DEUTSCHE INSTITUTE FÜR
TEXTIL+FASERFORSCHUNG

WHITE PAPER -

# TEXTILE MICROFACTORY AND DISTRIBUTED PRODUCTION – DIGITALISATION AS A GAME CHANGER FOR BACKSHIFTING

A RESPONSE TO CHANGING ENVIRONMENT AND CONSUMERS.
WHY TEXTILE MICROFACTORIES AND DIGITALISATION WILL CHANGE THE FUTURE OF TEXTILES

Dipl. – Kfm. Alexander Artschwager
Dr. rer. pol. Marcus Winkler
Lucie Brunner B.Sc.

DITF.de

# Executive Summary

This White Paper highlights a set of implications of the assumed shift from centralized mass production to a distributed textile Microfactory model across Europe, through the demonstration of already existing structures as well as trends like regional distributed production, sustainability, individualisation, digitalisation and automation technologies within the textile- and clothing industry (TCI). Distributed production within regional networks, as well as the digital fabrication, which are addressed in this paper, enable to deploy their potential in the small-scale manufacturing field, scalable and on-demand production.

Furthermore, the objective of this paper is to show the future of manufacturing, in terms of business models, customers, (organisational) structures and used technologies. Especially, customers expect high-quality and functional items, and in addition, there is a strong trend towards individualisation in sustainable products. In this way, products are specifically adapted to the individual customer demands. There are different customization applications, such as made-to-measure products, personalised designs and colours or labelling. But it is also assumed that sustainable products will be considered as a standard by the next decade. The trend towards individualisation, personalisation and sustainability is already leading to develop customer-oriented value chains, as well as to structures that create new opportunities through end-to-end digitalisation.

The trend to individualisation and sustainability leads to decreasing lot-sizes, customisation with regards to morphology, size and fit, colour, style as well as design. Subsequently, local production is an ecological possibility, due to economic priorities. As mentioned, there are different drivers aiming at the production of small batch sizes, reduction of the time-to-market as well as at local productions. This includes, on the one hand new business processes and models, and on the other hand a number of new technologies, like for example virtual garment simulations, digital textile printing, automated cutting technologies and networked manufacturing.

To highlight this aspect of the change process there are highlighted four use cases of the companies: Assyst, ErgoSoft, Mitwill and Zünd, showing innovative technology opportunities, which are inalienable for the textile future. These technologies are important milestones, supporting not only textile Microfactories, but also distributed creative networks within Europe.

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Authors Dipl. – Kfm. Alexander Artschwager
Dr. rer. pol. Marcus Winkler
Lucie Brunner B.Sc.
Layout Zünd Systemtechnik AG

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# 1 Introduction

Within the last decades, the textile and clothing industry (TCI) had to face high labour and production costs, poorly calculable procurement prices as well as increased legal framework conditions. Under the influence of these aspects, most European companies of the TCI developed new strategies, such as automation and flexibility, in order to achieve faster and more efficient production.

Currently, textile supply chains are still structured both local and global, and they are constantly transformed in order to remain competitive, as adaptability and speed of reaction are particularly necessary in the fashion industry. Furthermore, the industry is increasingly affected by changes in demand towards individualisation, Industry 4.0 and digitalisation options along the value chain. Besides the options of Industry 4.0, which support the as well the trends of individualisation and personalisation, big data as well as circular economy and sustainable developments. Especially the digital transformation enables new approaches for opening up new processes, new production scenarios and new business models. Furthermore, there are companies shifting to niche markets such as technical textiles to circumvent low price competition (Winkler et al. (2019) and Winkler/ Tilebein (2019)).

Additionally, the mass production of textile goods has been detected as being highly responsible for negative environmental impact, within the last decades. On the one hand, institutions and policy makers are pushing companies to switch to circular economy, but on the other hand there are new studies showing that recycling alone can't solve all problems; it seems to work only if the amount of textile and clothing production decreases. Therefore, digital fabrication builds a driving force to adress theses issues. This nascent approach is showing that high quality, sustainable, affordable and long-lasting textiles can be realized through the setup of new business processes and models focusing on local manufacturing, high-tech, as well as on-demand products. There are already a number of different possibilities to enable new forms of local production, such as Microfactories, FabLabs, Hackerspaces, Makerspaces as well as the TCBL Foundation (TCBL (2021)).

This paper highlights a set of implications of the assumed shift from centralized mass production to a distributed regional production within Europe, through the demonstration of already existing structures as well as digitalisation and automation technologies within the TCI. In addition, current trends such as sustainability, personalisation and digitalisation are described in order to draw attention to the associated challenges and consequently provide possible responses through case studies, showing already existing technologies. Overall, the objective of this paper is to show the future of manufacturing, in terms of business models, customer orientation, structures and technologies, as well as the potential in the small-scale manufacturing field, scalable production and on-demand production.

# 2 Global Trends for Textile and Clothing Industry

In general, there is a variety of global trends concerning the Textile and Clothing Industry (TCI). However, the most important trends described in this paper are regional distributed production, sustainability, demographical change and technology, which will be described in a nutshell in the following chapters.

### 2.1. Regional Distributed Production and Urban Production

> There are several examples for clusters, like the Italian leather fashion cluster, which consists of shoe companies, suppliers of footwear components, machinery, models, design services, as well as tanned leather. Additionally, there is another cluster for textile fashion. A big advantage of these clusters is the multiple linkages, synergies and trust grown over a long period of time (Porter (1998)).

However, the fast aging of the global population effects increasing pressure and demand, especially in urban areas. Consequently, both, the young declining population as well as growing elder population will have influence on economic, social and environmental urban development. As technology will be important to improve quality of life in cities, future challenges will also be defined by people's values, behaviour and demands (ESPAS (2018)).

The European Union belongs to one of the most urbanized regions in the world (ESPAS (2018)). London, Paris, Amsterdam, Stockholm, and Berlin are at the head of a physically and digitally connected, knowledge-based world (ESPAS (2018)).

Here regional production can offer various business opportunities. Whether lifestyle objects, clothing or furniture-manufactories in the city produce high-quality, design-oriented products and they are seen as pioneers who are reclaiming urban spaces as production locations (Zukunftsinstitut (2021)). Anyway, transitions back to an industrial area in consequence will not likely happen overnight even with fantastic new technology or hole-proof business models for material re-valuation (Cities of Making (2017)). This needs time, enthusiasm and realistic and clear concepts for production supported by digital services.

Furthermore, several networking organizations, as for example the Sourcebook based Matching platform in Berlin, are connecting different actors of the TCI, with the goal to support and generate regional production structures. The aim of these networks using platforms that connect designers, producers and sales agencies with the focus is on sustainable structures and circularity (e.g. Sqetch (2021)).

### 2.2. Sustainability

> Among other things, greenhouse gas emissions from upstream activities could be minimised through innovative design technologies, as well as modern cutting techniques, as this would help to reduce waste (Berg et al. (2020)).
>
> Furthermore, 39 million tonnes of greenhouse gas emissions could already be saved through the use of sustainable transport and the integration of digitalisation and demand-focused regional supply chains, as well as nearshoring (Berg et al. (2020)).

The topic of sustainability is already known as a so called 'mega trend'. Therefore, it is assumed that sustainable products will be considered as a standard by ten years from now. Moreover, there are increasing demands for western societies to change their lifestyles (Zukunftsinstitut (2021)).

A McKinsey study shows that around 2.1 billion tonnes of GHG emissions were generated in the global fashion industry in 2018. In this context, 70% of the emissions from the fashion industry are generated by upstream activities, such as the production of materials, manufacturing, preparations and processing. The remaining 30% were found to be related to downstream transport, packaging, retail, the use phase, and end-of-use activities. If no further action is taken in the future, greenhouse gas emissions from the fashion industry are expected to increase to 2.7 billion tonnes per year by 2030 and to 2.1 billion tones under the current pace, which would miss the 1.5-degree pathway by 50%. However, there is also the possibility of minimising the GHG Footprint to half the current level in the next 10 years (Berg et al. (2020)).

Finally, it would be possible to save 158 million tonnes by reducing overproduction, for example through demand forecasting or on-demand production. In addition to the goal of reducing negative environmental impacts, improving working conditions are considered, which includes higher wages, no forced labour, appropriate working hours and occupational safety (Fifka (2018)).



### 2.3. Change of Customer Demands and Demography – Individualisation

> Chris Anderson described this phenomenon in his book The Long Tail: "an increased shift away from mainstream products and markets at the head of the demand curve, replaced by a gravitation toward multiple, ever-expanding niches that constitute the curve's long tail." (Hagel et al. (2015))

One of the main challenges of European cities is the growing population as well as the fast-ageing process. Nowadays, customers are spoilt by multi-channel shopping as it includes an ever-increasing range of products and makes any products available at anytime and anywhere.

Accordingly, customers expect high-quality, functional and even interactive items, and in addition, there is a growing trend towards individualisation. In this way, products are specifically adapted to the individual customer demands (Moltenbrey/Tilebein (2020)). There are different customization applications, such as made-to-measure products, personalised designs and colours or labelling. In the recent years, more and more companies around the world have focused on made-to-measure clothing. Companies such as Bivolino, Levis Strauss & Co. or Citizen Wolf Pty. Ltd. already offer customised clothing. There are various supporting made-to-measure technologies, such as 3D body scanning that have been developed and integrated into the made-to-measure process to determine individual body measurements and optimise the fit (Anderson et al. (2018)).

Since there is the problem, that 30% percent of population doesn't fit into standard sizes, based on internal evaluations (Avalution (2021)). Consequently, the return rate is between 25 and 50 percent, with 89 percent being due to fit problems.

The trend towards individualisation and personalisation is already leading to develop customer-oriented value chains, as well as to structures that create new opportunities through end-to-end digitalisation (Winkler et al. (2019)).

Subsequently, digital technologies used via the Internet, make personalization and customization possible to a wide range of customers. Following this, tailored products for niche markets are becoming increasingly available, raising consumers' expectations getting individualised products instead of mass- produced items (Hagel et al. (2015)).

The trend to individualisation leads to decreasing lot-sizes, customisation with regards to morphology, size and fit, colour, style as well as design. Subsequently, local production is an ecological possibility, due to economic priorities. There are different drivers aiming at the production of small batch sizes, reduction of the time-to-market as well as at local productions. This includes, on the one hand new business processes and models, and on the other hand a number of new technologies, like for example virtual garment simulations, digital textile printing and automated cutting technologies (Fischer (2018)). Furthermore, consumers expect more transparency across the entire value chain and information about the quality and the origin of the products (ESPAS (2018)).

### 2.4. Technology Advantage – Virtualisation, Automation & Industry 4.0 as Drivers of Change

> "Digitalization will lead to increasing penetration in the coming years and will greatly change the economy." (Gottlieb et al. (2019))
>
> "A new survey finds that responses to COVID-19 have speed the adoption of digital technologies by several years- and that many of these changes could be here for the long haul." (LaBerge et al. (2020))

Due to the global competition in the field of mass-produced textile products, companies have already focused on new and/or niche products such as technical textiles or exclusive fashion. This shift is driven by various innovative products and manufacturing processes, which also includes 'digital manufacturing'. This is an integrated manufacturing approach that focuses on computer-based systems, such as 3D technologies, artificial intelligence, augmented reality and robotics, including Industry 4.0 approaches and micro factories. (Winkler et al. (2019))

Additionally, the production of high-quality clothing requires rapid adaptation to fashion trends as well as to changes in customer requirements, market changes up to individualisation and small series production. In the case of technical textiles, on the other hand, it is a matter of developing new products (e.g. like fibres) and production technologies. (von Wascinski et al. (2018)) Industry 4.0 creates opportunities for SMEs in the TCI to increase sales, gain competitive advantages, structure the value chain and create innovative business models. (von Wascinski et al. (2018))

Currently, companies are undergoing a transformation, for example due to changes in customer needs towards individualisation, due to Industry 4.0 and continued digitalisation in the value chain. In this context, challenges arise as different batch sizes, cost-efficient production of innovative and individualised products. (Winkler et al. (2019)

In relation to Industry 4.0, digital technologies present on the one hand challenges for companies and on the other hand many opportunities for the areas of energy and resource efficiency, demographic change, as well as enabling an improvement of the entire value chain. Consequently, the production through intelligent networking has large potential as flexible productions through more efficient coordination of individual actors along the value chain. Furthermore, modular structured production chains enable individualised and customer-oriented production. Additionally, algorithms can help to optimise logistics and therefore to enable a resource-saving circular economy. (Winkler et al. (2019))

# 3 Responses to the Challenges of Global Trends – New Business Models

There are many companies in the TCI adopting new business processes and models, technologies and production processes to reduce the effect of global warming and its related environmental effects. These aspects are shown in the following Figure 1:

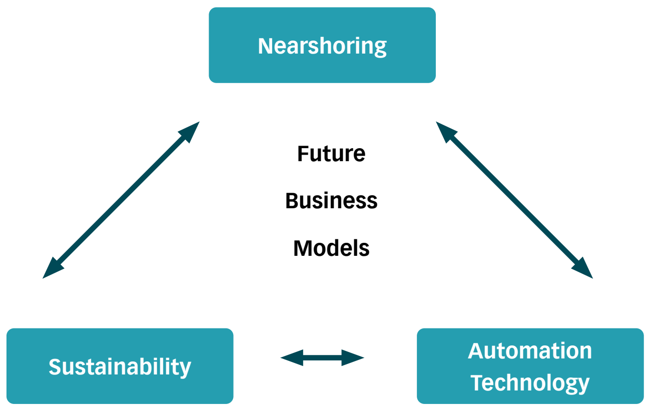


Figure 1: Future Models

The term nearshoring describes the relocation of a company or parts of a company to a nearby foreign country. Thus, it is the opposite of farshoring and is often defined as a special form of offshoring (Rodrigue (2020)). The advantages of nearshoring are mainly related to the reduction of geographical distances, sustainable supply chains, a maximisation of business efficiency and a reduction of personnel costs. (InterVenture (2019))

Hence in order to make further sustainable improvements, it is important that fashion companies continue to make systematic changes and restructure the production networks towards nearshoring. This requires collaboration and disruptive technologies to drive the fashion industry's sustainability performance. (Lehmann et al. (2019)) And nearshoring builds an answer to individualisation, on-demand production, small batch sizes. In the future the mass market of apparel brands has to consider the promise of technology, as factors in near- and onshoring viability. Moreover, relocating production closer to the consumer will require local governments and garment industries to develop the required skills and capacities of manufacturing. (Anderson et al. (2018)) There are already diverse promising strategies and so-called future models, which can be observed in the textile and garment industry and which are drivers towards nearshoring. These changing strategies will be described in this chapter.

## 3.1. Local Value Chain Networks, Near- and Onshoring to meet Challenges

> In the future, the apparel companies will enhance the value chain on two fronts: automation and nearshoring, will be successful. The connection of both as well as the focus on sustainability is inalienable. (Anderson et al. (2018))

Due to the globalisation of the German TCI, several worldwide production networks can be identified. The German company Van Laak GmbH in Mönchengladbach, for example, has production facilities in Tunisia and Vietnam in addition to its German sites. Kümpers GmbH, on the other hand, produces in Eastern Europe (Czech Republic and Slovak Republic). (Gloy (2021))

Currently, some of the relocations to the Far East are being counteracted by developments such as the return to Europe. Consequently, there are the described advantages such as shorter delivery times; further automation enables an enormous shortening of production time, as well as a lower consumption of resources. Nevertheless, the use of possible automations in the garment industry is currently still expandable. (Winkler et al. (2019))

Moreover, speed and flexibility seem to be winning against the marginal cost advantage, so there is a change of thinking on the procurement and production processes of mass market brands. Therefore, the increasing nearshoring and automatization models support sustainability and circular economy. (Anderson et al. (2018))

According to a McKinsey study, 63% believe that fabric production will move towards nearshoring by 2025 as regional networks should be increasingly supported. In Figure 2 the percentage of sourcing volume is visible, coming from nearshoring in 2018 and 2025. However, there will be no question of clothing companies increasing speed and flexibility, for example through design and simulation software. (Anderson et al. (2018))



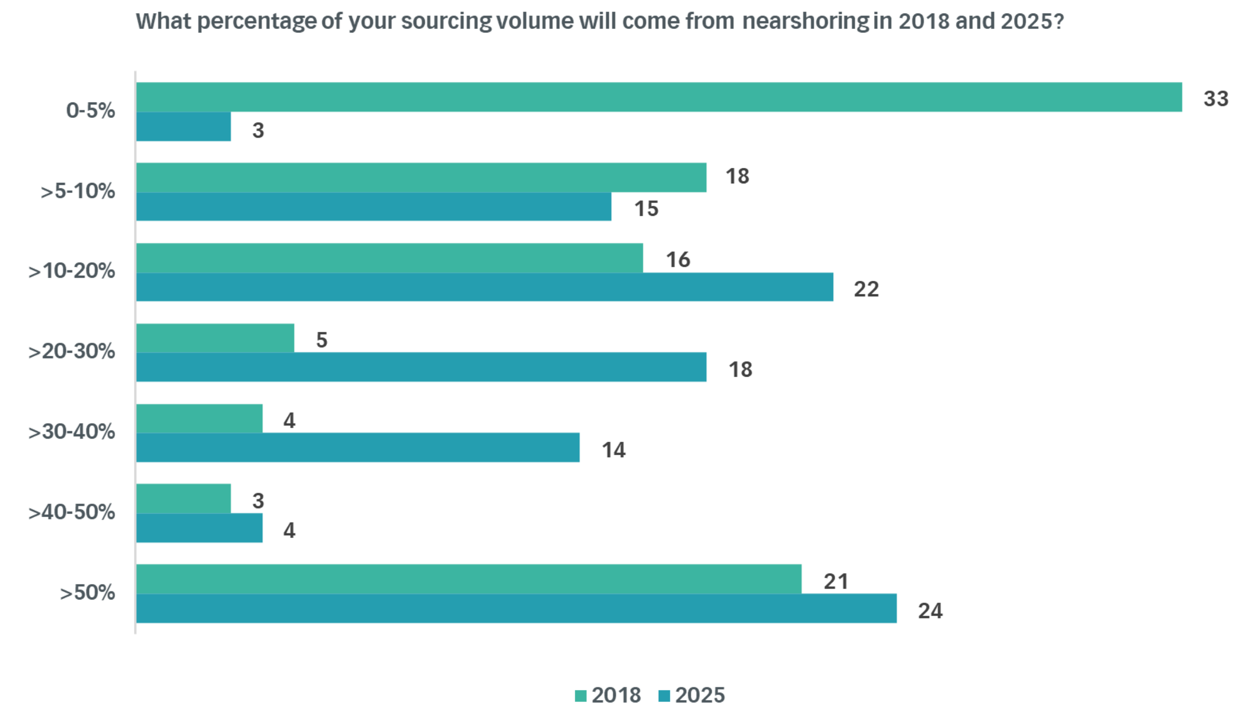


Figure 2: Aspiration level for a shift to nearshoring (Anderson et al. (2018))

The main advantage is the reduction of transport costs, which is one considerable advantage of nearshoring. It reduces the distance of the plants and main markets, which then reduces the transport costs, as well as transport times. Furthermore, the reduction of lead time between design, production and final sales increases the flexibility as well as faster responses to consumer demands. This has also positive influence on the delivery and storage efficiency. Furthermore, there are operational advantages, due to better coordination, which is enabled by easier face-to-face contacts between the headquarter and manufacturing plants. (Piatanesi/Arauzo-Carod (2019))

## 3.2. Sustainable Supply Chain Management and Circular Value Chain

Today, fast fashion companies use flexible supply chains to react quickly to changes and to new trends. These companies need about 15 to 30 days from the development of a collection to the delivery to retailers, whereas traditional fashion companies, on the other hand, need about four to twelve months. Besides speed and flexibility, sustainability is of high importance. The European Union defined CSR (Corporate Social Responsibility), as the responsibility of companies for their impact on society already in 2011. The assumption that followed was a concern that companies should implement procedures to integrate social, environmental, ethical, human rights and consumer concerns into their operations and core strategy in collaboration with stakeholders. (Fifka (2018))

The changing societal and political awareness of environmental impact of traditional fashion companies, which is affected by water consumption, electricity, textile waste and air pollution, leads to new sustainable mind-sets and therefore to the use of new environmental management systems.

One example of this is the Five-R model shown in Figure 3, covering recycle, reuse, reduce, re-design and re-imagine, which has already been implemented for example by the Swedish company Filippa K. Therefore, near- or onshoring is important, in order to establish proximity to the individual actors and production plants and therefore forms a basis for the 5R model. (Strähle (2017))

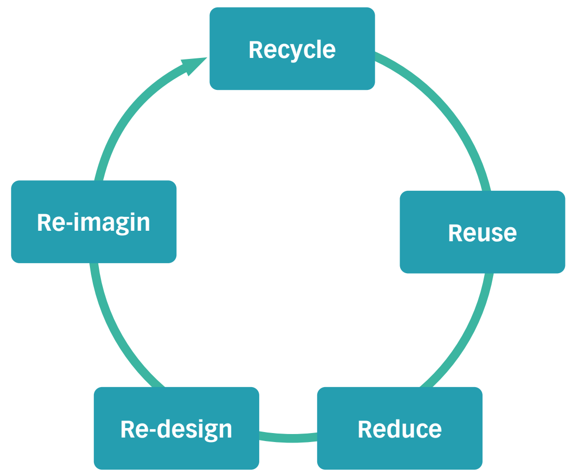


Figure 3: 5R's of sustainability. Own figure based on Esty and Winston (Strähle (2017))

Another approach that is very widespread nowadays and that is emerging with the trend of sustainability is the circular economy. As Figure 4 shows, nearshoring and automation play an important role in creating circular apparel value chains.

The circular economy describes a concept, where the goal is to fully reintegrate used raw materials into the production process beyond their life cycle. This covers in addition pre-production waste (waste in the production process) and post production waste (e.g. overproduction). Consequently, economic development should be balanced with protection of environment and resources, due to the reduction of textile waste and resource. The principle of the circular economy can be implemented in conjunction with closed-loop supply chains in a textile value chain to generate a sustainable business model. (Arretz/Meyer (2018)) That makes nearshoring to be an important enabler in building up a circular value chain (see Figure 4).

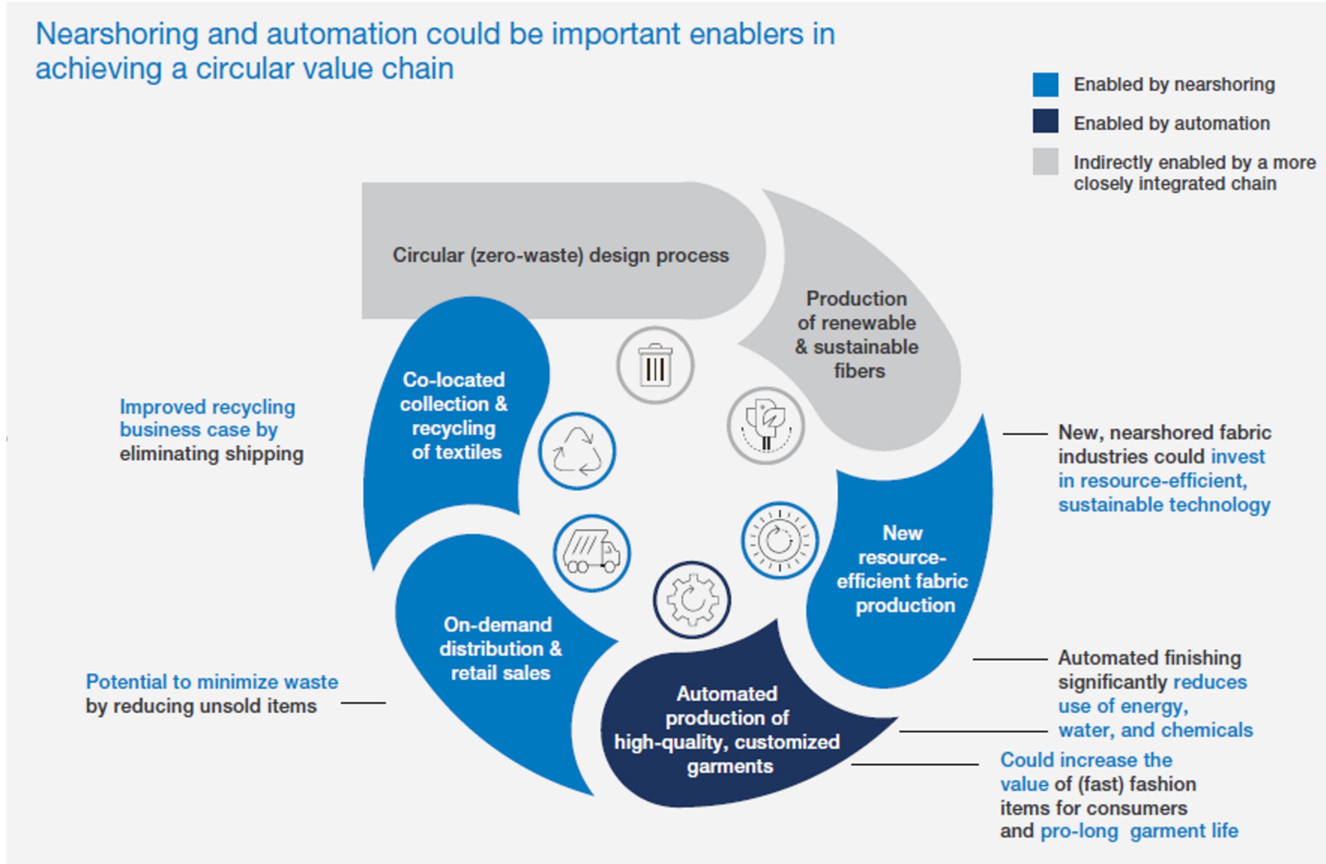


Figure 4: Nearshoring and automation could be important enablers in achieving a circular value chain. (Anderson et al. 2018, S. 7)



### 3.3. On-Demand, Platform Concepts and Open Manufacturing

Nowadays, new products are coming onto the market more and more quickly, and in the clothing industry there are often up to 12 collections a year or even more. This poses a challenge for the clothing industry with very short innovation cycles. (Moltenbrey/Tilebein (2020) In order to make established value chains more flexible, information about the entire value chain should be made available to all actors of production (suppliers, service providers). Consequently, the horizontal integration is a core characteristic of Industry 4.0. (von Wascinski et al. (2018))

**On-Demand Production:**
The competition within the fashion industry increases due to changing consumer demands, and fast reacting pure-play companies on new styles. Subsequently, there is pressure on the profitability because of the decreasing full-price-sell-through[1] and increasing awareness on the environmental impact of overproduction, which contributes to smaller batch size production and on-demand replenishment. As a result, fashion retailers try since several Years to differentiate themselves in the market, due to increasing competitive and aim an optimal business model, efficient production pattern as well as good cooperate values. (Strähle (2017))

Consequently, today push models are often transformed to pull models, which means that trends are more common to pop up from the streets. Especially influencer, celebrities or stylish consumers are trendsetters and therefore have impact on the design and development process. On the one hand, there are already on-demand companies like Li & Fung, which uses for example virtual 3D renderings at the point of sale. Here the production process starts only after consumers' orders were received. On the other hand, mass market brands and retailers have problems to adapt to the pull model and so continue in mass production of stock in bulk orders. (Anderson et al. (2018))

**Platform Concepts:**
The connection of the trend of personalization and customization, together with the success of platform- centric business models effect manufacturers to rethink products as physical platforms, which build the center of an ecosystem in which third-party partners create modular add-ons. By using successful platforms, the speed and cost of innovation can be lowered, since the entry costs and risks are reduced through common interfaces as well as plug-ins. Hagel et al. (2015) Following, digital platforms have become one of the most successful business models in the digital economy.

Especially manufacturers, have to consider, if development, design and procurement processes could be supported and transacted via platforms. There are perceptions that value and service can be represented more effectively, quicker, cheaper and more transparently by communicating on the internet. (Schumann (2018))

There exist already different platforms for on-demand production, as for example spoonflower, which is an online platform for printed fabrics. Customers can upload designs for printing and make them available to other Spoonflower customers for a fee. (Schlommski (2017)) Also, the company Mitwill has a design network as well as an own Microfactory. Therefore, the business model consists of design (international design community), production (Microfactory) and logistics. This use case will be described more detailed within chapter 4.1.

**Open Manufacturing and Microfactory:**
Since there are limits of production and consumption, from both, an economic and ecological point of view, often a demand for a more sustainable use of resources occurs. This is reinforced by economic and social trends such as the do-it-yourself movement and the sharing economy. Consequently, there are new business models that deal with new materials, technologies, combinations of processing methods as well as the use of old craft manufacturing methods.

One new business and production concept is the textile Microfactory, which enables new ways of design, production, integration of new products and processes, and forms of cooperation, whereas the main difference is that the micro-factory is demand and not production driven, according to the paradigm "Sell, Produce, Deliver".

The following chapter will show the use case of the developed textile Microfactory at the DITF.

1 "Sell through rate is a calculation, commonly represented as a percentage, comparing the amount of inventory a retailer receives from a manufacturer or supplier against what is actually sold to the customer" (Hudson (2018))

# 4 Distributed Creativity and Production within Regional Networks – The Textile Microfactory and Technology Solutions to Meet the Challenge

Today, traditional manufacturing in TCI is developing faster, then ever before, since multiple technologies are now available building a sustainable option to conventional production. Traditional business models in the TCI for mass production carry often enormous risks and are very resource intensive. Following to the need for sustainable supply, traditional suppliers are looking for new opportunities, like the textile Microfactory, covering printing and manufacturing on demand as well as in different volume, minimising stock. There are several developments in CAD/CAM, augmented reality software, online workflow, digital printing and digital cutting, which can be implemented within a Microfactory and following provide possibilities to reduce risks and minimise the consumption of resources. (McKeegan (2018))

This chapter proposes solutions to the trends and currents presented in the previous chapters. Therefore, use cases of four different companies will help to show und understand already existing solutions as response to challenges described at the beginning of this paper.

### 4.1. Textile Microfactory and Distributed Production as an integrated Concept

> The international technology advisors FutureBridge describes a microfactory as "a "small-to-medium scale, highly automated, and technologically advanced manufacturing setup, which has a wide range of process capabilities". (FutureBridge (2020)) These facilities output can be scaled by replicating units in larger numbers rather than growing the size of a plant." (Gibbons et al. (2021))

The DITF has built a textile Microfactory since 10 Years, together with different partners to discuss one model of on-demand production. (DITF(2020)) This textile Microfactory enables to produce and deliver within 24 hours- in comparison traditional models could only provide from a huge, expensive stock. And, characteristic for the Microfactory is, that it enables to implement on-demand production, as well as personalised production, lowering transport emissions and costs, following to create more local jobs and supply chains while preventing leftovers and storage. (Romano (2019) and DITF (2020))

The textile Microfactory of the DITF shows a technology approach for clothing production, in which an end-to-end networked design and production process is integrated, from the 3D simulation of the individual garment to digital printing and cutting to the finished product (Figure 5). This seamless digital, integrated process is a milestone for Industry 4.0, as conventional production in TCI traditionally involves manual, more labour-intensive steps. This can be reduced to a minimum by a Microfactory, as it enables a continuous integrated workflow. Hence, a customisable production of batch size 1 is possible, and if, for example, a body scanner is integrated at the beginning made-to-measure products can easily be produced. (Moltenbrey/Tilebein (2020) and Fischer (2018))

The textile Microfactory shows an integrated concept that covers all technological and value creation steps in one place. This concept allows the following production scenarios:

- Factory-in-Shop: A textile Microfactory in a retail and selling environment focusing to customer and consumer interaction.
- (Standalone) Factory, with upscaled capacities: Using the principles of integration, digitisation and sustainability for flexible on-demand production with high(er) production capacities, e.g. high-speed printing and/or multiple printers.
- Factory-in-Factory: A textile Microfactory as a workshop in a textile or garment factory (site) for dedicated production jobs.
- Technological Centre / Lab: A textile Microfactory as part of a technological centre or a lab (following the fab lab concept) for design, experimenting, co-creation, training & education (or just for demonstration) of textiles and clothing. (DITF (2020))

Encouraged by the textile Microfactory economic benefits, a trend towards in-house manufacturing for many fashion retailors can be observed (see Factory-in-Factory production scenario), to control their supply chain and to have the benefit of speed to market as well as sustainability. (McKeegan, D. (2018)) In this way the Microfactory serves the local and decentralised production, like it is figured out in the idea of Nearshoring.

Besides those integrated production scenarios, a decoupled or single use of technologies are very promising and will be described in the next chapters.

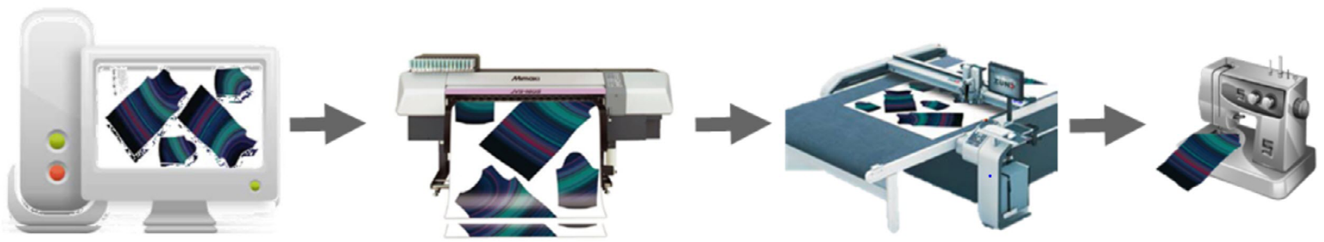

Figure 5: Microfactory @ DITF, Simulate Print and Go (DITF (2020))



### 4.2. Creativity and Individualised Design Platform as Driver towards Nearshoring

> The trend of nearshoring sets creativity back into focus, which is also reflected in rising prices. Nevertheless, design will be the new gold. As customers demand for highly individualised and more sustainable fashion, highly efficient local factories will be able to realise almost any idea. (Angerer (2019))

Industry 4.0 already provides for TCI technical solutions to facilitate the networking of individual components and to support nearshoring. In the future, however, it is important that the technologies are implemented and used by individual players in the clothing industry. The connection of digitalisation and nearshoring can help to set the focus back on creativity and also to meet the trend of individualised design; and this can be supported by developments, as cloud-based services, design networks and integrated design into production.

Product design plays a central role in influencing the use of resources along the entire product life cycle. (Ecodesign Kit (2015)) As the creative economy accelerates during an unpredictable and changing global economy, the ability to innovate is more important than ever. Creativity and innovation are more critical than ever to success in developed economies. Consequently, design is increasingly interlinked to technologies, today. Fashion brands for example use increasingly artificial intelligence (AI) to adapt product design according to customer demands. Nevertheless, the results of human-free AI designs aren't always runway-ready. But the gap to human-made designs is decreasing.

The high-speed internet builds new channels and platforms for even the most niche products, which is especially interesting for any creative mind, to extend the value chain from design to product. Additionally, the covid-19 pandemic has shown that proximity to customers or suppliers plays an enormous role and should be shortened in the future to avoid problems.

The development of social networking website such as Instagram, Facebook, Twitter give designers new inspiration as well as new ways to present their designs. Following, from the fashion blogs to the live streaming of catwalk shows, from the main fashion weeks to the social shopping, there are since several Years different options on these platforms and it has become a most important runway for the fashion industry. (Amed et al. (2019))

The digital economy builds a designer fashion community as well as a broader creative sector, compelling opportunities to develop new business models, as new ways emerge of engaging, creating, interacting and selling, driven by mobile connectivity. The designer fashion community of the UK for example, builds a designer fashion business, which is a driver of innovation and inspiration for the fashion industry. (Black et al. (2015)) Therefore, the interaction of individual actors and nodes play a central role. Consequently, within Europe there are already various platforms that try to network different actors in the fashion industry in order to promote them and also to build regional on- or nearshoring structures, such as Nemona (https://nemona.de/), Sourcebook (https://www.sqetch.co/), the Textilerei Mannheim (https://textilerei.next-mannheim.de/) as well as Mitwill (https://mitwilltextiles.com/).

The concept textile Microfactory can be used either as networked production (see chapter 4.1) or it can be used specifically for the production of prototypes, like the Use Case Mitwill will show.

# **USE Case** Mitwill – "Design to Print"

"We network digital textile clusters – Hervé Francois"

Mitwill Textiles Eupre was founded with the vision to integrate textile creativity with European production in novel ways. With modern IT and high-tech production tools, Mitwill gives space to professionals from all textile backgrounds to design remotely and produce locally. Hosting events, attending fairs, participating in European projects and bringing young creatives together, Mitwill projects creativity into business and commercial practice.

Every Mitwill print is based on an authentic creation from the international Mitwill designer community. This network of professional textile designers collaborates to develop 100+ ready-to-print patterns per month with their technical data for processing in digital on-demand printing in the textile Microfactory.

Mitwill's personalized design work is judged by Vera Mont to be an important part of the collection development," states Heike Schaible, product manager at Vera Mont Division of Betty Barclay Group GmbH & Co. KG; www.bettybarclay-group.com

Figure 6: Authentic print design creation in a collaborative digital environment

Production facilities are organised in a textile printing Microfactory which allows rapid prototyping for industrial orders and small batch on-demand production for bespoke customers. Printcubator.net is an e-commerce-site linked to the textile Microfactory and provides digital printing service to textile start-ups, young professionals, capsule collections, students, and artists.

The textile Microfactory concept at Mitwill was fine-tuned thanks to the experience gained in demonstrators together with DITF. The textile Microfactory operates state-of-the-art digital printing with reactive, pigment and sublimation printing technologies.

Based on available open-source software, Mitwill developed a cloud-based custom PLM-ERP tool that covers the full process from design to the finished garment. Smoother processes, less errors, speedier prototyping, constantly updated product, pricing and production information – these benefits all translate into time and money savings.

The tools for color profiling provided in the Ergosoft RIP software, together with sophisticated color measurement equipment, allow to define calibrated color catalogues for use in the networked production locations. Color management is an essential step to ensure the reproducibility of colors on different substrates and in different production stages.

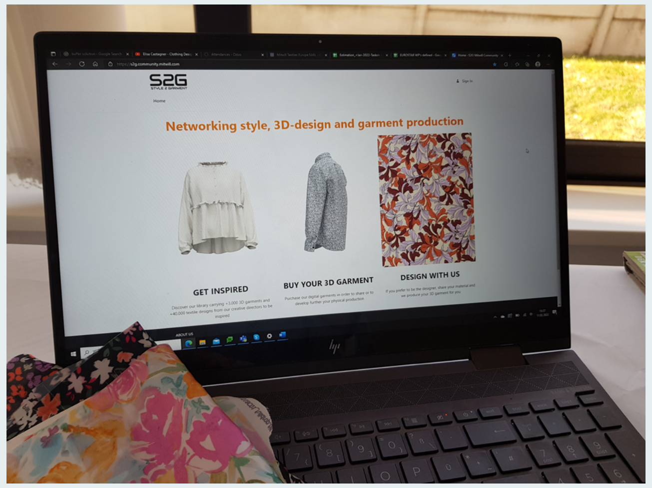


Figure 7: Garment community linked to the digital textile microfactory

Mitwill continues the virtualisation of product development with 3D simulations of finished garments. The simulations are used as virtual prototyping and for communication with customers and production sites. Thus, print, garment style and visualisation are combined to make the sampling process more efficient. Mitwill is thus bringing together the potential of textile Microfactories, collaborative work environments and an international designer and supplier network in a start-up spirit.



#### 4.3. Virtual Solutions

> 3D design and virtual prototyping represents a real game-changer! Today, 3D simulations are major development to create interactive garments by connecting design, pattern as well as material. Following this, the product development time can be reduced, as well as time-to-market and sustainability increases. (DITF (2020))

The transition from traditional manual design to 3D design could unlock far-reaching innovation in design. Today, 3D simulation systems are already being used in garment development and production to complement classic 2D design systems. Made-to-measure is the origin of garment production, therefore central digital components of a made-to-measure production already exist, as digital cutter, configurators, 2D cutting kits. Photorealistic simulations and visualization of garments help to replace physical samples for presentation and consequently save a lot of time in the product development process as well as reduce textile waste. In addition, the trend of personalization can be implemented through made-to-measure production by creating avatars (based on body scans) of the customer. Thus, the traditional tape measure is replaced by digital measurements on the avatar. (Altenburg et al ((2020))

There is the possibility to link the 3D sample directly to marker efficiency, so that drive can improve efficiency and waste reduction in automated cutting processes. Moreover, the 3D design and virtual prototyping enables close collaborations through the production development process as well as within suppliers. (Berg et al. (2017))

The textile Microfactory of the DITF presents a networked production of clothing at one place, which has already been described before, including the entire process from design to production. CAD and design build the first station of this textile Microfactory, so that the created designs are linked to the subsequent processes as for example textile printing, cutting and sewing. (Gloy (2021))

Therefore, a 3D simulation software is used to edit the design for the following cutting and sewing process (Figure 8). Consequently, QR codes and position markers are included into the production order. (DITF (2020))


Figure 8 : 3D simulation for virtual prototyping (DITF (2020))

After the 3D design has been developed, it is stored in print and cut ready pdf-files (Figure 9), which are the basis for a cross-linked production. The pdf-file contains a multi-layer concept to hide or show layers for drill holes, notches, contours and textures. These different layers are important for the RIP and for the cutting of the printed marker. (DITF (2020))

**Resilient Design: Prepare Marker for the Workflow**

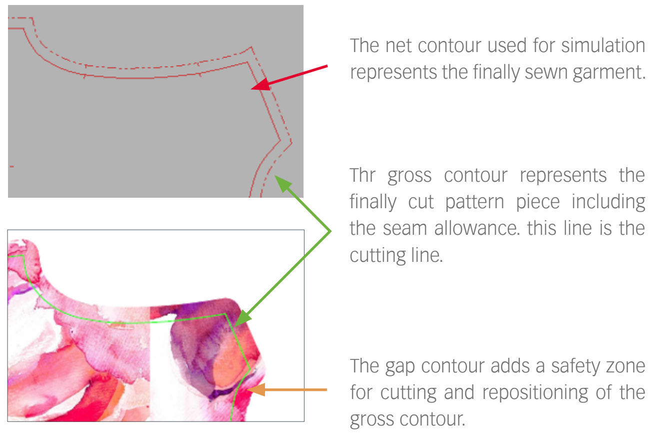


Figure 9:Marker for the workflow.

The following use case shows an example for 3D simulation/visualisation and photorealistic avatars, bringing a wide amount of benefits in the process from 3D to production.

# **USE Case** ASSYST GmbH – "3D form idea to shelf"

"End to end integration of 3D in Design, Development and Distribution is key to succeed transforming the go to market process in fashion business".

The IT company ASSYST has focused on integrated 2D/3D CAD and PLM solutions for efficient collection development in the apparel industry since the mid-1980s. ASSYST is the world's leading technology provider and focuses on innovations for automation, 3D simulation/visualisation, process design and data management. Flagship products are 3D-Vidya, Cad.assyst, Avatars, digital assets and the cloud solutions automarker.com and Autocost.

ASSYST customers are enabled to respond to consumer requests much faster and more accurate due to drastically shortened go to market timelines. Associated risks in inventory or missed trends can be minimized by ASSYST users to far extend.

**Vidya 3D- Simulation**
With Vidya, 3D products, complete digital samples can be developed fast, always based on the associated and approved CAD construction, digitized or real materials and colours and the body measurements of the target group. ASSYST enables the direct connection between 3D and CAD. Vidya can be integrated into different workflows with CAD and PLM. Even individualised and made-to-measure products can be produced directly.

**High End Visualization Pipeline – 3D Vidya Avatar-photorealistic visuals at the touch of a button**
With Vidya, avatars of a wide variety of target groups can be created in any clothing size – with real measurements, shapes and realistic fits throughout the size run. With integrated 3D digital showrooming, the entire preparation of marketing content can be automized and is digitally ready. Customers can adapt consumer requests instantly.

**End to End integration**
ASSYSTS software suite centres around 3D product readiness and the guarantee for fit, based on the integration of 2D and 3D solutions. Associated to this, upstream or downstream adaptions to products are always build on consistent data. No information is lost.

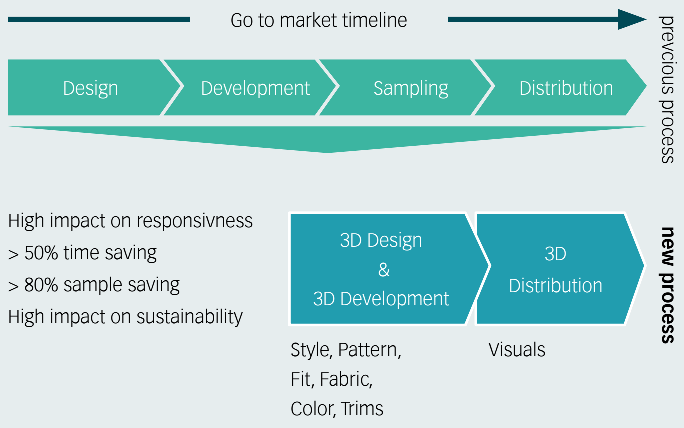


Figure 10: Idea to shelf – new end2end solution

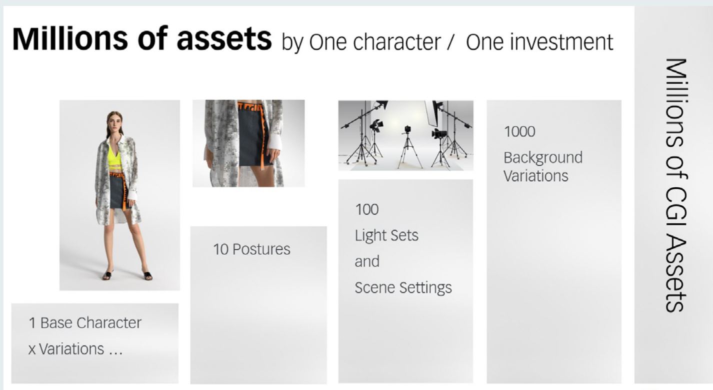


Figure 11: High End Visualization Pipeline

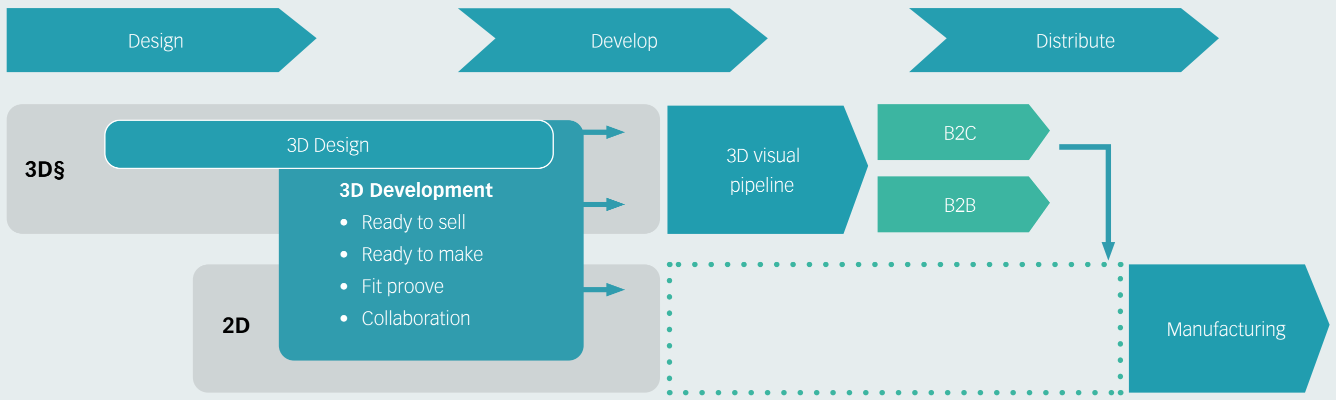


Figure 12: End to End integrated workflow



### 4.4. Large Format Textile Printing

"The growth of the digital textile printing sector will encourage the development of microfactories, given this finishing equipment can give producers the tools to create innovative and often bespoke designs to order." (Gibbons et al. (2021))

Challenges like rapid changing trends, changing consumer demands, personalisation, sustainability, reshoring to Europe, as well as business models driven by technology are drivers towards digital printing. Traditional printing needs a large amount of energy, water and precious resources. Compared to this, the textile Microfactory offers sustainable manufacture, including digital textile printing.

Today, the development and implementation of textile Microfactories has enormous potential to trigger a fundamental change in processes within the TCI. This is also supported by developments in digital printing. Textile printing is one of the textile Microfactory's core services, as it is very environmentally friendly, adaptable and can be integrated into digital design software. This way, designers can already assess whether a print will be feasible. The processes of the textile Microfactory should be completed by standardised communication between all links in the manufacturing and supply chain. (Gibbons et al. (2021))

Consequently, textile Microfactories can be expand through the implementation of digital printing, due to the growth of this sector, it will encourage the developments of textile Microfactories. Furthermore, it can enable producers to create innovative design to order. So, detailed design can be produced fast in small digital printing units for limited amounts or alternative sent to larger printers. (Gibbons et al. (2021))

The Federation of European Screen Printing Associations (FESPA, digital printing, and textile printing community), has predicted that the traditional fashion industry has to be reorganised by using the Microfactory model. Especially using print to order, can help to reduce inventory and following means "no end-of-season sale clear-outs, but also no unsellable clothing being destroyed and burned or going to landfill either." (Gibbons et al. (2021))

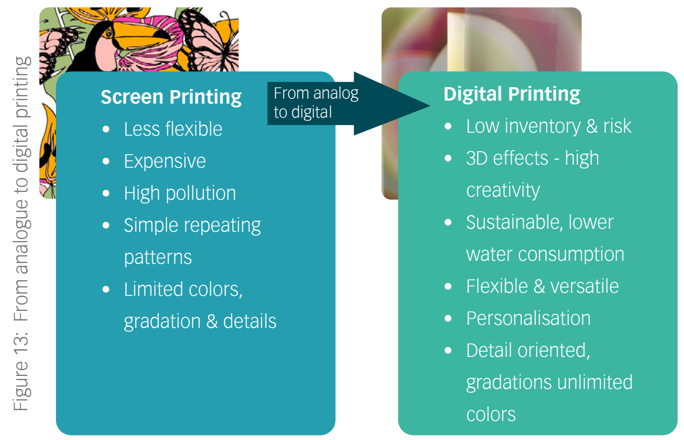


Figure 13: From analogue to digital printing

"Polyester, cotton, viscose, linen, nylon, modal, rayon, and silk-based fabrics can be combined with original colour-accurate digital print designs, using less water, chemicals, and power, says print service provider Hollyflower, based in Gujarat, India." (Gibbons et al. (2021)) In contrast, conventional printing processes of printing require larger minimum amounts of fabric, with longer setup times that do not mesh well with Microfactories, while small digital printing units can offer a greater variety of designs and colours (Figure 14). (Gibbons et al. (2021))

Regardless of the technology, digital printing is more environmentally friendly than its analogue counterparts, since the machines are more energy efficient and the usage of inks and water much lower. Additionally, for on-demand process, digital printing helps to reduce inventory, as the item is only printed when it has already been ordered and paid for. Digital printing is regarded as the most advanced aspect of digitization in apparel manufacturing. Together with digital cutting, it could reduce the production time enormous, increase flexibility, and reduce waste. The digital printing should always be seen as part of a fluent digitized process that includes 3D design, virtual grading, virtual size fits and costing.

"Nearshoring from Europe, boosted by the diversification of sourcing prompted by the Covid-19 pandemic, is driving demand, with Turkish garment manufacturers using small digital printers to send samples to Europe within 48 hours via courier for approval before printing the larger order." (Gibbons et al. (2021))

Figure 15 is showing the differences of a conventional printing process compared to printing using inkjet technology.

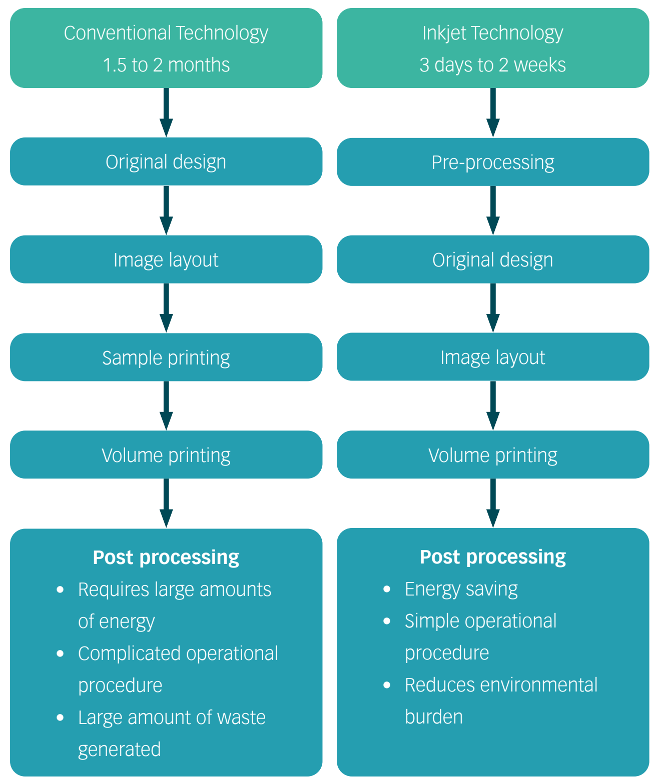


Figure 14: Printing Process of conventional technology vs. inkjet technology

# **USE Case** Ergosoft – "Design to print"

Connect "the dots" with Ergosoft!

Since the beginning of digital printing, Ergosoft has been one of the leading players in this industry. With a strong focus on innovation and technology, Ergosoft delivers a complete solution to ensure the correct output of your design on any media. The Ergosoft RIP Software Suite process all different file formats and provides color control throughout the entire workflow.

Adjustable colors are essential to address different markets. More vibrant colors, fewer gradients, handling of spot colors, support of various standard color libraries are just some of the many features Ergosoft offers.

To allow output on any device, Ergosoft supports a wide range of devices. For example, measurement devices to accurately measure colors and ensure perfect prints, an extensive range of printers to address any customer setup, and various cutters to provide a streamlined finishing process.

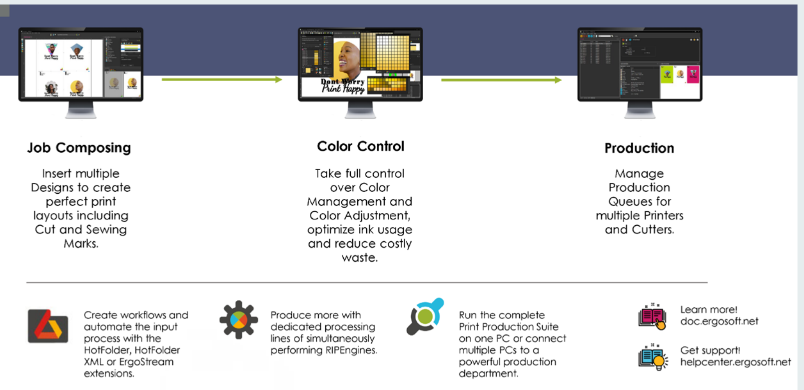


Figure 15: Ergosoft Print Production Workflow

Ultimately, the Ergosoft Software Suite contains several modules to make the solution complete. Set up your production workflow in the JobComposer, process your files with the RIPEngine, and organize your production with the PrintQueue.

To automate the processes in the context of a textile Microfactory, Ergosoft offers several automation options:

1. Simple and easy automate jobs by using the Hotfolder Workflow
2. For more sophisticated automation, Ergosoft offers the Delta Automation interface to remote control the JobComposer
3. Ergostream is connecting any order platform directly into your printing production.

So, whatever you need – Ergosoft provides the connection from file input to file output.

After the marker creation, usually a series of images is sent to the printer, which prints it on a roll of fabric including guides for the cutting. Once printed and fixes, the fabric pattern is cut using a digital cutter, which delivers the pattern to the sewing department ready to be finished. (WhichPLM 2018)

The following figure shows the complete development and production workflow for the "Simulate, Print and Cut" prototype, with the focus on the topic "color".

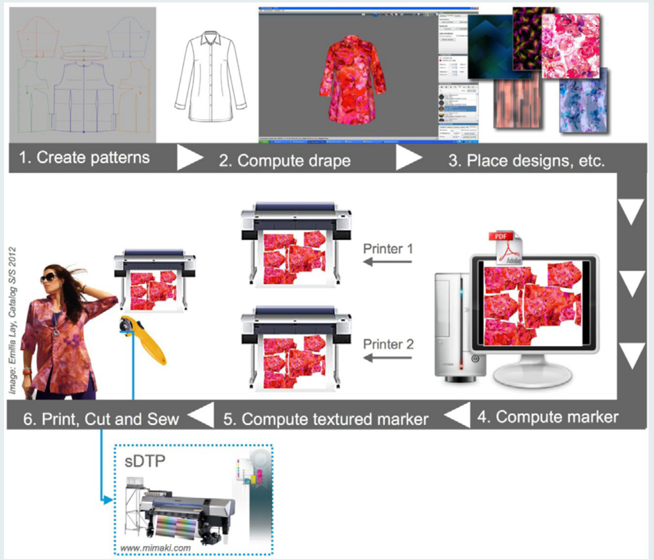


Figure 16: Overall workflow CMM visualization and inkjet printing

The dimensions of the final results are dependent on the textile composition and post treatment process. Therefore, the shrinkage and expansion rates for a given textile must be measured during testing and the result included in the print environment. The transformation will then be automatically counteracted in the print dimensions.

The Ergosoft RIP Production Suite provides powerful automation features to execute operations such as scaling, image placing, repeats, and production length and adding cut markers without manual interference. In addition, the versatile JobComposer provides an easy-to-use, WYSIWG interface to set up Color Management (Density Linearisation, ICC Profiling, Rendering Intents, Ink Limit) and Company Standards.

### 4.5. Digital Cutting

Trends like digitalisation, nearshoring and individualisation lead to new opportunities, which can be implemented with the help of digital cutting technologies. Furthermore, digital cutting is a driver towards smaller batch sizes, as well as the current process of change in cutting technologies is also an important aspect in supporting nearshoring structures. The shift from multiply to single-ply cutting enables on-demand production and consequently helps to reduce negative environmental impacts.

Today's challenge is to optimize the entire production workflow, where the cutting process plays a central role. There are several ways to increase the sustainability of the production process, starting with an analysis of the entire workflow. Here, non-conventional optimization methods can change the cutting process. For example, by using post-cut digital cutter: that works by first preparing the print design and calendering, then cutting the material follows afterwards. By doing this, production costs will be minimized, while maintaining high-quality products and reducing the amount of fabric waste. (Horsten (2020)) The German office furniture manufacturer König+Neurat already uses single-ply cutter by Zünd, with the target of a 10% to 15 % reduction in material waste. Thomas Selbach (chair production manager of König+Neurat) explained: "Currently we are at an improved fabric utilisation and still have room for improvement".

While cutting plain patterns, which doesn't need pattern matching, the material consumption can be reduced by 1 to 5 percent, using single-ply cutting. Overall, there is a shift form multiply cutting to single-ply cutting, that allows on- demand production and is in most cases more sustainable and easier to be digitised. Multiply cutting has the advantage, that it is more productive compared to single ply cutting, even if the preparation process is highly work intensive (Table 1). Anyway, single-ply cutting is the more flexible method and moreover it is ideal for an maximum of automated processing. (Donovan (2020))

| Multiply Cutting | Single-ply Cutting |
|---|---|
| Mass production, high volume & efficency | Prototype & small size production |
| Short production cycle | On-demand and made-to-measure production |
| Global sourcing | Nearshoring network and Microfactory |
| Low cost products | High value goods |
| Less accurancy | High cutting accurancy, position details |
| High material consumption | Low material consumption |
| High personnel expenses | Low personnel expenses |
| Require more space | Require less space |

Table 1: Multiply Cutting vs. Single-ply Cutting

Compared to multiply cutting process, where layers have to be laid manually and which can hardly be automated, single-ply cutting achieves labour savings through a high automation potential. Consequently, the breakeven of single-ply cutting moves upwards at a quantity of 5 to 8 layers. On the other hand, cutting less than 5 layers, single-ply cutting would be more efficient.

Furthermore, multiply cutting requires more staff members and takes up more space, including the laying table.

Additionally, the single-layer cutting of textiles enables a flexible reaction to changing trends. Especially since order sizes are getting smaller, order cycles are getting shorter and the trend towards individualisation is increasing. High-performance cutting systems enables fully automated cutting without manual intervention. Furthermore, the single-layer cutter contains a wide range of automation options. For example, from feeding and material recognition to cutting. (Zünd Systemtechnik AG (2021))

There is also the option to process individual printed textiles, since cutters can be easily integrated into existing workflows (or print & cut workflows) and enable the cutting of individually printed textiles. (Zünd Systemtechnik AG (2021))

Single ply cutters are able to cut up to 30 mm compressed material. The material can be fed straight from the roll using automatic winding and rewinding devices, fabric roll storage systems and loading devices. Single-ply cutting is especially used for the sample production, made-to-measure manufacturing and fully automated cutting of digitally printed fabrics. (Vilumsone-Nemes, (2018))

**Nesting & Cutter Driving Software**

The nesting and cutter driving software can be used to connect the CAD drawings and the cut output. The nesting helps to arrange the pattern pieces in the most economical way regarding the amount of material. Afterwards, the optimal speed and tool for the cutting process can be selected. Finally, the task is sent to the cutting device. Sending the task to the cutting system. (Vilumsone-Nemes, (2018))

Software is also integrated into the digital cutting workflow, which contains comprehensive data and guide the personnel through the complete cutting process. Consequently, error and resources can be minimized. (Zünd Systemtechnik AG (2021))

**Marking of the cut components**

There are different marking tools to identify cut components for the subsequently processing. This marking includes for example, mark attachment points, size, bundle ID, order number, dates and barcodes. (Vilumsone-Nemes, (2018))


Figure 17: Steps of the cutting department

**Identification and off-loading of cut components (kitting)**

By using conveyorized cutters, as robotic off-load systems can be used, to automatically pick- up cut parts from the machine. (Vilumsone-Nemes, (2018))

The digital cutters can be individually integrated and assembled in the workflow. For example, it is possible to integrate an automatic feeding and unwinding unit. This enables a quick exchange of the textile rolls for different materials and achieves a constant material tension. For the automatic material transport, a conveyor belt is used which serves both as a cutting base and as a conveyor belt and thus enables the automatic removal of the cut parts.

# **USE Case** Zünd – "Smart factory, intelligent cutting technology"

"We quickly realised that individualised apparel textiles would be the next big thing."

Figure 18: Digitally printed sportswear - Zünd's Print&Cut workflow provides the necessary data consistency for processing custom-printed textiles.

Zünd Systemtechnik AG, a globally active Swiss family business, is the specialist for digital cutting systems. Zünd has been designing, producing and marketing modular cutting systems since 1984 and is one of the world's leading manufacturers.

Its customers are commercial service providers and industrial companies in the graphic arts, packaging, garment, leather, textile and composite industries. The company's research & development, marketing and production are located at the headquarters in Altstätten. In addition to its own sales companies and service organisations, the company works with independent and long-standing distribution partners worldwide.

Zünd Cutters are market leading in their support of open standards. Many file formats are supported and also metadata and job information can be imported easily and fully automated. Next to receiving job information, Zünd offers additional software products and API's enabling an easy but comprehensive integration of the Zünd cutters into a Microfactory environment. Zünd Connect makes the cutting performance and efficiency visible and automatic job reporting and APIs allow other workflow software solutions to connect into the cutting process.

**Micro Factory, "the next big thing"**
In 2019, Victor and Michal Tracz set the course for digitalisation in the family business. In the case of Print Logistic, the solution is called web-to-print, a market in which digitalisation and automated production systems are the growth drivers. In the apparel industry, fully integrated, intelligent production cells, so-called micro factories, are emerging. Victor and Michal have recognised their potential and realised their own micro factory, one of the first ever in Poland. Tracz says: "We quickly realised that individualised apparel textiles would be the next big thing."

**Digital cutting as a central building block in the smart factory**
Today, Print Logistic can produce thousands of personalised garments within a maximum of 72 hours from receipt of order. "For this, we need smart production equipment, digitalised cutting, even printing is done digitally, direct-to-garment, from roll to roll. Digital cutting is a central building block in the smart factory. "It accounts for 33% of the success, with digital printing and sewing each accounting for another third." In Smart Factory, printing, cutting, sewing and logistics mesh like well-oiled cogs. Without digital cutting, the workflow would not be feasible at all: "Every garment is individual. To be profitable, the throughput times have to be very short, that is the key to success. And cutting is very fast. Be it the cutting speed of the Zünd S3 cutter itself, the job identification via barcode scan or the short set-up times".

"We can also be satisfied with the investment in digital cutting technology from Zünd in economic terms, not just in technological terms." However, the realisation of a Smart Factory alone is by no means the end of the story. It is a challenge on many levels. And it remains central to be able to meet high quality requirements at a constant level while keeping an eye on the return on investment. There is still a lot of potential in the further automation of sub-processes. "The lemon is far from being squeezed."

**Sustainably reliable**
Tracz sees perhaps the greatest advantage of the smart factory in its sustainability: "We don't tie up capital in large warehouses, we don't have to throw away unsold stock. Thanks to digital cutting with the Zünd S3 Cutter, we can make perfect use of the material and have no significant material waste."

For Michal Tracz, an important key to success is production equipment that can be seamlessly integrated: "With the Zünd Cutter, we have opted for a cutting system that can cope with a wide range of materials without compromising on performance or the quality of the cut. Cotton, linen, elastic textiles made of viscose fibres, textiles made of bamboo fibres, their properties in processing are as diverse as the textiles used. Says Tracz: "The textiles have different unwinding behaviour and in the cut we have to be able to reliably compensate for shrinkage and warpage. You can see that Zünd has a lot of experience in textile cutting."



### 4.6. Nearshoring in Practice

As already shown there is considerable interest nowadays in reshoring and nearshoring structures within the TCI and especially the fashion industry, which has also been indicated by different sources. (Anderson et al. (2018), Bootle (2019), ILO (2019), Kucera/ Mattos (2020)) According to the McKinsey study by Anderson et al. (2018), even companies with a previously low proportion of nearshoring, anticipate a move to over 10 percent of nearshoring volume of total sourcing volume.

Of course, there are also different possibilities to implement nearshoring. In practice, different structures (onshoring, nearshoring, offshoring) are often combined. This is especially true when the procurement of ingredients is considered, as these are very limited regionally. Small companies and start-ups usually implement nearshoring automatically, as this allows them to avoid the problem of minimum purchase quantities for the most part. In addition, sustainability and transparency play a greater role, especially for new, smaller fashion labels. For example, production often takes place in countries such as: Portugal, Turkey and Poland. Furthermore, small quantities are even produced locally (onshoring), as shown by examples in Berlin.

Some practical nearshoring cases which have already been implemented, will be shown by the following use cases.

**Bivolino**
New business models provide the opportunity to efficiently implement customer wishes in production. The company Bivolino is an example for made-to-measure as well as nearshoring production. (Winkler et al. (2019))

Following, two long-term advantages can be defined for Bivolino, in comparison to companies having their production plant in Asia. On the one hand, rising air transport costs do not have a negative impact on the company. On the other hand, there is the possibility of increasing efficiency and profitability of existing machines in Tunisia. At the moment, Bivolino uses processes from online order, fabric preparation, CAD (computer-aided design), programming and CNC cutting, which are completely automated. But the sewing process and fabric placement for the cutting machines is still manual. The Figure 20 shows, that Bivolino minimizes transport time and costs enormous due to nearshoring structures as well as automated processes. New business models provide the opportunity to efficiently implement customer wishes in production. The company Bivolino is an example for made-to-measure as well as nearshoring production. (Winkler et al. (2019))

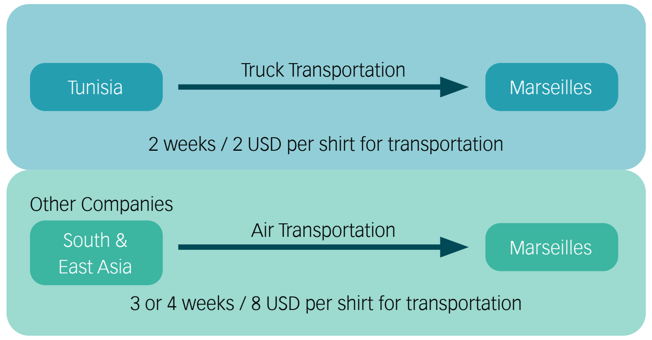


Figure 19: Transportation Advantages through Nearshoring (Altenburg et al. (2020)

**Zund UK** have partnered with Fashion-Enter to demonstrate a sustainable micro-factory concept in London, using the Zünd D3 Digital Cutting technology. The combination of high-performance digital cutting systems from Zund with highly advanced yet intuitive software, enables fully automated digital cutting with minimal manual intervention. The Zund UK and Fashion-Enter partnership builds a showcase for a sustainable micro-factory concept in the UK which uses the latest technology and advanced workflow processes.

Figure 20: Digitisation and automation are the path to the future, with single-ply cutting providing the solution to changing demands across the textile industry

Dean Ashworth, Sales and Marketing Director at Zund UK said, "The project is aimed at brands and retailers; we want to demonstrate to them how they can create a sustainable manufacturing facility in the UK. We believe onshoring apparel manufacturing will support the growing trend for made-to-order and ethical production. Furthermore, technology and production strategies are developing to deliver the capabilities needed to reshape the fashion industry. Zund single-ply cutters are setting new standards in speed, efficiency, and accuracy. The Zund D3 cutter delivers ultimate performance and productivity with two cutting beams operating simultaneously with sophisticated nesting algorithms increasing material yield and helping to keep production costs low." (Zünd Systemtechnik (2021))

# Acknowledgements

## About the Authors

**Alexander Artschwager** studied economics at the University of Stuttgart and is working since 1987 at DITF in the Center of Management Research. Together with the companies named in the whitepaper, he is responsible for the first conception and implementation of the Digital Textile Microfactory worldwide as well as the first realizations as show cases at trade fairs – with an influence on worldwide developments and implementations. At DITF he is jointly responsible for the conception of the Industry 4.0 activities and the setting up and expanding of a multifunctional laboratory with focus on digitization, demonstration and learning for industry and research.

**Marcus Winkler** studied economics at the University of Stuttgart and has been working for the Center of Management Research of the German Institutes of Textile and Fiber Research Denkendorf (DITF), since 1995. The research of Dr. Marcus Winkler includes Internet 4.0, Supply Chain Management and Business Models in national and international research and consulting projects.

**Lucie Brunner** made her Bachelor of Science in "Textile and Clothing Management" at Hochschule Niederrhein- University of Applied Sciences. She is currently a master student at Reutlingen University in "Textile Chain Research" and working as a research assistant at DITF, involved in the topics of nearshoring, Microfactory and related technologies.

## Contact options

**Mitwill Textiles Europe sarl**

Name: Hervé Francois

Address: 104 rue des Bains, F-68390 Sausheim

Phone: +33 688122112

Email: herve@mitwill.com

mitwilltextiles.com

**Assyst GmbH**

Name: Hans Peter Hiemer

Address: Max-Planck-Str. 3, 85609 Aschheim-Dornach

Phone: +49 89 90505-271

Email: hp.hiemer@assyst.de

assyst.de

**ErgoSoft AG**

Name: Anna Tobler

Address: Moosgrabenstr. 13, 8595 Altnau, Switzerland

Phone: +41 71 694 6666

Email: es.info@ergosoft.net

ergosoft.net

**Zünd Systemtechnik AG**

Name: Rolf Köppel

Address: Industriestrasse 8, 9450 Altstätten, Switzerland

Phone: +41 71 554 81 00

Email: rolf.koeppel@zund.com

zund.com

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Deutsche Institute für
Textil- und Faserforschung
Denkendorf
Körschtalstraße 26
73770 Denkendorf
Telefon: +49 711 9340-0
www.ditf.de