3D Body Processing Interoperability, State of the Art and Outstanding Issues

Carol McDonald*[1], Nick Clayton*[2], Andrey Golub*[3]
[1] Gneiss Concept, Washougal, WA 98671, USA;
[2] Savitude Inc., Ann Arbor, MI 48104, USA;
[3] ELSE-Corp, Italy

https://doi.org/10.15221/21.09

1. Introduction

The 3D Body Processing Industry Connections (3DBP IC) Working Group, an adjunct group of IEEE P3141, Standard for 3D Body Processing (3DBP), brings together diverse entities devoted to making recommendations for 3D body processing interoperability. This objective implies the ability to share 3D obtained from different technologies, where raw data has to be curated and processed to be compatible. In the past three years, 3D has continued making inroads in product development, but the Covid-19 pandemic has accelerated the utilization of online retail, increased the number of phone apps for scanning, and increased usage of 3D Apparel CAD software. 5G technology and improved camera optics have also become pervasive, enabling faster file transfers and better image quality.

Individual body model storage has grown as the volume of scans has greatly increased. Privacy laws and regulations to protect personal identifiable information (PII) are becoming of greater importance.

As noted in the recently released white paper [1], 3D body processing is creating a new ecosystem over various devices or scanning methods (such as phone apps or booth scanners) over various types of networks with different levels of security. Different devices require different connectivity options; however, all devices must exist in a “trusted” environment. Avatars generated from individuals may contain personal identifiable information (PII). Therefore, individuals should have a right to privacy protection to prevent disclosure to unauthorized parties within the “trusted” environment.

For technologically advanced platforms, access to 3D data may be a crucial element to find the best fit for a specific set of measurements and the best style based on body or foot type. Interest in 3D to solve the fit and size problems and reduce returns in retail has grown.

The processing and exchange of 3D data must protect personal data while also protecting the derived data, which could have value for commercial use such as associated clothes models, custom annotations, measurement models, etc. This brings to the table a new paradigm of data protection by design: considering data protection issues as part of the design and implementation of systems, services, products, and business practices; and making data protection an essential component of the core functionality of our processing systems and services (sometimes called Digital Rights Management).

2. Avatars

The next question becomes, “what makes sense for Retail?” Retail Use Cases range from Ready to Wear (RTW) to Body Shape Categories (body shapes) to fully Bespoke Apparel, Footwear, and Eyewear. These Use Cases may require different types of 3D representations. Body avatars may vary from complete body scan avatars to population data avatars or modifiable body-shape models.

These avatar types can be used for Apparel and Footwear, though a whole-body avatar is helpful when interpreting “fit.” Detailed explanations are described in the following paragraphs and tables. Examples of different body shapes are shown in Figure 1 and summarized in Table 1.

Population data or fixed dimension avatars are statistically generated 3D models that can be from population averages, focus populations, and defined body shapes with measurements (either by sizing standards or by body shape categories).

* [1]carol@gneissconcept.com, [2]nick@savitude.com, [3]a.golub@else-corp.it

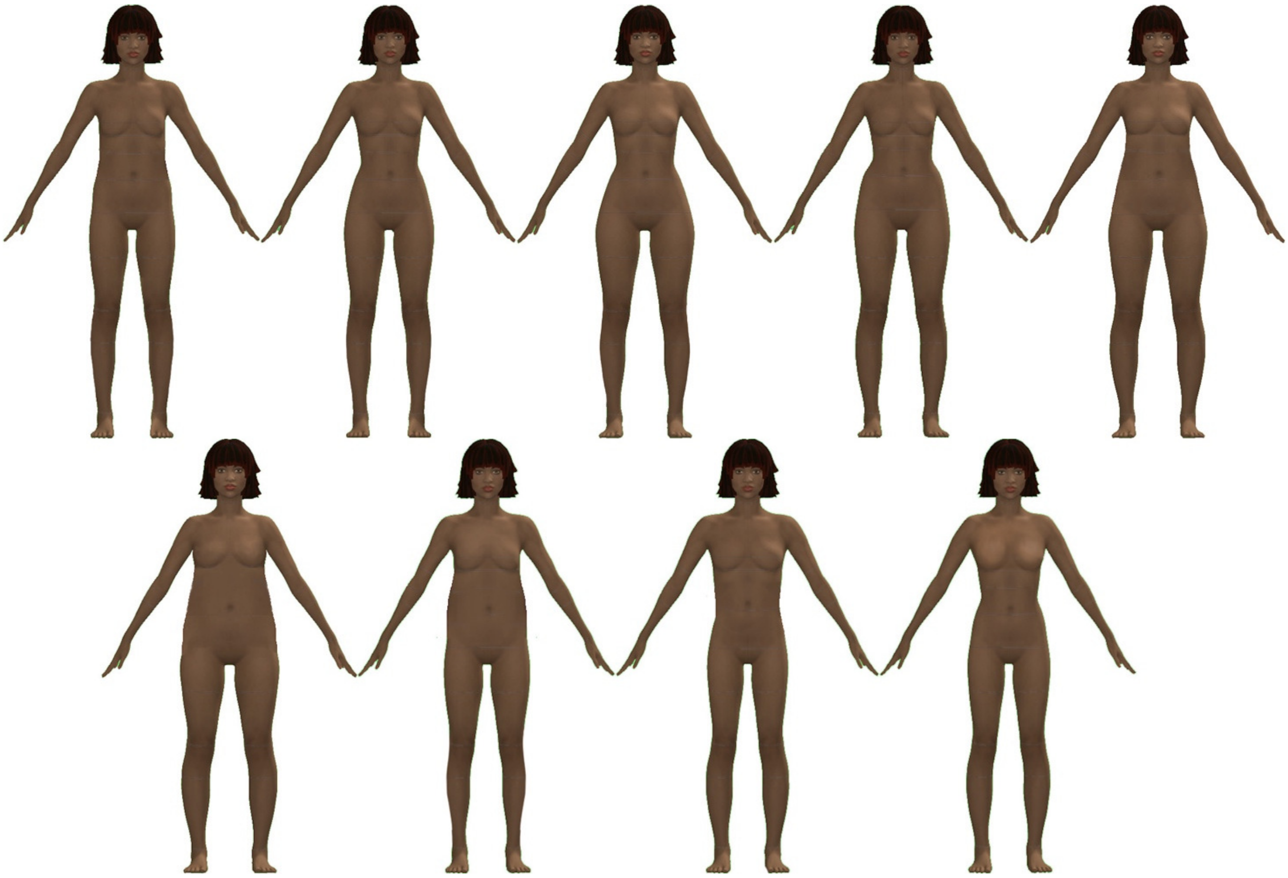

Fig. 1. Body shape avatars. (Savitude)

For reference, the “fit“ of a garment is defined as Body shape plus “ease” of the garment. Fit can vary depending on the relationship of body shape to the garment. Ease is the delta between the body shape and garment, which can range from compression to very loose fit and is dependent on garment usage, and individual preference.

Fixed Dimension model avatars have fixed shapes for each graded size. They are a source of fixed body measurements that apparel designers can use as a basis upon which to add "fit" and "ease" values, etc., during the design process. In practice, Fixed Models are created in groups that represent, for example, varying body shapes. These sets of Fixed Models will also vary from one designer to another.

Fixed Model avatars can be used as a basis for the Form Modifying Avatars. Key measurements can be extended or reduced within a software system to change the shape of the avatars. None of the avatars discussed so far represent a direct scan of an individual.

Individual Static Avatars are derived from the 3D point cloud of an individual in a static pose. This type of avatar reflects the individual’s body shape and measurements. The majority of the surface of this avatar will be a direct scan of an individual, and where there are holes, for example, because an area is occluded, those can be filled based on surrounding points (“patched”).

An Individual Form Modifying Avatar is derived from a 3D point cloud of an individual reflecting only their body shape. The avatar can be a static, rigid pose or a composite with an added layer for soft tissue modeling and skin/ hair texturing. The avatar can also comprise multiple frames to form an animation or contain skeletal rigging to allow for articulated poses and animations.

The Perfect Clone avatar may be considered a “deep fake” and possesses a voice and facial movements. The Perfect Clone would be generated from a composite avatar and highly programmed rigging to copy body movements, facial movements, and other personal identifying body markings.

Table 1: Avatar Types

	Avatar Type	Description	Data Type
1	Fixed Dimension	Fixed body shapes. Can be graded sizes or of different population groups	Population or algorithm
2	Form Modifying	Adjustable body shape by certain measurements provided	Population or algorithm
3	Individual Static	Scan of a person with “patched” areas if necessary	3D point cloud of person w/wo “patched” areas
4	Individual Form Modifying	Additional layers that may include soft tissue, texturing, rigging, etc.	3D point cloud of person, plus additional layers
5	Perfect Clone	“Deep fake” level with voice and facial movements and other individual characteristics	3D point cloud of person, plus additional layers including identifying characteristics

3. Body Data

3.1. Interoperability Considerations

Interoperability of data is still an issue for 3D environments, particularly for 3D models generated by capturing a real human body (3D body scans), material properties such as fabrication, and wearables. Body scans may include a soft tissue layer to better model the interaction between garments and the 3D body. Garments are modeled in 3D using “soft physics,” but there is no common agreement on modeling, physical testing, or algorithm treatment of such data. Data interoperability is required between consumer-facing individual 3D displays and designer-facing statistical data analytics on their customer population.

3.2. Soft Tissue

A good example of the impact of soft tissue on clothing modeling is a belt on a person with soft belly tissue. Any scan that does not include soft tissue modeling would be either a rigid body or one with universal soft tissue properties for the whole body. Neither will properly reflect the compression of the soft tissue by garments. As shown in Figure 2, from [2], the images marked “Uniform” and “Measured” are both soft tissue finite element method (FEM) simulations. If one models the “body with a belt” scenario and only uses the default modeling technique of “circumference of body at various heights along with the diameter of the belt” (with continuous tissue properties on the whole body), then the modeling will look like “Uniform.” However, if one models the avatar with the “Measured” soft tissue response, the avatar will look closer to the “Real World” photo of a belt on an individual. While better than hard body models, measured data-driven avatars are better and look closer to the “Real World” photo of a belt on an individual.

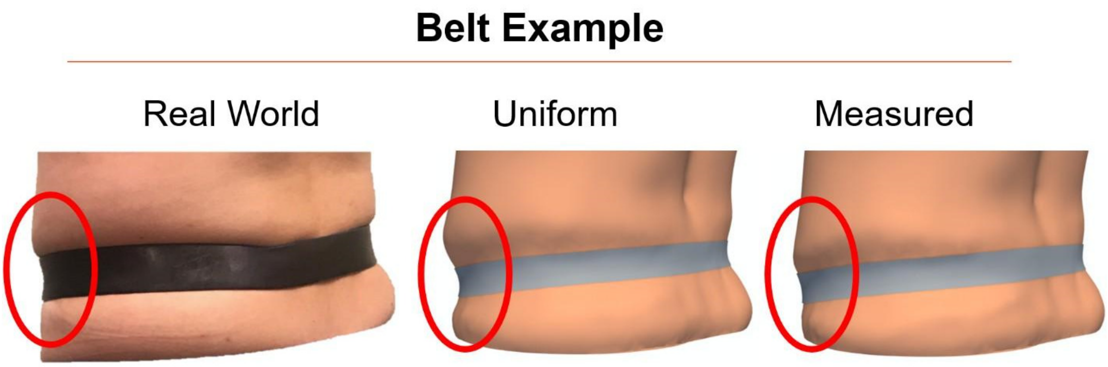

Fig. 2. Deformation of a belt with and without soft tissue modeling. [2]

3.3. Soft Physics

Soft physics for fabric includes draping, grain, and modeling the movement of fabric as the body moves. Scanning fabrics that are particularly shiny or fur-like is tough. Modeling the fabric under various lighting conditions impacts the virtual presentation of the fabric. The fabrication method of a garment can also impact the drape of the garment. Apparel CADs such as CLO, Browzwear, Lectra Opitex, Seddi each have their own method for modeling seams, test methods required for fabric properties, and assumptions used to model the fabric within their respective software. This makes it difficult to share between one Apparel CAD and another.

3.4. File Formats

Compounding the issues are the file formats, which are not universal. Some can be used to scan bodies and materials, but not all can be used in the Apparel CAD software. Consider the list of file formats generated by P3141 IEEE 3D Body Processing Standards Group as an informative reference for future standard work as shown in Table 2.

Table 2: Examples of file formats

Output file formats	3MF; ASC (point cloud) Armored ASCII file; BTX (Artec exports this point cloud format); DAE (COLLADA); FBX (Filmbox; Autodesk exchange); MA (Maya ASCII format); OBJ (Wavefront); OFF (Princeton); PLY; PTS; PTX (Artec exports this point cloud format); STL; VRML (Virtual Reality Modeling Language, superseded by X3D); X3D; XYZ (Artec exports this point cloud format); glTF
Other formats	TXT; ORD; RBD; PDF; BIN; CSV; XLSX
Other formats	JSON via Scanatec(TM) API Connect Service; printable PDF; X3DZ (compressed X3D Scene); ZPR; WRI (Microsoft Write); P3 (Primavera, acquired by Oracle, used by Pretty Good Privacy, not supported after 2010; ASCII; 357; USDZ; GLB; MTL; ZPF; XYZRGB; AOP
Material Formats	AXF; U3M; Adobe Substance

4. Digital Twin

To understand what is next for Retail, the goal of common taxonomies for 3D environments becomes particularly important. How are the terms around 3D, Digital, Virtual, Fit, Twins, avatars defined for the Retail industry when the applications range from AR to bespoke garments? Terms need to mean the same for consumers and the retailers so that the points of view of consumers and retailers are in alignment.
New areas of the 3D Body Processing Environment are the definitions of the Digital (Virtual) Twin or Digital (Virtual) Clone and how these pertain to Retail in relation to the Internet of Things (IoT). In Retail, Digital Twin real-time data can include the addition of consumer purchases to the consumer's body avatar to better understand fit preferences. The Table 3 provides quoted definitions of the digital twins as found on the publicly available sources listed.

Table 3: Digital (Virtual) Twin definitions

	Definition	Sources
1	"A digital twin is a virtual representation (set of correlated digital models and supporting data) of real-world entities and processes, synchronized at a specified frequency and fidelity."	Digital Twin Consortium [3], released December 3rd, 2020
2	"Human Digital Model consists of the physical entity, the virtual counterpart and two-way communication between them, surroundings, and other entities (relatives, medical information, etc.) over the person's entire life span."	Science Direct [4]
3	"Digital twins are software models of real-world items. They are, essentially, virtual replicas of objects, places, or people used to run simulations before solutions are deployed in real-life."	Here360 [5]
4	"A digital twin is a virtual/digital replica of physical entities such as devices, people, (customer personas), processes or systems that help businesses make model-driven decisions."	AI Multiple [6]
5	"The digital twin is commonly defined as a representation of a physical product, service, or process of the real world in the digital world. The extent of the digital twin may vary from "data twins" that collect data from/for the physical objects up to "simulation twins" that are especially used for product development and construction of complex objects."	Arvato- Systems [7]
6	"A digital twin is, in essence, a computer program that uses real world data to create simulations that can predict how a product or process will perform. Digital Twin Prototype (DTP) – Created before a physical product is created. Digital Twin Instance (DTI) – Created once a product is manufactured to test different usage scenarios. Digital Twin Aggregate (DTA) - Gathers DTI information "	TWI Ltd [8]

5. SizeSpan (Morphotypes, or Body Shape Inclusion)

Size Span refers to the grading of sizes adapted to the properties of the garment and, hopefully, the population. In an example of size span created for shirt production (represented in Figure 3.), the designer selected "Height" as primary measurement and "Chest Girth" as secondary. The designer uses this information to request aggregated data of the 3D avatars representing each of the sizes and a set of aggregated measurements derived from them. According to changes of the two measurements selected, each of all bodies from different sizes were dressed with the same model of a shirt. The designer completes the product definition in CAD using the 3D avatars, then checks it on real users using the body measurements to find the suitable model deformation range. When the designer is able to estimate visually and replace avatars with different main measurements, the optimization of the size grading scale process goes faster and allows the designer to achieve the best quality.

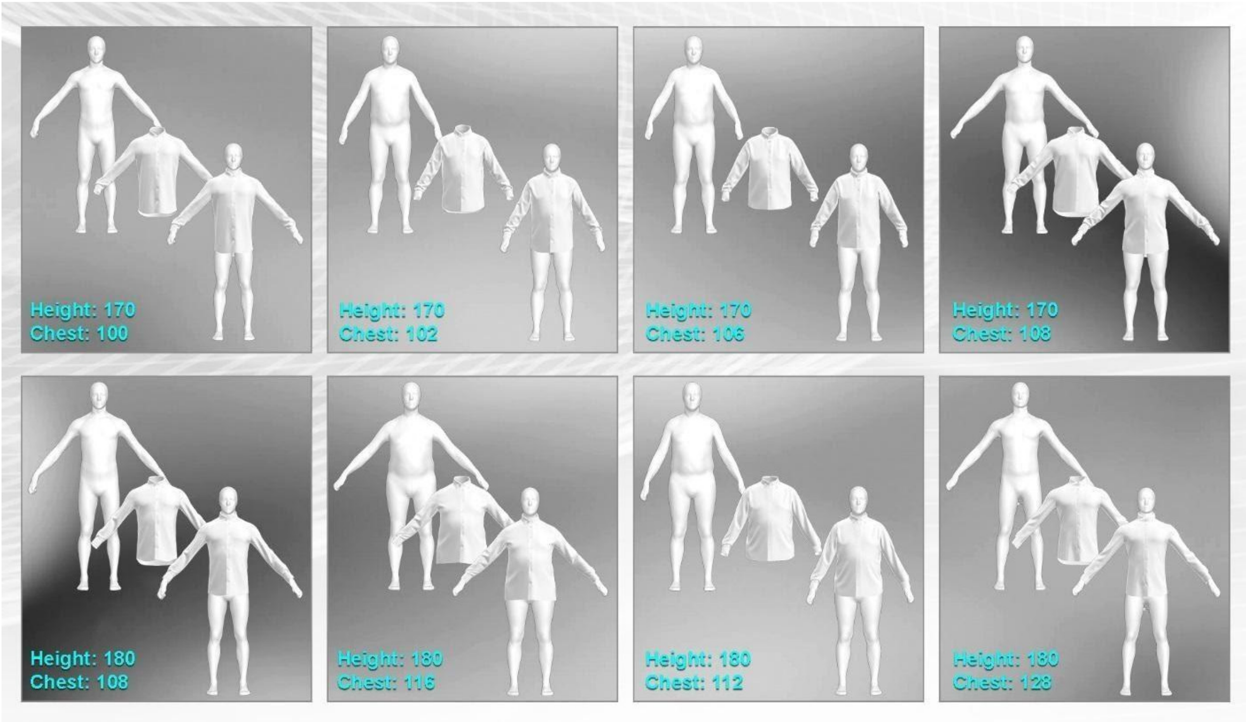

Fig. 3. An example of a Size Span representation for a shirt. (ELSE-Corp)

By optimizing size span by automatic algorithms, there are time improvements for production planning. Nonetheless, automated work in design should be checked visually by a person. This step is an obligatory quality control made by the designer to avoid possible style deformations while grading. The designer can see a simulated garment on all body types and make timely decisions if some construction corrections are needed. Visualizing all body types allows the designer to select silhouettes and design details that match those shapes, promoting a more diverse and inclusive collection. This process is an iterative work process that finally allows an improvement on a particular size span for each garment collection.

For mass production, it is better to have fewer sizes of one garment. However, for the customer, it is preferable to have more sizes covering a broader range. This presents a root of conflict that could be solved. By taking a consumer population defined geographically, by those that shop at a particular retailer, or any other demographic, and analyzing that population's body data, one can optimize garment properties, such as silhouette, design details, sizing, or 3D geometry within an assortment to better match that population. This can save resources, avoiding unnecessary work of the production units for industrial clients, and potentially better satisfying the final customer.

6. Market Scenarios

The apparel and footwear industries are going digital, and more brands are joining this inevitable process every day. Eventually, traditional product photography and 2D images may become outdated because items are increasingly presented and delivered digitally. Assets should be visualized in a three-dimensional format that demonstrates the real physical properties such as material, texture, color, and physical product construction. In addition, 3D items are shown on realistic bodies and body parts.

The importance of the 3D data lies in 3 scenarios:

- Manufacturing Scenario (also called Industrial Made to Measure): To enable companies to produce garments that are almost made to measure but still manufactured by industrial methods. This allows individual fitting by finding the most suitable items for the consumer
- Design Process: To help brands and designers create new collections related to specific avatars, groups of people, and target markets.
- Marketing & Operations: Reliable 3D data allows better segmentation and understanding of specific markets. The information can be used to make more accurate decisions regarding brand positioning, distribution channels, and allocation.

6.1. Manufacturing

The footwear and apparel manufacturing processes are complex. In the case of Made to Measure production, the complexity and operations increase significantly. Made to Measure items must fit the person, and at the same time to be produced together with other orders to maintain efficiency at an industrial level. The use of reliable information on body measurements allows manufacturers to create more flexible production lines. The 3D data can be utilized to improve production planning and to better understand orders placing. By applying consumer 3D and body shape data to production, manufacturers can avoid generating waste by overproducing for certain body shapes while underproducing for others.

6.2. Design

In the design scenario, anthropometric data is key. Currently, one of the most important stages of design collection creation and production is determining the size grading, which is traditionally based on statistical data. This data is often outdated because it is difficult to renew such a huge quantity of statistical information in a short period of time. It represents an inconvenience for the apparel manufacturing industry because the body parameters of the average person change more often than when the statistics are updated. Based on the dimensions of the past, the so-called "bullwhip effect" is created when designers still use a single size range that differs significantly from reality. As a result, the market is overflowing with clothing that fits only a small portion of the buying population, while there is simultaneously an undersupply of clothing for many buyers.

Based on the value created by Digital Design and 3D Avatars, it is now becoming a reality for the clothing industry to create products, which cover all parameters of the human body. It is important for producers to classify data and match designs according to the target audience’s criteria (shape, gender, age, etc.) and account for regional variations.

Fit is more than a matter of linear measurement: a 3D profiling of body shape reveals large differences across similar measurements [9]. Traditional body data in charts can often give the designer a blurry view of the body. But with the use of 3D Modeling, it is easier for designers to understand the overall complexion and make measurements of any part of the body that is necessary for sewing a separate unit of clothing. The Digital Design + 3D Avatars technology allows not only for the production of relevant products but also reduction of the output of unsuitable clothes, thereby creating only what will be worn.

Digital analogs of the human figure can help to understand the proportions of the body. The use of Digital Design and 3D Avatars along with designers’ creativity provides the ability to create a unique style based on individual characteristics of the body. The correct selection of clothing models will emphasize the advantages and provide aesthetic enhancements based on precise measurements.

6.3. Marketing & Operations

In the era of Body Positivity, which focuses on challenging body standards, it becomes important for people to be able to wear clothing that will be tailored to their individual standards. According to Deloitte, on average, 36% of consumers expressed an interest in purchasing personalized products or services [10]. Nowadays, it is possible to save the parameters of body types and measurements for its further use, and thanks to 3D modeling, brands are able to modify collections according to the figure of a specific person or market, producing products that fit perfectly without compromising any of its features.

By getting statistical data about body measurements, it is possible to reduce costs because by knowing the exact size stage and body shapes, brands can buy the necessary quantity of materials.

After adjusting some necessary parameters (height, chest, waist, etc.) and using 3D modeling as a tool, the perfect collection for a market can be created and sent to production. Another advantage that the 3D data offers is the possibility of segmenting orders by body type, enabling businesses to optimize their distribution channels and reduce transportation and warehouse costs.

Nowadays, e-commerce represents an essential revenue stream for businesses around the world. Even though online sales are already a developed form of retail, there are still disadvantages, especially for products that have a measure for fitting. Sizing issues are one of the main reasons that shoppers return online orders. According to research performed by Global Web Index in the U.S. and U.K., 52% of people had to return an item because the fit was not right, and they could not try it on before they bought it [11]. The use of avatars and anthropometric data segmented by ranges of age and country could solve the fitting problem for online retailers.

The benefits of a reliable database of body measurements do not stop there. The information can be utilized to develop better shipping and return policies. Almost 50% of online shoppers buy multiple sizes of a product in order to ensure the right fit [12]. In addition, 14% of customers buy items they don't need so they could qualify for free shipping [11], with the intention of returning them after. A more accurate size segmentation and access to a reliable database could help online retailers reduce losses for returns. In the U.K., returns represent costs up to £20 billion a year [13]. American consumers returned $428 billion in goods in 2020, a return rate of 10.6%. In 2020 e-commerce was $565 billion of total US retail sales with apparel being 12.2% of total [14] or $57.3 billion.

7. Made to Measure

Made to Measure oriented design: Starting from manual measures of the customer or those generated by a 3D body scanner, a 3D avatar is created. The 3D avatar is the customer's body that can be based on a synthetic/ statistical generation procedure or be more individual and more realistic. The designer can then visually check the projected garment and make corrections according to the customer's ergonomics and fitting preferences.

In the case of Made to Measure services without technology, the client has to be measured manually by an expert. Measurements are entered manually in various CAD software, the patterns have to be created by experienced designers, and after hours of preparation, the fabric can be cut. When the cutting has been completed, a tailor could spend the full day for a jacket and another day for pants and a shirt preparation. This is only the initial procedure for the suit's first try-on. The client has to come two times as a minimum for fitting correction and adjustments of the garment. Only in the last try-on meeting, the customer can see how the final garment looks.

In the virtual fitting process, the person is scanned in seconds to a couple minutes in the scanner, with some additional minutes for instructions and post processing. Nowadays, privacy is one of the most valuable assets for customers. Automation of virtual fitting on 3D body avatars in an anonymous way is one of the obligatory tasks.

The customer can visualize almost immediately on a screen how the selected items may fit and will look like as shown in Figure 4. Despite the fact that virtual fitting is a fast operation, it is impossible to describe it quickly in all procedural details. The process is explained in short descriptions and illustrations because the explanation is only feasible in a schematic way.

Fig. 4. An automatically generated standard set of garments for a statistical avatar and a Made to Measure set of garments for a customer-specific avatar. (ELSE-Corp, Savitude)

The Made to Measure virtual fitting service not only saves time for clients and staff but also saves money. It makes possible the democratization of bespoke clothes due to affordable pricing. The mass market of Made to Measure services is also an attractive option for people who have a different or particular body. This takes them out of the traditional size span. For some types of clothing like corsets, slim-cut suits, or items made of non-stretchy materials, it may be hard to fit perfectly for all body types, and even the size span would be divided into hundreds of sizes. Along with the democratization, comes the need for privacy as one of the most valuable assets for customers. Automation of virtual fitting on 3D body avatars in an anonymous way is one of the obligatory tasks.

In the case of simulation of Made to Measure clothing, every detail and each millimeter of measurement are important. It makes a big difference and influences the best fit when projected garments are in a multi-layer set. Any under layer is changing measurements to some extent depending on the fabric thickness and quantity of drapes. The projection and simulation of all items are necessary, not separately but together as a full set. Moreover, the simulation must be checked dynamically. Using the software, the designer can visually check (Figure 5) the projected garment and make corrections according to the client’s preferences of ergonomics and fit.

Fig. 5. Separated and united representation of assets. (ELSE-Corp)

8. Data Interoperability

A reliable database provides essential information for a more accurate approach to apparel and footwear design. 3D Body Data and its interaction with garment data can act as potential unifiers for the industry.

Many product hierarchies are created by individual retailers ad-hoc and may even change season over season, making retrospectives and comparisons of past performance difficult or impossible. Through interoperability of individual sizing standards with standards in 3D Body data, a standard product hierarchy can be created and added to any existing taxonomies to allow for comparison. Garments can be grouped by the morphotypes they are designed for, fit, or flatter. This grouping can be created as products are designed or via a retrospective analysis that can be performed automatically.

By standardizing products through the body data they match, a reliably consistent hierarchy can be achieved for analysis year over year and between retailers allowing them to learn from history and other perspectives. Where existing taxonomies overlap or where visual analysis can provide common descriptors, these can also be used to augment the analysis. This normalization of product hierarchy is beneficial for multi-brand retailers or collaborations between brands but can also be used to bridge data gaps within a retailer over time as their product hierarchies change.

Since every fashion company has their own interpretation of sizing and body shape, which are used as a starting point for designers and manufacturers, visual recognition of the details and quantitative analysis is often difficult and subjective, while sizing and assortment allocations are arbitrary. Standard body morphologies and 3D models provide a reference for apparel design, planning, and data analysis, regardless of category, retailer, or brand, while also assuring fit for consumers.

Disconnected communication between departments, brands, and seasons makes for limited analytics and collaborations. Providing standards for communication can improve collaboration internally and externally and increase profitability.

8.1. EU BodyPass

An example of Interoperability research was the EU project "BodyPass," completed in the beginning of 2021. The mission was to introduce an API- ecosystem for cross-sectorial (health sector and consumer goods sector) exchange of 3D personal data, useful in analyzing and extracting shape information from large samples of 3D data while giving special attention to personal data privacy protection. Thus, highlighting that the direction of processing and exchange of 3D data must protect personal data, while protecting the derived data which could have commercial value such as associated clothes models, custom annotations, measurement models.

In order to make original raw scan data treatable by the multivariate analyses that will render shape information exploitable in product design and health services, the project team developed a procedure of conversion of the original data into a common and manageable 3D mesh structure based on the correspondence of homologous points. Following this objective, BodyPass has defined a method based on a common parameterization on a reference mesh so that any partner can conduct a template/model fitting process using its proprietary template and afterward, compute the mapping between both templates. The method generates random (on-the-fly) templates in order to protect the IP rights of the data nodes. This method has been tested on several pilots, both healthcare and consumer goods/ retail-related. BodyPass has processed and shared data from Medical scanners (CT scans), Body scanners, and Mobile phone scanning.

As a second main objective of the project, Personal 3D Data Protection, BodyPass defined the privacy and security restrictions related to the handling of raw 3D data at hospitals and consumer goods, concretely realized through Data filtering, aggregation, and anonymization software. Only sufficiently anonymized avatars can be transferred from partner to partner. This includes the measures for anonymization of the data and legal restriction for delivery that assures data privacy: data averaged over a sufficient number of subjects or applying anonymization procedures. The anonymization includes, for example, the elimination of distinctive facial details and ears, followed by resampling to low-resolution 3D models.

Also, it was considered how these restrictions are enforced in the software and architecture. In order to analyze and extract shape information from large samples of 3D data, BodyPass created services that allow extracting and showing information to clients and professionals. The services defined for the consumer goods were grouped into four types of services:

1. Data curation
2. Personal data management
3. Data Retrieval
4. Data visualization

9. Outstanding Issues / Conclusion

The remaining outstanding issues include alignment and interoperability of file formats and quality levels of scans required, and a common taxonomy for the Retail environment. The start of art should develop to assist with the outstanding issues of avatars, interoperability of data, digital twins, manufacturing, and product fit.

Through the use of digital twins and avatars, Designers can better understand their customer population and optimize assortments which in turn improves the customer journey and customer satisfaction. Customers who use virtual fitting and Made to Measure will return less thereby reducing waste in the industry. Interoperable data will improve workflows and reduce time to market while also allowing insights to be more easily generated and shared throughout the industry.

Acknowledgement

The authors would like to thank Camilla Olson from Savitude for her inspiration.

References

[1] M. Hernandez, et al, "Summary and Recommended Actions for Communications, Security, Privacy and Trust (CSPT) [IEEE P3141]", New York, New York, USA, September 2021

[2] D. K. Pai, A. Rothwell, P. Wyder-Hodge, A. Wick, Y. Fan, E. Larionov, D. Harrison, D. R. Neog, and C. Shing, "The Human Touch: Measuring Contact with Real Human Soft Tissues," ACM Transactions on Graphics (Proc. SIGGRAPH), Volume 37, Issue 4, Article 58, (August 2018), Paper available here: https://sensorimotor.cs.ubc.ca/2018/08/02/measuring-contact-with-real-human-bodies/

[3] Digital Twin Consortium, Accessed 15 Aug 2021, https://www.digitaltwinconsortium.org/initiatives/the-definition-of-a-digital-twin.htm
https://blog.digitaltwinconsortium.org/2020/12/digital-twin-consortium-defines-digital-twin.html

[4] S. Wei, “Is Human Twin Possible?”, Volume 1, 2021 https://doi.org/10.1016/j.cmpbup.2021.100014 https://www.sciencedirect.com/science/article/pii/S2666990021000136
[5] J. Reimer, “What’s a digital twin and why is it important to retail now?”, Posted August 14, 2020, Accessed 15 Aug 2021 https://360.here.com/digital-twin-technology
[6] C. Dilmegani, “15 Digital Twin Applications / Use Cases by Industry”, Updated on July 5, 2021, published on August 26, 2020, Accessed 15 August 2021 https://research.aimultiple.com/digital-twin-applications/
[7] C. Mehrmann, “On the Relevance of Digital Twins for Consumer Products”, posted 29 June 2021, Accessed on 15 August 2021, https://www.arvato-systems.com/blog/on-the-relevance-of-digital-twins-for-consumer-products#10 9658
[8] N.A., “What is Digital Twin Technology and How Does It Work?”, N.D., Accessed 15 August 2021, https://www.twi-global.com/technical-knowledge/faqs/what-is-digital-twin
[9] J. Suominen, F. Piller, M. Ruohonen, M. Tseng and S. Jacobson, “Mass Matching - Customization, Configuration & Creativity: Proceedings of the 5th International Conference on Mass Customization & Personalization MCPC 2009”, Aalto University School of Art and Design, 2017, https://documents.pub/document/mass-matching-customization-configuration-creativity.html
[10] Deloitte, "The Deloitte Consumer Review Made-to-order: The rise of mass personalization", Deloitte.com, 2019. [Online]. Available: https://www2.deloitte.com/content/dam/Deloitte/ch/Documents/consumer-business/ch-en-consumer-business-made-to-order-consumer-review.pdf
[11] K. Gilsenan, "Online Shopping Returns: Everything Retailers Need to Know", globalwebindex.com, 2018. [Online]. Available: https://blog.globalwebindex.com/chart-of-the-week/online-shopping-returns/
[12] A. Berthene, “Sizing issue is a top reason shoppers return online orders", digitalcommerce360.com, 2019. [Online]. Available: https://www.digitalcommerce360.com/2019/09/12/sizing-issue-is-a-top-reason-shoppers-return-online- orders/
[13] A. Ram, "UK retailers count the cost of returns", Ft.com, 2016. [Online]. Available: https://www.ft.com/content/52d26de8-c0e6-11e5-846f-79b0e3d20eaf
[14] N.A., $428 Billion in Merchandise Returned in 2020, January 11, 2021, Accessed 16 August 2021, https://nrf.com/media-center/press-releases/428-billion-merchandise-returned-2020