The Future of Fabrics

Digital Fabric Roadmap

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International Apparel Federation
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Definitions:

Apparel Industry: Actor in the supply chain responsible for developing textile products, such as fashion brands.

Avatar or digital human: Digital representation of a human body based on body dimensions.

Parametric Avatar: Avatar with adjustable sizes, posture and form

Body scan: Scan of a human body, which can be imported in 3D software, or the measurements can be used to adjust the parametric Avatar.

Simulation: A fabric draped on an Avatar, based on the measured fabric physics such as weight, stiffness, stretch and shear.

Rendering: Photorealistic image or animation generated from the simulation, taking viewpoint, lighting and shading into account.

Optical or visual characteristics or properties: These properties give the fabric its visual identity. I.e., texture, print and structure.

Physical properties of a fabric: 'A physical property is any aspect of an object or substance that can be measured or perceived without changing its identity, such as weight and shrinkage.' [1]

Mechanical properties of a fabric: 'The properties that describe a material's ability to compress, stretch, bend, scratch, dent, or break.' [1]

Maps: jpg or png files with optical or visual characteristics, for example optical texture maps.

Bending or stiffness of a fabric: Represents the flexural rigidity of the fabric

Buckling: The ability of a fabric to fit to a different shape object without wrinkling.

Friction: Resistance of the fabric against rubbing or movement

Tensile or elongation or stretch: How a fabric reacts to force being applied.

Textile Industry: Actor in the supply chain responsible for supplying the fabric, this can be a fabric supplier, a fabric printer or a garment supplier

Shear bias extension, shear rigidity: How a fabric reacts to force being applied in bias direction. Shear rigidity is calculated from the bias extension.

Fit map visualisation: Specific maps to visualise the interaction between the fabric and the body, they give extra information to check the fit.

Stress map: Specific fit map to illustrate the force applied to the garment of the material

Strain map: Specific fit map to illustrate the amount the garment or material is stretched

Tiling: Continuation of a report, print, or a weave structure such as for example in a twill weave.

1. Introduction

1.1 Why this paper?

Reflecting on 2020, we have concluded that the apparel and textile industry are having a difficult time surviving. The fashion industry has been hit especially hard. Shop closures, travel restrictions and uncertainty are having an enormous impact on spending behaviour. Supply chains have been disrupted and vulnerabilities have become more apparent than ever. Companies, NGO's, and consultants cry out for a reset and a sustainable path forward. The consequences of this damage to the economy will only fully be clear far in the future. With the global pandemic keeping people at home, 2020 may be remembered as the year in which fashion retail made a definitive shift online. Over a period of just eight months, e-commerce's share of fashion sales nearly doubled from 16 percent to 29 percent globally, jumping forward six years' worth of growth [2]. Apparel brands and manufacturers are adopting 3D design and fit tools. The current situation has forced suppliers and buyers to cooperate remotely, accelerating the need for digital product development. This technology provides 3D visualisation of garments in real time, enabling companies to share and modify their designs, carry out virtual fit reviews and approvals, as well as buying sessions across the supply chain on true-to-life virtual avatars. The process also helps speed the product development time, reduces the need for physical samples, can improve the workflows and decision-making – and critically, lets companies be more agile and responsive to changing market needs. Better decision making also means better prediction and answering of consumer demands, translated in less overflowing production. Adding to these benefits, 3D solutions can also have a substantial impact on sustainability and waste reduction, with fewer samples meaning less material waste and a smaller carbon footprint. [3] [4] [5]

In order to create a true to life virtual garment sample or digital twin, the fabric needs to look, behave and drape exactly the same as the physical sample. [6]

However, as with any modern technology, it is taking time for the industry to gain critical mass in using 3D design and prototyping software. Industry professionals have pinpointed a crucial stage in the product development process, which is slowing down the digitisation process going mainstream. When it comes to materials simulation based on physical and mechanical properties, the industry is still underdeveloped. In an ideal world, measurements would be standardized so fabric suppliers can provide a swatch of materials complete with all general properties needed to simulate materials and garments in any 3D environment without the need of a physical sample. [7]

When it comes to materials simulation based on physical and mechanical properties, the industry is still underdeveloped.

To address this complicated issue, IAF and Modint, supported by CLICKNL, gathered international experts, academia, and stakeholders around a digital round table to discuss The Future of Fabrics on 11 November 2020. This whitepaper is a follow up of this discussion.

1.2 Aim, contribution, questions and methodology

The main aim of this paper is to pave the path for the digitalisation of fabrics and to incorporate this important stage of product development in the digital process. By providing an overview of the current status, technical background and a roadmap of what needs to be done, we wish to align textile producers, garment manufacturers and buyers, as well as providers of technology. This will accelerate the implementation of 3D product creation. The digitalisation of fabrics will enable a clear and more effective communication between the textile industry and its supply chain partners. This will help all stakeholders to reduce waste in the development process, as well as enhance their agility.

The Key Question: How can we involve fabric suppliers in the digitalisation of fabrics?

To find this out, we investigated the following sub-questions:

- What is the current status of Digital Transformation in the apparel Industry?
- Why is it important to simulate garments based on the fabric's mechanical and physical properties?
- What are the required fabric mechanical and physical properties and how can they be obtained?
- What are the required optical fabric characteristics and how can they be obtained?
- Which steps need to be taken to inform and educate the textile industry?

We based this whitepaper on secondary and primary research. The recent investigation by the 3DRC innovation Committee's and their published works have served as a foundation to start a discussion and to explain the process. To illustrate the current situation with examples, we explored the websites from Pixel pool and Premiere Vision. To illustrate practical implication, a basic skirt has been simulated digitally to visualise the importance of fabric's mechanical properties. Primary data was gathered during the Round Table: 'The Future of Fabrics', including various stakeholders. Their opinions and ideas have been analysed and presented in the overview of the current state and have been incorporated in the roadmap, which will conclude this document.

In chapter 2 we outline the current status of digital transformation in the apparel Industry, the benefits of the changes and the efforts already made by the industry. In chapter 3 we explain the process of creating digital samples and digital fabrics, why it is important, as well as the properties we need and how they are measured. Moreover, we explain how to capture and generate the optical characteristics. We end chapter 3 with sharing of data and the involvement of stakeholders. In chapter 4 we present the findings of the round table discussion. In chapter 5 we present the digital fabric roadmap, with the joint actions and the roadmaps for the stakeholders, additionally we sketch the future fabric landscape.

2 The status of digital transformation in the apparel industry

2.1 Digital product creation

During the development and selling process, the apparel industry uses prototypes and samples for design, fit, production approval, colours and business to business (B2B) sales. This varies between 2 to 25 samples prior to producing a garment [8] [9] [10]. To reduce this large number of samples, the global apparel industry is currently implementing or using 3D virtual product creation. Currently, several brands are replacing their physical samples with virtual ones. Virtual samples are used during the development process for design and fit decisions, as well as for improved communication with production facilities. [3] [4] [5] In novel virtual showrooms (Hugo Boss, 2017 [11]; PVH, 2019 [12]) developed by companies as for example Hatch [12] and Pixelpool [13] virtual samples supported with real fabric swatches replace the large amount of B2B samples and colourways (Figure 1).

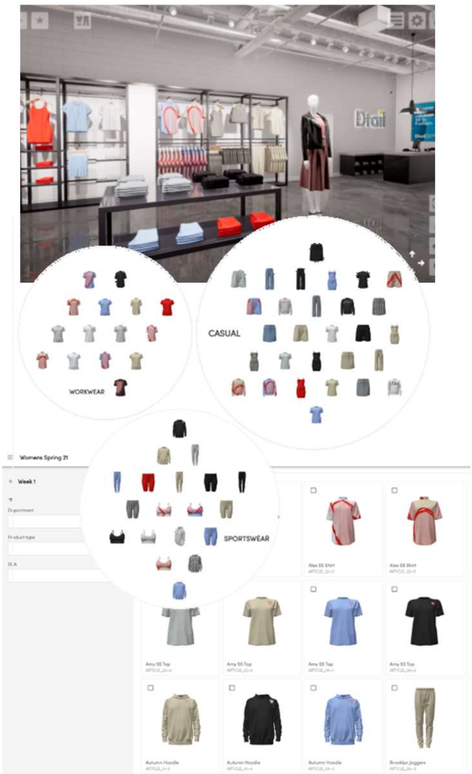


Figure 1: Virtual showroom and virtual samples [13].

2.2 Benefits in the development process

Before the disruptive influence of COVID-19, Digitalisation was an important part of long-term business strategies, setting the base for a future proof company. 2019 has accelerated the need for speedy adaptation and implementation due to changing customer demands and a forced collaboration change with supply chain partners. Futureproofing your company requires continuous evaluation of strategies and activities, balancing Design, Digitisation and Sustainability in order to be innovative and competitive (Figure 2).

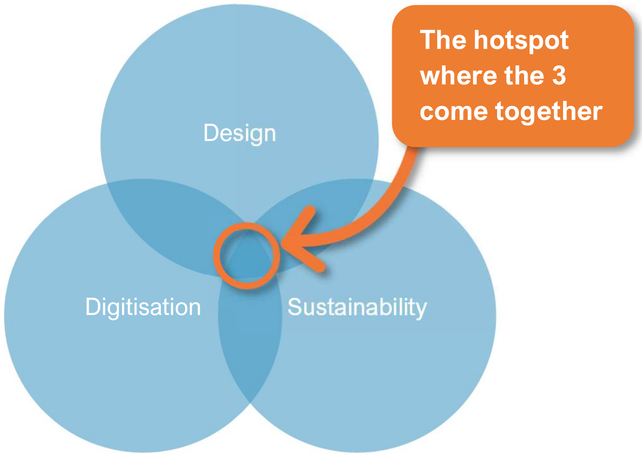


Figure 2: Balancing Design, Digitisation and sustainability, Modint 2020.

3D design, product development, fit technology and digital product representation can deliver significant long-term rewards for companies:

- Shorten the time to market
- More agility and flexibility to address current market needs
- Reducing their inventory, better cash flow
- Sustainability
- Cost reduction

Physical sampling takes time. Depending on availability of materials, the process can take up to many weeks. Rework and design changes will demand more time. In case a company decides to use digital sales samples, the time gain is even bigger [5].

Testing new styles by engaging customers in the product review process allows a fast and precise response to future inventory needs. Also, AI is being used to predict new trends by collecting information which will influence fashion up to a year from now. This will enable designers to create products, based on relevant data [14]. This enables companies to align their inventory with market demand with less risk of leftovers.

The textile and apparel industry are producing pre-consumer textile waste in each phase of its manufacturing process [15]. By using less development resources and optimising inventories, pre-consumer waste and costs will reduce.

A virtual twin material also offers the advantage of storing all fabric data in one central place. An example is the Aware verification technology, which links the physical fibres to the proof of authenticity, stored in its digital twin [16].

2.3. Industry efforts and contribution

During the past years, a hurdle in the digitisation process, was the lack of coherency between physical measurement methods and the result of virtual garment simulation in different 3D apparel software programs [7].

Some 3D software developers use currently available measurement technologies to obtain the physical and mechanical properties. Others develop their own instruments. This is to facilitate the user's needs to digitalize their material, including the mechanical and physical behaviour. The latter is a key requirement to enable true virtual fitting. The fabric should be simulated exactly as it is, also representing the shortcomings of the material. Faults in patterns or a mismatch in material choice can only be detected with accurate representation of the fabric [7].

In 2017 the 3D Retail Coalition (3DRC) [17] formed the 3DRC Innovation Committee to investigate scalability of fabric measurement for virtual fabric simulation. The group started with investigating the instruments used for this purpose, indicating the differences and similarities, as well as recommendations to increase accuracy, simplify and standardise the measurement process [7]. This was followed by the next step: Testing and comparing the methods to find the most accurate method enabling a single measurement of a fabric for multiple 3D apparel software applications. Three fabrics were tested for different properties and assessed for conversion of these values. The committee concluded that all software applications need the same properties for fabric simulations, but the means of measuring, calculations and the unit of results might differ. Also, the requirements for physical fabric swatches differ between methods. This work will be followed up by a Standard Operation Procedure (SOP) for fabric testing to obtain five fabric physics needed for virtual fabric simulation [18].

> A standardised dataset which will be accepted uniformly by all software systems would be a leap forward in the digital transformation of the textile industry.

A comprehensive SWOT analysis of different measuring system can be found in the IEEE whitepaper by 3DRC on measurement methods of relevant fabric properties their differences and how software applications use the information. In general, the same properties are measured in most of the cases according to a similar principle with slight differences. Often, they do not follow existing standards in their methods. Testing protocols are unclear, tests are done under random condition, swatch sizes differ and palliative measures are taken to retrieve the properties. In some cases, only one fabric specimen is tested. Calculation and output data are in most cases not transparent. It is unclear how the inaccuracies are corrected in the software, or to what extend the software is able to use the refinement and interaction between the properties [7].

3 The process of creating digital samples and digital fabrics

3.1 Virtual samples

To create the virtual samples as illustrated in Figure 1, digital patterns are digitally stitched together and placed on an Avatar or digital Human in apparel software programs like Browzwear [19], Vidya [20], CLO3D [21] or Optitex [22]. Once the garment is placed on the Avatar it is simulated.

3.2 Properties

In garment simulation the fabric's physical and mechanical properties are required for the true behaviour and drape. The optical properties give the fabric its visual identity, by interacting with the light responsible for the visual look of the material. (Cusick 1962 [23]).

The simulation, a fabric draped on an avatar, gives already sufficient information to judge design, fabric, fit and look. These simulations are the base to generate the rendered images or rendered animations which are used to present the garments in for example digital showrooms (Figure 1). The rendered images give a complete look and the same garment can be rendered on different backgrounds or stages or with different lightning. Rendering can be done in the software packages or in the cloud.

Physical & mechanical properties

- Weight
- Shrinkage
- Thickness (Compression)
- Bending rigidity – calculated from the bending length
- Shear rigidity calculated from the bias extension measurement
- Tensile
- Elasticity (elongation, stretch)
- Friction

Optical or visual properties

- Texture
- Print
- Structure
- Colour

Key properties needed for fabric simulation are bending, shear and tensile in relation to the fabric weight. We will explore the importance of these properties for fitting in 3.3. How these key fabric properties are used to simulate the garment will be explained in 3.4 These required fabric properties can be measured with regular textile testing instruments. An overview of the methods and instruments to measure the properties is given in 3.5. Optical maps are generated by using a scan of the fabric. The optical maps are placed as an image on the draped garment, to show a realistic structure of the fabric. The optical maps as jpg or png files are placed as images on the draped garment. Methods of generating these optical maps will be explained in 3.6.

3.3 Accurate representation

For selection and decision making based on virtual prototypes and samples, it is of key importance to have an accurate presentation of the digital fabric and the digital human or Avatar. To enable the apparel and textile industry to make decisions about the chosen material, fit and design details, before a physical sample is made the fabric needs to look, behave and drape exactly the same as the physical sample.

The 3D virtual technology used in the apparel industry, uses fabric weight in combination with physical and mechanical properties to create a digital fabric [24]. This is important to create the virtual twin.

Digital fabrics can be draped different types of pedestals as illustrated in Figure 3. This is very helpful for designers to interpret the behaviour of the fabric [25].

Figure 3: Simulated fabrics with different fabric properties.

The simulations of a skirt pattern block in Figure 4, 5 and 6 are made with CLO3D [21] using an Alvanon Avatar [26]. All virtual representations of the skirt are based on the same pattern. Figure 4 shows the skirt pattern simulated without correct mechanical properties.

Figure 4: Virtual skirt simulated without the fabric physical and mechanical properties.

Figure 5 and 6 show the same skirt pattern on the same avatar simulated with measured fabric's mechanical properties, Figure 5 shows a 192 g/m^2 100% CO gabardine and Figure 6 a 259 g/m^2 65%AC, 32% PA, 3%EL.

Figure 5: Virtual skirt simulated with the fabric physical and mechanical properties.

Figure 6: Virtual skirt simulated with the fabric physical and mechanical properties.

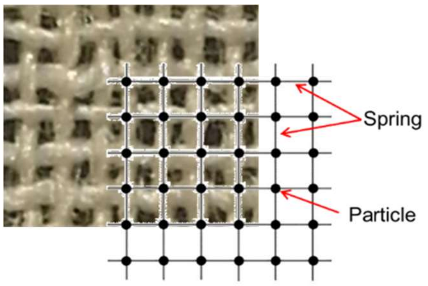
The differences between the simulated skirts in Figure 4, 5 and 6 illustrate the importance for accurate fabric properties to enable the fitting process. Figure 4 illustrates how easily a virtual sample might be approved based on the virtual fit. This is misleading, since there is no relation with a real fabric. The virtual cotton skirt in figure 5 shows buckles and might need pattern adjustments to get the appropriate fit. The heavier and stretchable material used in 6 might need minor pattern adjustments. Besides offering a tool for assessing the fit of a garment, the correct virtual visualisation of the fabrics makes it possible to see how a product will look like in different fabrics.

Precise material properties play a very important role, since only they can guarantee the technical and aesthetical "feasibility" of a new garment [6]. For a successful performance of 3D product development, a seamless highly accurate and reliable interaction between virtual bodies, fabrics and patterns is required [27].

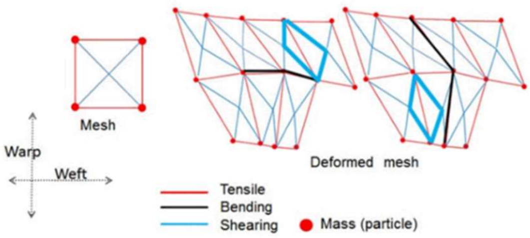
3.4 Translation into a particle mesh

Physical fabric swatches usually come with information on care instructions, information on properties as weight, composition, width, stretch, colour, weave/knit, yarn count or gauge. Additionally, more technical data can be provided. This may include information on dimensional stability, pilling resistance and stretchability. Usually this is measured using standard testing procedures from ISO, ASTM, NEN, BS.

Fabric simulation is based on weight and the values of bending; shear; tensile or elongation. The value of thickness (compression) is required as an optical characteristic which facilitates accurate visualisation. In the virtual fabric the measurements are translated into a mesh with particles and springs as illustrated in Figure 7.



a



b

Figure 7: Translation of physical fabric parameters into a particle mesh [28].

A value for friction is necessary to represent the fabrics behaviour in relation to other materials or the human skin. Most 3D software suppliers set a default value for friction. The bending property is used to let the virtual fabric bend. It is an important property to express the stiffness of the material. The tensile or elongation is the warp and weft stretch in the material, the shear represents the bias stretch (figure 7b). Virtual garments also have options to show fit maps, such as stress and strain maps which give additional insight in the behaviour of the fabric and how this relates to fit. (Figure 8)

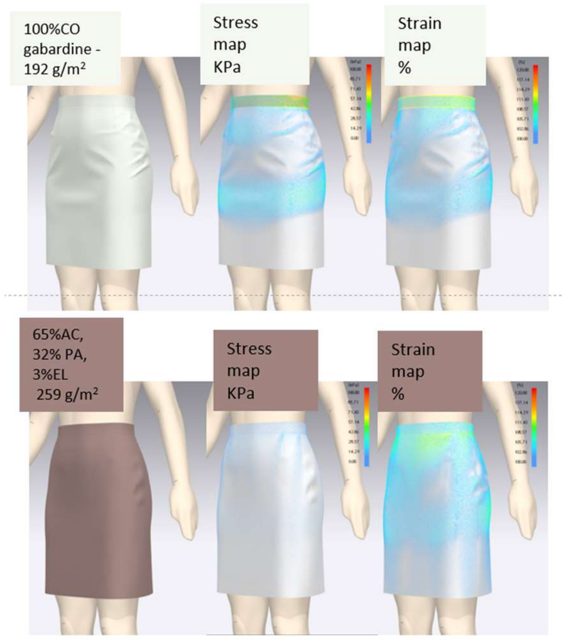


Figure 8: Simulated results with stress and strain maps for a skirt in different fabrics.

3.5 Measuring properties

Most of the required properties can be measured with regular instruments often already used in fabric testing labs. Devices developed by independent companies, like James Heal [29], Mark 10 [30], Instron [31], ZwickRoell [32] or SD Atlas [33], are preferred above the software dependent instruments and kits [7].

This section gives an overview of the required properties and the measurement methods. Appendix 1 provides an overview of the standards to use or to develop.

3.5.1 Weight in g/m2

Weight obtained with a scientific scale standard.

The weight in g/m2 given by the fabric manufacturer can be used in almost all 3D apparel software. CLO3D uses an approach based on the fabric specimen prepared for the testing.

Action for the apparel industry: Request CLO3D to facilitate inserting standard fabric weight in g/m^2 in their software.

A conversion for fabric weight for CLO3D can be found in appendix 2.

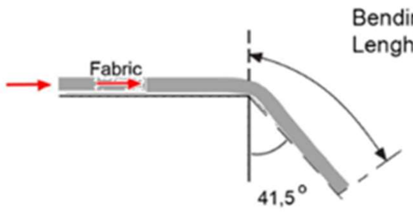
3.5.2 Bending

The bending length measurement is used to calculate rigidity.

How the fabric bends, Cantilever principle.

Suitable for most 3D apparel software configurations. Required: bending length (Figure 9a) and bending rigidity. Fabric Stiffness Tester (FST): Manual measurement of bending length and calculation of flexible rigidity. For example, SD Atlas (Figure 9b).

Fabric Assurance by Simple Testing FAST2: Automated measurement of bending length and calculation of flexible rigidity (Figure 9c).



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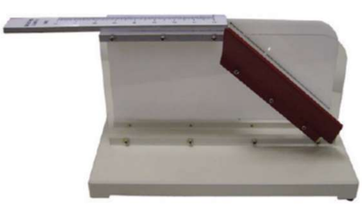


b

c

Figure 9: Cantilever bending: (a) principle, (b) FST source SD ATLAS, (c) FAST2 bending test source: AMFI [34].

Exceptions:

CLO3D measures the bending slightly different to the cantilever method and they do not follow the standard [7] With some adjustments it is possible to obtain the bending with a regular cantilever device [18].

Browzwear uses another method which is not according the cantilever principle [7]. There is not enough information on the used method available to convert the measurement data [18].

Actions for the apparel industry:

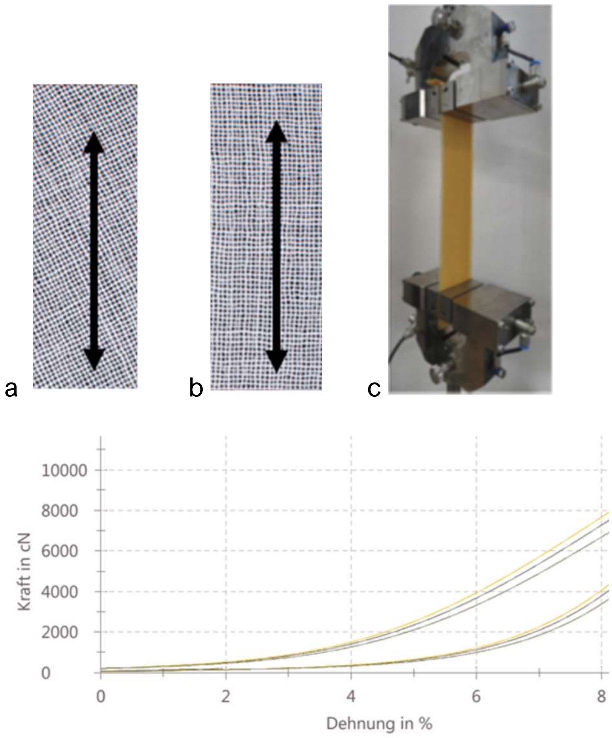
- Request from CLO3D to add the possibility to insert bending length measured according the standard into their software.
- Request from Browzwear to add the possibility to insert bending length measured according the standard into their software.
- General request: Bending rigidity or flexible rigidity could be calculated in the software programs.

3.5.3 Tensile and shear

The elongation or stretch in relation to force.

The measurement needed is extension of the fabric by applying a low force, for which no standard test method is available yet. Future standards can be built on the standard procedures (appendix 1) which are already used in the industry [7].

Testing can be done using regular tensile test equipment, on a warp and weft specimen to obtain the elongation/force curve. The shear or bias stretch is calculated from the bias extension (Figure 10).



d

Figure 10: Tensile and shear elongation in (a) warp and (b) bias direction (c) ZwickRoell tensile test device and (d) elongation/force curve.

Input data for 3D software can be taken from the elongation/force curve (stress-strain curve), as Anja Sick from Hugo Boss explained during her presentation at the Future of Fabrics Roundtable Webinar [35]. This is also illustrated in the work of the 3DRC Innovation Committee [18].

3.5.4 Compression or thickness

This property is not used to simulate the fabric, thickness in mm is required for a realistic optical visualisation of the fabric.

The various 3D software uses different methods to obtain thickness. Since this is currently only used optically and not for simulation, this is not a problem [18]. In our opinion, when software will take this into consideration, more precise measurements are needed. To achieve accuracy and measurement precision we recommend standard testing with a more robust lab device as for example a thickness-gauge-d-2000. Additionally, it might be worth discussing with the testing equipment producers if an ad-on for a tensile test device is possible.

3.5.5 Friction

Friction is ignored in most 3D apparel software programs, where it is set to a default value which can be manually adjusted. Considering the friction interaction in real garments between the fabric itself, different fabrics, or the skin and the fabric, it could be considered an important property for a realistic simulation of fabrics and garments. In case 3D apparel software would be able to apply friction properly, its measurement can be built on existing standards for plastic film and sheeting. See recommendations in appendix 1 and the standardised tests executed at ZwickRoell with fabrics and leather to replace the skin [7]. With additional tools, the tests can be done with a regular tensile tester.

Need for standard test methods of textiles:

- Elongation or stretch in relation to force
- Thickness (compression)
- Friction

3.6 Optical fabric texture maps

The mechanical and physical properties represent the behaviour and drape of the fabric. The Optical characteristics play also another important role in creating the virtual twin: They visualise the print, texture and structure of the material. Next to a clear scan or photograph of the fabric, several maps are needed to create realistic renderings. In addition, tiling functions are essential for a good visualisation of the fabric. Table 1 lists and explains the function of the different maps.

Table 1: Optical texture maps

Map	Function
Base colour texture	Photograph or scan of the material, base to create the other maps and contains the colour and texture of the material. (Also Albedo)
Normal	Based on red, green and blue the normal map creates bump in the simulation
Displacement	For the depth in the rendering (in addition to the normal map).
Roughness	Created based on the roughness of a surface (matt vs gloss) sharpness of reflection. Sometimes gloss (works the opposite).
Specular/Metalness	Amount of shininess or lustre, reflection. Specular is slightly more accurate (more information). Metalness has a much smaller file size (only black and white) and is sufficient for most cases [36].
AO ambient occlusion	Usually blended with the metalness map or specular map

File format is png (for transparent fabrics, mesh, lace, etc) or jpg
After creating the maps, a tiling function needs to be used to get a seamless result.

Eventually these maps can be realised based on a good quality scan, created in Adobe Photoshop, or generated by PixPlant [37]or cpetry.Github [38]. Adobe Photoshop and PixPlant also have tiling options. A more professional result can be obtained in an automated and faster process with Vizoo [39], consisting of a box with a camera on top to capture the material, the connected xTex^{tm} software creates the maps automatically and has various options for seamless tiling (Figure 11), as well as to recolour multicolour materials. Vizoo also has a scanning or renting service.

Another instrument to capture the fabric's visual characteristics is the TAC7 Scanner or the X-Rite scanning Service.
The data is stored in the AxF format. The format is also supported by e.g., Optitex and Gerber. Physical material samples are scanned to measure and create highly realistic and accurate digital materials specifications in AxF format. Alternatively, existing AxF files can be accessed from digital material catalogues such as the PantoneLIVE Cloud. AxF files can be centrally stored and distributed to other software applications [40].

In addition, more solutions to capture the visual maps are planning to enter the market.

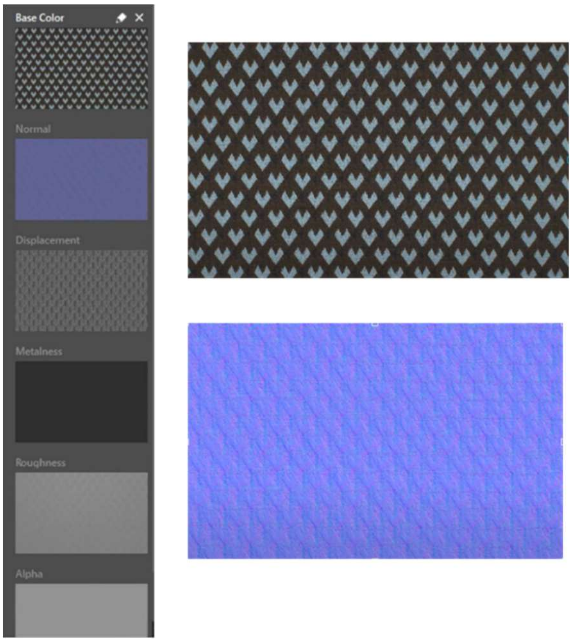


Figure 11: Vizoo maps output and larger example of the Base colour and Normal map

3.7 Sharing data

The process of fabric digitisation should be supported by a standardised means of sharing the data. The industry will not benefit from different file formats and the possible need for conversions

Currently only data measured by Browzwear's Fabric Analyzer (FAB) and Vizoo is stored in the U3M format [41] and used for material simulation. The format is also supported by e.g., Optitex and Assyst.

Another file format for storing data is the AxF format from Xrite. The format is also supported by e.g., Optitex and Gerber [40].

> An open-source file format will contribute to the accessibility of the technology and will accelerate the development in the textile industry.

3.7 Involvement of stakeholders

Industry wide implementation of 3D virtual product creation involves various disciplines and expertise. The stakeholder group involves also less traditional actors. YKK cooperates with Browzwear and Optitex to enable designers and product developers to integrate YKK fastening products in their 3D digital garments and experiment with them in their designs. The specifications of the used zippers can easily be tracked during later in the process, thus reducing production errors [42] [43].

New business models arise such as the earlier mentioned digital showrooms developers, or companies like the Diigitals [44] introducing new virtual marketing Avatars like Shudu. To facilitate accurate fit, companies such as Alvanon [26], create reliable Avatars based on size survey data. To make this transformation successful, we also need accurate fabric data. As illustrated in the fitting examples, this will enable accurate fitting (Figure 5 and 6). The textile industry is an important stakeholder and knowledge partner in the digitalisation of the industry. This part of the supply chain will also benefit from this development: Replacing a physical sample by a virtual sample will reduce costs, time and the environmental impact.

Using accurate virtual fabric swatches, based on physical fabric properties, (Figure 3) designers can select fabrics, without ordering sample material. Ideally, the sample material has no need to exist in this stage. With this virtual fabric, it is possible to design, redesign and fit the garment (Figure 5 and 6). Another part of the development process, designing fabrics, prints and artworks, will benefit in the same manner. Sourcing in general, handlooms, strike offs and print recolorations can all be done digitally.

The textile and apparel industry needs to involve all stakeholders, a wide collaboration and acceptance is needed for a successful and efficient implementation.

Key Stakeholders:

- Apparel industry
- Textile industry
- 3D Software suppliers
- Testing equipment manufacturers
- Test labs
- Digitisation hubs
- Industry Associations
- Standard committees/Bodies

4 Round Table discussion

The Round Table discussion was held November 11th, 2020, organised by IAF and Modint and Powered by CLICKNL in the context of the Dutch textiles and clothing innovation network NL NextFashion and Textiles.

The involvement of the textile industry will make or break the digital transition. Simeon Nachev, Value Chain Manager at Lenzing explains how they consolidate digital initiatives in their services.

Lenzing uses blockchain technology to support its TENCEL™ branded fibre business, ensuring complete transparency and traceability for brands and consumers of its fibres in the finished garment. The TextileGenesis™ platform allows digitization and traceability of any textile asset fibre, yarn, fabric, or garment through Fibercoins™. Simeon agrees that, without substantial involvement of the textile manufacturers, a big part of the supply chain is missing and would like to join the mission. Lenzing's digital certification services facilitate inserting a variety of information about the material. This could include properties needed to simulate fabrics. It will be amazing to use technology to stop sending sample fabric and garments around the planet. It will save a lot of transport costs and more.

The need for accurate physical properties discussed in 3.3 Importance of accurate representation is confirmed by Anja Sick who refers to research done by BA students at Hugo Boss. This research showed that physical properties make a big difference for the result of the simulation and illustrated how accurate a digital sample represents a physical sample.

According to Anja Sick if the fabric testing is done at the fabric mills and test labs, results will be more consistent. The mills and test labs use industry standard instruments to measure the properties. Labs do not need to make extra investments. She encourages the fabric suppliers to start preparing, so their companies become digital ready. If we use those standard devices there is no need to test a fabric twice if you sell the same fabric to Hugo Boss and to PVH for example.

Within the 3DRC innovation committee. Anja Sick is working on a standard operation procedure for testing (SOP). At the moment of the publication of this paper, the expected publication is in Q2 2021.

Further, Anja points out the U3M format (developed by Browzwear and Vizoo – ed.) in which all the fabric data is combined. The fabric mill can insert the optical and physical properties and a fashion brand can drag and drop this data on their virtual garment.

Ton Wiedenhoff (Alvanon) confirms the importance and complexity of the seamless interaction between the avatar and material we discussed in section 3.3. He also adds that the positioning of the garment on the body is key in this interaction. This should be standardised and proceeded according alignment points. Currently this is randomly decided by the software. Currently the end users are digitizing fabrics, but Ton points out that the fabric mills should play the ball there.

Moreover, Ton stresses the importance of standardisation in the 3D virtual creation area on fabric properties, avatars and more. Currently a lot of parties are working on this, he is convinced that this needs to be globally addressed and sees IAF as a powerful initiator.

Puck Martens explains that as a digital designer, they experience time consuming trial and error processes, especially when working with traditional companies. Transparency and collaboration are key words for the future, she explains.

Miriam Geelhoed (Modint): 'In practice, we see that costs, unfamiliarity with the topic and the lack of skilled people influences the pace of the implementation in our industry. With the Digital Fabric Roadmap, we aim to pinpoint concrete steps for the different actors in the chain, so more companies can profit from this important development.'

Matthijs Crietee (IAF): 'standardisation is one of the most important preconditions for rolling this out to the textile industry. Fabric mills don't have to test the fabrics twice in a similar way. IAF will work closely with its sister federation, ITMF (International Textile Manufacturers Federation) on this topic

5 Conclusion

5.1 Digital Fabric Roadmap

Digitisation of the textile industry is a crucial stage in the product development process, which is slowing down the digitisation process of the apparel industry going mainstream.

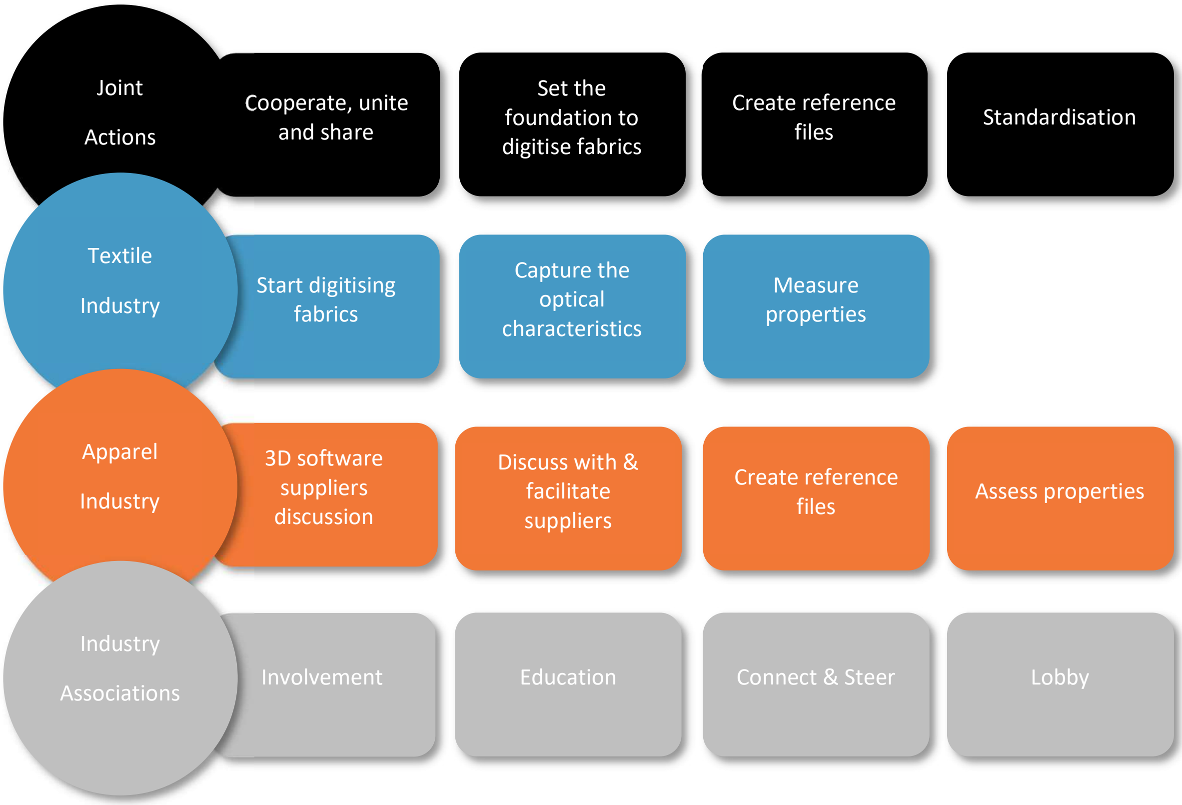
Companies and academia united in 3DRC innovation committee worked together on uniformity of fabric measurement. The measurement systems, how and what is measured were critically reviewed. Interoperability between the different ways of measuring were investigated and are now being translated into a Standard Operating Procedure (SOP) for delivering information about fabrics in a uniform way so that all the software platforms can use it to create the best possible digital representation of a garment. This document is a large step in the right direction. Currently the correct digitisation of fabrics presents the main barrier on the quest to the ‘authentic digital garment’.

What is needed right now is alignment between the different actors in the supply chain, standardised testing methods, research for additional methods, education and uniform implementation by the stakeholders of the outcomes. This is needed to create a universal system for measuring, calculating and precise data. The 3D software suppliers need to develop their systems to be compatible with this data. The compatibility should include input as well as the expected output.

In short:

What the industry needs is a workable standardised set of data, which can be shared in an open-source file format, which will be accepted uniformly by all software systems, who will interpret the data, so that the differences in outcomes between systems are negligible.

We designed this roadmap to enable the industry to set the first next steps, anticipate on the further process and create an opening for global discussions and collaboration. The roadmap has been divided in specific action points for specific industry actors, but also shows the joint actions.



5.2 Joint actions for the textile and apparel industry:

Cooperate, unite, share:

Be clear with your supply chain partners on your ambitions and work together to achieve the goals. Share as much knowledge, data and resources. Explore the possibilities of setting up and sharing testing hubs, which can be used by multiple companies. Share fabric data within the supply chain. Share this Digital Fabric roadmap and other information with your supply chain partners:

- Digital Fabric Physics Interoperability 3DRC Innovation Sub Committee, 2020, published at Kalypso, Pierson, S., Greenhouse, M., Sick, A., Okazaki, C., Johnson, Y., Croneberger, E., Young, J., Goodwin, P., Bakhoum, M., Camarda, G., and Sahoo, A. [18]
- The measurement of fabric properties for virtual simulation – a critical review, published at IEEE 2020, Kuijpers, A.A.M., Luible-Bär, C. and Gong, R.H. [7]
- The SOP t/b published by the 3DRC committee in Q2 2021

Start setting the foundation for organising the fabric data:

Create a digital library of your fabrics and include as much information which is already present. Start with setting up a dataset with all the attributes relevant for the fabrics. Make sure to do this in a way that you can easily create overviews of missing information.

Create reference files of real versus virtual swatches:

Link the physical swatches to the library and digital swatches. This information should be shared between the textile and apparel industry.

Develop standard test methods and testing equipment:

Determine which standard test methods can be used and develop new methods when needed. The focus should be on inexpensive and easy to implement methods, preferably using existing testing equipment. Suppliers of testing equipment should be involved in this process.

5.3 The Roadmap for the textile industry:

Start digitizing fabrics:

Start with basic fabrics, for example carry over and never out of stock.

Capture the optical characteristics:

This can be done with Vizoo [39] or similar. Again, do explore the possibilities of sharing equipment or outsourcing this task.

Measure the fabric’s mechanical properties:

This should be done as accurate as possible. When performing in house testing, make sure the testing equipment is calibrated and maintained and the operators are trained. Testing should be done under standard atmosphere conditions [45]. Inform your customers which fabrics are available in your digital fabric library.

5.4 The Roadmap for the apparel industry:

Discussion with 3D software suppliers:

To make sure standardisation will be adopted industry wide, it is needed that 3D software can work with of bending measurements obtained with a cantilever according the standard. Also, there is a need for a user-friendly solution for the different stretch data.

Discuss and facilitate:

Discuss with your supplier your need to have fabric mechanical measurement and optical capturing done at the mills, testing labs and/or digitisation hubs. Communicate clearly what you need and help your supplier in search of solutions.

Create reference files of real versus virtual garments:

By comparing real and virtual garments, you will be able to see if the digital representation is accurate. Start with basic garments, for example carry over or never out of stock items. Start as soon as you get data from your supplier, so alterations to the process can be done as soon as possible.

Assess tested fabric properties on accurate simulation:

Using your reference files of real versus virtual garments, check if all tested fabric properties and characteristics are simulated accurately. Discuss the results with your supplier and adjust the process when necessary.

5.5 The Roadmap for industry associations

Involvement:

Get involved with leading brands and retailers to understand the current set of standards, to communicate these with members and to structurally feedback from companies requests for additions and modifications to these standards.

Educate:

Organise meetings and trainings to educate members on digitization and to stimulate them to get started, with an emphasis on creating digital libraries.

Connect & Steering:

The apparel associations need to continue to seek out the connection with the textile industry and vice versa. They need to connect to the different stakeholders, keep a sharp view on upcoming needs and provide steering for the actors in the chain.

Lobby:

To communicate with governments that digitization is the most crucial element of a necessary industry transformation requiring all the available support.

5.6 What next?

From Digital Fabric Roadmap to Digital Twin

In this case, the digital twin is a virtual representation of a product. This can be a garment, fabric or even a trim.

What will the ideal future look like?

Standardised test procedures and fabric testing instruments are available and accessible withing the supply chain. The measurement of the fabric's mechanical properties and optical capturing is done at the fabric mills, testing labs or in digitisation hubs. Garment buyers will specify their communication protocol in their supplier manual, so their suppliers can supply the relevant information. Digital fabric fairs will be truly digital, including virtual swatches. Designers will be able to create with digital content and the fitting process will be supported by avatars representing their customers. B2B sales will be done using digital samples. Daring companies will start presale selling to consumers with virtual products.

To achieve this, transparency and cooperation will be key. With this paper we aim to have contributed to the Fabric of the Future.

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Appendix 1

Standards for testing the fabric's mechanical and physical properties

Fabric property	Standard	
ALL	ISO 139:2005 (en).	Textiles — Standard atmospheres for conditioning and testing
Weight g/m2	EN 12127:1997 (en)	Textiles - Fabrics - Determination of mass per unit area using small samples
Bending length & Bending rigidity	BS 3356:1990	Method for determination of bending length and flexural rigidity of fabrics
	ASTM D1388-96 (2002)	Standard Test Method for Stiffness of Fabrics
Tensile elongation under force & Shear bias elongation under force	Not available yet	Follow the SOP of the 3DRC to be published in Q2 2021
	Build on EN ISO 13934-1	Tensile properties of fabrics - strip method
	Build on EN ISO 14704-1	Determination of the elasticity of fabrics
	Build on ISO 20932-1:2018	Determination of the elasticity of fabrics
	Build on DIN 53835-13	Testing of textiles; determination of the elastic behaviour of textile fabrics by a single application of tensile load between constant extension limits
Compression/thickness	ISO 5084: 1996	Textiles—Determination of thickness of textiles and textile products.
	ASTM D1777-96	Standard Test Method for Thickness of Textile Materials
Friction	Build on ASTM D1894-14	Standard Test Method for Static and Kinetic Coefficients of Friction of Plastic Film and Sheeting
	Build on ISO 8295:1995	Plastics—Film and sheeting—Determination of the coefficients of friction.

Appendix 2

Conversion for CLO3D users converting standard textile weight to the weight CLO needed for the CLO3d software.

Select in the fabric emulator of the software: size Width/Height (mm) 220 x 30.

Conversion of the standard given textile weight in g/m^2:

With 3 fabric specimen of 220 mm X 30 mm the total area is 220 mm X 90 mm = 19800 mm^2

or 0.0198 m^2

Standard textile weight in g/m^2 multiplied by the total specimen area, CLO3D uses to measure the weight:

Weight in g/m^2 x 0.0198 = weight value for CLO3D

Contributors

The International Apparel Federation (IAF) is the world's leading federation for apparel manufacturers, (SME) brands, their associations, and the supporting industry. IAF's membership now includes apparel associations and companies from more than 40 countries, a membership that directly and indirectly represents over a hundred thousand companies and over 20 million employees. IAF brings its members together to jointly create stronger, smarter and more sustainable supply chains, it provides its members with valuable information and guidance and it represents its members on several international platforms working incessantly on more industry standardisation and harmonisation, industry collaboration and inclusiveness of solutions.

Modint is the Dutch trade organisation for the garment and textile industry, counting over 400 members, including manufacturers, importers, agents, dealers and brands. Its members operate in fashion, accessories, carpet and (interior) textiles. Modint supports its members collectively and individually by supporting entrepreneurship, sustainable development and technical expertise. Internationally, Modint participates and cooperates in many industry initiatives.

CLICKNL is an initiative for creative professionals and enterprising researchers. The creative industry is a driver of innovation. It delivers human-oriented solutions for societal challenges. To be able to continue to deliver that impact, CLICKNL, Top Consortium of the top sector Creative Industry, wants to enhance the creative professional's knowledge base. In doing so, we strengthen the sector and the innovative capacity of the Netherlands. To that end, CLICKNL, together with experts from the creative industry and knowledge institutions, is drafting the Knowledge and Innovation Agenda for the Creative Industry. This agenda outlines what knowledge is needed to prepare the creative professional for the future and to which issues the professional can and must contribute.

Simeon Nachev – Value Chain manager - Lenzing AG

Lenzing AG is the world's leading producer of wood based cellulosic fibres. Simeon is responsible for making the Business & Supply Chain of Lenzing ready to adapt to the new international business "norm" – Disruption.

It will be amazing to use technology to stop sending sample fabric and garments around the planet. It will save a lot of transport costs and more.

Simeon holds hold a MSc in International Trade & numerous certifications for Project and Lean Management. With a more than a decade experience in supply management, he has led many Transformation Projects ultimately leading to lowering costs, attracting new customers, delivering exemplary customer service and resolving a wide range business and process issues. Throughout the years I managed to successfully combine my IT savviness, strong business acumens and visions for the future, turning me into a true Digitalization "frontrunner".

The positioning of the garment on the body is key to interaction. It needs to be standardised, also the alignment points. At this moment, end users are digitizing fabrics, the fabric mills should play theis ball.

Ton Wiedenhoff – Executive Director, Europe - Alvanon

About Alvanon: We are an innovation company, focused on the body. We are the science behind the art of fit. Alvanon employs the latest technology and body shape data along with deep industry knowledge. We advise brands on optimum fit & sizing strategies. We provide education, workshops and an on-line learning platform to help close the skills gap on how to execute fit consistently internally and across the supply chain (incubated Motif.org)

Sandra Kuijpers – MPhil (UoM) - Teacher/Researcher AMFI

Preparing for a PhD to scale fabric digitalisation. Interests: trustworthy virtual fitting through accurate translating of physical into digital material; prepare students for future positions.

From 1990-2003 Sandra led the transfer from manual into digital pattern drawing managing CAD-CAM departments at DP&DB and Articles. After working for Hugo Boss in Germany Sandra left the fashion industry to teach digital pattern drawing at the Amsterdam Fashion Institute. Sandra researches 3D virtual prototyping since 2007, which she teaches since 2009 and the creation of digital textiles since 2016. Sandra holds a Master of Philosophy (MPhil) from the University of Manchester, where she researched the correlation between physical and virtual fabric drapes created from objective fabric properties. Sandra published work and has presented in various events on this topic such as Product Innovation Apparel. As part of the Fashion Research and Technology group she is preparing for a PhD to scale fabric digitalisation and further define this part of the textile area. Interests: trustworthy virtual fitting through accurate translating of physical into digital material; prepare students for future positions.

Using digitized fabrics is a very exciting new field in the textile industry and I enjoy working on this topic with other companies worldwide to enable our suppliers to provide us with the necessary information.

Anja Sick – Team Leader Materials Quality Fabrics – Hugo Boss

Anja studied Textile Technology at Reutlingen University. After having worked in spinning and weaving mills, she started working at Hugo Boss 15 years ago as technical responsible for the physical laboratory in Hugo Boss. Anja is also a member of an ISO working group for the standardization of physical textile testing. Since Hugo Boss was investing very much in digital development of garments during the last years, its lab was involved in implementing the testing methods needed for 3D virtualization.

Puck Martens – Studio PMS

Studio PMS is a digital fashion collective that strives for a more sustainable & innovative fashion industry. We work on interdisciplinary projects and collaborations using 3D modelling, virtual reality, animations and augmented reality. As a digital consultant and a creative studio, we collaborate with established brands and explore the possibilities and purposes that digital fashion can have. We believe in bridging the gap between physical and virtual.

Digital designers experience time consuming trial and error processes, especially when working with traditional companies. Transparency and collaboration are key words for the future.

The Digital Fabrics Roadmap aims to act as a catalyst for a global and industry-wide collaboration to accelerate 3D virtual visualiszation.

Mattijs Crietee – Secretary General – IAF

Matthijs has a Masters degree in International Economics and Economic Geography and is the Secretary General of the International Apparel Federation (IAF). The IAF now represents the interests of apparel industry associations representing in turn over 60 countries on all continents in the international arena. Before he joined the IAF in 2012, Matthijs was deputy director of the Dutch fashion industry association MODINT during which time he built up an important part of MODINT's consultancy activities.

Miriam Geelhoed – Consultant - Modint

Miriam is a graduate of AMFI and has been working in the apparel and textile industry in both the technical and commercial field. She also worked in the IT industry for six years as a software consultant, implementing both e-commerce and data applications. At Modint, Miriam is a consultant working on product compliance, innovation, quality and sustainability.

Modint has a unique position. Our member base represents all stakeholders involved. The Roadmap provides clear steps for our members and us. The shift will be beneficial for our planet and the companies.

Authors:

A.A.M. Kuijpers (Fashion Research & Technology Group, Amsterdam University of Applied Sciences)
M.W. Geelhoed (Modint)
M.A. Crietee (IAF)
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