (i.e., do not pursue)

This prioritization of requirements was subsequently validated by a second group of stakeholders on 15 February 2017. During this review, capability and functionality requirements were further reorganized, additional requirements were identified, and the prioritization was modified. The resulting prioritization for the 1D and 3D anthropometry tool sets is shown in Annex C: Validated and revised prioritization of Functionality and Capability – 1D and 3D anthropometry tool. For ease of reading, these requirements are presented in Table 17 through Table 20 for the requirements of the 1D anthropometry tool set, and in Table 21 through Table 23 for the requirements of the 3D anthropometry tool set. It should be noted that all stakeholders felt that it was equally critical to develop both the 1D and 3D anthropometry tool sets. Clothing and equipment SMEs also voiced the importance of a clothing module, especially having the ability to export anthropometric data in a file that can be processed by external programs such as GERBER. It was envisioned that a sizing proposal could be created and exported to GERBER, which would cut the pattern based on the sizes. SMEs also reiterated that GERBER is a well-developed tool for designing clothing and apparel, and it would be a better investment to purchase GERBER and to develop complementary capability within the web-based anthropometric tool for the CAF. Several other comments were also made during the stakeholder meeting. These are summarized in Annex D: Summary of stakeholder focus group and interview comments (2017).

Table 17: Priority 1 – 1D anthropometry tool set requirements

Priority	Domain	Sub-priority	Potential Requirement "The web-based anthropometry tool set should allow for the user to…"
1	Visualization module	1	• Compare multiple data sets (e.g., LF97, ANSUR)
		1	• Incorporate scan extracted and predicted values
		1	• Select data based on demographic criterion(ia)
		1	• Visualize uni and bivariate data
		1	• Visualize histogram/scatter plot with confidence ellipses
		1	• View and select boundary cases for bivariate data
		1	• Combine multiple queries on one plot (e.g. male vs female) with separate summary statistics for each query.
		1	• Visualize multivariate data – indicate data points in (accommodated) and outside (dis-accommodated) of ellipse or ellipsoid in different colours
		1	• "Drill down" into specific sub-populations or even down to specific individuals from a more general overall presentation
		1	• View summary statistics o Percentiles o Frequencies o Means o Standard deviations o Standard Error o Skewness o Kurtosis o Coefficient of Variance o Normality (Anderson-Darling statistic for normality) o Pearson's r coefficient • Analyze statistics o Flag data that is not normally distributed o Identify nearest neighbour cases based on user input o Identify number of inclusion/exclusion points
		1	• Generate user selected (e.g. 90%, 95%) accommodation ellipses (or ellipsoid in the case of multivariate data)
		1	• Visualize tri-variate data
		2	• Specify adjustment to body measures based on clothing and equipment correction factors
1	Accommodation Module	1	• Determine accommodation based on multiple anthropometric criteria
		1	• Evaluate adjustable design (e.g. adjustable seating/workstation)
		1	• Perform multiple regression analysis o Possible approaches: ▪ Nearest neighbour (priority 2) ▪ Stochastic evaluation (priority 2)
		2	• Access 2D CAD library of CAF platforms, vehicles, equipment etc.

1	Principal Components Analysis (PCA) module/calculator	1	• Specify principal components based on user defined demographic and measurement criteria (i.e. PCA variables input from visualization module (max #))
		1	• Specify/predefine intermediate/boundary cases: Can return specification of CAF determine standards (e.g. authorized set of manikins for bid evaluation)
		1	• Identify variables which are highly correlated and provide ability to deselect correlated variables
		1	• Follow published approach (e.g. aCadre)
		1	• Specify up to 3 principal components and have up to 27 manikins returned
		1	• Identify redundant manikins
		1	• Perform summary statistics o Provide Kaiser-Meyer Olkin measure of sampling adequacy and o Bartlett test of sphericity o Provide scree plot of principal components o PCA based on covariance coefficient (TBC) ▪ Normalized inputs ▪ Varimax rotation ▪ Kaiser criterion (Eigen values >1) o Ability to export Eigen values, factor loading, factor coefficients and raw PCA scores based on # selected PC's (*.csv file) o Boundary cases selected on user selected accommodation ellipse/ellipsoid ▪ Boundary cases at intersection of Principal Components (PC) axis and ellipse/ellipsoid ▪ 45° points along PC axis ▪ Define cases within the distribution (e.g. see Oudenhuijzen paper) o Reverse PCA – return anthropometric dimensions of each boundary/distributed case ▪ Input body dimensions and show where case sits in PCA space – good for confirming representation of test participants
1	Clothing Tariffing tool	1	• Use a sizing and tariffing box tool o Change out the size of the sizing and tariffing boxes o Alter the size of the sizing and tariffing boxes for non-symmetric distribution (within specifying clothing sizes, ability to have different sized boxes in the bivariate/scatter plots). o 'Output' tariffing for each sizing box o Specify custom sizing rules ▪ New sizing rules may be based on analysis body shape data (e.g. incorporate preference or other body measurements) o Fit mapping tool (unimportant requirement)
		2	• Perform simple tariffs based on NATO sizing rules
		2	• Incorporate outputs from RTG-266

		4	• Link into GERBER/Electra standards output
		4	• Access a grading tool
1	Data output	1	• "Lock" output data so that it cannot be tampered with
		1	• Output CSV files of univariate and multivariate and trivariate data sets
		1	• Export plots/graphs ○ Gaussian functions ○ Frequency distribution ○ Percentile curves ○ Pie ○ Bar ○ Area ○ Scatter plots
		1	• Output a table of boundary/distributed cases
		1	• Output 2D specifications of individuals, boundary and distributed cases
		1	• Output a 3D CAD model of a manikin
		2	• Relate measurements back to GERBER/Electra standards when buying COTS/Military-Off-The-Shelf (MOTS)

Table 18: Priority 2 – 1D anthropometry tool set requirements

Priority	Domain	Sub-priority	Potential Requirement "The web-based anthropometry tool set should allow for the user to…"
2	Manikin picker/ NRC predict body shape based on 2D anthropometric dimensions (boundary ratio)	2	• Pick/predict body shape based on 2D anthropometric dimensions (boundary ratio)
2	Clothing and Equipment Offsets/Correction Factors	2	• Specify offset/correction factors based on future clothed and equipped anthropometric survey (future capability)
		2	• Access a database of design offsets based on measured offsets for standard set of PPE (future capability)
		2	• Incorporate the envelope of the body from semi-nude, clothed, to equipped. The user should have the ability to manipulate these outputs (future capability)
2	Functional anthropometry	2	• Reference strength data
		2	• Reference biomechanical data
		2	• Reference Range of Motion data

Table 19: Priority 3 – 1D anthropometry tool set requirements

Priority	Domain	Sub-priority	Potential Requirement "The web-based anthropometry tool set should allow for the user to…"
3	Boot strapping analysis	3	• Estimate requirements for multiple occupants

Table 20: Priority 4 & 5 – 1D anthropometry tool set requirements

Priority	Domain	Sub-priority	Potential Requirement
X	Proportionality constants calculator	X	• Do not pursue

Table 21: Priority 1 – 3D anthropometry tool set requirements

Priority	Domain	Sub-priority	Potential Requirement "The web-based anthropometry tool set should allow for the user to…"
1	Principal Components Analysis (PCA) Analyzer	1	• Generate 3D shape manikins based on PCA for select demographics (e.g. sex, environment, pilots)
		1	• Extract body measures from PCA scans (including digital measuring tape)
		1	• Conduct PCA on segmentation of whole body model (e.g. torso or leg models)
		1	• Identify critical PC's and dimensions for design
		1	• Explore range of body shapes based on defined constraint (e.g. all body shapes associated with 32" waist circumference)
		1	• Explore allometric scaling (how body scales from small to large) to aid in clothing/equipment sizing and design
		2	• Access hand, foot and/or head scan models (future capability)
		3	• Define segmentation (e.g. paint and apply template) (future capability)
1	Data output	1	• "Lock" output data so that it cannot be tampered with
		1	• Output 3D specifications of individuals, boundary and distributed cases
		1	• Export models (semi-nude/clothed/equipped)). Files should be in the following formats o Critical ▪ Image (e.g., *.png, *.bmp) ▪ CAD (e.g., *.jt, *.stl, *.obj) o Unimportant ▪ JACK (e.g., *.fig) ▪ VRML (e.g., *.wrl) ▪ Santos ▪ RAMSIS

Table 22: Priority 2 – 3D anthropometry tool set requirements

Priority	Domain	Sub-priority	Potential Requirement "The web-based anthropometry tool set should allow for the user to…"
2	Clothing module	2	• Perform virtual dressing – assess virtual garments based on clothing pattern, size and body shape
		2	• Accomplish heat mapping to show ease/fit
		2	• Model/visualize draping
2	Shape Viewer	2	• View shape library of raw scans. Select extremes or specific scans for design evaluation (e.g. real person close to PCA model?)
2	Clothing and Equipment Offsets/Correction Factors	2	• Specify offset/correction factors based on future clothed and equipped anthropometric survey (future capability)
		2	• Access a database of design offsets based on measured offsets for standard set of PPE (future capability)
		2	• Incorporate the envelope of the body from semi-nude, clothed, to equipped. The user should have the ability to manipulate these outputs (future capability)
2	Functional anthropometry	2	• Reference strength data
		2	• Reference Biomechanical data
		2	• Reference Range of Motion data

Table 23: Priority 3 – 3D anthropometry tool set requirements

Priority	Domain	Sub-priority	Potential Requirement "The web-based anthropometry tool set should allow for the user to…"
3	Internal organ shape analyzer	3	• Apply models of internal organs relative to external anthropometry to evaluate coverage or optimal placement of PPE across a wide range of shape and sizes, both sexes.
		3	• Apply models of the skeletal system relative to external anthropometry
3	Blending/Re-targeting	3	• Carry out realistic animation of 3D scans to illustrate mobility or restriction due to clothing and equipment
		3	• Pose scans for crew station design (including equipped/clothed). Predict fit, posture, sight lines, reach envelopes, and clearance. Determines posture for DHM tools
3	3D CAD library of CAF platforms, vehicles, equipment etc.	3	• Access 3D CAD library of CAF platforms, vehicles, equipment etc.

4.9 Propose a software architecture (Task 6.0)

Based on the TTA consultation, conduct of the technology review, review of past efforts, and stakeholder meetings, and the resulting requirements as identified for a web based anthropometric tool, the following notional software architecture is proposed. This software architecture is depicted in Figure 24 and Figure 25, and described in more detail below. In support of this notional architecture, a preliminary technology stack review was also conducted and is discussed in the subsequent section.

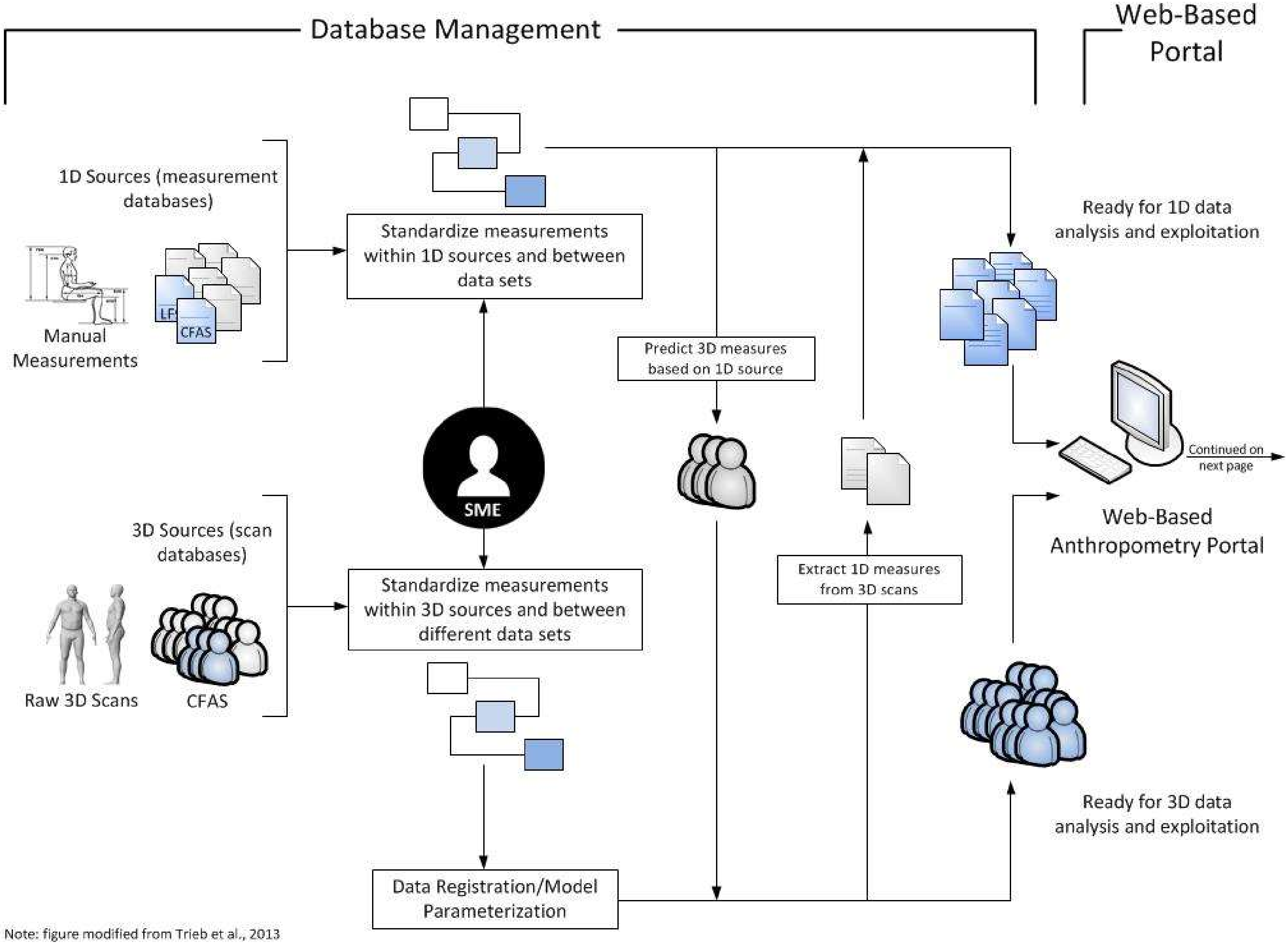


Figure 24: Notional software architecture – page 1

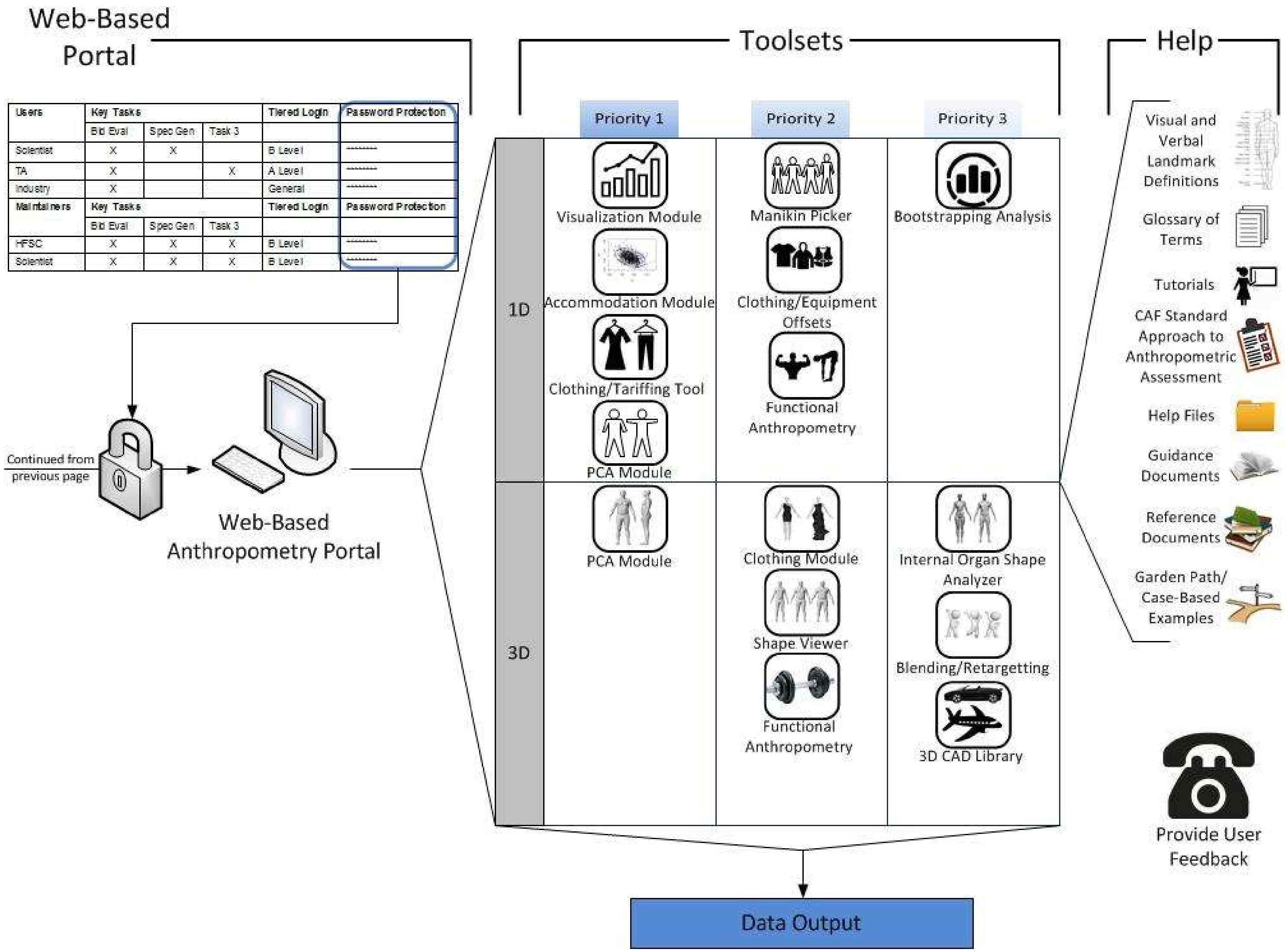


Figure 25: Notional software architecture – page 2

4.9.1 Notional software architecture

The following section describes Figure 24 and Figure 25 in more detail.

4.9.1.1 Database Management:

The database will contain two data streams; 1D and 3D. 1D sources include manual measurements collected during the CFAS 2012 and 1997 Land Forces survey. This database will be scalable to incorporate additional 1D sources (e.g., ANSURI, ANSURII). Prior to issuing a usable data set, if required, manual measurements within 1D sources and between data sets will be standardized by the anthropomotrist or SME. This data can also be used to predict 3D measures based on 1D sources. Once this data process is complete, the data is ready for 1D data analysis and exploitation.

3D sources will include the raw scans collected during the CFAS 2012, and will be standardized by the anthropomotrist or SME through data registration/model parameterization processes. This data can also be used to extract 1D measures from 3D scans. Once this data process is complete, the data is ready for 3D data analysis and exploitation.

4.9.1.2 Web-Based Portal:

The web-based anthropometry portal will require controlled access to approved users with issued passwords with expiry dates. This access will be based on security clearance, user profile, and a tiered login system for different levels of information (e.g., B/A/General).

4.9.1.3 Toolsets:

Access to 1D and 3D toolsets or applications (apps) will be based on user profile and tiered login system. Note in the figure above, the toolsets/apps are categorized based on prioritization for software development.

4.9.1.4 Help:

The user will have access to, an extensive set of guidance documents to aid in the correct use of tools, help files and tutorials, garden path or case based examples, established CAF standardized approach to anthropometric assessment, reference documents, glossary of terms, and will be able to search for visual and verbal definitions for landmarks. The user will also be able to provide feedback.

4.9.2 Proposed technology stack for a web-based anthropometry tool

The tool set requirements for the web-based anthropometry tool are based around the managing and statistical analysis of data which can be best organized into tables. For this tool to be centralized and easily accessible, the feasibility of meeting the preliminary *strawman* SOR (Annex E) for a web-based application was explored by GiantGoat web development. The following provides the results of this review.

4.9.2.1 Backend Technology Stack

At the bottom of the technology stack we propose using Linux as an operating system, MariaDB for data storage, either nginx or apache for web services and PHP for server side processing. This is a highly scalable and proven technology stack in web development. The open source nature of it means there are no licensing costs for the software and readily available documentation and extensions.

4.9.2.2 Application Framework

Using a pre-existing framework like Drupal 8 will allow for many tertiary requirements (user management, access control) to be fulfilled by pre-existing, proven software. Drupal 8 is an object-oriented framework based on Symfony. It has a large open source community and a security team that releases security notices for any discovered vulnerability.

All requirements based in calculations or a specific logic can be handled by building Drupal modules to complete all the computations. Drupal also comes with a built in tool called Views which allows for the searching and display of data. With some extension Views can also be used to export results as a CSV or XML.

4.9.2.3 Visualization

Understanding and analysis of the data contained within the CFAS requires complex computation. There are a number of Javascript libraries that can assist in presenting the data. For most of the 2D requirements D3js (https://d3js.org/) can be used to present, uni-variate, and multi-variate graphs (https://bl.ocks.org/mbostock/3884914).

Some 2D requirements like the reach tool (http://dined.io.tudelft.nl/en/reachenvelopes/introduction) have been implemented using kinect js (https://github.com/ericdrowell/KineticJS/). There is a potential that the existing work can be improved upon with the 3D tools currently available.

Two possible libraries can be used to solve the 3D requirements. The first library is three js (https://threejs.org/) which has a lot of power in the realm of 3D rendering. One example presented by the three js team has a direct relationship to the CFAS requirements (https://threejs.org/examples/#webgl_morphtargets_human). Three js also has documentation which suggests it is capable of rendering a skeletal structure which should allow for the movement and manipulation of a rendered human body. The second possible library, OpenJSCAD (https://openjscad.org/), for 3D rendering shows less capability for manipulating the human body but it may be better at handling CAD files.

4.9.2.4 Saving of Information

The suggested JS libraries are capable of saving their graphics as images. By the virtue of this proposal making CFAS a web application the web browser is capable of saving content as a PDF or printing the output. Libraries to read, create and edit many of the requested file formats could not be found. Depending on the nature of the file formats this could require custom programming or purchasing a library from the maintainer of the file formats.

5. Discussion

A systematic approach was followed in order to carry out initial planning for the development of a suite of web-based anthropometric software tools and associate databases, based on the CFAS 2012 data for use in Canadian Armed Forces acquisition processes. In the course of carrying out this effort, however, it became evident to the authors for the need to alter the scope of this project and provide to the client a more meaningful deliverable. That is, to deliver an initial *strawman* for a Statement of Requirements (SOR) for a suite of web-based anthropometric software tools. It is in the opinion of the authors that this revised deliverable, will further facilitate a software engineering firm to begin coding the anthropometric tools and reduce development time. This initial SOR *strawman* is presented in Annex E: Preliminary SOR strawman for a web-based anthropometry tool.

For the follow-on phase of this project, it is recommended that this SOR strawman be used and an iterative software development process be employed. This development cycle should begin with the conceptualization and system design of the web-based anthropometry tool, storyboarding the software tool sets/applications, and coding/programing the software. While requirements validations, integration assessments, trade-off analysis and usability evaluations with users be conducted throughout the evaluation process.

6. Conclusion

Throughout this project, stakeholders affirmed the importance, utility, and need for a 1D and 3D web-based anthropometry tool. Furthermore, stakeholders stated that even having access to the prototype CFAS Explorer (1D) tool, and the capability to select, filter, plot and export CFAS data as well as perform basic analysis of the bivariate distribution of selected measures, has been very beneficial. It is envisioned that the development of a suite of web-based anthropometric software tools, in consort with the SSA software[1], will therefore greatly aid the Canadian Armed Forces acquisition processes.

[1] As part of the Soldier System Effectiveness (SoSE) project, an Architectural Framework (AF) was developed for the Canadian Armed Forces (CAF) soldier system in fiscal year 2014/2015, and a Soldier System Architecture (SSA) software demonstrator of the SoSE AF, functionality and toolsets was developed in fiscal year 2015/16 which is being further refined in FY16/17. It is envisioned that the CFAS 2012 Explorer and 1D Data Visualization tool and 3D Shape Analyzer tool will be incorporated into the SSA software.

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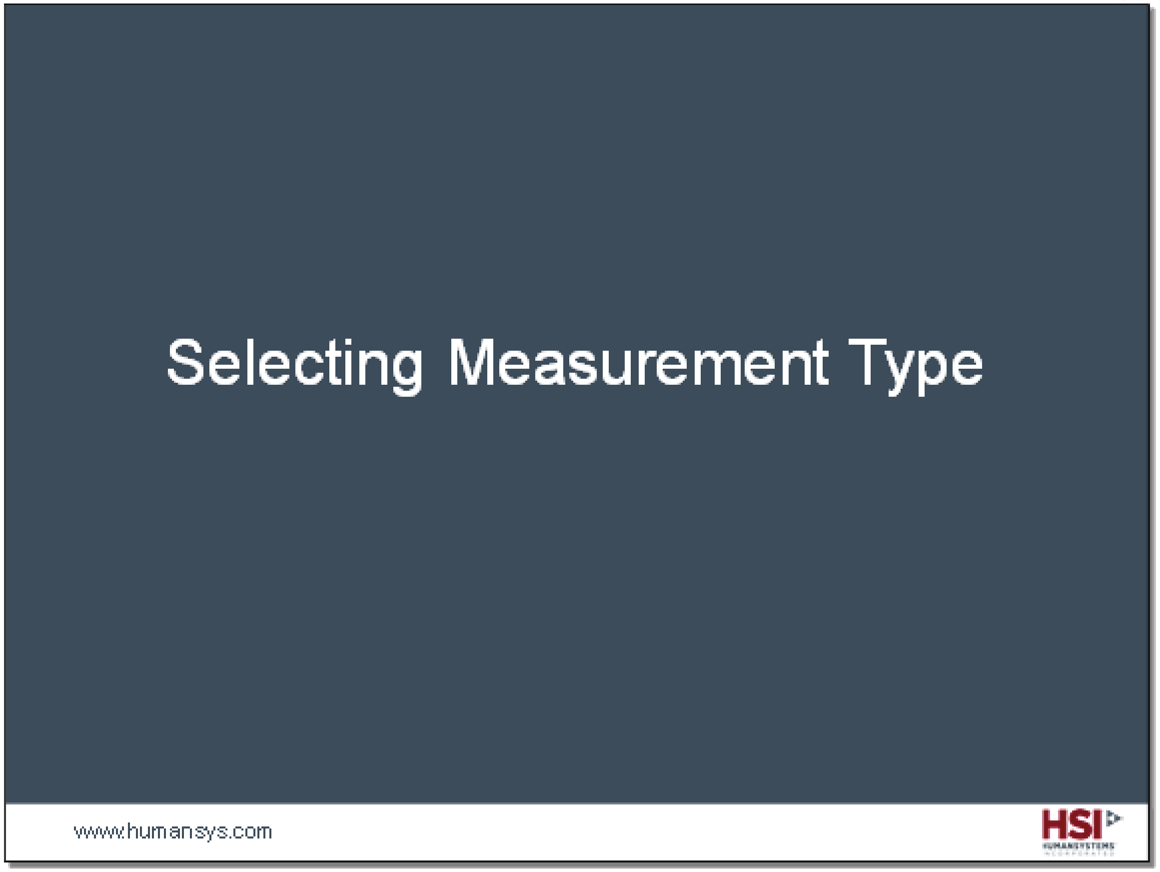
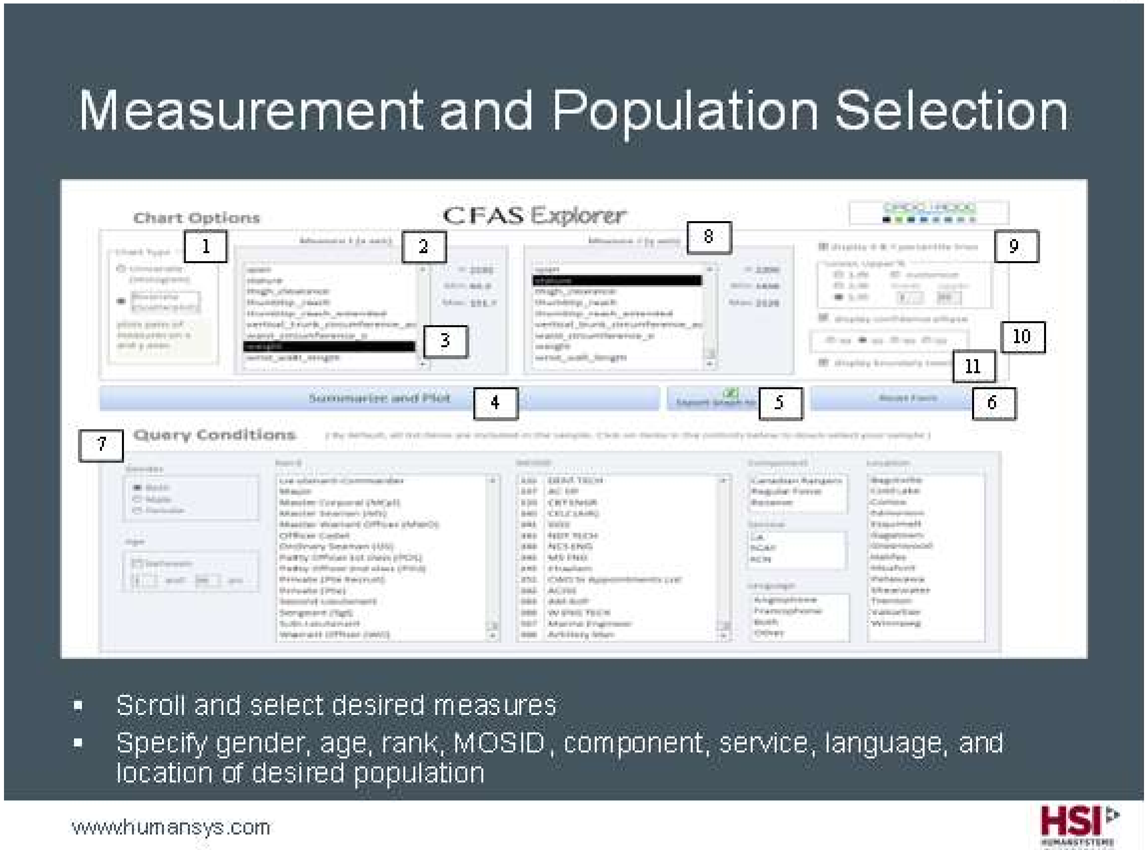
List of Acronyms/Abbreviations

AF	Architecture Framework
AFRL	Air Force Research Laboratory
AHP	Analytic Hierarchy Process
AMI	Anthropometric Measurement Interface
ANSUR	U.S. Army Anthropometry Survey
API	Application programming interface
ASAS	Anthropometric Sizing Analysis System
ASCII	American Standard Code for Information Interchange
AWAS	Australian Warfighter Anthropometry Survey
BMI	Body Mass Index
CAD	Computer-Aided Design
CAESAR	Civilian American and European Surface Anthropometry Resource
CAF	Canadian Armed Forces
CANDID	CANadian Defence Information Database
CBDN	Collaborative Biomechanics Data Network
CDP	Criterium Decision Plus
CETT	Comprehensive Ergonomic Tools and Techniques
CF	Canadian Forces
CFAS	Canadian Forces Anthropometric Survey
CODATA	Committee on Data
COTS	Commercial-Off-The-Shelf
CSC	Canadian Surface Combatant
CT	Computerized Tomography
DGMPD	Director General Major Project Delivery
DHM	Digital Human Model
DLR	Director Land Requirements
DND	Department of National Defence
DRAPE	DRessing Any Person
DRDC	Defence Research and Development Canada
DSSPM	Director Soldier Systems Program Management
DTAES	Directorate Technical Airworthiness and Engineering Support
DWAN	Defence Wide Area Network
GUI	Graphical User Interface
HFSC	Human Factors Support Cell
HSI	HumanSystems® Incorporated
IEC	International Electrotechnical Commission
ISAK	International Society for the Advancement of Kinanthrop

ISO	International Organization for Standardization
ISSP	Integrated Soldier System Project
IT	Information Technology
JASS	Job Assessment Software System
JSS	Joint Support Ship
LCMM	Life Cycle Materiel Manager
MC	Marine Corps
MOSID	Military Occupational Structure Identification
MOTS	Military-Off-The-Shelf
NATO	North Atlantic Treaty Organization
NHANES	National Health and Nutrition Examination Survey
NPB	National Printing Bureau
NRC	National Research Council
PCA	Principal Components Analysis
PDF	Portable Document Format
PMO	Project Management Office
PPE	Personal Protective Equipment
PWGSC	Public Works and Government Services Canada
SAE	Society of Automotive Engineers
SD	Standard Deviation
SOR	Statement of Requirements
SoSE	Soldier System Effectiveness
SOW	Statement of Work
SSA	Soldier System Architecture
STANAG	Standardization Agreement
TA	Task Authority
TAPV	Tactical Armoured Patrol Vehicle
TBC	To Be Confirmed
TBD	To Be Determined
THUMS	Total Human Model for Safety
TTA	Technical Task Authority
TTCP	The Technical Cooperation Program
UK	United Kingdom
UMTRI	University of Michigan Transportation Research Institute
US	United States
WEAR	World Engineering Anthropometry Resource
XML	extensible markup language

Annex A: Trade study of Commercial-Off-The-Shelf anthropometry based tools – presentation


Selecting Measurement Type
www.humansys.com
HSI



CFAS Explorer Tool

1. Chart type. Toggle between univariate (histogram) and bivariate (scatterplot) analyses.
2. Measure 1. This will be plotted on the x-axis for both histograms and scatterplots. Scroll and select.
3. Clicking on a measure in the list box will display the number of data points available (n), and the minimum and maximum values for that measure.
4. Summarize and Plot. This button will produce a histogram or scatterplot of the selected data within Microsoft Access. Summary statistics and percentile information will accompany the graph.

5. Export Graph to Excel. This button will generate a new Microsoft Excel workbook that contains worksheets with: 1) raw data for the selected measure(s), 2) the appropriate graph, and 3) summary statistics for the measure(s) including the query parameters for the sample upon which the graph is based. This option is very powerful as it allows you to extend and manipulate the graph, and gives you access to the raw data.

6. Reset Form. Handy to clear list boxes and start a new search. Given that this software is still under development and you may encounter bugs in the user interface, simply reset the form if required.

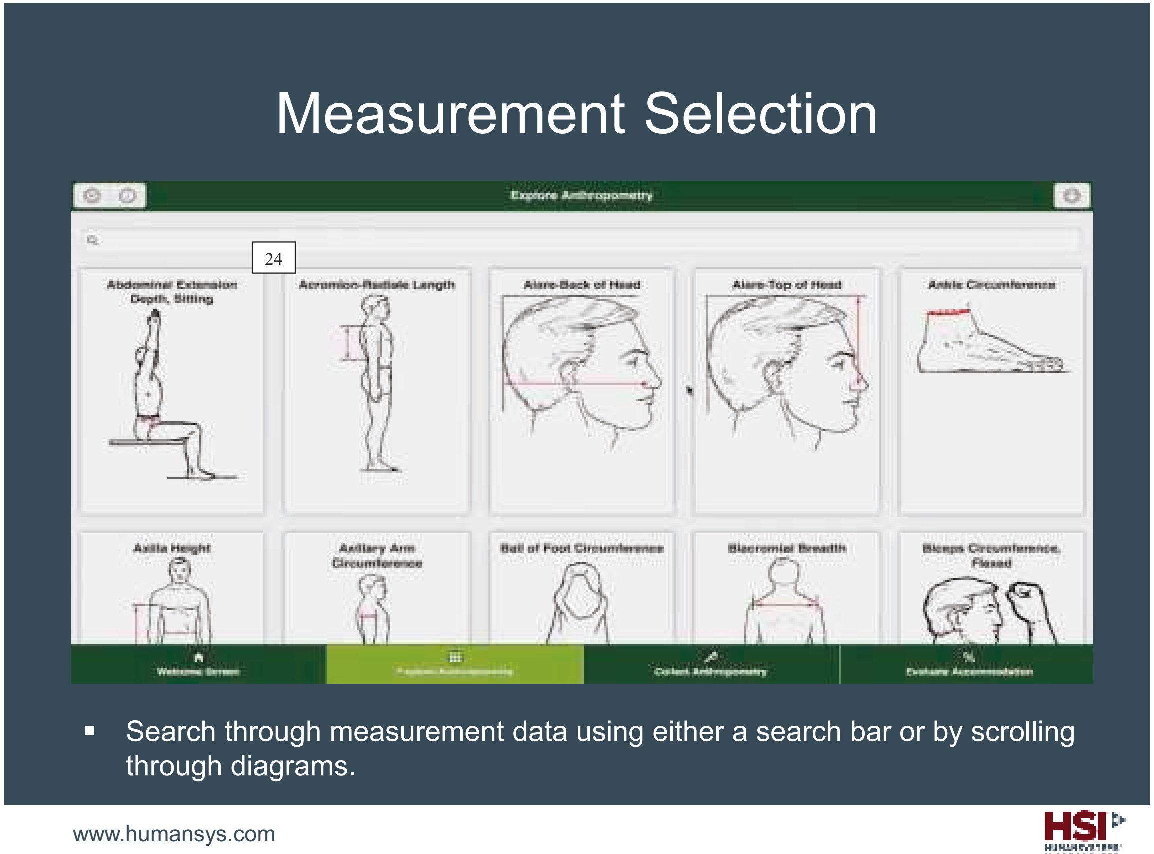
7. Query Conditions. By default, searches are based upon the entire CFAS dataset. Use the Query Condition controls to impose selection criteria on your data. Any changes in the Query Conditions will result in a change in the *n* value for a measure. Note that you will need an *n* of at least 5 to generate graphs. Selections within a category are treated as a boolean *OR* (e.g. Rank = Major OR Captain). Selections between categories are treated as a boolean *AND* (e.g. [Rank = Major OR Captain] AND [Gender=Male]) . TIP: Because of the need to scroll within list boxes, it is wise when changing your search to reset the form explicitly to ensure there are no Query Conditions selected but hidden.

8. Measure 2. This will be plotted on the y-axis for scatterplots. Scroll and select. The full set of 47 measures are available for both measures.

9. In bivariate mode, the user can display percentile lines directly on their graph. Selecting this option does not reduce the sample upon which the graph is based, rather it simply overlays a line on the scatterplot where the percentiles fall within the distributions for each measure. Notice the option to specify a customized set of upper and lower percentiles.

10. In bivariate mode, the user can display a percentile ellipse over the plotted data. The ellipse represents the probability that a new point would fall within the middle n^{th} percentile on the combination of 2 measures

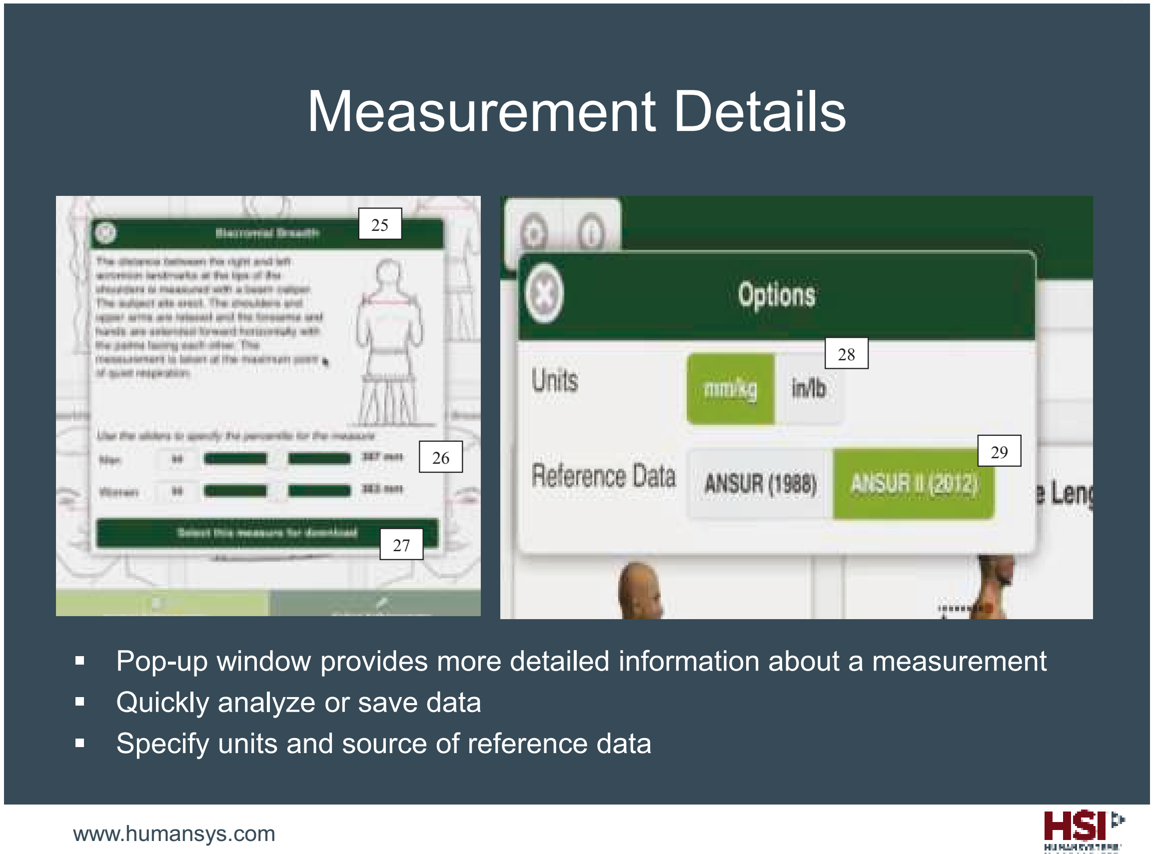
11. In the case that the user opts to display a percentile ellipse, they can also choose to display markers on the ellipse that represent a family of boundary cases for a particular percentile.



(Accessed from https://www.youtube.com/watch?v=yewOFd8r6AA, reprinted with permission from Garneau)

MARC Tool – Explore Anthropometry

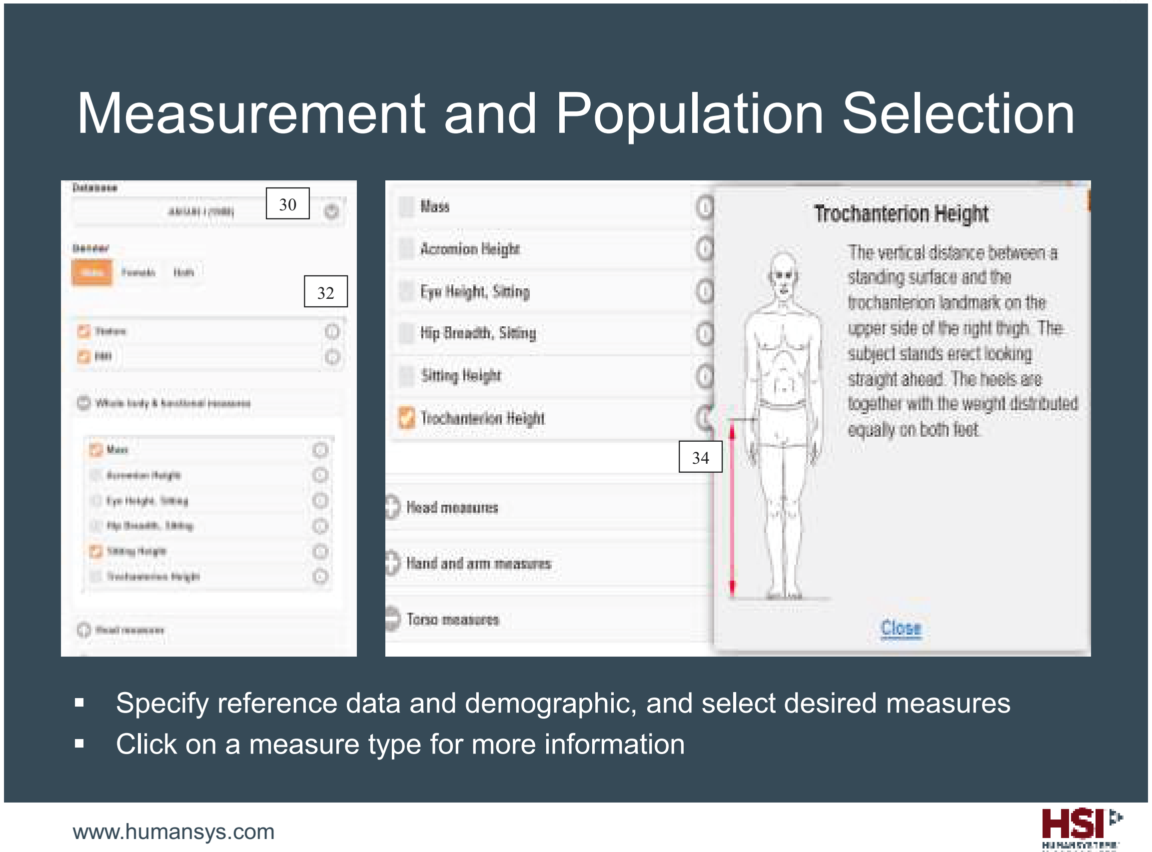
24 Search bar. Type a measurement type into the search bar to find the desired measure. Measurement types are labelled with diagrams. Scroll and select.



(Accessed from https://www.youtube.com/watch?v=yewOFd8r6AA, reprinted with permission from Garneau)

MARC Tool – Explore Anthropometry

25. More information. Clicking on a measure will open a pop-up window with detailed information.
26. Sliders. Adjust the sliders to view the percentile values for the selected measure.
27. Download. This button allows you to download and save the data for this measure.
28. Options. Clicking the box in the top left-hand corner will open a pop-up window with additional options.
29. Units and Reference Data. Specify the source of reference data as well as measurement units.



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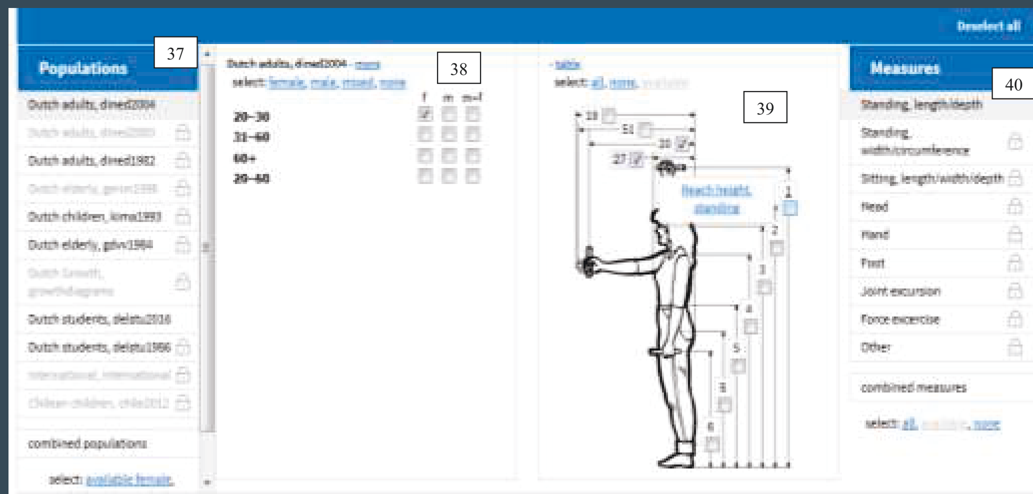
Penn State Open Design Lab – Database Explorer

30. Database Selection. Specify the source of the reference data to be analyzed.

32. Query Conditions. Users can specify gender and which anthropometric measures to explore. Measures are divided into categories (ex. “Whole Body and Functional Measures”). Clicking on the category titles will reveal all of the measures available in that section.

34. Information. Clicking the information button next to a measurement type will open a pop-up window with a diagram and additional information about the measurement.

Measurement and Population Selection



- Select population data and desired demographic from list
- Select desired measures from list or from diagram

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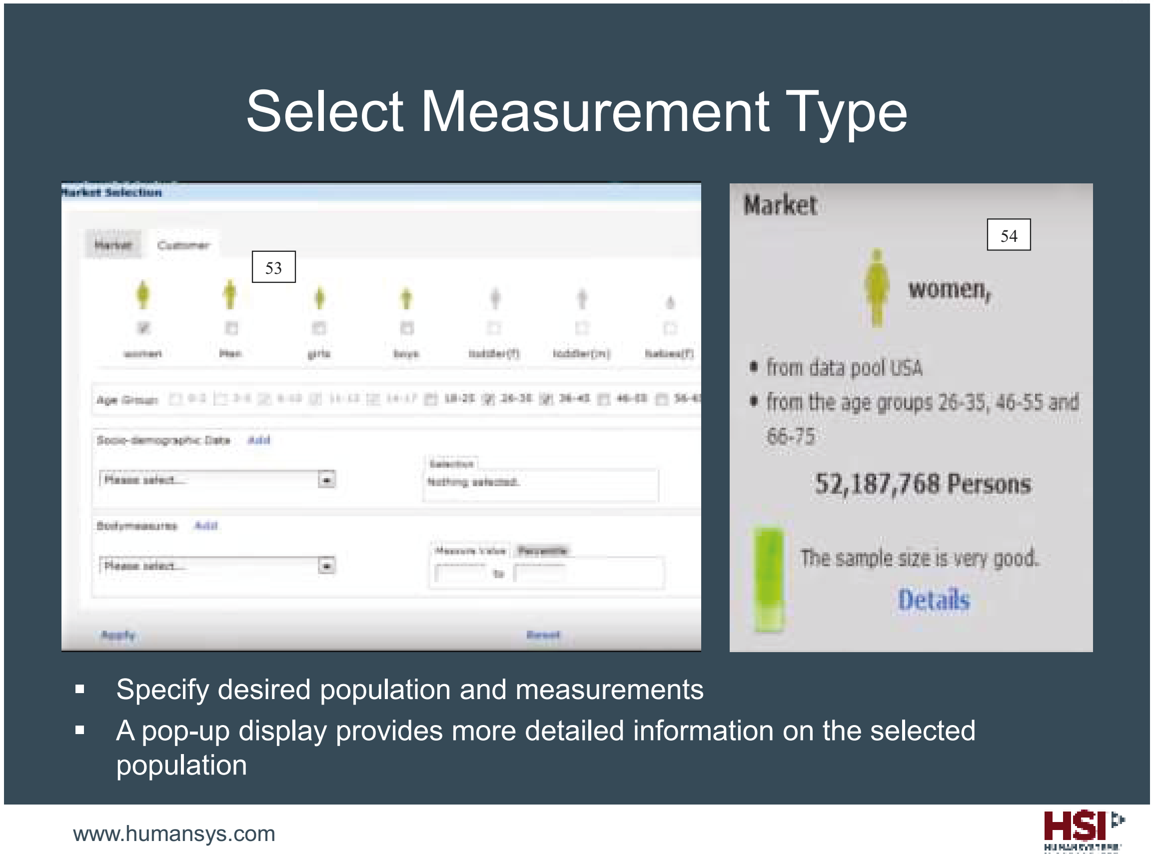
(Accessed from http://dined.io.tudelft.nl, reprinted with permission from Johan Molenbroek TUDelft)

TUDelft – 1D Database Explorer

37. Populations. Users can select multiple populations to directly compare to one another, as shown on the y-axis in Figure 9.
38. Age range and gender may be specified from the population.
39. Hovering over a check box will show which measurement the check box refers to.
40. Measures. Displays available measurement data based on the selected population.



(Accessed from https://www.youtube.com/watch?v=1m0PhcFWiy4, reprinted with permission from Luebke, Human Solutions Inc.)

Size North America – iSize

53. Customer. Specify the gender and age of the target customer. Users may also narrow their search based on criteria such as socio-demographic data and body measures.

54. Market Data. A pop-up window provides additional information on the selected market, including the number of individuals from the database that satisfy the criteria.

Display Measurement Data

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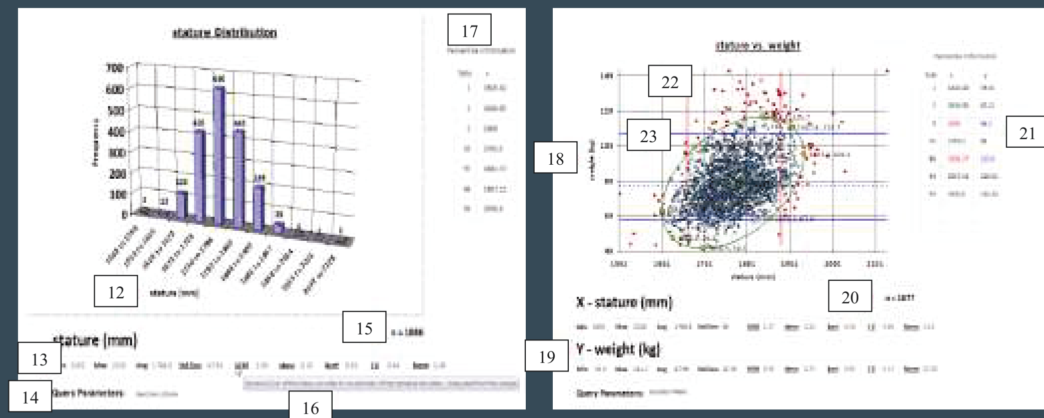
Display Univariate and Bivariate Data



- Univariate data is displayed on a histogram
- Bivariate data is displayed on a scatterplot
- Provides user with information about data set, such as min, max, and SD
- Summary of query parameters is shown below graph

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CFAS Explorer

12. Measure 1 (units of measurement)
13. Summary Statistics. Included are the min, max, avg values. Also some distribution characteristics including Standard Deviation, Standard Error of the Mean, Skewness, Kurtosis, Coefficient of Variance, and the Anderson-Darling statistic for normality.
14. Query Parameters. This identifies how the histogram data was down-selected.
15. n. The number of data points included in the sample.
16. Tool Tip. Underlined labels generally have an instruction or definition available in a tool tip. To activate the tool tip, simply hover over the label.

17. Percentile Information. Though no percentile information is integrated into a histogram graph, some standard percentile values for the data set are displayed.

18. Measure 2 now placed on the y axis.

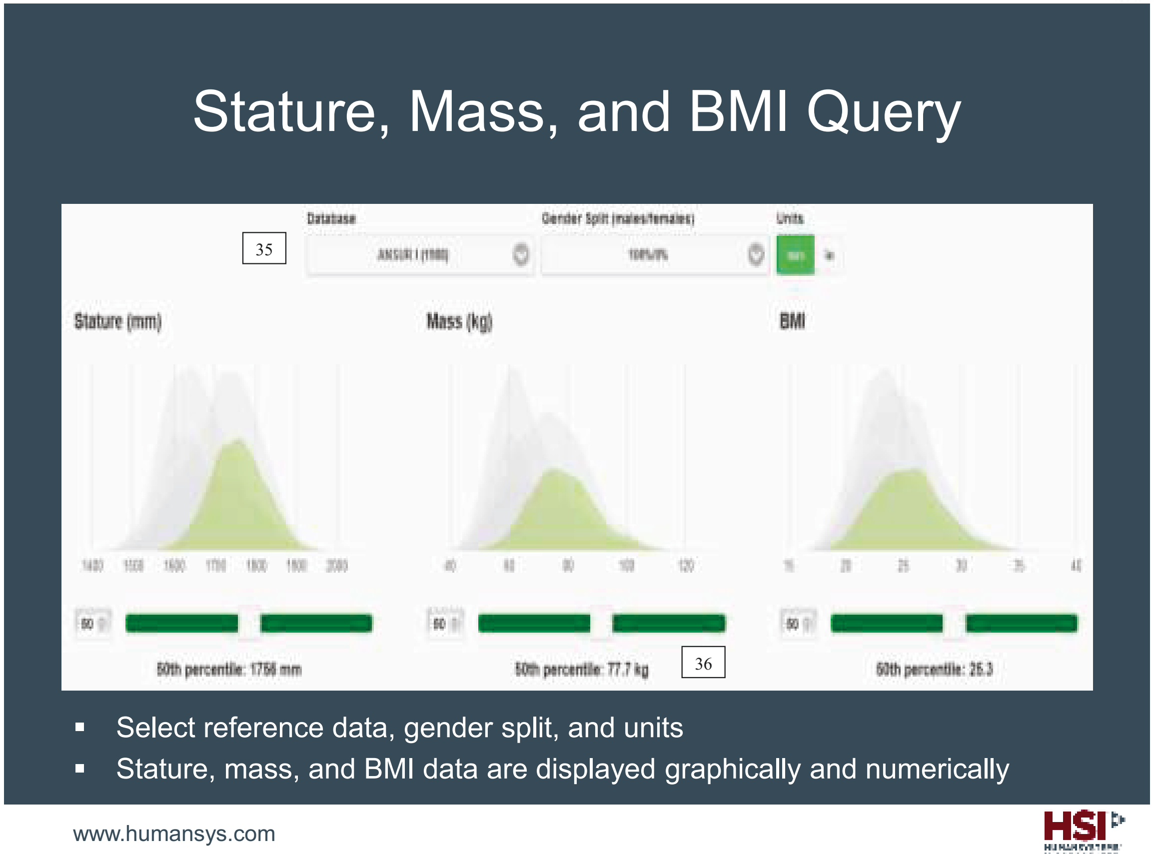
19. Summary statistics for measure 2 now added.

20. n. Notice that this n represents the number of cases where data exists for BOTH measures. This means the n can be lower for scatterplots as opposed to histograms as cases must have data on two measures, rather than just one.

21. Percentile Information. Similar to the histogram, however the chosen upper and lower percentiles are highlighted in red for measure 1 and blue for measure 2. Note that had the user specified custom percentile limits, they would appear in the last two rows of the Percentile Information table. Note that the 50th percentile for each measure is displayed by default. Also important to note - the percentile values displayed in the scatter form are based upon the univariate data set for each measure, rather than the (often) slightly reduced bivariate dataset.

22. Red percentile lines for measure 1 (x axis), matching the red numbers in the Percentile Information table.

23. Blue percentile lines for measure 1 (x axis), matching the blue numbers in the Percentile Information table.

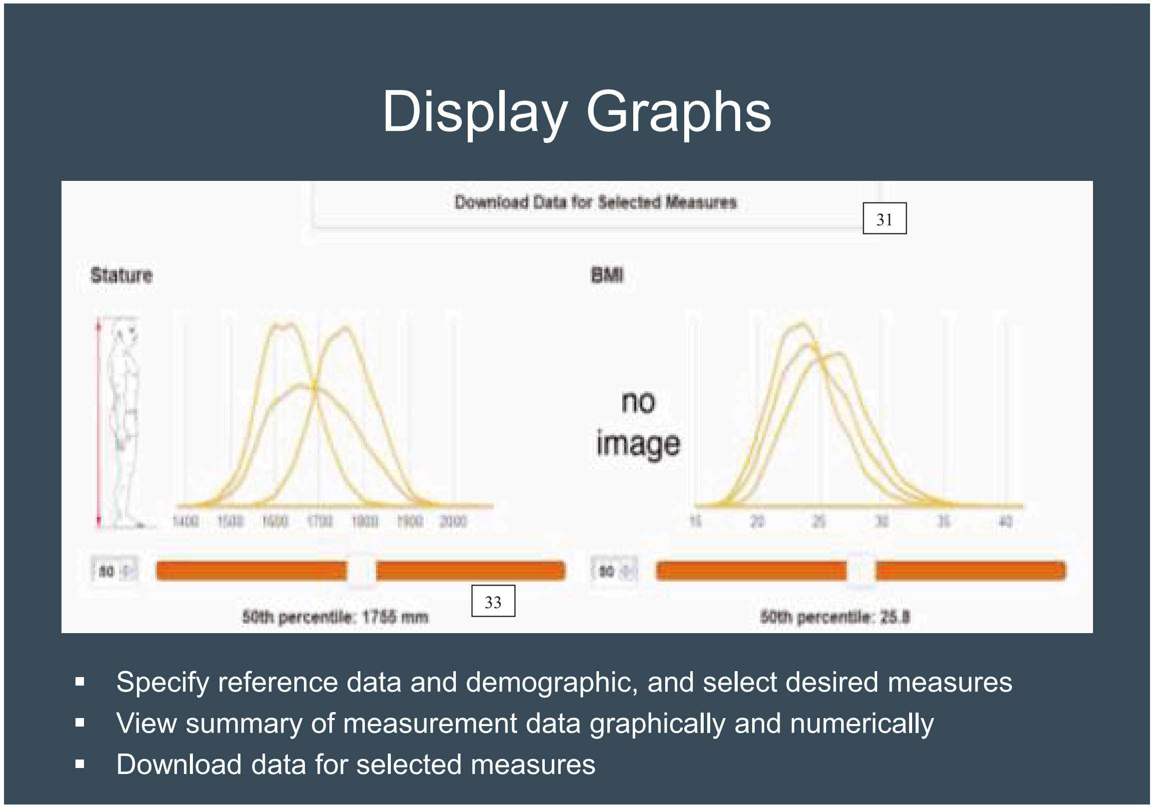


(Accessed from http://openlab.psu.edu/, reprinted with permission from Parkinson)

Penn State Open Design Lab – Data Explorer Lite

35. Database Selection and Query Conditions. The population data from the selected database, gender split, and units will appear in green on the graphs below. Note that the grey outlines represent other gender split options, while the green represents the distribution of the selected gender split

36. Sliders. View the percentile values associated with different measurement values by adjusting the sliders.



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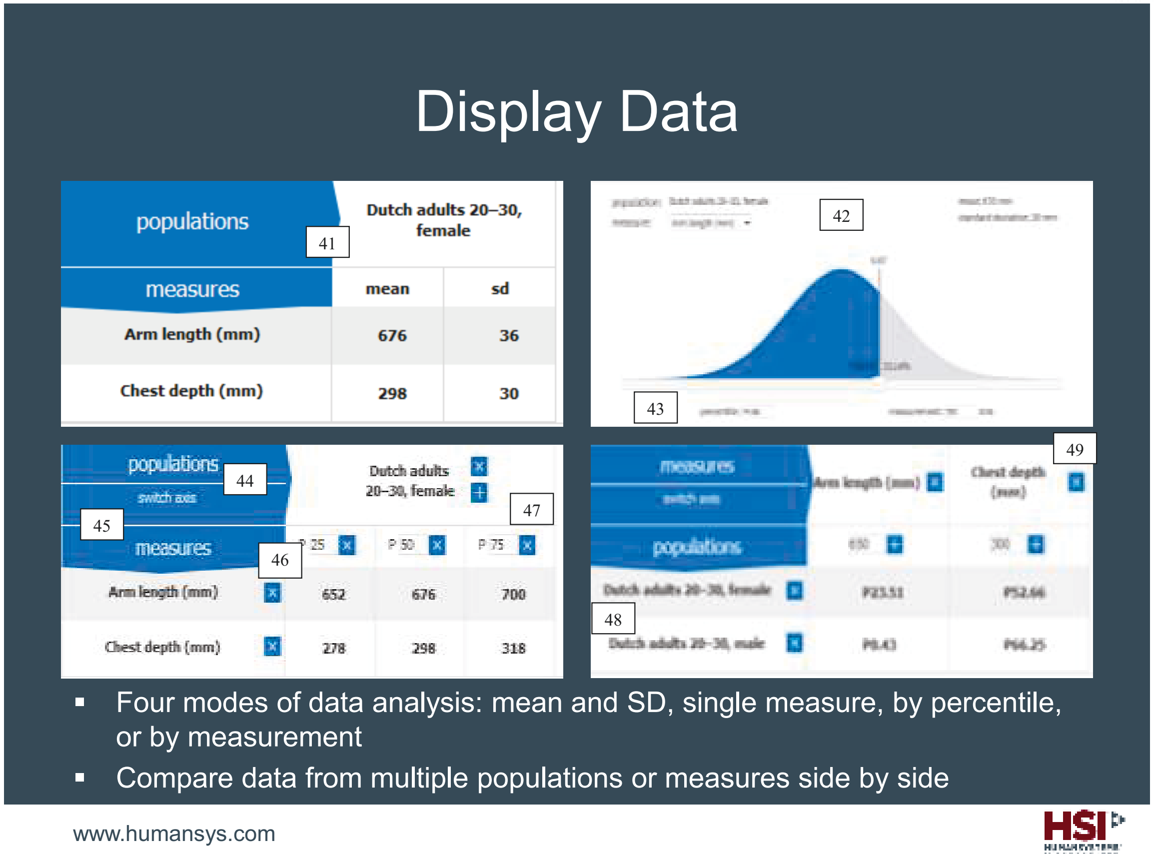
Penn State Open Design Lab – Data Explorer

Note: the three lines represent male, female, and combined data. There does not appear to be any way to specify which is which, other than by looking at percentile data.

31. Download Data. Click here to download an excel file with the data for the selected measures.

33. Sliders. Adjust the sliders to see the measurement value for a specific percentile.



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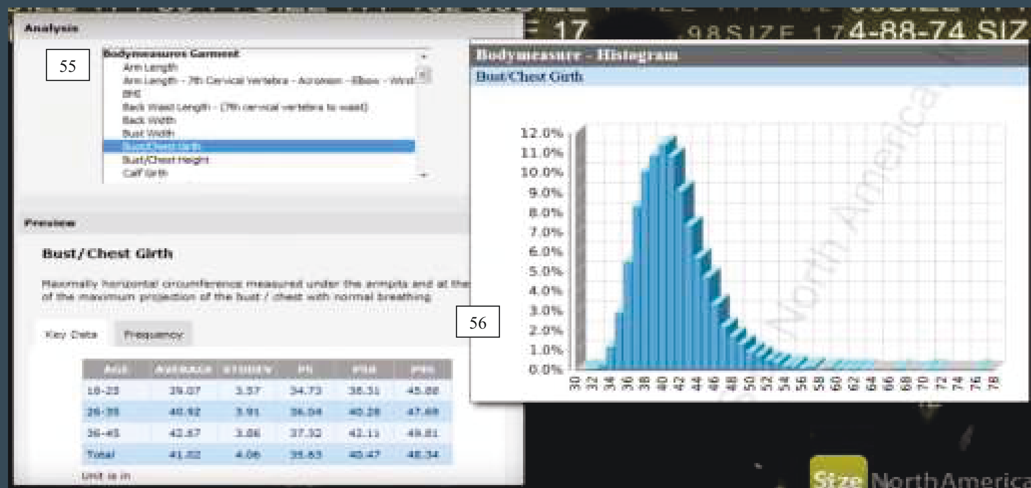
TUDelft – 1D Database

41 Mean and Standard Deviation (SD). Display mean and SD for selected data.
42 Single Measure. See distribution of single measure.
43 Percentile and Measurement. Input a percentile value to see the corresponding measurement value and vice versa.
44 Populations. Data from multiple populations can be displayed on this panel, allowing for easy comparison between populations.
45 Switch Axis. Users have the option to switch the axis of the chart on which the data is displayed. In Figure 9 the chart axes are switched.

46 Measures. Allows users to view data from multiple measures on a single chart.
47 Percentiles. Measurement values at different percentiles can be displayed in a chart. Useful for comparison within and between populations.
48 Measures and Populations. Measurements are now on the x-axis with populations on the y-axis.
49 Set Measurements. Input percentile values to see the corresponding measurement values.

Display Data



- Distribution of univariate data is displayed in a histogram
- Chart includes more detailed information (average, standard deviation, etc.)

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(Accessed from https://www.youtube.com/watch?v=1m0PhcFWiy4, reprinted with permission from Luebke, Human Solutions Inc.)

Size North America - iSize

55. Univariate analysis. Scroll and select a body measure.
56. Key data is presented in a chart, while the frequency of univariate data is displayed in a histogram.

Data Collection and Analysis

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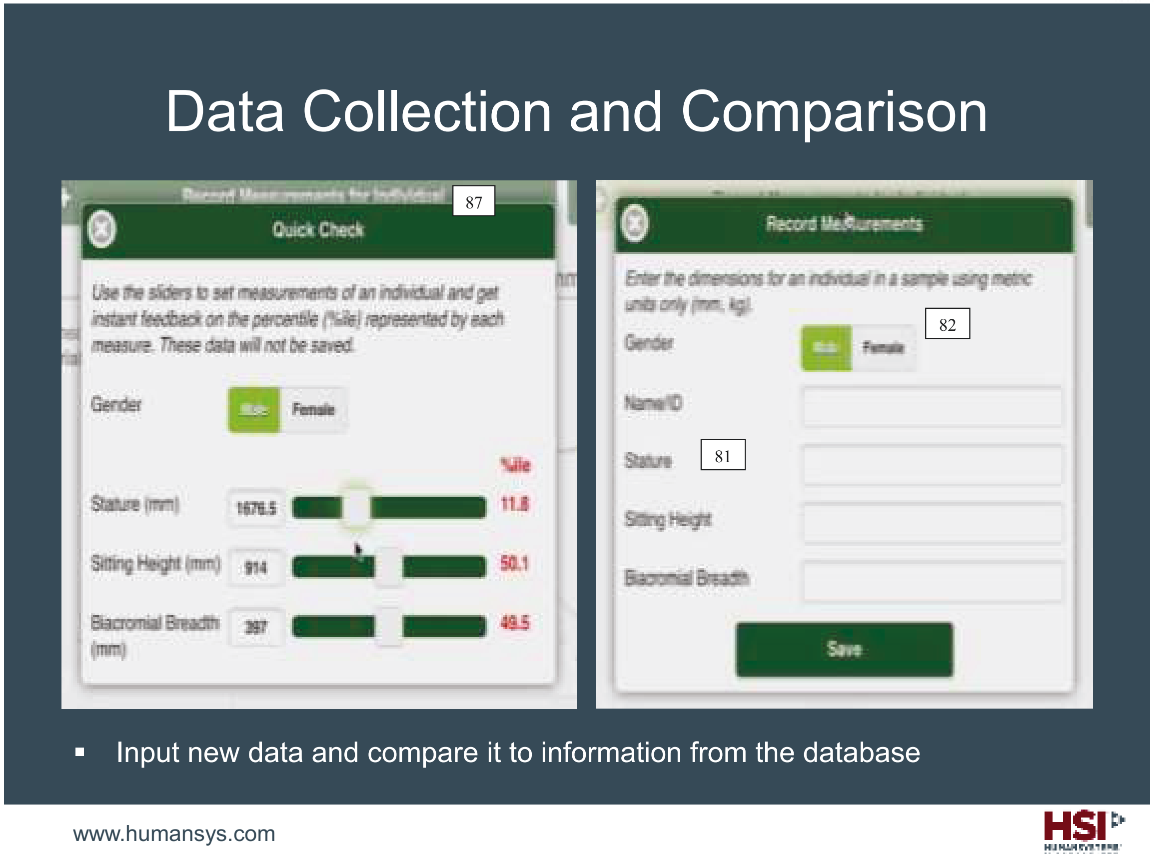
15



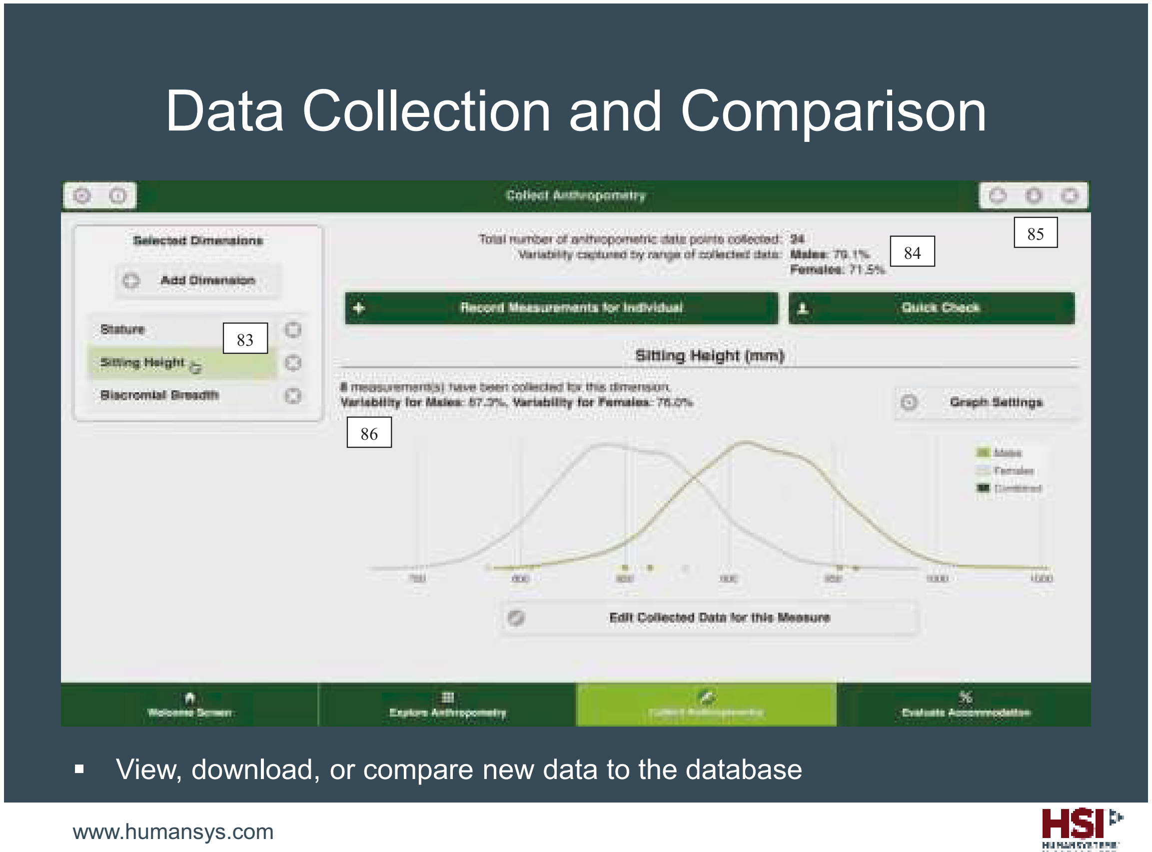
(Accessed from https://www.youtube.com/watch?v=yewOFd8r6AA, reprinted with permission from Garneau)

MARC Tool – Collect Anthropometry

87. Quick Check. Useful for comparison of single values or values of one individual to the reference data. Adjust the sliders next to the various dimensions to see the percentiles represented by each measurement value.

81. Selected Dimensions. Displays selected dimensions for measurement and allows dimensions to be added or removed.

82. Record Measurements. Useful for comparing data from multiple individuals. Clicking “Record Measurements” will open a pop-up window where data can be inputted.

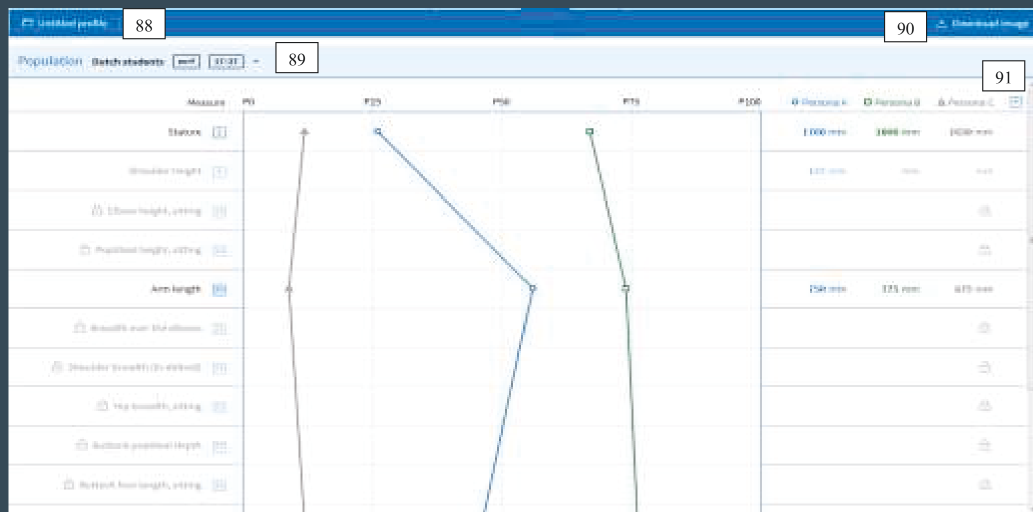


(Accessed from https://www.youtube.com/watch?v=yewOFd8r6AA, reprinted with permission from Garneau)

MARC Tool – Collect Anthropometry

83. Select Dimension. Click on the dimension to see a summary of the data collected.
84. Data Summary. An overview of all of the anthropometric data collected is shown here.
85. Print or Download. A summary of the data collected can be printed or saved for further analysis.
86. Real-Time Comparison. The data collected can be compared to reference data in real time. Users may specify the source of reference data as shown in Figure 3.

Data Collection and Comparison



- Input measurement data for one or more personas
- Compare measurement data to selected population

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(Accessed from http://dined.io.tudelft.nl, reprinted with permission from Johan Molenbroek TUDelft)

TUDelft – Profiler

88. Profiles. Data for multiple profiles can be saved here.
89. Populations. Select the population against which to compare the profile data.
90. Download Image. Download SVG images of analyses that can be included into documents or edited further.
91. Measurement Values. Input values for the desired measures here, to see them compared to the population data.

2-Dimensional Reach Analysis

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19

2-Dimensional Reach Envelope

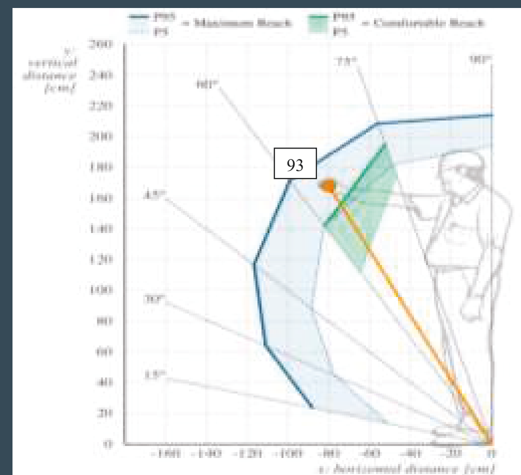
Population

20 - 30 years of age, stature < 175 cm

92

	comfortable					maximum				
angle (°)	n	σ	P5	x̄	p95	n	σ	P5	x̄	P95
90						49	6	194	204	214
75	34	6	181	191	201	60	8	188	204	216
60	49	11	123	147	164	60	9	164	184	198
45						60	11	125	149	165
30						53	12	89	110	128
15						27	13	53	73	91

All values shown in the table below were measured from the *heel* at the specified angle. All values are in *cm*.



- Select population based on age and height
- 2-Dimensional reach data is presented in a chart and on a graph
- Manipulate object on graph to determine whether or not it lies within reach

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(Accessed from http://dined.io.tudelft.nl, reprinted with permission from Johan Molenbroek TUDelft)

TUDelft – 1D Reach Envelope

92. Population. Select population data from drop down menu.

93. Drag and drop the object (orange circle) to any location on the graph to see whether it is out of reach, within the maximum reach range, or within comfortable reach.

3-Dimensional Models

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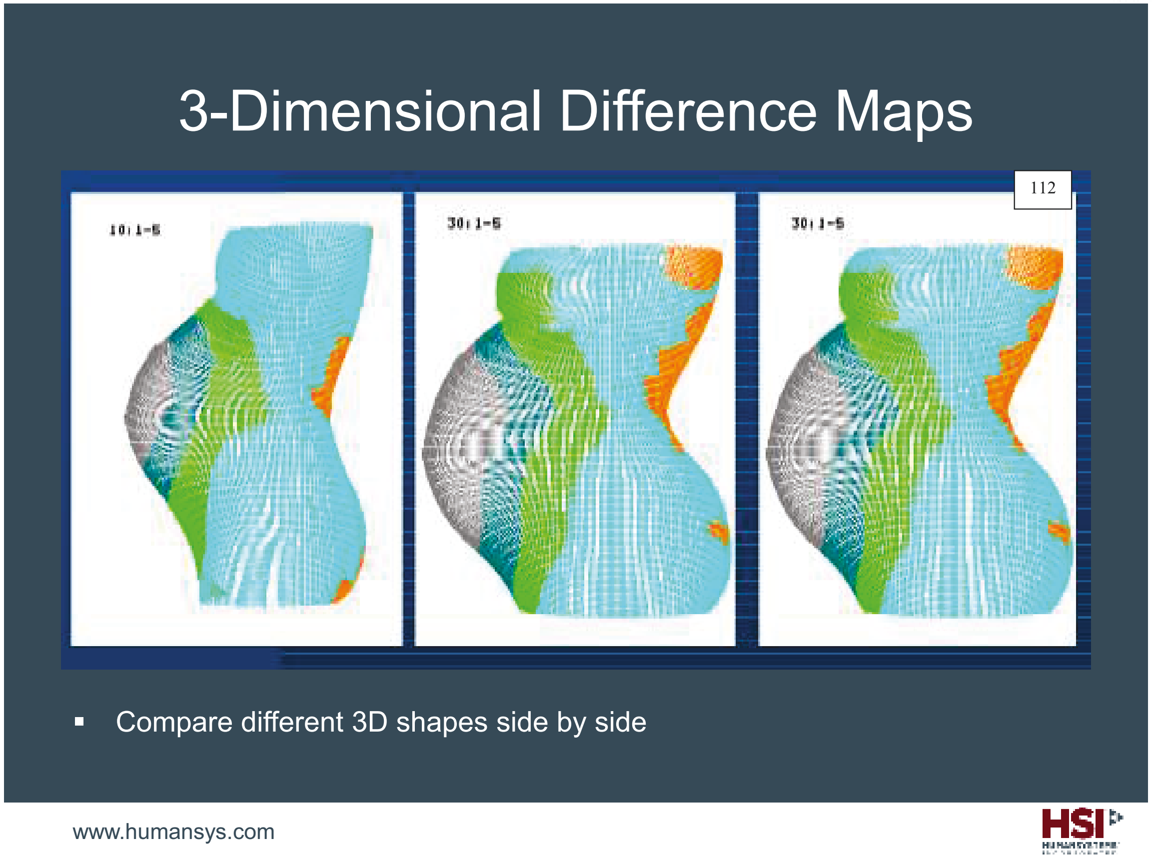
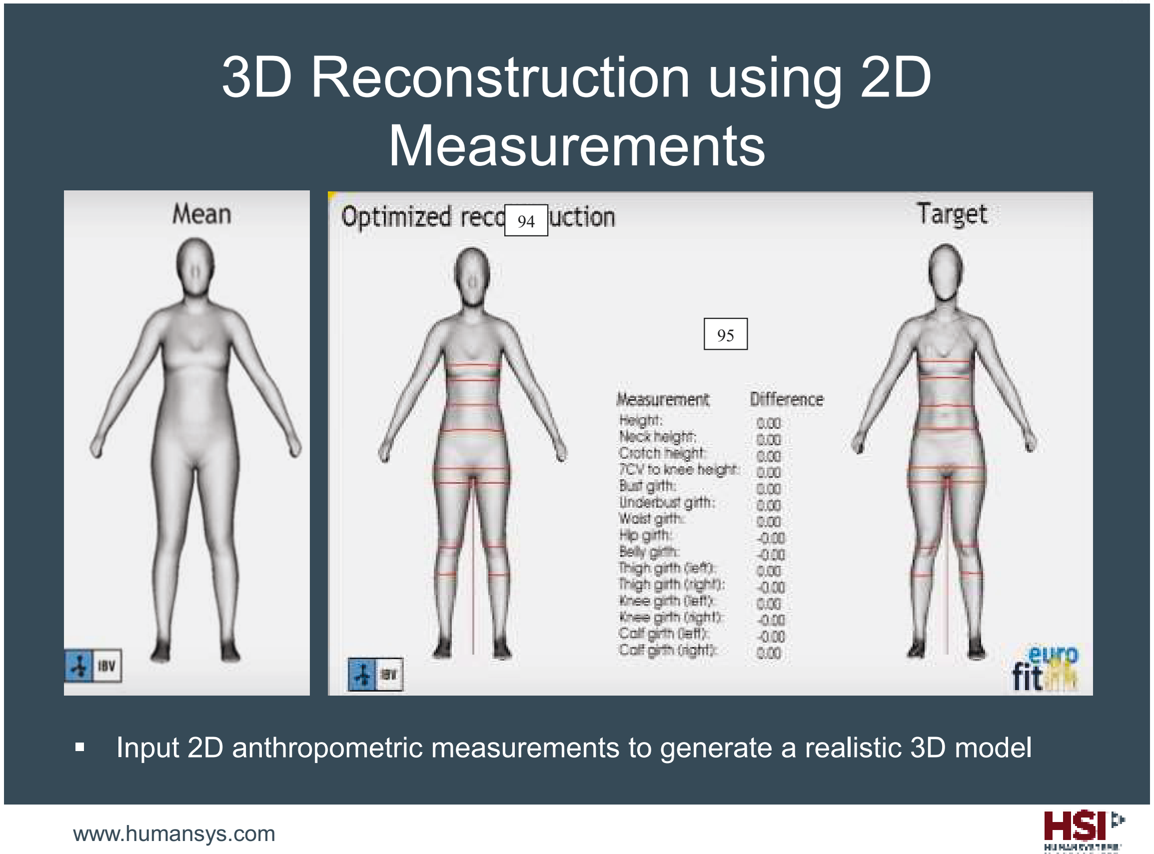
21



(Perkins, T (1999) as referenced by Robinette (n.d.). Accessed from http://webapp1.dlib.indiana.edu/virtual_disk_library/index.cgi/3725325/FID3800/speakers/robinett.pdf, reprinted with permission from Robinette)

3D Difference Maps

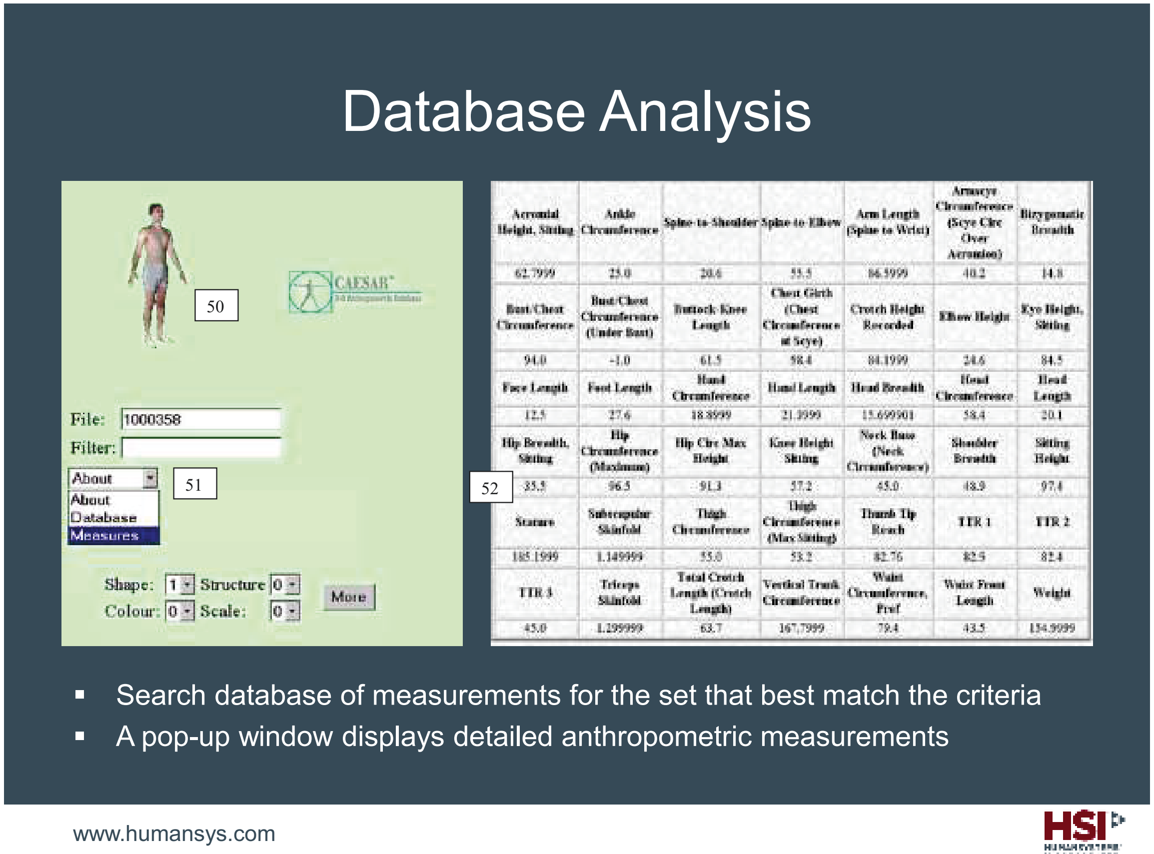
112. Allows for side-by-side comparison of different 3D shapes.



(Accessed from http://www.slideshare.net/AlfredoBallesterFern/20150602-cadans-seminar-v08slideshare04, reprinted with permission from Ballester)

EuroFit – 3D Reconstruction

94. 1D Calculations. Anthropometric measurements are taken from the target person and the difference from the mean is calculated.
95. 3D Reconstruction. The mean model is adjusted based on the measurements from the target individual to create a realistic 3D representation of the person.

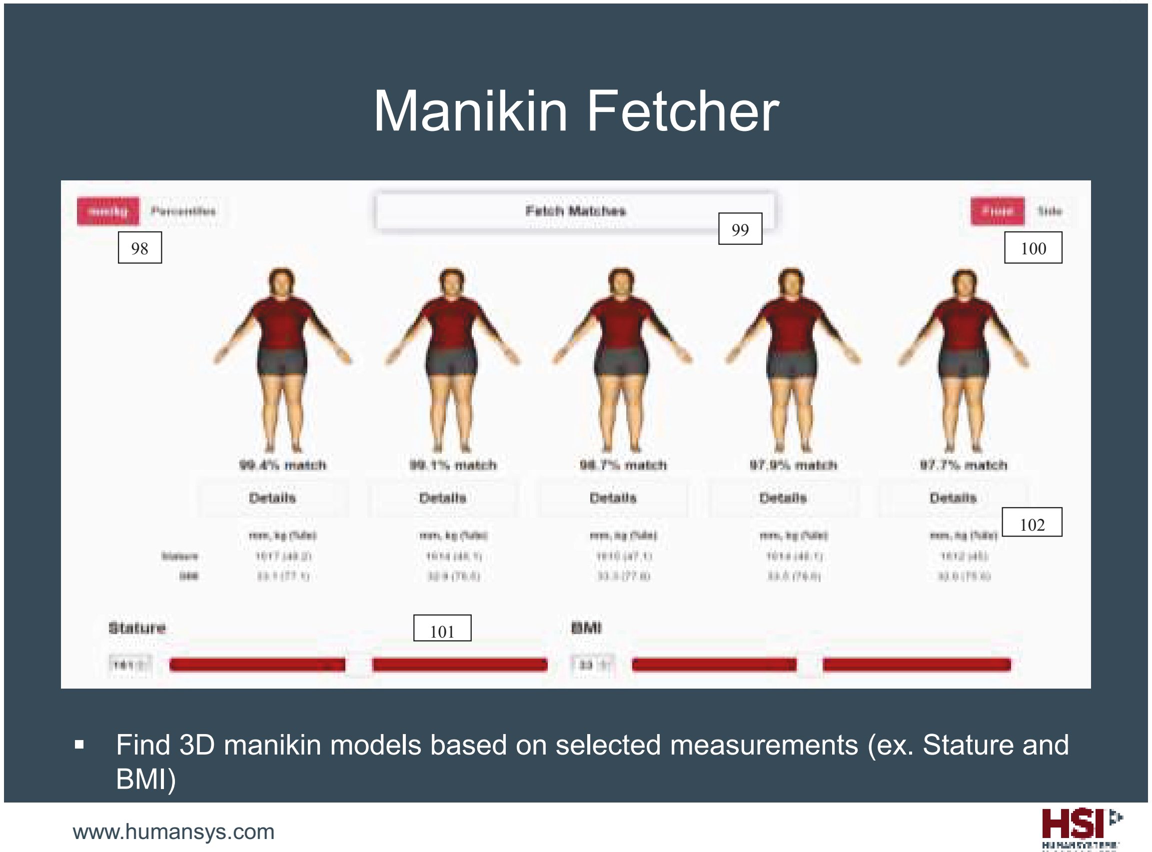


Acromial Height, Sitting	Ankle Circumference	Spine-to-Shoulder	Spine-to-Elbow	Arm Length (Spine to Wrist)	Armscye Circumference (Scye Circ Over Acromion)	Bizygomatic Breadth
62.7999	25.0	20.6	55.5	86.5999	40.2	14.8
Bust/Chest Circumference	Bust/Chest Circumference (Under Bust)	Buttock-Knee Length	Chest Girth (Chest Circumference at Scye)	Crotch Height Recorded	Elbow Height	Eye Height, Sitting
94.0	-1.0	61.5	98.4	84.1999	24.6	84.5
Face Length	Foot Length	Hand Circumference	Hand Length	Head Breadth	Head Circumference	Head Length
12.5	27.6	18.8999	21.3999	15.699901	58.4	20.1
Hip Breadth, Sitting	Hip Circumference (Maximum)	Hip Circ Max Height	Knee Height Sitting	Neck Base (Neck Circumference)	Shoulder Breadth	Sitting Height
35.5	96.5	91.3	57.2	45.0	48.9	97.4
Stature	Subscapular Skinfold	Thigh Circumference	Thigh Circumference (Max Sitting)	Thumb Tip Reach	TTR 1	TTR 2
185.1999	1.149999	55.0	53.2	82.76	82.5	82.4
TTR 3	Triceps Skinfold	Total Crotch Length (Crotch Length)	Vertical Trunk Circumference	Waist Circumference, Pref	Waist Front Length	Weight
45.0	1.299999	63.7	167.7999	79.4	43.5	154.9999

Accessed from http://webapp1.dlib.indiana.edu/virtual_disk_library/index.cgi/3725325/FID3800/speakers/robinett.pdf, reprinted with permission from Robinette)

CAESAR Database

50. Full-body representations of each shape are shown.
51. Query Conditions. Search by database or measures.
52. Measurement details. A pop-up box opens with specific measurement information.

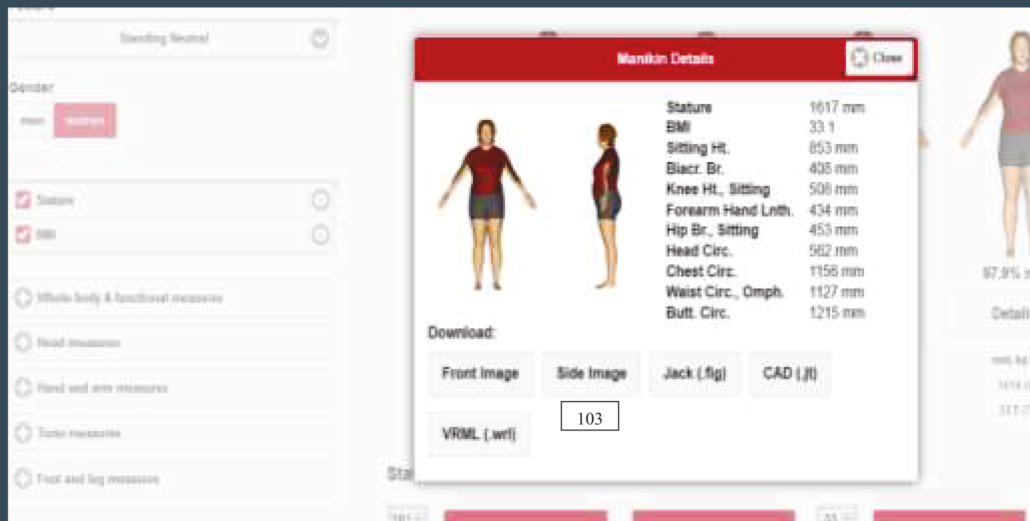


(Accessed from http://openlab.psu.edu/, reprinted with permission from Parkinson)

Penn State Open Design Lab – Manikin Picker

98. Search for manikins based on either mm/kg or percentiles.
99. Fetch Matches. Clicking this button will display the manikins that best represent the selected anthropometric measurement values.
100. Toggle between front and side views of the manikins.
101. Sliders. Use these sliders to set the desired anthropometric measurement values for the manikins. Note that after making any changes the user must click “Fetch Matches” to refresh the manikin results.
102. Details. Clicking this button will open a pop-up window with all of the manikin’s measurement values.

Manikin Fetcher



- View measurement details of a specific manikin and download the manikin in one of several file formats

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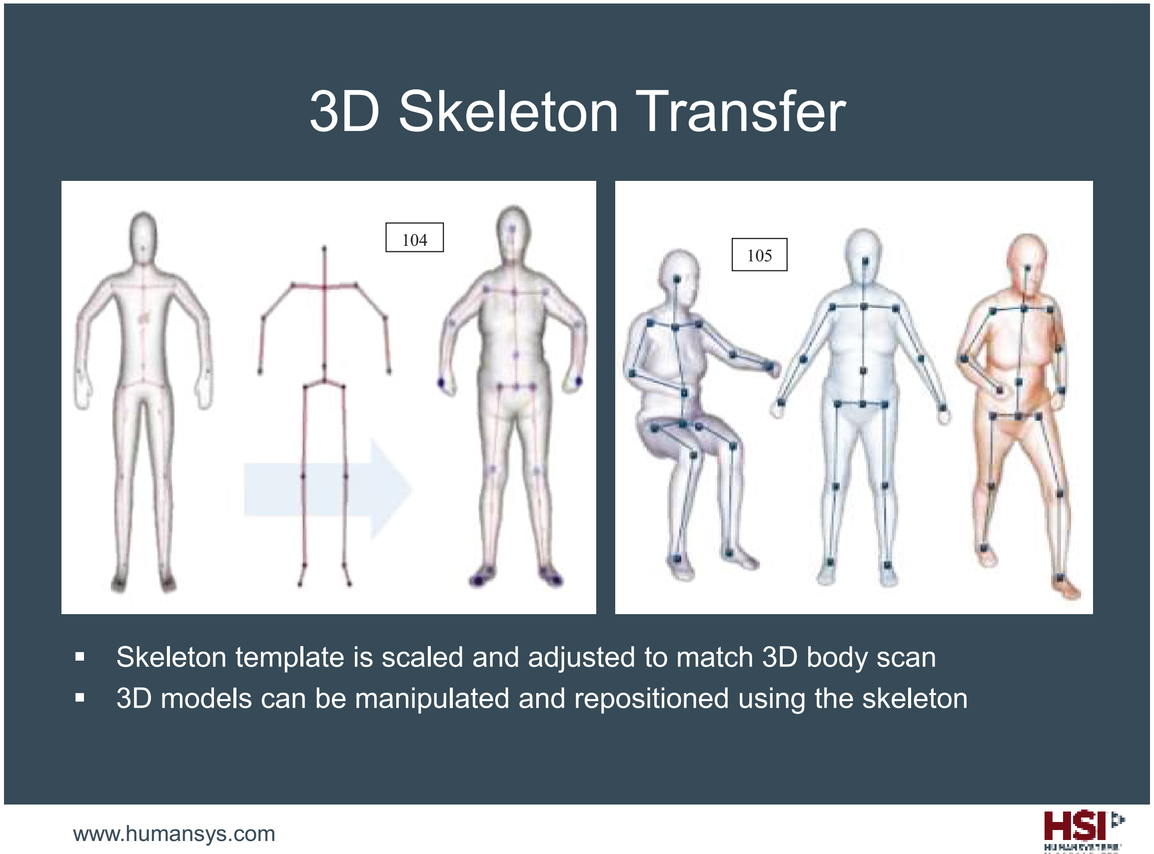
(Accessed from http://openlab.psu.edu/, reprinted with permission from Parkinson)

Penn State Open Design Lab – Manikin Picker

103. Download Options. Users can download a front image or side image of the Manikin as a Jack file (.fig), a CAD file (.jt), or a VRML file (.wrl) by clicking on the appropriate button.

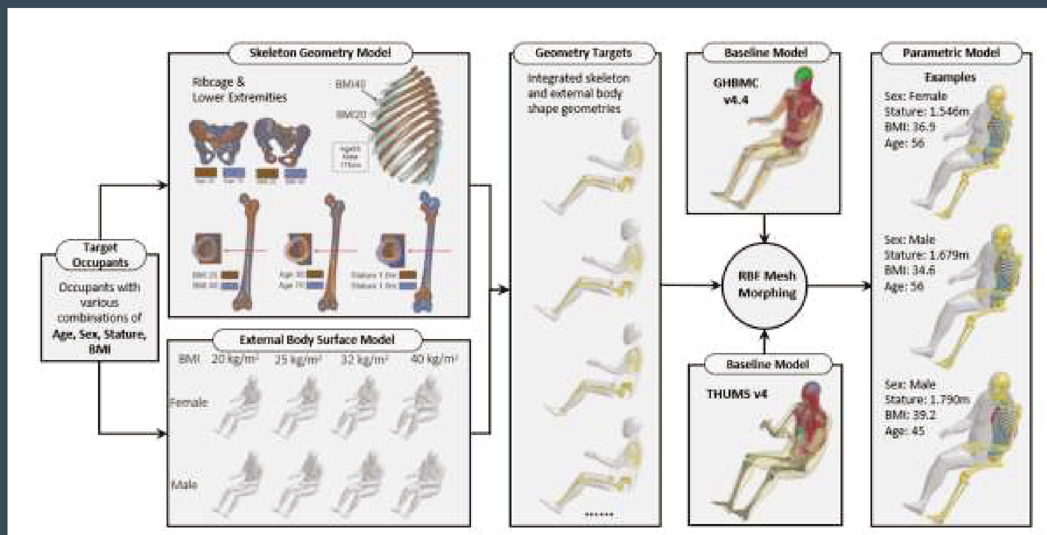


(Accessed from http://www.slideshare.net/AlfredoBallesterFern/20150602-cadans-seminar-v08slideshare04, reprinted with permission from Ballester)

EuroFit Project – Skeleton Transfer

104. Skeleton template is scaled and adjusted to match 3D body scan
105. 3D models can be manipulated and repositioned using the skeleton

3D Skeleton Transfer



- Combine skeleton geometry and body surface models to generate parametric human models

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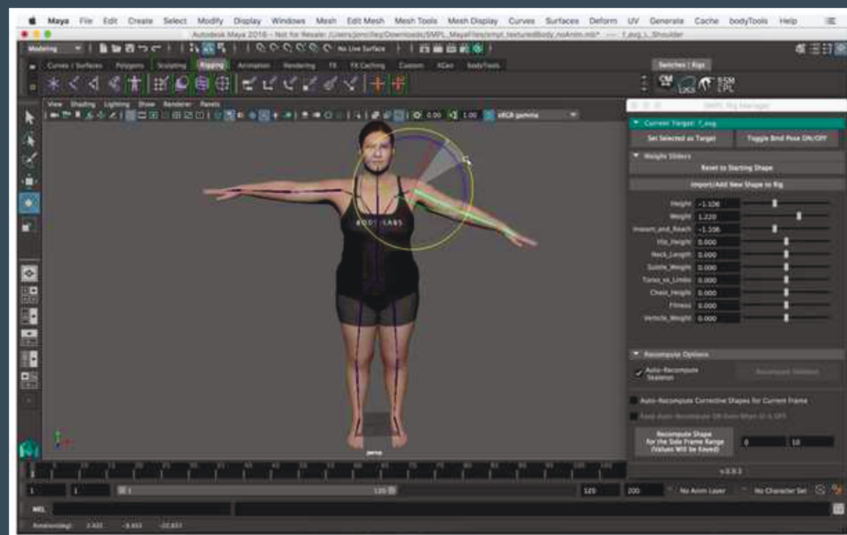
(Accessed from https://www-esv.nhtsa.dot.gov/Proceedings/25/25ESV-000314.pdf, reprinted with permission from Hu, 2017)

UMTRI – Parametric Human Models

107. Skeleton Geometry Model. Skeleton models are created using statistical parametric geometry models.
108. External Body Surface Model. External body surface models based on whole-body laser scans and computed tomography scans.

Animate 3D Avatar

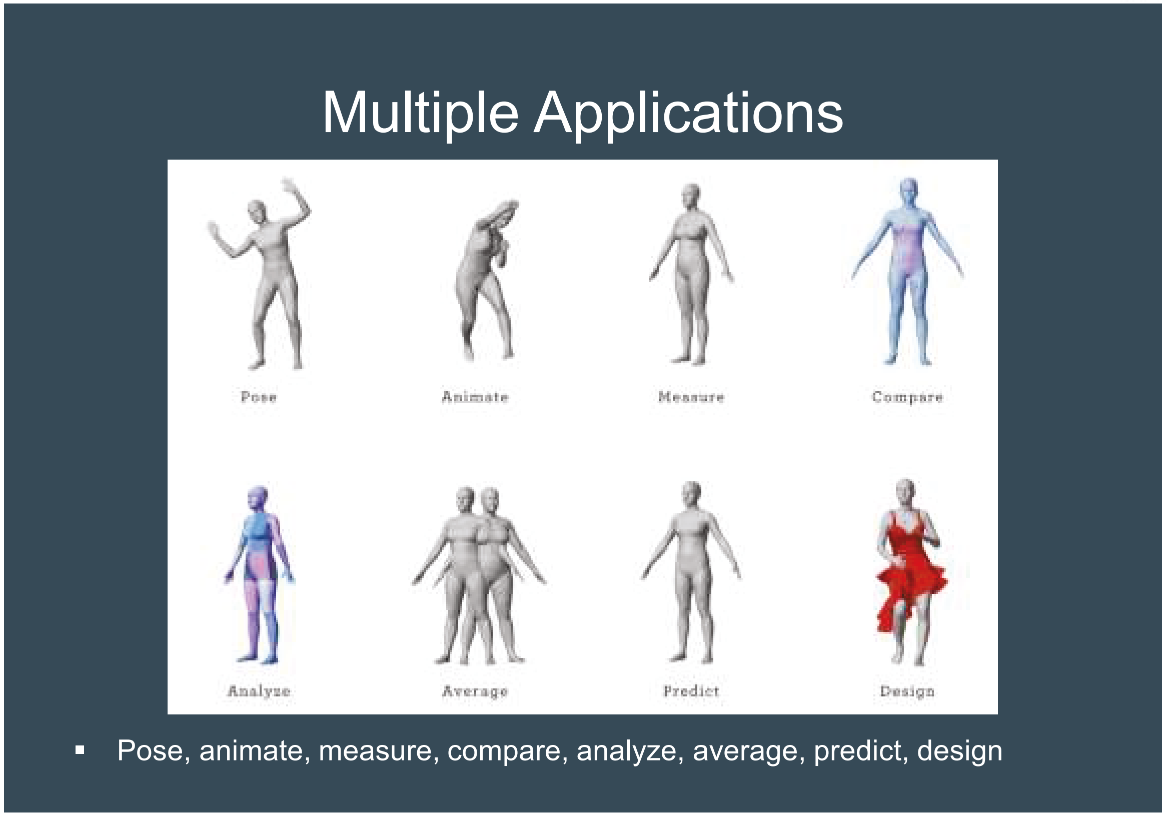


- Integrate processed body models into animation, gaming or virtual reality applications

www.humansys.com

BodyLabs

Easily add textures and integrate processed body models into animation, gaming or virtual reality applications. Animate any body model by easily applying motion capture sequences — even if the sequence was not originally captured by the same subject.

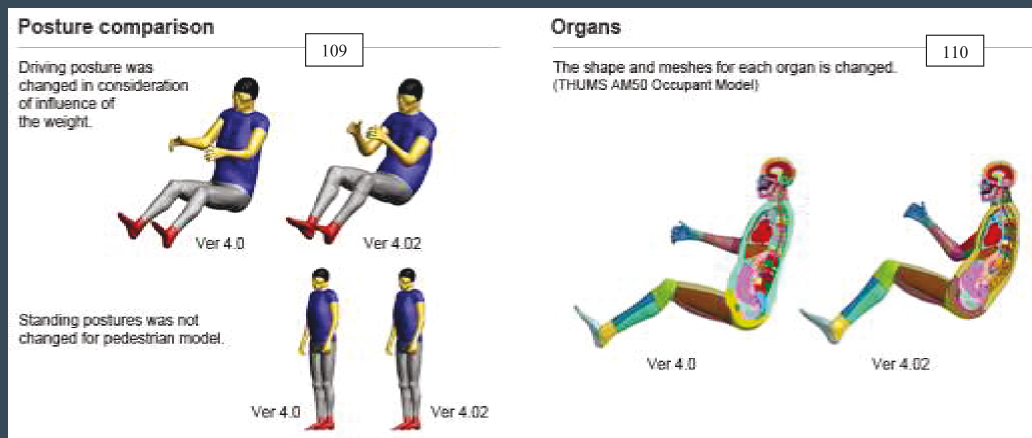


www.humansys.com

BodyLabs

Turn Imagery into Robust & Reusable 3D Avatar
3D avatars can be posed, animated, measured, compared, analyzed, averaged between individuals, used to predict outcome, and for design

Finite Element Human Models



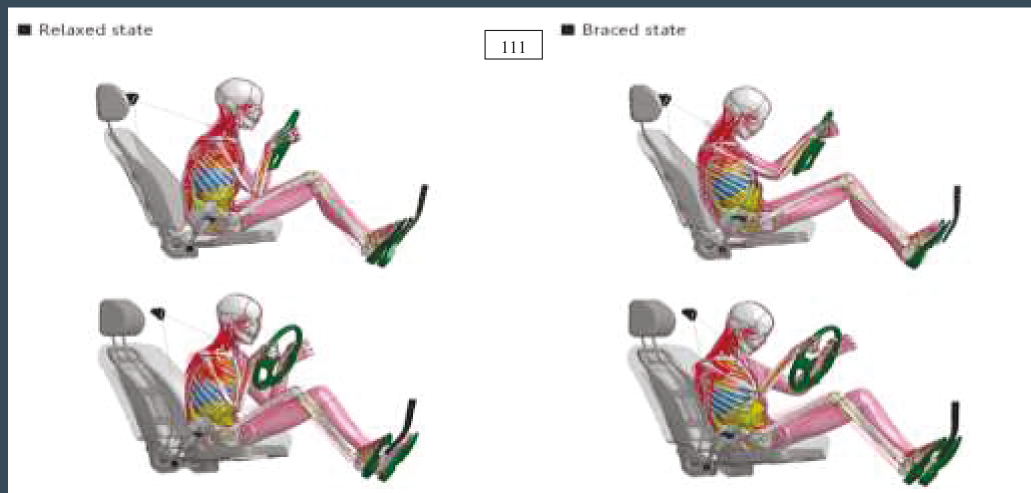
- Whole body models represent a range of ages, sexes, and body types
- Seated and standing postures are available for each model
- Model includes skeleton, brain, and organ models

www.humansys.com

JSOL – Total Human Model for Safety

109. Posture Composition. Seated and standing versions of each model are available and updated in version 4.02.
110. Organs. THUMS version 4.02 includes organ models intended to predict damage to organs during simulations.

Finite Element Human Models



- Model the action of a human body going from a relaxed posture to a braced posture

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JSOL – Total Human Model for Safety

111. Muscle Model. THUMS version 5 has the ability to model the action of a human body going from a relaxed posture to a braced posture to more accurately predict the effectiveness of safety equipment.

Digital Measurement

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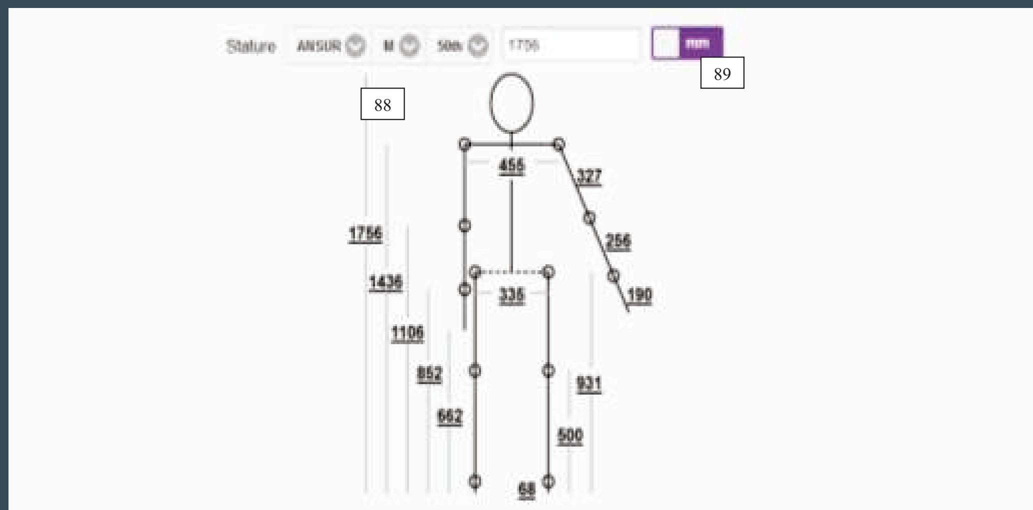
Scaling Calculator



- Predict the length of body segments based on stature

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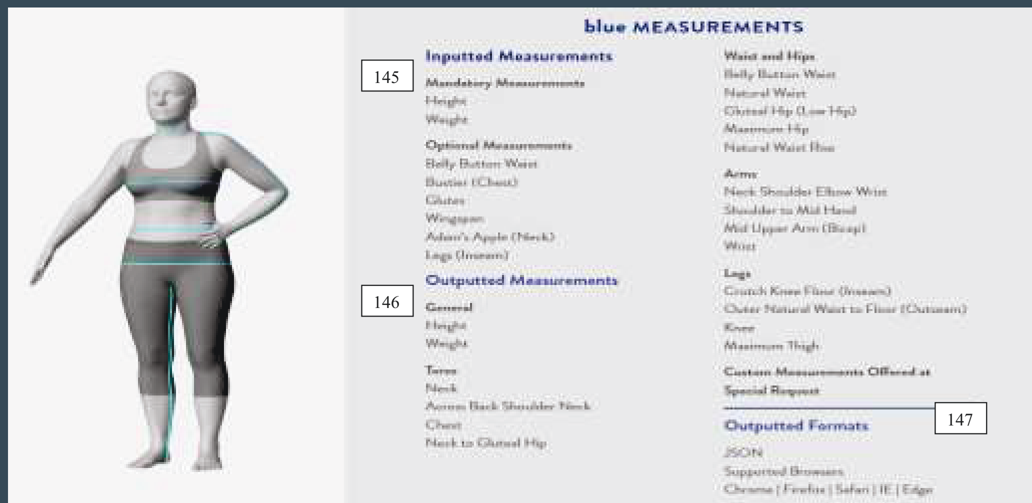
(Accessed from http://openlab.psu.edu/, reprinted with permission from Parkinson)

Penn State Open Design Lab – Scaling Calculator

88. Stature Adjustment. Specify the stature by selecting a percentile from the drop down menu, or by inputting values in mm or inches.
89. Pre-defined point searches and measuring functions based on common body references.

Body Measurement Prediction



- Predict 17 body measurements based on height and weight
- Input 6 key body measurement values to increase accuracy of predictions

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BodyLabs – Blue

145. Inputted Measurements. BodyLabs Blue will predict 17 body measurements based only on height and weight. Users can also provide the program with 6 of the measurements (belly button waist, bustier, glutes, wingspan, neck around the Adam's apple, and leg inseam) to increase the accuracy of the other 11 values.

146. Outputted Measurements. A total of 17 measurements are generated based on information from the user.

147. Outputted Formats. Data can be exported to JSON, Chrome, Firefox, Safari, IE, or Edge.

Refine Measurements

- Each measurement comes with a video and written instructions for the user to ensure that measurements are taken properly

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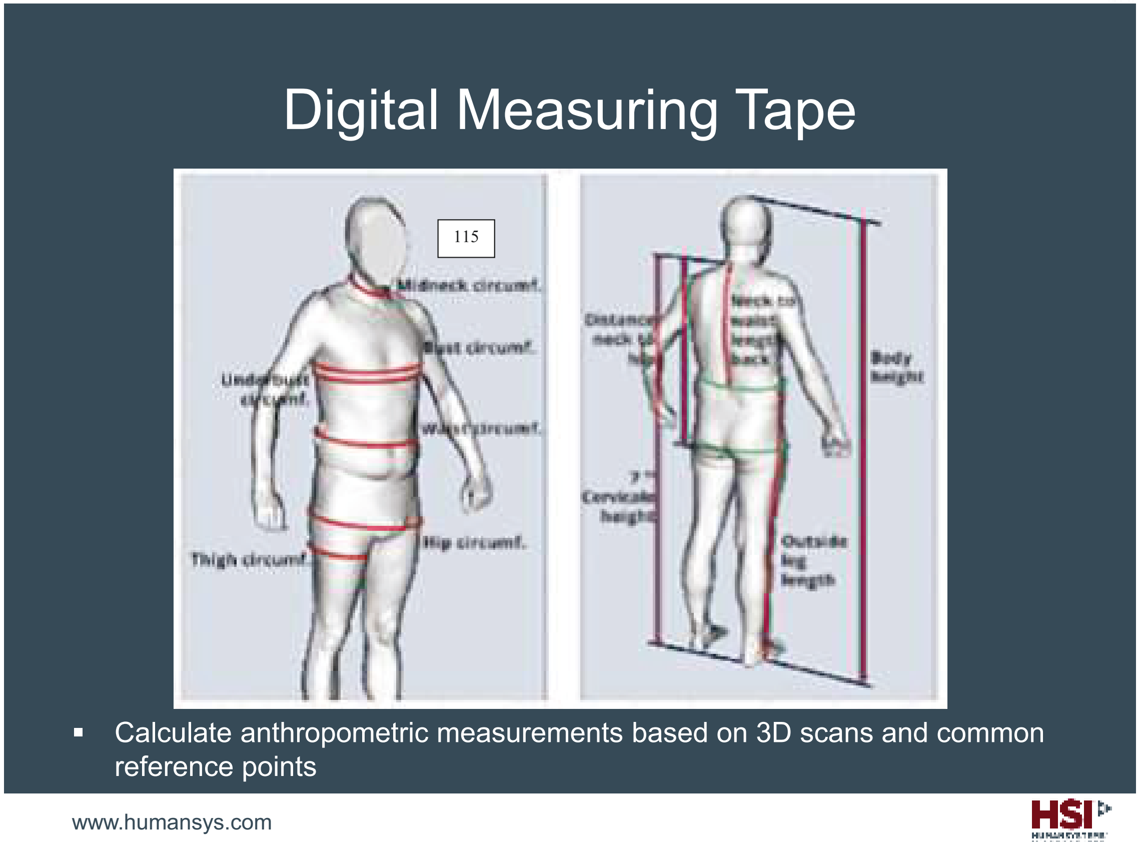
BodyLabs – Blue

148. Refine Measurements. Users can manually measure and input these measurements in order to generate a more accurate shape profile.

149. Measurement Instructions. The program provides written and visual instructions to ensure that the measurement is taken properly.

150. Input Measurement. The measurement value predicted by the program is displayed. The user can input the measured value next to the predicted value to refine their shape profile.



(Accessed from http://www.slideshare.net/AlfredoBallesterFern/20150602-cadans-seminar-v08slideshare04, reprinted with permission from Ballester)

EuroFit Project – Digital Measuring Tape

115. Pre-defined point searches and measuring functions based on common body references.

3-Dimensional Clothing and Equipment Design

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34

3D Clothing Design

- Edit 2D clothing patterns and apply to 3D manikins, or edit clothing on 3D manikins and view changes to 2D clothing pattern

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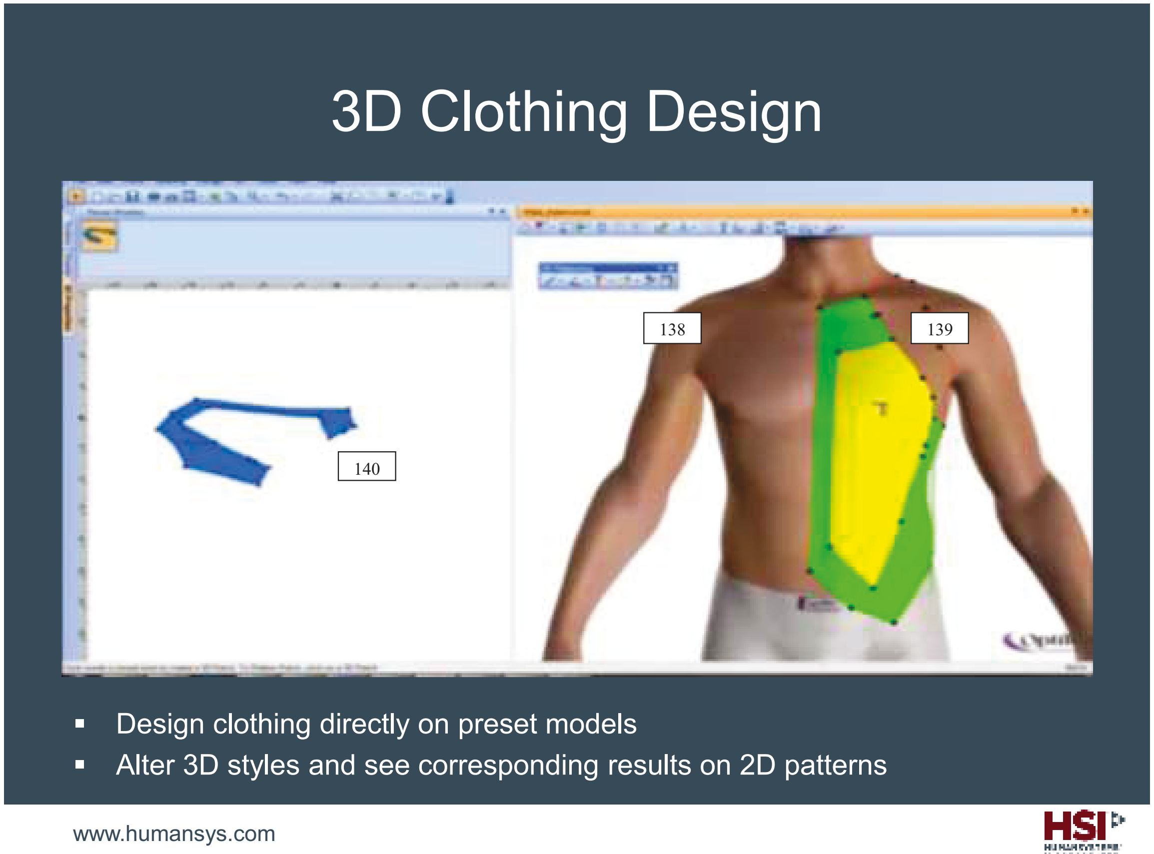
(Accessed from http://www.cs.columbia.edu/cg/SC/SC.pdf, reprinted with permission from Umetani)

Sensitive Couture

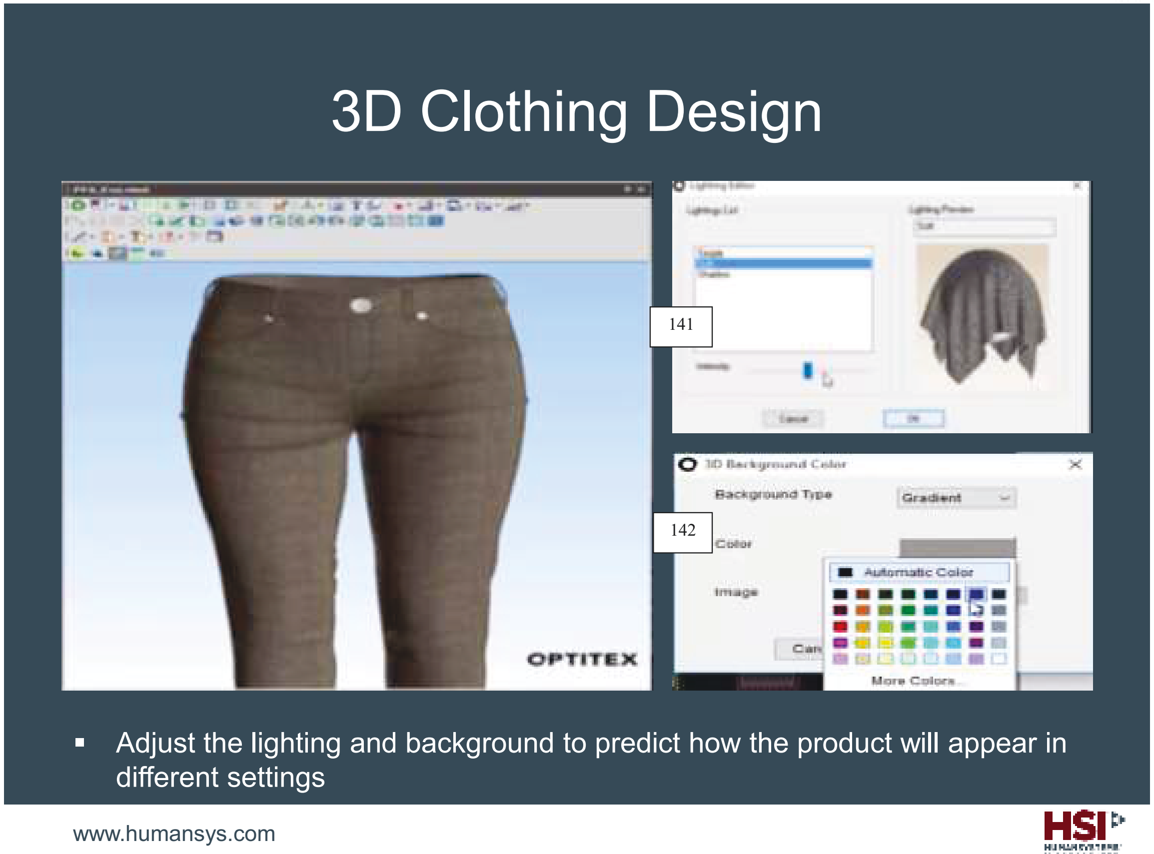
136. 2D and 3D Interaction. The garment is shown in both 2D and 3D views.
137. Editing. Users can edit the 2D form and immediately see the changes in the 3D view, and vice versa.



(Accessed from http://optitex.com/solutions/odev/3d-production-suite/, reprinted with permission from EFI Optitex)

Optitex – O'Dev 3D Production Suite

138. Build a library of custom models including a virtually unlimited number of body types by adjusting body shape, height, circumference, muscle mass, and dozens of other measurements.
139. Simulate and fit samples on custom-fit virtual avatars without having to cut any fabric.
140. Alter 3D styles and see the corresponding results on your 2D patterns on the same screen.

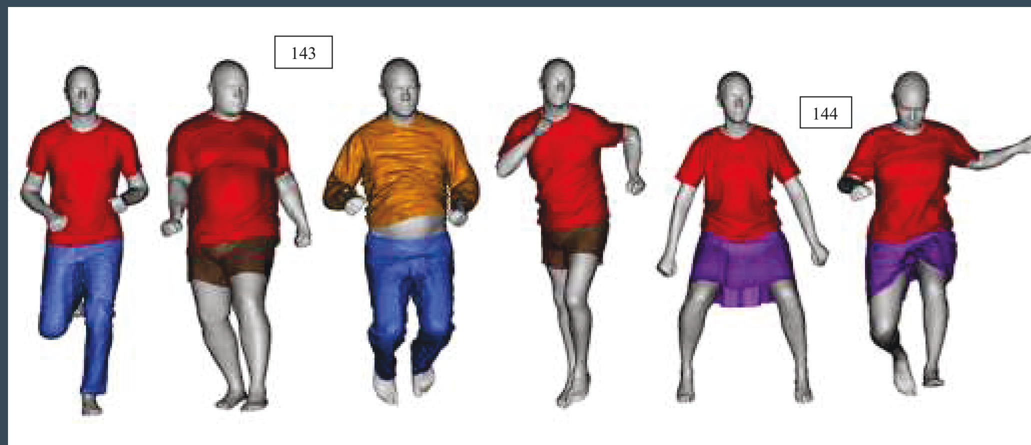


(Accessed from http://optitex.com/solutions/odev/3d-production-suite/, reprinted with permission from EFI Optitex)

Optitex – O'Dev 3D Production Suite

141. Lighting Editor. Adjust the lighting and intensity to see what the product will look like in different conditions.
142. Background Editor. Change the background colour to see how the fabric appears against different coloured backgrounds.

Clothing Fit Simulation



- Simulate clothing on bodies of different shapes and sizes at the same time
- Predict clothing deformations on characters while moving

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Body Labs – DRAPE

143. Clothing Deformations. The DRAPE model approximates the clothing deformation caused by body shape and pose.
144. Animation. DRAPE can be used to dress static bodies or animated sequences with a learned model of the cloth dynamics.

Accommodation Analysis

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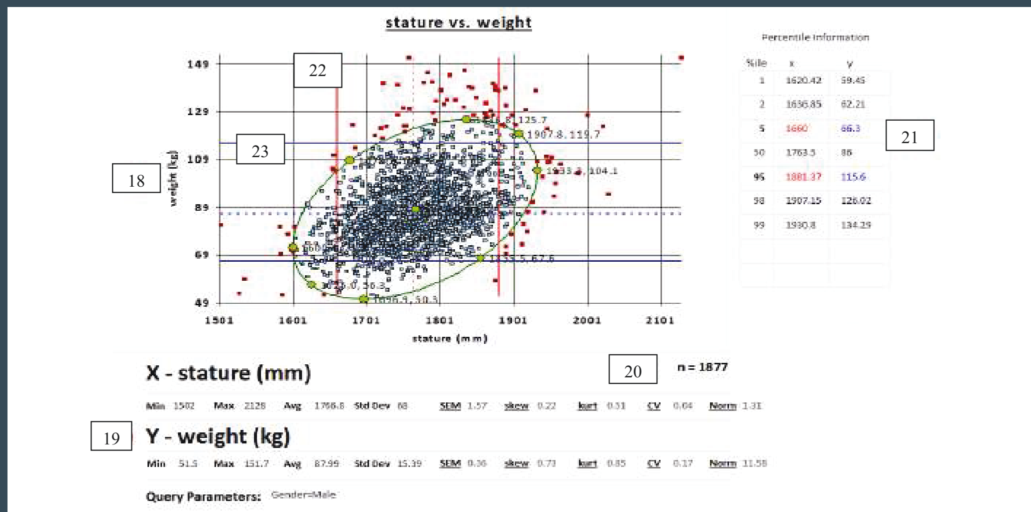
Confidence Ellipse



- Ellipse represents the probability that a new point would fall within the middle *n*th percentile on the combination of 2 measures.

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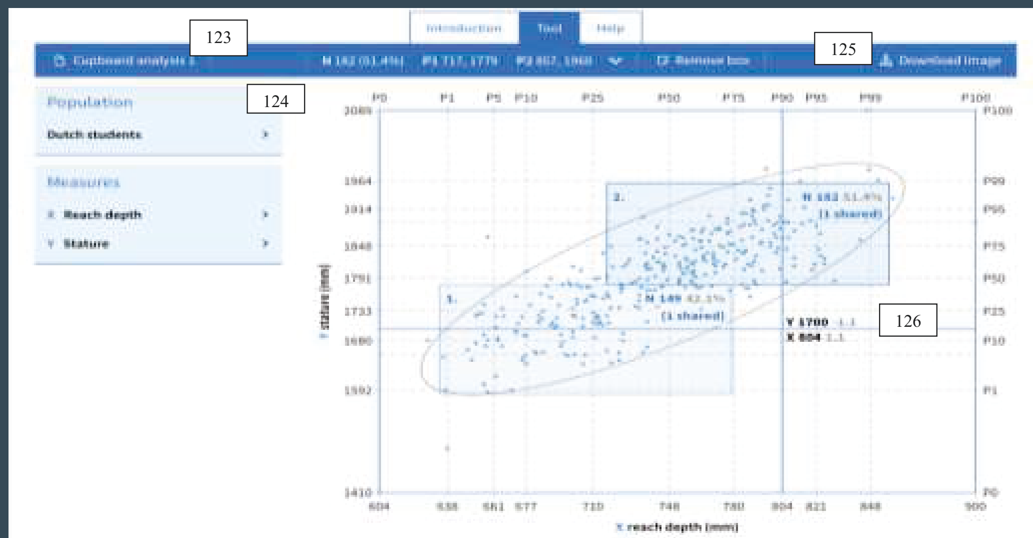
CFAS Explorer

18. Measure 2 now placed on the y axis.
19. Summary statistics for measure 2 now added.
20. n. Notice that this n represents the number of cases where data exists for BOTH measures. This means the n can be lower for scatterplots as opposed to histograms as cases must have data on two measures, rather than just one.
21. Percentile Information. Similar to the histogram, however the chosen upper and lower percentiles are highlighted in red for measure 1 and blue for measure 2. Note that had the user specified custom percentile limits, they would appear in the last two rows of the Percentile Information table. Note that

the 50th percentile for each measure is displayed by default. Also important to note - the percentile values displayed in the scatter form are based upon the univariate data set for each measure, rather than the (often) slightly reduced bivariate dataset. Looking at the percentile values for stature in the univariate histogram and bivariate scatterplot demonstrates that they are the same. In this way, one can explore each measure's unique distribution properties, as well as its relational properties with a second measure in on graph. It also retains consistency between the histogram and scatterplot.

22. Red percentile lines for measure 1 (x axis), matching the red numbers in the Percentile Information table.
23. Blue percentile lines for measure 1 (x axis), matching the blue numbers in the Percentile Information table.

Multivariate Accommodation Analysis



- Draw rectangles to see accommodation percentage of the selected area

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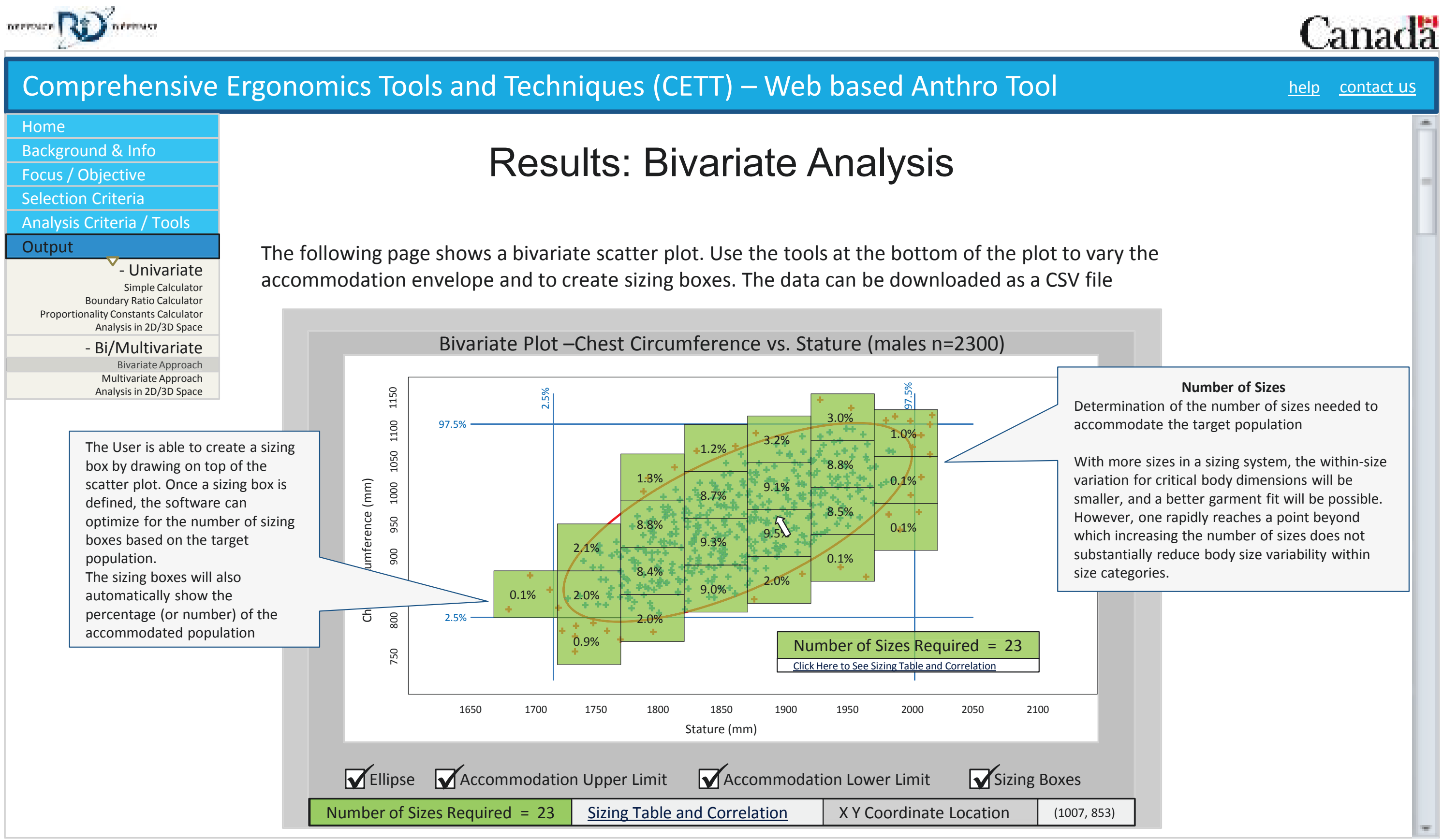
(Accessed from http://dined.io.tudelft.nl, reprinted with permission from Johan Molenbroek TUDelft)

TUDelft – Ellipse

123. Cupboard Analysis. Save multiple analyses online for reference or to work on at a later time
124. Query Details. Select population and measures as in 1D Database. See Figure 6.
125. Download Image. Download SVG images of analyses that can be included into documents or edited further.
126. Boxes. Draw boxes to quickly determine what percentage of the population fit certain dimensions.

Analysis Criteria / Tools

(1. Bivariate Analysis)



CETTs storyboard – Sizing Boxes

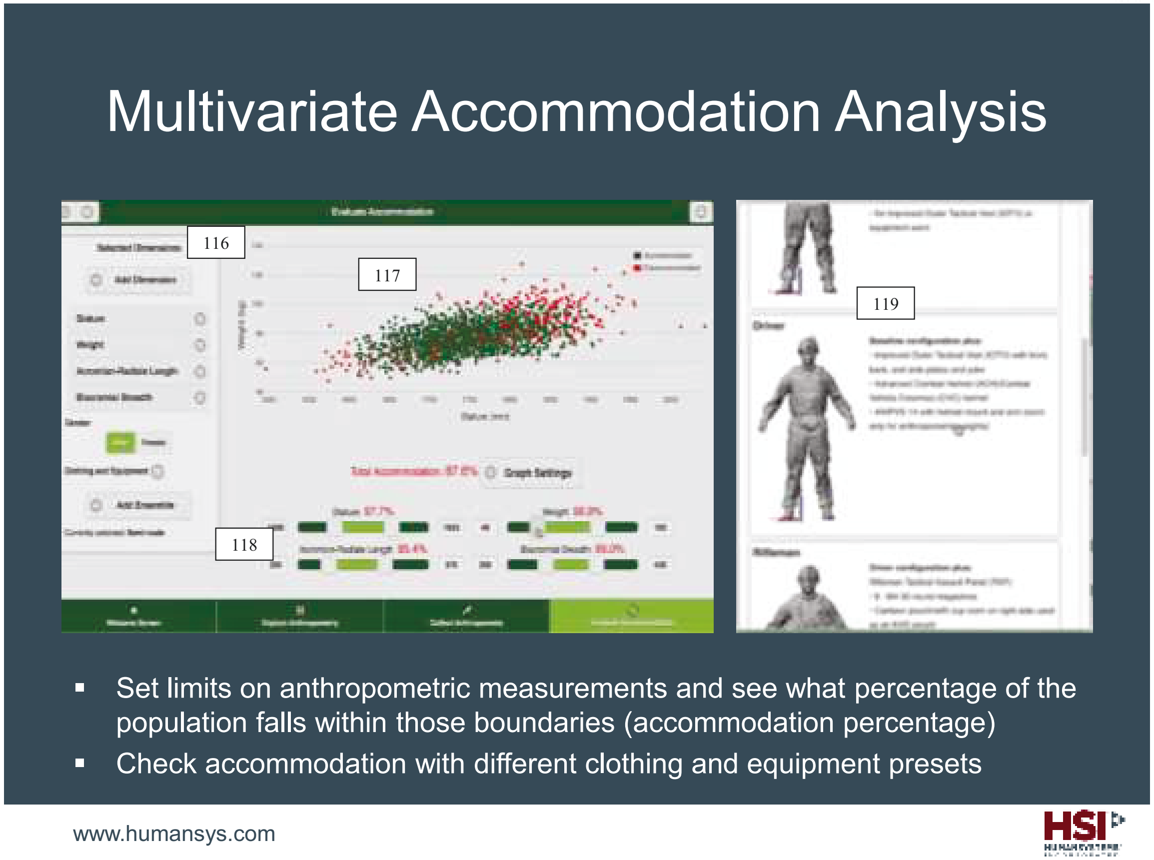
(note: this was a mock-up storyboard created for the CETTs project, and is included for illustration purposes only)

The user chooses the Sizing Boxes tool by placing a check mark in the selection box and new information is presented in the scatter plot:

Defining Sizing Box = the user is able to define and create a sizing box by drawing on top of the scatter plot. Once a sizing box is defined, the software can optimize for the number of sizing boxes based on the sample population. For this example the software shows that a total of 23 sizes are required. The sizing boxes will also automatically show the percentage (or number) of the accommodated population within each box. This information tip is presented via the information bubble. A preference model could also potentially be built into the software algorithm that would consider the acceptable range of individual tolerance for fit (e.g. clothing tightness/looseness) within a given shirt size.

Determining Number of Sizes within Sizing Box = The software can automatically determine the number of sizes needed to accommodate the target population (tariffing). With more sizes in a sizing system, the within-size variation for critical body dimensions will be smaller, and a better garment fit will be possible. However, one rapidly reaches a point beyond which increasing the number of sizes does not substantially reduce body size variability within size categories. This information tip is presented via the information bubble.

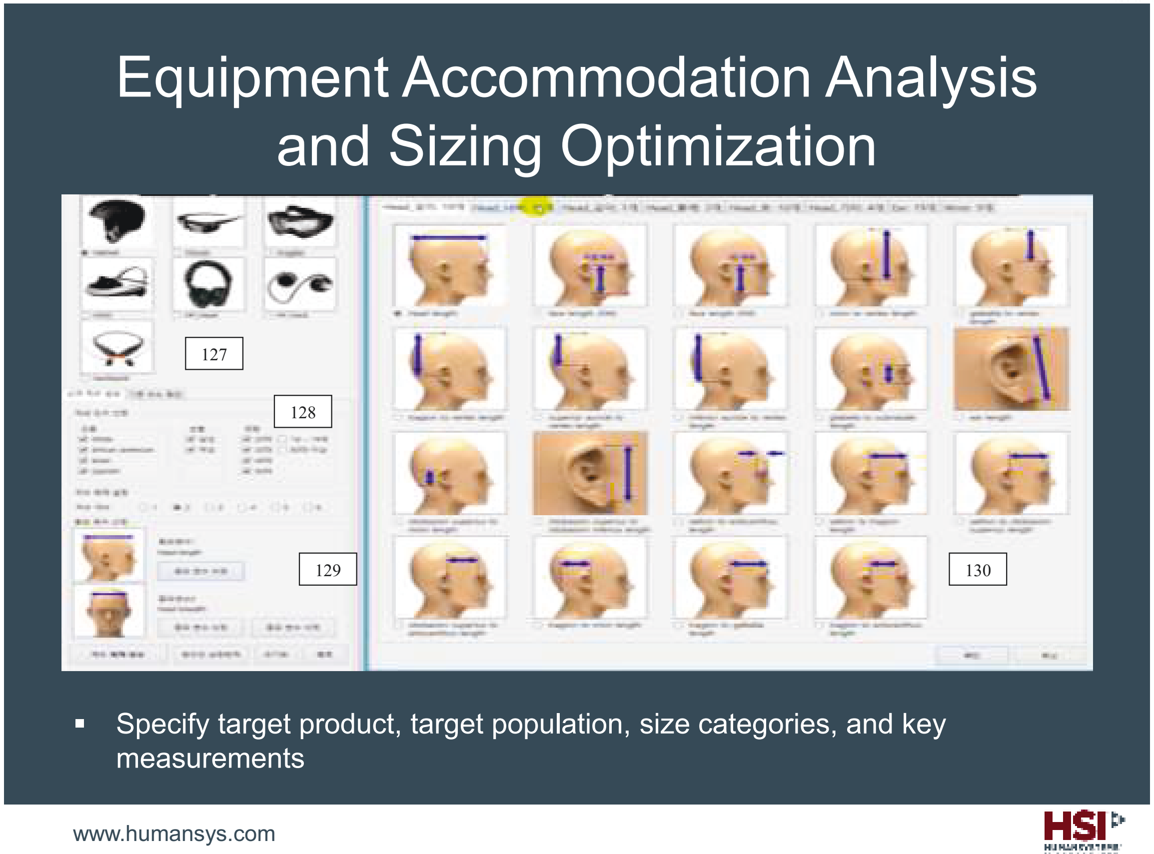
Output = as previously stated, the user can view the plot data in table format and view the associated correlation matrix (not shown) by selecting the hyperlink located on the graph. The data can also be exported as a CSV file.



(Accessed from https://www.youtube.com/watch?v=yewOFd8r6AA, reprinted with permission from Garneau)

MARC Tool – Evaluate Accommodation

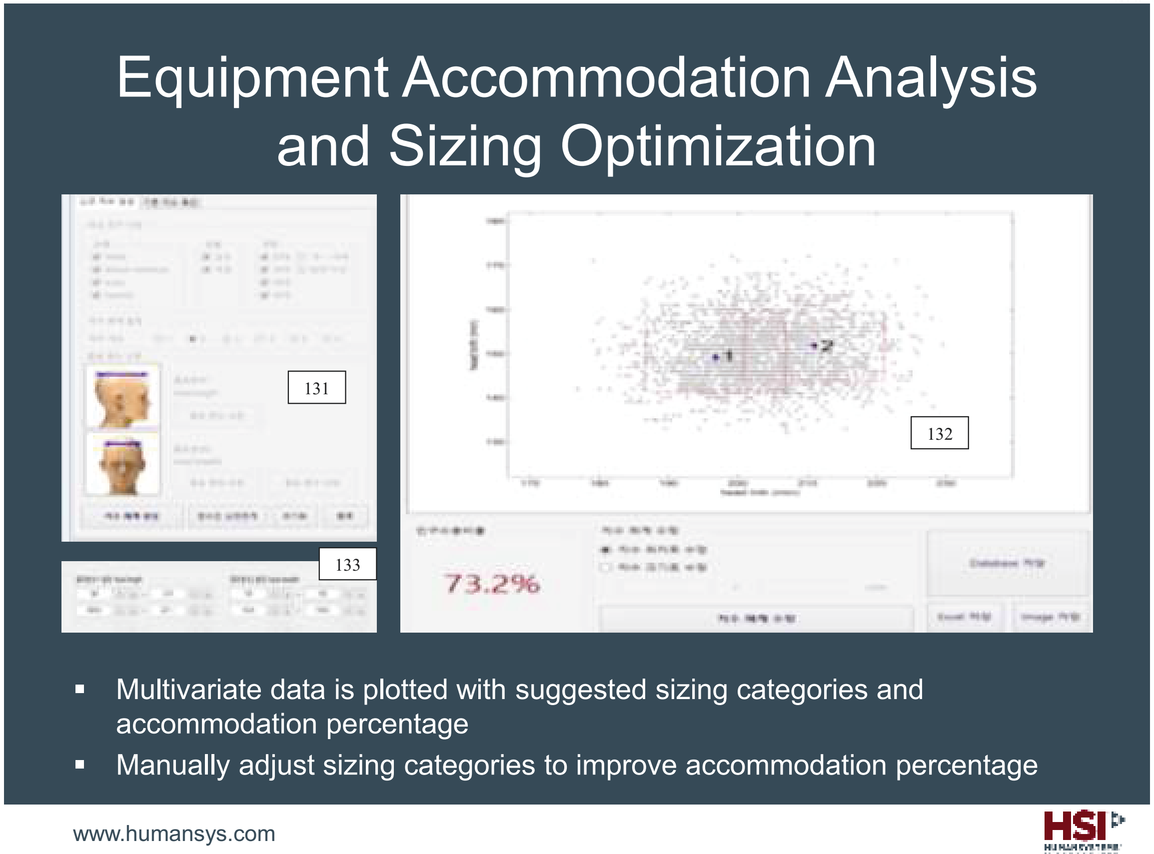
116. Select Dimensions. Add the relevant dimensions using this box. Male or female data can be specified under “Gender”.
117. Graph. Accommodated and disaccommodated data points are shown in different colours for easy analysis.
118. Sliders. The range of each dimension can be adjusted using the sliders.
119. Add Ensemble. In addition to anthropometric data, the user can calculate the accommodation of the selected dimensions while taking into account different clothing and equipment. Scroll and select the desired ensemble.



(Accessed from https://www.youtube.com/watch?v=xZQUeWhfqXk, reprinted with permission from Lee)

EDT Lab

127. Target Product. Select target product from list provided.
128. Selection of Target Population. Specify ethnicity, gender, and age.
129. Sizes. Select the number of size categories in which the product will be available.
130. Key Dimensions. Select the dimensions relevant to the sizing of the target product. Diagrams and written descriptions are used to identify the measurement types.

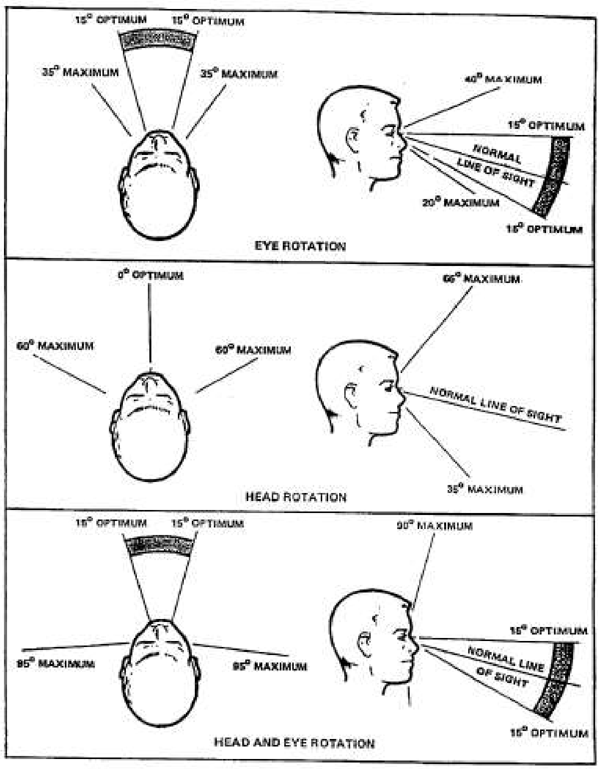


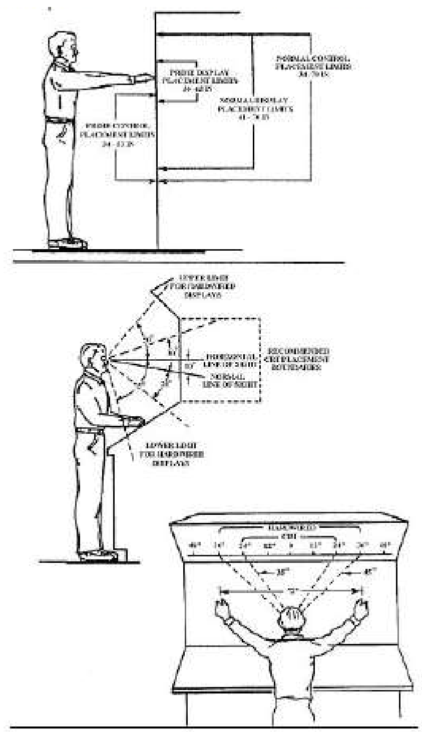
(Accessed from https://www.youtube.com/watch?v=xZQUeWhfqXk, reprinted with permission from Lee)

EDT Lab

131. Plot distribution of multivariate data.
132. Sizing Recommendation. Recommended sizes are calculated and accommodation percentage is displayed in red.
133. Manual Adjustment. Users can manipulate sizing system to improve accommodation percentage.

Example Reference Material





Left Figure = Vertical and horizontal visual fields (MIL-STD 1472F, 1999)

Right Figure = Control and display limits for vertical and stand consoles where see over capabilities are not required (FAA, 2007).

Note: the figure above is included to demonstrate example reference material that may be included in the web based anthropometric tool.

Annex B: Web-based anthropometry tool – summary of key stakeholder requirements (2012 and 2015)

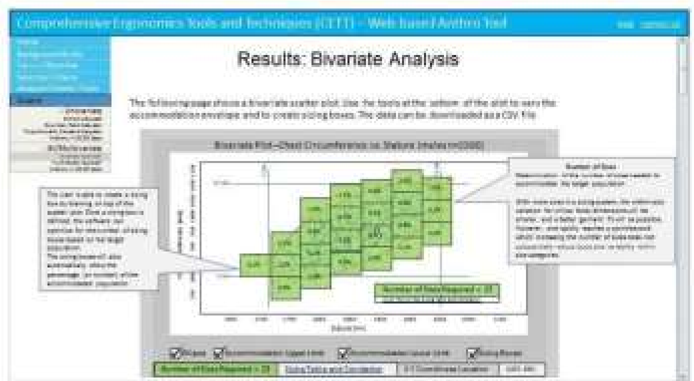
Three focus group meetings were held with key stakeholders to define requirements for a web-based anthropometry tool. The first two stakeholder meetings were held in 2012 as part of the Comprehensive Ergonomics Tools and Techniques (CETTs) project, while the third meeting was held in 2015 as part of the Soldier System Effectiveness Architecture Framework (SoSE AF) development project. All meetings were held at the Louis St. Laurent Building in Gatineau, Quebec. A list of the attendees is presented in the table below.

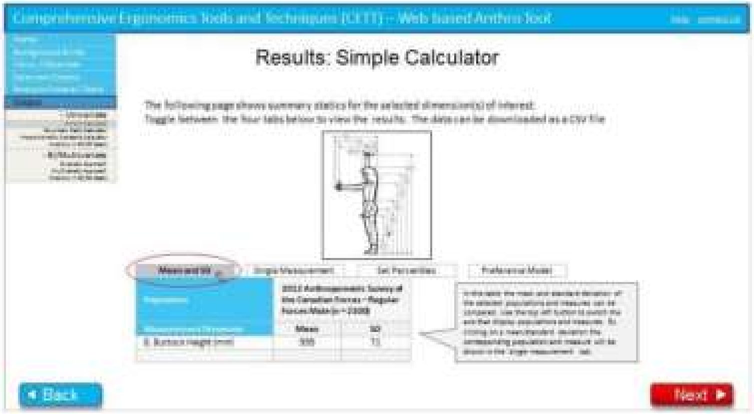
Table 24: List of attendees

2012 stakeholder meeting			
Major Neil Cameron (Army DLR)	Major Stephan Dufour (C Army DLR)	Tara Foster-Hunt (ADM(Mat), DTAES)	Major Graham Fisher (ADM(Mat) DTAES)
Major ALEXANDER NATALE (ADM(Mat) DSSPM)	Patricia Brown (ADM(Mat) DSSPM)	Major Guilbault (ADM(Mat) DSSPM)	Major Gaby Salloum (ADM(Mat) DGMPD(L&S))
Alice Kwong (ADM(Mat), DGMPD(L&S))	Kevin Fitzpatrick (ADM(Mat) DGMPD(L&S))	Capt William Swann (ADM(Mat), PMO CSC)	James Menard (ADM(Mat) PMO JSS)
Major Jameel Adam	Rex Bishop	WO XX	Randy James
2015 stakeholder meeting			
Fern Smith (ADM(Mat) DSSPM 2 – clothing)	Monique Loney (ADM(Mat) DSSPM 2 – dress and ceremonial clothing)	Carol Cracknell (ADM(Mat) DSSPM 2 – clothing design and development)	MWO Stutzinger (ADM(Mat) DSSPM 9 – weapon systems)
Patricia Brown (ADM(Mat) DSSPM 3 – Operational Equipment)	Sean Cale (ADM(Mat) DSSPM 3 – LCMM personal ballistic equipment)	Major Mark Rutley (ADM(Mat) DSSPM 10 (ISSP) – Human Factors Support Cell)	James Kuang (ADM(Mat) DSSPM 10 (ISSP) – LCMM, anthropometry – BOSS)
MWO Amirault (ADM(Mat) DSSPM 10 (ISSP) – Human Factors Support Cell)			

The following provides a summary of key stakeholder requirements for a web-based anthropometry tool that were derived from these meetings.

<table>
<tr><th>Category</th><th>Sub Topic</th><th>Comment</th></tr>
<tr><td></td><td>Soldier Triangle</td><td>Anthropometry:
Encumbered, semi-nude anthropometric data and 3D shape models developed within DRDC based on CFAS 2012 should be included.
In 2012 and for this current effort, a focus group was conducted to identify stakeholder needs, requirements and functionality for an anthropometric tool. The focus related to the requirement for the exploitation of the CFAS 2012 database and a provision of easily accessible tools to provide the ability to independently and correctly apply CF anthropometric data.
- Ability to find out what the required critical dimensions are for various items (e.g. Life Cycle Materiel Manager (LCMM) involved in the pistol replacement program, should be able to go into the CFAS 2012 database and will be able to find out the critical dimensions required to select a pistol (e.g. hand breadth, finger length) as well as the range of individuals that you are designing towards). For someone in DSSPM designing a combat shirt these critical dimensions may be measures such as chest circumference, and abdomen size.
- For clothing requirements, the ability to link into the output such as the GERBER system (Electra is the other standard), would be ideal. When you are buying COTS/MOTS it would also be beneficial to take the measurements and relate it back to the GERBER system.
- Standards currently do not exist in the dress manual (e.g. where the item should fall on the arm). This however, should be stated in the SOR.
- The key is having body measurement data, and understanding what are the critical dimension required for that specific piece of equipment. It would also be desirable to go into the data set to investigate specific measures (e.g. for the sleeping system, it is important to accommodate for individuals such as females with big hips and also strategically design the foot box. What I need to be able to do is go into the data set and interrogate the data further. There should be pre-selected measures for something like a combat shirt, and then I should have the ability to drill down into the information based on different filters such as, Gender, Age, MOC.
- As a commander, have the ability to specify in the AF the required effects, and a tool should be able to tell you that these are the potential weapons that would meet these requirements.
- Ability to know where on the body to measure, what landmarks to use, how clothing/ROM affects items such as sling length, as well as in what context you would be using this item (e.g. Purchasing a sling you need to know how one uses it, encumbered anthropometry, ROM (reaching over the shoulder), use of sling in the standing vs. kneeling vs. prone conditions. For something like a sling, you also need to know what are the holds, the environments of use and conditions of use and SOPs are. Part of the problem is knowing what a sling is, knowing how the sling is used in different environments, tasks, carries, as well as different clothing options).
- Ability for a tool that would export a CAD drawing/point cloud data set of a statistical representation of the critical dimensions for a range of the CF.
- With the 3D tool the ability to draw (e.g. sling) around the 3D manikin and be able to have a slider tool to explore (virtual tape measure) what the range of sizes are required.
- Include the ROM of individuals
- For new equipment items, sometimes the critical dimensions are not well established. Thus, an anthropometry tool needs the ability to generate 3D mannequins based on a principal component analysis of CFAS data (e.g. a 3D, rotatable male or</td></tr>
</table>

Category	Sub Topic	Comment
		female shape where on the right of the screen you have "slider" controls that control PCA components (in order of variability) and on the left of the screen you have the ability to select dimensions of interest from drop down lists of ISO standard anthropometric dimensions. As you slide the PCA sliders around, the size and shape of the 3D mannequin changes, and you can explore the relationships between dimensions when specifying new equipment items to help identify which ones truly are critical. Also, the tool needs to "calculate" a specified anthropometric dimension based on aggregate CFAS data and the PCA settings. Anthropometric dimensions needs to be in an ISO standard, and must be selectable). - Ability to "compare" various datasets within CFAS (e.g. select specific occupational groups such as the infantry and be able to compare it to other occupational groups, ability to compare CFAS data to the '97 Canadian Land Forces Survey). - Ability to identify boundary cases from bivariate (and PCA) plots of critical dimensions for identifying the size of CAF members needed to properly validate a scale of measure while conducting fit validation during bid evaluations. - Ability to specify clothing and worn equipment based on the size of an individual (e.g. knowledge of the size of the individual will tell you boot size. Then knowing what the boot size is and the circumference around the calf, a clothing designer within DSSPM will be able to figure out the required circumference of the pant leg). - Ability to run a cost analysis (e.g. include a slider tool for each piece of equipment to model associated costs)  - For bivariate plots, it would be helpful if the tool generated a pearson's r correlation coefficient to be able to determine if some dimensions are captured and reflected in other ones, thus reducing the number of critical dimensions (if PCA is not being used). - Ability to define the size of the clothing size boxes on the bivariate plot (e.g. based on industry standards or customizable) with an optimizer tool. The benefit to a visualization tool such as the scatter plot above is the ability to see (especially in the

Category	Sub Topic	Comment
		outliers), what the cost benefit analysis is to adding another size. If you see a cluster of outliers, it will be more cost effective). - Ideal if each sizing box included a sensitivity analysis (e.g. specifying a minimum number of sizing in order to accommodate people, missions, etc., It is item, mission dependent, the ability to apply the ranges that occur in the current anthropometric scatter plot would be useful then as a designer, I can work out from this baseline). - Within the sizing box tool, it would also be useful to have the means within each of the boxes to see where the average size within each of those boxes are.  - It would be helpful to have the measure pictorially depicted of front, view, side view, and how that measurement was collected. Similar to the 97 CAF Anthro survey. E.g. when you are designing a pant, you don't need the waist measurement because males don't wear pants at the waist but they wear it below the waist.
	Use Cases	Desirable to have use cases built in the AF - Helmet procurement project - Ability to export digital representation of the body (CAD files of a family of head sizes that the helmet should be designed to) to give to industry. - Including performance based data in the AF (e.g. FSAR baseline shooting performance, CAN LEAP) - As a DLR or even an operations officer in the unit (e.g. a new OC), they can go into the AF and state the mission, duration and they would be able calculate number of batteries, weight, etc.

Category	Sub Topic	Comment
		- Requirements generation and accessing past Statement of Requirements (SORs) (Knowledge Management System): A lot of requirements are based on historical requirements. It would be invaluable to be able to access historical information that resulted in this requirement. Some of these requirements are still driving acquisition, but sometimes we have no idea why these requirements still exist or why it was initially a requirement. This requirement may have been derived from a previous POC, however, in many cases this POC has changed or even retired and this knowledge has been lost.
	Toolsets	Critical Dimensions Tool: Selecting an item of clothing or equipment, the tool will identify critical anthropometry dimensions and bivariate relationships, and provide graphical and tabular data from CFAS. Size Tariffing Tool: Selecting an item of clothing or equipment, the tool will generate a tariffing tool calculator to provide optimized sizing ranges and acquisition percentages for a given number of sizes.
Usability		Avoid developing a tool that is too complex and is not usable. Goal is to design an AF that is simple to use, intuitive, but also desirable to use.
Miscellaneous	Concerns	Security Classified information (this do out needs to be investigated further) - A lot of information on body armour and weapons is going to be controlled goods therefore security implications - Do you make it as a standalone (downside is updating) - We cannot host it on DRENET (i.e. Controlled Goods) - Centralized on the network (e.g. host on TITAN due to information like shooting performance) "Care and feeding" of the AF (it needs a client to pay for and maintain it such as DSSPM. One way to ensure success is if it is made as part of a program such as DNDAF and mandated. - Need to secure a client (have Champions) that will use this tool and get buy in early on in the process. - One stakeholder raised the question if the Surgeon General would want to take on this initiative. - DRDC will not fund it because as it currently stands, it is not R&D - Conversely one stakeholder mentioned that "This AF is therefore an exploitation tool for S&T for DRDC and to keep the knowledge current. This also becomes the driver" "This is the brain" - Could potentially add a tariff for projects to use the AF information - There could be a "subscription" fee applied to the use of the SoSE AF. If the sponsors believe that it is a useful tool they can pay a "subscription fee" and help maintain and further develop this tool (e.g. currently DLR5/DSSPM/CAWLC are the sponsors for this project (CAWLC is the specific sponsor for the soldier), but other organizations such as the Army Lessons Learned Centre may also be interested in a tool like this). - One stakeholder raised a concern that currently there is no custodian for a lot of the information (e.g. the DRDC KMS). It would take forever…it would be never ending for someone to be tasked to do this. - Another stakeholder, however, pointed out to this individual that out of all of the Defence Scientists (DSs) that are working in the soldier system domain, ½ of the DSs are represented in this room (in today's meeting), so the task of keeping the AF is not that onerous. - Our biggest challenge is that everyone wants to use it and access this SoSE AF, but no one wants to host it, pay for it, be responsible for it. DLR5 has discussed about contributing $25k/year (not $50k as originally thought), and potentially a Class

Category	Sub Topic	Comment
		A reservist to maintain it. With respect to the project, populating the database is one issue, but the major constraint is going to how and where it is going to be supported. - We need to demonstrate the value of the AF. We need to focus on one or two areas and showcase how the AF is useful and demonstrate what the return investment to the stakeholder. Our battle is what happens after four years. - What we are looking at is a spiral design process that you would want to revisit annually rather than after the end of the project. After the first year, even being able to collect all of the information (regardless of being able to data mine this information), I'm thinking would be a huge benefit to this AF. This would be year 1's return on investment. Accessing the information: a concern was raised by a stakeholder regarding the accessing and handling of information. There may be a concern that the AF could potentially be too overwhelming for someone accessing that information - The AF would need to specify the different types of stakeholders whom would potentially be using this AF and the tools that they would like to access. A suggestion was made that when you access this database, you are able to specify if you are a DS, Commander, desk officer, etc., and being able to filter through this information located in the database. Various individuals would have access to different types of information within the database depending on their user profile. - The AF could potentially be managed by prioritizing the information, and assigning a weighting factor. Literature vs. marketing materials vs. SOR/tech specs and assigning reliability scores: For the repository of papers (e.g. research, scientific papers), and information (e.g. product glossies) to be included in the AF, it would be ideal to be able to apply a rating scale in terms of relevance. This would be ideal to have a rating of the quality of the data. - Dedicated SMEs would be required to rate these papers (internal consistency and validity) - A needs analysis with stakeholders, including desk officers should be conducted. - Potentially adopt a two-step process for accessing the AF. For the Technical Authorities (TAs) who know what they want, could have access to a simple tool that would provide the answer, but for more complex problems, perhaps the experts such as the HF Cell would be tasked to use the AF to take a more in-depth analysis and be able to provide the LCMM with these answers.

Annex C: Validated and revised prioritization of Functionality and Capability – 1D and 3D anthropometry tool

Validated and revised prioritization of Functionality and Capability – 1D anthropometry tool sets

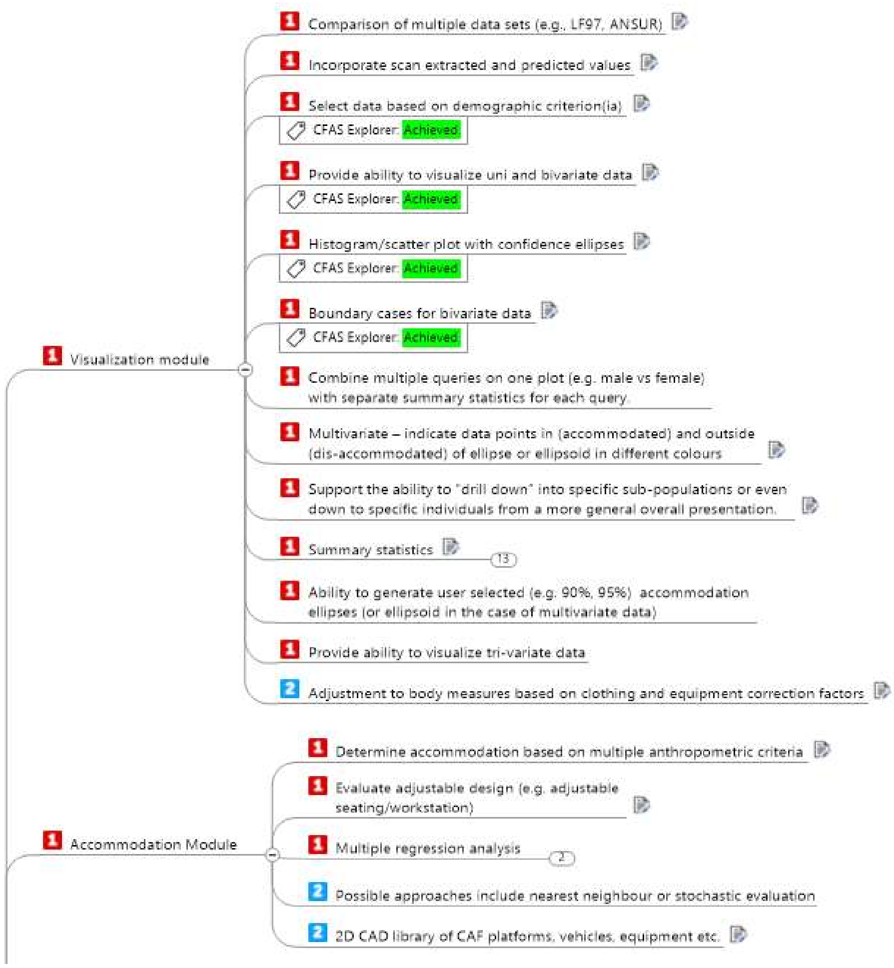


Figure 26: Prioritization of 1D anthropometry tool sets – priority 1

Figure 27: Prioritization of 1D anthropometry tool sets – priority 1 (continued from above figure)

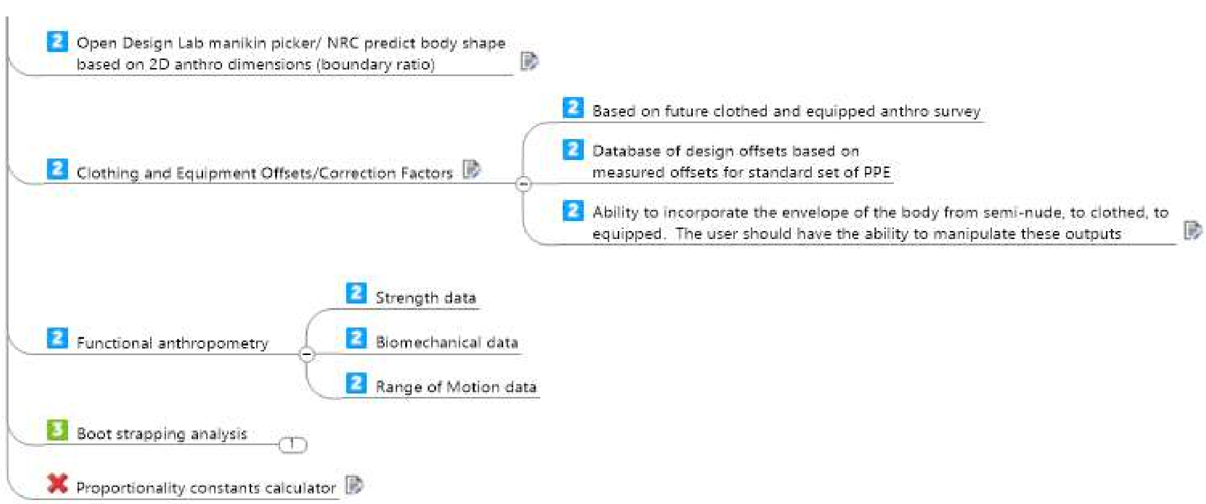


Figure 28: Prioritization of 1D anthropometry tool sets – priority 2+

Validated and revised prioritization of Functionality and Capability – 3D anthropometry tool sets

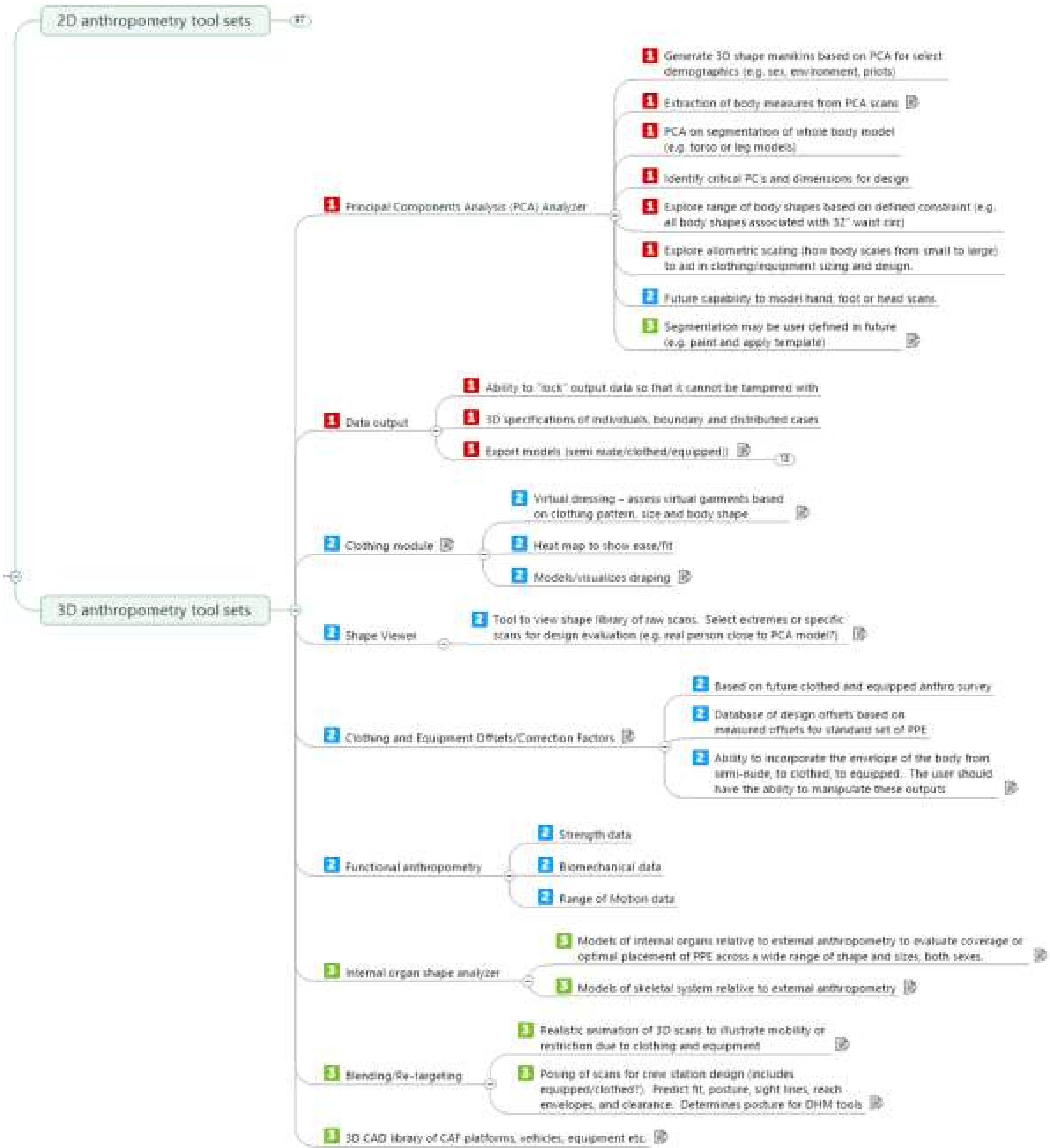


Figure 29: Prioritization of 3D anthropometry tool sets

Annex D: Summary of stakeholder focus group and interview comments (2017)

Category	Domain	Comment
Traditional Toolsets	Data Output	• It would be useful to be able to export important data in a file that can be processed by external programs • The GERBER system is fairly flexible when it comes to what kind of data it can accept o A sizing proposal could be created and exported to GERBER, which would cut the pattern based on the sizes • It is necessary to be able to export image and CAD files to industry to help with visualization, but it may be easier to export data in a text file to an external program that will create Jack or Santos models • This idea should be fleshed out with the NATO panel as well, to get a better idea of how this would work and what capabilities are important
	Proportionality Constants Calculator	• This feature was not considered a priority • The TTA pointed out that the calculations used to generate predictions are often inaccurate • Although the ability to predict body measurements that were not included in the survey was acknowledged, stakeholders agreed that the digital measuring tape would accomplish this task more effectively
	Use 2D measurement to create 3D model	• Could be a low-cost way of estimating 3D scans • Tools like this are fairly accurate when the individual is within one or two SD of the mean, but become much less effective in extreme cases • Certain regions (ex. Belly, crotch height) are more difficult because they vary so much within the population • The anthropometry data and 3D scans from the 2012 CFAS could be used to validate the 3D models produced using this feature • Applications for vehicle accommodation and design are limited, since their focus is on the 5th and 95th percentiles
	Blending/ Re-targeting (Functional Anthropometry)	• The functional anthropometry data that would be needed to support this capability does not currently exist, but is something to keep in mind for future research • Many possible applications in vehicle and equipment design, for example when determining how heavy a piece of portable equipment can be, strength data would be very useful to the designer
3D Toolsets	PCA Analysis	• Full-body PCA analysis as well as PCA analysis on specific body segments would be useful in "troubleshooting", for example identifying the cause of an outlier in the dataset • Visualization of PCA-generated model • General users should not have access to PCA, but may be allowed to see the results, such as boundary cases • Manikin Generator • It was noted by the TTA that there are published standards for the generation of manikins • The ability to identify redundant manikins, particularly with male and female data sets, would be useful
	Internal Organ Shape Analyzer	• Although this capability would be useful, there is not enough data available at this point to support this feature • This could be developed later on as part of a separate effort
	Shape Viewer	• The shape viewer is similar in many ways to a manikin picker, and would be a very important capability
	Boundary Cases:	• Identify boundary, intermediate, and distributed cases within the database o It was noted that this is more easily accomplished when looking at raw data than PCA analysis • Generate a set of pre-defined test cases for general use

		• Expert users could be provided with the ability to define custom test cases as well
Accommodation Module:	Univariate and Bivariate Data	• Visualization of univariate and bivariate data allows the user to see why individuals are dis-accommodated • The capability for the user to decide how much data (summary statistics) is presented is important • The ability to draw custom rectangles for accommodation analysis (refer to TU Delft tool) could be applied to clothing sizing • It may in fact be more productive to focus on managing anthropometric data, and providing the ability to export data into an existing tool
	Unit Conversion	• Ability to easily switch between metric and imperial units was identified as very important, particularly for clothing and equipment analysis • While most countries tend to take measurements using metric system units, industry measurements are often in imperial units
	Clothing and Equipment	• Begin by establishing definition of “full fighting order” • Work towards the ability to analyze different layers of clothing and how they interact with one another
	Evaluate Adjustable Design	• Compile a library of CAD models for accommodation analysis – currently most of the CAD models belong to the manufacturers • This feature could be applied to vehicle or airframe design as a method of assessing the accommodation percentage of existing designs • Although this capability would not replace manual assessments, it could be used to predict dimensions that could cause problems with accommodation • It was noted that identifying individuals who are/may be dis-accommodated would still be difficult to carry out logistically
Clothing Module:	Fit Mapping:	Fit Assessment • May be useful for bid evaluations • It is difficult to account for personal preference within this tool – many people do not actually order the size that is “right” for them based on measurements • This feature could be used to analyze/visualize why people stray from the sizing categories that are expected to fit them, for example certain aspects (ex. fit around thigh) force people to size up because they want more mobility • CC: heat mapping is only really useful if you're showing equipment and clothing together - more of an equipment and clothing feature Virtual Fit • The TTA felt that this could be useful, especially since there is already a large database of 3D scans of the Canadian Forces • Stakeholders suggested that for the purposes of this project, the focus be on validation of existing sizing categories within the DND’s designs, and continuing to gather information for the database (i.e., collect relevant/current data and see if the current DND sizing charts are correct). • More information on the encumbered soldier would increase the potential of this feature • Some stakeholders felt that it would be more worthwhile to invest in purchasing GERBER, rather than trying to create a new clothing tool
	Clothing and Equipment Offsets	• Could allow users to see how different combinations of equipment influence accommodation • Although there is a large database of 3D scans from the 2012 CFAS, the correction factors associated with different pieces of equipment are not yet well understood • This feature would likely be developed as a separate module in the future, or adapted from another tool • Potential applications for this module in load carriage analysis, equipment design, and vehicle design • Soldiers often buy their own equipment or modify the equipment that is issued to them, and this is difficult to measure
	Specify Custom Sizing Rule	NATO Sizing Rules • There is a NATO standard where all countries have to identify their unique sizing rules and how they fit within NATO standards – this is meant to facilitate sharing of combat gear for NATO mission they know how sizing from a certain country compares

		• These are not well maintained, other than having NATO sizing listed on combat clothing Sizing, Tariffing, and Grading • Sizing and tariffing box tool is important • Sizing and tariffing should include a fit mapping function – it could also work in conjunction with shape analysis but this would require further research • Grading is currently taken care of using a CAD system Custom Sizing Options • Important capability when looking at body scans • Within BOSS system the sizing rules are created such that it is impossible to know how people are going to wear it
3D Models	3D Manikins:	• AK: there are published standards of how to come up with manikins • The ability to identify redundant manikins is often useful with male and female data sets – it allows users to analyze data separately but also see where there are some very similar individuals that could be represented by a single manikin
	Repositioning of 3D Scans	• This capability is important because it means that if a 3D scan is done in an incorrect posture, the scan can be repositioned and kept in the database rather than being thrown out
	Digital Measuring Tape	• This feature has many applications, particularly to clothing design • Use case: clothing design requires measurements that were not taken as part of the anthropometric survey – digital measuring tape would allow the user to extract those measurements from the 3D scans or manikins • Stakeholders were interested in the idea of having soft tissue compression factors built into this tool in the future

Population Comparison	Profiler/data input	• The ability to input data from an individual and see where the individual lies relative to the data set (MARC tool/TU Delft tool) may be a useful capability
		• This tool could be used to visualize and compare small data set (ex. In data collection trials) by temporarily importing their to the database to see if population is represented within the trial
		• It was noted that the database would need to be secured in order to prevent people from inputting bad data or tampering with data already in the database
		  o Alternatively, the database data could be sent to an external program to compare against new data
		• Frequent use case: on-site accommodation evaluation
		  o Find border cases, take measurements of extremes and use that as representation
		  o This software tool could then be used to identify the CFAS percentile values associated with those measurements

Database Structure	Scalability	• Populating the tool is a topic that requires further discussion o There should be a way to add data from data sets other than the 2012 CFAS into the tool • Scalability refers more to adding modules, but importing data is also important for future

	Tiered Access	• Different types of information within the database require different levels of access
		• A tiered login system, where this ability is only made available to select users, was proposed
		  o B level with contact information for health services
		  o A level just information with sizing
		  o General - would never be able to see protected A or B

Annex E: Preliminary SOR strawman for a web-based anthropometry tool

1. Introduction

1.1 Aim

The aim of this tasking is to carry out initial planning for the development of a suite of web-based anthropometric software tools and associate databases, based on the Canadian Forces Anthropometric Survey (CFAS) 2012 data, for use in Canadian Armed Forces acquisition processes.

1.2 Background

The 2012 CFAS, provides a comprehensive set of traditional (i.e. manual) body size measurements and 3D body scans of Canadian Army, Royal Canadian Air Force and Royal Canadian Navy personnel. These data are used by DND to inform the design, development, specification and evaluation of warfighter clothing, equipment and platforms.

1.3 Capability Deficiency

Previously, anthropometric data was typically provided to the Human Factors practitioner as a list of summary statistics and cumulative frequency or percentiles tables. With the advent of more valid and sophisticated analytical techniques, it is necessary to provide a capability to access and analyse the full dataset. Currently, efforts are underway to develop tools to visualize, analyze and interpret the CFAS 3D body size and shape data. In consort with this effort, DND has identified a similar requirement to develop a comprehensive suite of web-based tools to support the visualization, analysis and interpretation of the traditional measures.

1.4 Project Constraints

A draft SOR for a suite of web-based anthropometric software tools was not budgeted for this project phase and is outside of the current scope. The following section, therefore presents only a strawman SOR, intended to achieve the following:

- Document the systematic approach that was taken during this project, and present it in a coherent, and standardized format;
- Convey to a software engineering the high level requirements for a web-based anthropometric tool, in order to allow them to provide a rough order of magnitude estimate and reduce development time;
- Dovetail into future project phases by facilitating and accelerating the iterative software development cycle. These phases may include:
    - Conceptualization and system design of the web-based anthropometry tool
    - Storyboarding the software tool sets/applications
    - Programing and testing software code
    - Conducting usability evaluations

1.5 Current Situation

A prototype Microsoft-Access based tool, called the CFAS Explorer (1D) tool, has been developed to provide users with a capability to select, filter, plot and export CFAS data as well as perform basic analysis of the bivariate distribution of selected measures (e.g. probability ellipses and boundary cases). Efforts are also underway to develop tools to visualize, analyze and interpret the CFAS 3D body size and shape data.

1.6 Related Projects

To date, two efforts initiated and led by the Defence Research and Development Canada (DRDC) – Toronto, have been conducted to advance the development of traditional measures tools. First, a preliminary investigation into user requirements and notional concepts for a web-based anthropometric tool has been completed (CETTs). Second, a prototype Microsoft-Access based tool, called the CFAS Explorer (1D) tool, has been developed to provide users with a capability to select, filter, plot and export CFAS data as well as perform basic analysis of the bivariate distribution of selected measures (e.g. probability ellipses and boundary cases). As previously discussed, DRDC is also developing tools to visualize, analyze and interpret the CFAS 3D Shape Analyzer tool.

As part of the Soldier System Effectiveness (SoSE) project, an Architectural Framework (AF) was developed for the Canadian Armed Forces (CAF) soldier system in fiscal year 2014/2015, and a Soldier System Architecture (SSA) software demonstrator of the SoSE AF, functionality and toolsets was developed in fiscal year 2015/16 which is being further refined in FY16/17. It is envisioned that the CFAS 2012 Explorer and 1D Data Visualization tool and 3D Shape Analyzer tool will be incorporated into the SSA software.

It should be noted that two external efforts, unrelated to DRDC, are also currently underway to refine and develop web-based anthropometric tools: TUDelft and Open Design Lab at Penn State.

2. System Operation

2.1 Missions and Scenarios

- To Be Determined (TBD)

2.2 Environment

It is envisioned that the web-based anthropometric software tool will adhere to a server-client distribution model (as opposed to a stand-alone app), and will most likely be housed on DND servers. It is also envisioned that users will have permission based access, and this will be achieved through desktop/laptop personal computers connected to the DND network (e.g., Defence Wide Area Network – DWAN).

2.3 Threats

- TBD

2.4 Concept of Operations

- TBD

2.5 Concept of Support

- TBD

2.6 Key Roles

Key roles for the web-based anthropometry software tool can be classified into two groups; Users and Maintainers.

Key Roles	
Users (may include…)	Requirements Officer
	Director Technical Airworthiness and Engineering Support (DTAES)
	Life Cycle Material Manager (LCMM)
	Human Factors Support Cell (HFSC)
	Technical Authority (TA)
	DSSPM 2: Subject Matter Experts (SMEs)
	Scientists
	Bioscience Officer
	Engineer
	Academia
	Contractors
	Industry
	Allies
Maintainers	HFSC
	Scientists
	Bioscience Officer

2.7 Key Tasks

Key tasks involving the use of the web-based anthropometric tool may include:

Category	Domain	Potential Requirement
Process requirements	Specification generation (Support the ability to generate procurement specifications related to fit and accommodation)	• Specify sizes in seating systems, hatches, etc. for univariate and multivariate critical dimensions to ensure population accommodation • Specify sight lines, reach envelopes, and clearance to controls, equipment, control rooms or vehicles based on population data. • Ability to identify and specify optimal sizes in a bivariate (or multivariate) plot given garment or equipment critical dimensions. • Tariffing of personnel into a manufacturer's known garment or equipment size • Ability to identify the required range of adjustability to accommodate different dress states (e.g., for specifying things like load carriage or LPSVs worn over winter or summer dress with and without body armour). • Ability to identify required sight lines, reach envelopes, and clearance for both nude and clothed/equipped occupants. • Ability to "animate" an avatar via motion captured movements to explore fit and accommodation in a virtual dynamic world.
	Bid evaluation (Support the ability to effectively conduct bid evaluations of specifications on fit and accommodation)	• Ability to import 2D CAD drawings of designs to assess workspace envelopes for reach, sight lines, posture, clearance (e.g., head strikes), etc. • Ability to use anthropometric boundary manikins to evaluate proposed designs. • Ability to identify percentage of population accommodated / dis-accommodated based on critical dimensions. • Ability to output boundary manikin anthropometrics into a JACK or Santos Human • Ability to package, export and send out to contractors/bidders data generated from the web-based tool such as bivariate plots and charts, boundary manikins, data tables, diagrams, etc.
	Verifying and validating design changes	• Verify and validate design changes
	Scientific research	• Statistical analysis

2.8 User Characteristics

Comment: User characteristics need to be defined in this section.

Key Role	User Characteristics
Requirements Officer	Recent operational experience
	Experience in the Combat Arms (Armour, Artillery, Infantry, Engineers)
	The rank of middle/senior Captain or Major
	Graduation from a Technical Staff Course (e.g., Kingston, Ontario)
	Limited experience in anthropometric methods and its application
Director Technical Airworthiness and Engineering Support (DTAES) Grants air worthiness for the Air Force (set all the tech air worthiness for the CAF)	Engineer with background in anthropometry
	Trained in identifying issues to communicate to the operators.

3. Design and Concept Guidance

The following section is intended to provide system design and concept guidance. *Industry should be given as much freedom as possible to propose a system that meets the user's needs.*

Category	**Domain**	**Potential Requirement** "The web-based anthropometry tool set should allow for the user to…"	**Concept Example** **[Annex A page number reference]**
Guiding requirements	Usability	• Convert units of measurement (Ability to convert between metric and imperial units is highly desired. This single improvement would save many (perhaps even hundreds of) hours in a year.) ○ mm <--> cm ○ cm <--> inches ○ metric <--> imperial • Filter data Support the ability to identify subgroups of CAF personnel, and support ability to both include and exclude filtered data from a data set. Possible groupings should be (but are not limited to) the following: ○ Gender ○ Age ○ Rank ○ MOSID ○ Component ○ Service ○ Language ○ Location ○ Ethnicity ○ Unit ○ Handedness ○ Corrective eyewear use • Have permission based access ○ User authority Based on the permission of the user, the	• Convert units of measurement ○ MARC Tool – Explore Anthropometry [p.65] • Filter data ○ CFAS Explorer Tool [p. 62, 63] ○ TUDelft – 1D Database Explorer [p.67] ○ Size North America – iSize [p.68] • Have permission based access ○ See Section 4.9 (notional software architecture) • Select language ○ Not shown • Receive content information via mouse over and pop up dialogue boxes and bubbles ○ Penn State Open Design Lab – Database Explorer [p.66] ○ TUDelft – 1D Database Explorer [p.67] ○ CFAS Explorer [p.70, 71] • Continuously be aware of which criteria have been selected ○ Penn State Open Design Lab – Database Explorer [p.66] ○ TUDelft – 1D Database [p.74, 75] ○ MARC Tool – Collect Anthropometry [p.79] ○ TUDelft – Ellipse [p.108]

			relevant tools should be highlighted and the user have access to those tools. The other tools should be grayed out but users (*aside from select users such as industry) would also have the ability to access these tools. Potential Users may include the following: **Select users: Sanitize input screen based on user authority (e.g. industry should only have access to simple demographics to ensure survey participant anonymity)* ▪ Bid Evaluation Specialist ▪ Requirements Generation Specialist ▪ Scientist ▪ General User ▪ Academia ▪ Contractor ▪ Industry ○ Tiered login system ▪ B level with contact information for health services ▪ A level just information with sizing ▪ General - would never be able to see protected A or B ○ Checks and balances Include checks and balances in the tool to prevent a novice user from over stepping their level of expertise (novice vs. experienced practitioner) ○ Controlled access Provide controlled access to the various tools/functions based on security clearance and user profile (similar to the CANDID system, or SharePoint permissions) ○ Password Issue passwords with expiry dates to approved users requesting access to the	○ MARC Tool – Evaluate Accommodation [p.111] • Modify criteria and have the changes reflected in the data in real time Example: if the current report is analyzing male stature, the User should have the ability to add females into the selection criteria to see how the new data set effects the results ○ MARC Tool – Explore Anthropometry [p.65] ○ TUDelft – 1D Database Explorer [p.67] ○ Size North America – iSize [p.68] ○ Penn State Open Design Lab – Data Explorer Lite [p.72] ○ Penn State Open Design Lab – Data Explorer [p.73] ○ TUDelft – 1D Database [p.74, 75] ○ MARC Tool – Collect Anthropometry [p.78] ○ MARC Tool – Collect Anthropometry [p.79] ○ TUDelft – Profiler [p.80] ○ MARC Tool – Evaluate Accommodation [p.111] • Save the defined parameters and to be able to lock those parameters ○ TUDelft – Profiler [p.80] ○ Penn State Open Design Lab – Manikin Picker [p.88] ○ BodyLabs – Blue [p.97] ○ TUDelft – Ellipse [p.108]

		web-based tool
		• Select language
		    ○ Bilingual
		    ○ Suitable for lay and experienced users
		• Receive content information via mouse over and pop up dialogue boxes and bubbles
		• Continuously be aware of which criteria have been selected
		• Modify criteria and have the changes reflected in the data in real time
		Example: if the current report is analyzing male stature, the User should have the ability to add females into the selection criteria to see how the new data set effects the results
		• Save the defined parameters and to be able to lock those parameters	

	Graphical User Interface (GUI)	• Interface with the software through a user friendly GUI (usability should be suitable for a novice to experienced user)
		    ○ Simple
		    ○ Intuitive
		    ○ Icon driven
		    ○ Follow best practices
		        ▪ Selection via single and double mouse clicks
		        ▪ Pull down menu
		        ▪ Radio buttons
		        ▪ Check boxes
		        ▪ Control buttons
		        ▪ Hyperlinks
		        ▪ Sliding tool bars
		        ▪ Clicking and dragging (ellipses, lines)
		        ▪ Mouse over
		        ▪ etc...
		    ○ Graphics
			• Interface with the software through a user friendly GUI (usability should be suitable for a novice to experienced user)
			    ○ Refer to entire Annex A: Trade study of Commercial-Off-The-Shelf anthropometry based tools – presentation

		▪ Graphics, showing measurements and definitions should be included to aid the user in measurement selection	
	Help	• Access an extensive set of guidance documents to aid in the correct use of tools ○ The tool should provide guidance for how to write SOR statements, and how to write and conduct Bid Evaluation, Qualification testing etc. (it is impossible to cover every single foreseeable SOR, Bid Evaluation, Qualification, etc., so this tutorial could potentially be based on SELECT use cases). For example for a User involved in a vehicle project, the process that was adhered to for the Tactical Armoured Patrol Vehicle (TAPV) project can be followed for writing the Statement of Requirements (SOR), Bid Evaluation to post Contract Award for anthropometry related issues. Within the tutorial discrete steps that were followed during the TAPV project can be outlined, such as the 7 step process as outlined below: 1. Identify the population data base 2. Select what they are wearing 3. Pick out the critical measures 4. Plot bi/multivariate confidence ellipses (for tri boundary ellipses, you would want to include the 3D human) 5. Select boundary manikins based on the ellipses 6. Export the boundary manikins 7. Etc. • Access help files and tutorials • Search for garden path or case based examples • Reference established CAF standardized approach to anthropometric assessment	• Access an extensive set of guidance documents to aid in the correct use of tools ○ BodyLabs – Blue [p.98] • Access help files and tutorials ○ Not shown • Search for garden path or case based examples ○ Not shown • Reference established CAF standardized approach to anthropometric assessment ○ Not shown • Provide User feedback ○ Not shown • Reference documents ○ Reference Material [p.114] • Access glossary of terms ○ Not shown • Search for visual + verbal definitions for landmarks ○ MARC Tool – Explore Anthropometry [p.64] ○ MARC Tool – Explore Anthropometry [p.65] ○ Penn State Open Design Lab – Database Explorer [p.66] ○ EDT Lab [p.112]

		• Provide User feedback
		  ○ Report missing data
		  ○ Provide feedback on the tool
		  ○ Upload use cases
		  ○ Request future studies
		  ○ Wiki/blog based website (community of experts)
		• Reference documents
		  ○ e.g., MIL STD 1472G, Scientific reports, ASTM 1166
		• Access glossary of terms
		• Search for visual + verbal definitions for landmarks	

4. System Effectiveness Requirements

4.1 General

- TBD

4.2 Operability

- TBD

4.2.1 Information Technology (IT) Requirements

Category	Domain	Potential Requirement "The web-based anthropometry tool set should be…"
Information Technology (IT) requirements	Software architecture	• Commercial • Open source Can distribute without requirement for additional licenses e.g. C++, Java, Python, rather than MatLab • Scalable Modular design with ability to expand (remove) functionality through additional modules/plugins (e.g., Application programming interface (API) enabled)
	Software distribution model	• Server-client via network/web

	Software hosting	• Personal Computer based • Client/server architecture
	Software updating and maintenance	

4.2.2 Database Structure Requirements

The following presents a high level overview of recommended requirements for the underlying database structure and database content.

Category	Domain	Potential Requirement "The web-based anthropometry tool set should…"

Database structure	Format	Support scalability of database
		• Ability to expand (remove) data fields and databases
		  ○ Addition of new/custom fields
		  ○ Addition of databases

	Coding	• Refer to ISO 15535:2012, ISO/IEC 8859, and ISO/IEC-1:1998
		• In addition, use an open source, reusable, extensible, and vendor-independent data format that can also encode character sets beyond ASCII, in order to accommodate international databases.

	Data	Support inclusion of multiple datasets. Need to determine equivalent measures for inter-survey comparison.
		• Requirement
		  ○ Canadian Forces Anthropometric Survey (CFAS) 2012
		  ○ 1997 Anthropometric Survey of the Land Forces (LF97)
		• Desired
		  ○ U.S. Army Anthropometric Survey (ANSUR I) 1988
		  ○ U.S. Army Anthropometric Survey (ANSUR II) 2012
		  ○ U.S. Marine Corps Anthropometric Survey (MC-ANSUR) 2012
		  ○ Australian Warfighter Anthropometry Survey

		(AWAS) 2012 ○ National Health and Nutrition Examination Survey (NHANES) ○ SAE international manikins ○ The Technical Cooperation Program (TTCP)
	Security	Require a tiered login system • B level with contact information for health services • A level just information with sizing • General - would never be able to see protected A or B
		Require controlled access • Provide controlled access to the various tools/functions based on security clearance and user profile (similar to the CANDID system, or SharePoint permissions)
		Require a password • Issue passwords with expiry dates to approved users requesting access to the web-based tool
		• Provide the ability to lock the data
		• Provide the ability to hide the data
	Database screening	Refer to ISO 15535:2012 – General Guidelines for the Establishment of Anthropometric Databases
	Data input	Refer to Table 4: Comparison of data integration methods
	Data entry	Refer to ISO *15535:2006 Sections 6.2, 6.3, and 7.1
	Structure	Refer to ISO *15535:2006 – General Guidelines for Establishing Anthropometric Databases (e.g., characteristics of the user population, sampling methods, measurement items, and statistics to be used when establishing an anthropometric database).
	Participant Information	• Refer to ISO 15535:2012 for a list of required and recommended background data to be included in the database
		• Include additional background information such as handedness, rank, MOSID, environmental affiliation, component, unit, and time of service
		• Refer to ISO 3166 contains for a complete list of

		internationally recognized letter and/or number codes used to identify countries and subdivisions
	Statistical processing Missing or Invalid Data	Refer to ISO *15535:2006
	Statistical processing Validation of 1-Dimensional Anthropometric Data	Refer to ISO *15535:2006
	Statistical processing Validation of 3-Dimensional Scans and Scan-Extracted Data	Refer to ISO 20685:2010
	Body Measures Definitions	• Refer to ISO 7250-1:2008 for a list of ISO-defined body measures definitions
		• Refer to ISO 8559-1:2017 for anthropometric definitions for body measurement including landmark points, lines, and planes, specifically for the designation of clothing sizes.
	Research Documents	Include background information and research that was used to design the anthropometric surveys
	Other information (General)	To include: • Measurement description (written and visual) • Individual landmark data • Landmarking tools and methods • Image of measurement • Clothing information • Any standards that reference measure (e.g. ISO, ANSUR I or II, ISAK) • Link to survey final report
	Other information (1D Measurement Data)	To include: • Raw individual anthropometry measurements • Histogram (univariate) or scatterplot (bivariate) to represent data
	Other information (3D Scan Data)	To include: • Identify if measure is scan extracted

		• Scanning tools and methods • Individual scans • Other scan postures/views available for selected individual • Clothing offsets • Nearest neighbour search

*ISO 15535:2006 has now been superseded by 15535:2012

4.2.3 1D Anthropometry Tool Set Requirements

The following is a prioritized list of 1D anthropometry tool set requirements.

Priority	Domain	Sub-priority	Potential Requirement "The web-based anthropometry tool set should allow for the user to…"	Concept Example [Annex A page number reference]
1	Visualization module	1	• Compare multiple data sets (e.g., LF97, ANSUR)	• MARC Tool – Explore Anthropometry [p.65] • Penn State Open Design Lab – Database Explorer [p.66] • TUDelft – 1D Database Explorer [p.67] • Penn State Open Design Lab – Data Explorer Lite [p.72] • TUDelft – 1D Database [p.74, 75] • CAESAR Database [p.86]
		1	• Incorporate scan extracted and predicted values	• Not shown
		1	• Select data based on demographic criterion(ia)	• CFAS Explorer Tool [p. 62, 63] • TUDelft – 1D Database Explorer [p.67] • Size North America – iSize [p.68]
		1	• Visualize uni and bivariate data	• CFAS Explorer Tool [p. 62, 63] • CFAS Explorer [p.70, 71] • Penn State Open Design Lab – Data Explorer Lite [p.72] • TUDelft – 1D Database [p.74, 75] • Size North America – iSize [p.76] • MARC Tool – Collect Anthropometry [p.79] • CFAS Explorer [p.106, 107]

				• TUDelft – Ellipse [p.108] • CETTs storyboard – Sizing Boxes [p.109, 110] • MARC Tool – Evaluate Accommodation [p.111] • EDT Lab [p.113]
		1	• Visualize histogram/scatter plot with confidence ellipses	• CFAS Explorer Tool [p. 62, 63] • CFAS Explorer [p.70, 71] • Size North America – iSize [p.76] • CFAS Explorer [p.106, 107] • TUDelft – Ellipse [p.108] • CETTs storyboard – Sizing Boxes [p.109, 110]
		1	• View and select boundary cases for bivariate data	• CFAS Explorer [p.70, 71] • CFAS Explorer [p.106, 107] • TUDelft – Ellipse [p.108] • CETTs storyboard – Sizing Boxes [p.109, 110] • EDT Lab [p.113]
		1	• Combine multiple queries on one plot (e.g. male vs female) with separate summary statistics for each query.	• Penn State Open Design Lab – Database Explorer [p.66] • Penn State Open Design Lab – Data Explorer Lite [p.72] • Penn State Open Design Lab – Data Explorer [p.73] • TUDelft – 1D Database [p.74, 75] • MARC Tool – Collect Anthropometry [p.79] • TUDelft – Profiler [p.80]
		1	• Visualize multivariate data – indicate data points in (accommodated) and outside (dis-accommodated) of ellipse or ellipsoid in different colours	• CFAS Explorer [p.106, 107] • CETTs storyboard – Sizing Boxes [p.109, 110] • MARC Tool – Evaluate Accommodation [p.111]

		1	• "Drill down" into specific sub-populations or even down to specific individuals from a more general overall presentation	• CFAS Explorer [p.106, 107] • CETTs storyboard – Sizing Boxes [p.109, 110]

		1	• View summary statistics
			  ○ Percentiles
			  ○ Frequencies
			  ○ Means
			  ○ Standard deviations
			  ○ Standard Error
			  ○ Skewness
			  ○ Kurtosis
			  ○ Coefficient of Variance
			  ○ Normality (Anderson-Darling statistic for normality)
			  ○ Pearson's r coefficient
			• Analyze statistics
			  ○ Flag data that is not normally distributed
			  ○ Identify nearest neighbour cases based on user input
			  ○ Identify number of inclusion/exclusion points
				• MARC Tool – Explore Anthropometry [p.65]
				• Size North America – iSize [p.68]
				• CFAS Explorer [p.70, 71]
				• Penn State Open Design Lab – Data Explorer Lite [p.72]
				• Penn State Open Design Lab – Data Explorer [p.73]
				• TUDelft – 1D Database [p.74, 75]
				• Size North America – iSize [p.76]
				• MARC Tool – Collect Anthropometry [p.78]
				• MARC Tool – Collect Anthropometry [p.79]
				• TUDelft – 1D Reach Envelope [p.82]
				• CAESAR Database [p.86]
				• CFAS Explorer [p.106, 107]
				• TUDelft – Ellipse [p.108]
				• CETTs storyboard – Sizing Boxes [p.109, 110]
				• MARC Tool – Evaluate Accommodation [p.111]

		1	• Generate user selected (e.g. 90%, 95%) accommodation ellipses (or ellipsoid in the case of multivariate data)	• CFAS Explorer [p.70, 71] • CFAS Explorer [p.106, 107] • CETTs storyboard – Sizing Boxes [p.109, 110]
		1	• Visualize tri-variate data	• Not shown
		2	• Specify adjustment to body measures based on clothing and equipment correction factors	• MARC Tool – Evaluate Accommodation [p.111]
1	Accommodation Module	1	• Determine accommodation based on multiple anthropometric criteria	• CFAS Explorer [p.70, 71] • CFAS Explorer [p.106, 107] • TUDelft – Ellipse [p.108] • CETTs storyboard – Sizing Boxes [p.109, 110]

				• MARC Tool – Evaluate Accommodation [p.111] • EDT Lab [p.112] • EDT Lab [p.113]
		1	• Evaluate adjustable design (e.g. adjustable seating/workstation, reach envelope)	• TUDelft – 1D Reach Envelope [p.82] • EDT Lab [p.112] • EDT Lab [p.113]

		1	• Perform multiple regression analysis
			  ○ Possible approaches:
			    ▪ Nearest neighbour (priority 2)
			    ▪ Stochastic evaluation (priority 2)
				• Not shown

		2	• Access 2D CAD library of CAF platforms, vehicles, equipment etc.	• Not shown
1	Principal Components Analysis (PCA) module/calculator	1	• Specify principal components based on user defined demographic and measurement criteria (i.e. PCA variables input from visualization module (max #))	• Not shown
		1	• Specify/predefine intermediate/boundary cases: Can return specification of CAF determine standards (e.g. authorized set of manikins for bid evaluation)	• Not shown
		1	• Identify variables which are highly correlated and provide ability to deselect correlated variables	• Not shown
		1	• Follow published approach (e.g. aCadre)	• Not shown
		1	• Specify up to 3 principal components and have up to 27 manikins returned	• Not shown
		1	• Identify redundant manikins	• Not shown

		1	• Perform summary statistics
			  ○ Provide Kaiser-Meyer Olkin measure of sampling adequacy and
			  ○ Bartlett test of sphericity
			  ○ Provide scree plot of principal components
			  ○ PCA based on covariance coefficient (TBC)
			    ▪ Normalized inputs
			    ▪ Varimax rotation
			    ▪ Kaiser criterion (Eigen values >1)
				• Not shown

			○ Ability to export Eigen values, factor loading, factor coefficients and raw PCA scores based on # selected PC's (*.csv file) ○ Boundary cases selected on user selected accommodation ellipse/ellipsoid ▪ Boundary cases at intersection of PC axis and ellipse/ellipsoid ▪ 45° points along PC axis ▪ Define cases within the distribution (e.g. see Oudenhuijzen paper) ○ Reverse PCA – return anthropometric dimensions of each boundary/distributed case ▪ Input body dimensions and show where case sits in PCA space – good for confirming representation of test participants	
1	Clothing Tariffing tool	1	• Use a sizing and tariffing box tool ○ Change out the size of the sizing and tariffing boxes ○ Alter the size of the sizing and tariffing boxes for non-symmetric distribution (within specifying clothing sizes, ability to have different sized boxes in the bivariate/scatter plots). ○ 'Output' tariffing for each sizing box ○ Specify custom sizing rules ▪ New sizing rules may be based on analysis body shape data (e.g. incorporate preference or other body measurements) ○ Fit mapping tool (unimportant requirement)	• CETTs storyboard – Sizing Boxes [p.109, 110] • 3D Difference Maps [p.84]
		2	• Perform simple tariffs based on NATO sizing rules	• Not shown
		2	• Incorporate outputs from RTG-266	• Not shown (Still a couple of years away)
		4	• Link into GERBER/Electra standards output	• Not shown
		4	• Access a grading tool	• Not shown

				(Grading tool is taken care within the apparel design (i.e., Gerber system)).
1	Data output	1	• "Lock" output data so that it cannot be tampered with	• TUDelft – Profiler [p.80] • TUDelft – Ellipse [p.108]
		1	• Output CSV files of univariate and multivariate and trivariate data sets	• CFAS Explorer Tool [p.62, 63] • Penn State Open Design Lab – Data Explorer [p.73]
		1	• Export plots/graphs ○ Gaussian functions ○ Frequency distribution ○ Percentile curves ○ Pie ○ Bar ○ Area ○ Scatter plots	• CFAS Explorer Tool [p.62, 63] • TUDelft – Profiler [p.80] • TUDelft – Ellipse [p.108]
		1	• Output a table of boundary/distributed cases	• Not shown
		1	• Output 2D specifications of individuals, boundary and distributed cases	• TUDelft – Ellipse [p.108]
		1	• Output a 3D CAD model of a manikin	• Penn State Open Design Lab – Manikin Picker [p.88]
		2	• Relate measurements back to GERBER/Electra standards when buying COTS/MOTS	• Not shown
2	Manikin picker/ NRC predict body shape based on 2D anthropometric dimensions (boundary ratio)	2	• Pick/predict body shape based on 2D anthropometric dimensions (boundary ratio)	• EuroFit – 3D Reconstruction [p.85] • Penn State Open Design Lab – Manikin Picker [p.87] • Penn State Open Design Lab – Manikin Picker [p.88] • EuroFit Project – Skeleton Transfer [p.89] • BodyLabs – Blue [p.97] • BodyLabs – Blue [p.98]
2	Clothing and Equipment Offsets/Correction Factors	2	• Specify offset/correction factors based on future clothed and equipped anthropometric survey (future capability)	• MARC Tool – Evaluate Accommodation [p.111]
		2	• Access a database of design offsets based on	• EDT Lab [p.112]

			measured offsets for standard set of PPE (future capability)	• EDT Lab [p.113]
		2	• Incorporate the envelope of the body from semi-nude, clothed, to equipped. The user should have the ability to manipulate these outputs (future capability)	• MARC Tool – Evaluate Accommodation [p.111]
2	Functional anthropometry	2	• Reference strength data	• Not shown
		2	• Reference biomechanical data	• Not shown
		2	• Reference Range of Motion data	• Not shown
3	Boot strapping analysis	3	• Estimate requirements for multiple occupants	• Not shown
X	Proportionality constants calculator	X	• Do not pursue	• Penn State Open Design Lab – Scaling Calculator [p.96]

4.2.4 3D Anthropometry Tool Set Requirements

The following is a prioritized list of 3D anthropometry tool set requirements.

Priority	Domain	Sub-priority	Potential Requirement "The web-based anthropometry tool set should allow for the user to…"	Concept Example [Annex A page number reference]
1	Principal Components Analysis (PCA) Analyzer	1	• Generate 3D shape manikins based on PCA for select demographics (e.g. sex, environment, pilots)	• Not
		1	• Extract body measures from PCA scans (including digital measuring tape)	• EuroFit Project – Digital Measuring Tape [p.99]
		1	• Conduct PCA on segmentation of whole body model (e.g. torso or leg models)	• Not shown
		1	• Identify critical PC's and dimensions for design	• Not shown
		1	• Explore range of body shapes based on defined constraint (e.g. all body shapes associated with 32" waist circumference)	• Not shown
		1	• Explore allometric scaling (how body scales from small to large) to aid in clothing/equipment sizing and design	• Not shown
		2	• Access hand, foot and/or head scan models (future capability)	• Not shown
		3	• Define segmentation (e.g. paint and apply template) (future capability)	• Not shown
1	Data output	1	• "Lock" output data so that it cannot be tampered with	• Not shown
		1	• Output 3D specifications of individuals, boundary and distributed cases	• Not shown
		1	• Export models (semi-nude/clothed/equipped)). Files should be in the following formats ○ Critical ▪ Image (e.g., *.png, *.bmp) ▪ CAD (e.g., *.jt, *.stl, *.obj) ○ Unimportant ▪ JACK (e.g., *.fig) ▪ VRML (e.g., *.wrl)	• Not shown

			▪ Santos ▪ RAMSIS	
2	Clothing module	2	• Perform virtual dressing – assess virtual garments based on clothing pattern, size and body shape	• Sensitive Couture [p.99] • Optitex – O'Dev 3D Production Suite [p.102] • Optitex – O'Dev 3D Production Suite [p.103]
		2	• Accomplish heat mapping to show ease/fit	• 3D Difference Maps [p.84]
		2	• Model/visualize draping	• Sensitive Couture [p.101] • Optitex – O'Dev 3D Production Suite [p.103] • Body Labs – DRAPE [p.104]
2	Shape Viewer	2	• View shape library of raw scans. Select extremes or specific scans for design evaluation (e.g. real person close to PCA model?)	• Not shown
2	Clothing and Equipment Offsets/Correction Factors	2	• Specify offset/correction factors based on future clothed and equipped anthropometric survey (future capability)	•
		2	• Access a database of design offsets based on measured offsets for standard set of PPE (future capability)	•
		2	• Incorporate the envelope of the body from semi-nude, clothed, to equipped. The user should have the ability to manipulate these outputs (future capability)	•
2	Functional anthropometry	2	• Reference strength data	• Not shown
		2	• Reference Biomechanical data	• Not shown
		2	• Reference Range of Motion data	• BodyLabs [p.91] • BodyLabs [p.92] • JSOL – Total Human Model for Safety [p.93]
3	Internal organ shape analyzer	3	• Apply models of internal organs relative to external anthropometry to evaluate coverage or optimal placement of PPE across a wide range of shape and sizes, both sexes.	• JSOL – Total Human Model for Safety [p.93] • JSOL – Total Human Model for Safety [p.94]
		3	• Apply models of the skeletal system relative to external anthropometry	• UMTRI – Parametric Human Models [p.90] • JSOL – Total Human Model for Safety [p.94]

3	Blending/Re-targeting	3	• Carry out realistic animation of 3D scans to illustrate mobility or restriction due to clothing and equipment	• JSOL – Total Human Model for Safety [p.94]
		3	• Pose scans for crew station design (including equipped/clothed). Predict fit, posture, sight lines, reach envelopes, and clearance. Determines posture for DHM tools	• EuroFit Project – Skeleton Transfer [p.89] • BodyLabs [p.91]
3	3D CAD library of CAF platforms, vehicles, equipment etc.	3	• Access 3D CAD library of CAF platforms, vehicles, equipment etc.	• Not shown

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