Far from the plastic baubles that fused filament desktop 3D printers fabricate layer after layer, new technology is inspiring innovation in traditional textile manufacturing.

Experimentation in 3D printing and textiles

The excitement surrounding 3D printing is turning the tables on traditional textile making, and particularly these machines' ability to produce objects of any shape, on the spot and as needed. Fabric and garment manufacturing rarely have the flexibility and customisation possibilities of 3D printing, and stand to gain by drawing on the abilities of these new devices. There is however one category of textiles that already functions on a basis similar to that of 3D printing: fully-fashioned knitwear is a process that knits in one go, a made-to-shape item of clothing requiring minimal finishing.

A technology talk at the trade show Performance Days in Munich last November discussed the possible links between 3D knitting and 3D printing. Joerg Hartmann, head of fashion & technology at Stoll, a company that manufactures flat-bed knitting machines, pointed out some of the similarities between the two techniques. Flat-bed knitting, he says, is "a highly versatile manufacturing method that produces fully shaped 3D panels". He went on to explain that flat-bed knitting is a form of "additive manufacturing" in that it "creates a product from the bottom up, as in 3D printing". In a way, he says, "we trick the machine to create a 3D shape out of a 2D panel".

In sports and medical uses, Stoll machines already knit to shape highly customised products. "We make high-compression braces that are based on body scans to fit each individual user perfectly. Like 3D printing, these products can be reproduced as needed," he explains.

Knitting is driving innovation in sports shoe uppers, as seen in Nike's Flyknit sneakers introduced in 2012. These are made of a single panel, knitted to shape, with no waste, and they can be engineered to offer varying degrees of support or



Hard Copy, the graduate collection of young designer Noa Raviv, is a subtle and intricate blend of pleated fabric and 3D-printed elements. "The tension between the real and the virtual, between 2D and 3D, inspired me to create this collection," she says.

Ron Kedmi



A 3-D printer developed by Carnegie Mellon University and Disney Research Pittsburgh feeds yarn into desired shapes and uses a needle to turn the yarn into a loose felt fabric object.

Carnegie Mellon / Disney Research

ventilation. A knitted shoe upper is said to take approximately 30 minutes to make. This is not a new technology, Japanese knitting machine maker Shima Seiki points out. "Almost any conventional knitting machine can knit shoe uppers. They are usually produced on 'shaping' machines that can knit products to shape rather than lengths of fabric from which product shapes are cut out and sewn together." Furthermore, it says that these uppers still require some sewing. "Shima Seiki goes one step further and offers a technology that knits an entire shoe upper in one piece without requiring any post-process sewing," says company spokesperson Masaki Karasuno. The machine produces a slipper-like shoe incorporating variations in knitting to form the upper and sole.

For sportswear, the Japanese company is introducing new developments in seam-free knitwear, a process it calls Whole Garment knitting. Thanks to progress made in material research, Shima Seiki says it can fine-tune the types of yarns and their placement to offer customised function and fit. Among the new options available, the company offers "pin-point pressure variations throughout the garment". Padding can also be knitted-in using spacer fabric knitting techniques, it says.

3D textile printers

While fully-fashioned knitting may be the textile industry's closest cousin to 3D printing, non-weaving may be the area where the new manufacturing paradigm could have the most impact. A number of research projects, in various stages of experimentation and scalability, are looking to produce non-woven textiles to specific shapes, like a 3D printer does. UK company Tamicare has invented a non-woven "textile printer" that makes disposable panties (see *WSA* January-February 2014, Fabrics: the next step in 3D printing?). CosyFlex, the name of the process, uses a patented combination of cellulose fibres and natural rubber latex that is sprayed onto a mould and produces a panty in just three seconds as it speeds along a conveyor belt. Different polymers can be combined and assorted ingredients or elements added during the process (cosmetic, medical or even electronic). "The options are virtually unlimited," says Tamar Giloh, founder of the Manchester-based company. Different surface effects are also possible, including mesh-like fabrics. In addition to the many customisation options, the company has focused on creating a machine capable of mass-production. Again, like 3D printing, CosyFlex produces no waste. "We reclaim the material that is over-sprayed during manufacturing," says Ms Giloh.

CosyFlex is one of the most advanced new machines in the pipeline, but has yet to come to market. Other non-weaving "printing" machines are in earlier stages of development. Californian start-up Electroloom is working on what it calls a "personal 3D printer for clothing". The process seems similar to electrospinning, as the three-person team's first experiments involved metallic chopsticks spewing out a web-like fabric. In June 2014, the first machine was up and producing seamless sheets, towels and pillowcases. The process starts "as a solution (in other words a liquid) of mostly synthetic polymers," says Joseph White, the company's computer engineer. He says that



An example of an object made by the 3D Weaver, the resin-coated 3D textile could be used for impact protection.

Guillaume Couche

the team has not yet focused on materials optimisation, and is prototyping various materials. It is not yet known either when the printer will be finalised.

Another nonwoven fabric printer in the works is a collaborative project between Carnegie Mellon University and Disney Research in Pittsburgh. The 3D textile printer turns wool or wool blend yarns into felt-like fabric objects. The project is headed by Scott Hudson, a professor at the University's Human-Computer Interaction Institute. The so-called felting printer operates like a 3D printer in that it starts with a digital file which determines the amount of yarn that will come out of the "printer head" and how it is placed. As the yarn comes out, it is pierced (or felted) by a barbed felting needle that scrambles the individual fibres into the accumulated layers underneath, entangling and bonding the layers together. This method is not capable of making a finished object with a precise shape, but can be used, Mr Hudson suggests, "to bridge soft and hard materials, to manipulate the degree of stiffness in soft objects and to incorporate electronic components."

A 3D weaving machine

Nigerian American designer and engineer Oluwaseyi Sosanya is working on a textile-manufacturing machine that is inspired both by traditional looms and 3D printers. He presented the 3D Weaver for his double masters degree at the Imperial College of London and Royal College of Arts in June last year, and says it has reached proof of concept stage. "Traditional textile looms create two-dimensional objects; even spacer knits have planar surfaces," he says. His research into ballistic textiles led him to try to produce a multilayered material, and this is where the connection with 3D printing comes in; the 3D weaver is based on a triple-axis structure, reproducing the X, Y and Z axes additive manufacturing machines use to make three dimensional objects. Mr Sosanya believes that without 3D printers, he would not have been inspired to imagine the workings of his invention. Like the Disney-Carnegie Mellon printer, Mr Sosanya's 3D Weaver uses a traditional yarn to make a 3D object, but on the 3D Weaver, each of the three axes can be adjusted to need. The first machine presented last June can produce textile structures with varying densities. The designer is now working on a second version that would have a "higher tolerance" and produce a "tighter pattern".

Focusing first on the different types of structures his 3D weaving machine can produce, Mr Sosanya has neither looked into



The 3D Weaver developed by Oluwaseyi Sosanya makes a 3D material using its triple-axis system that follows the same principles as the X, Y and Z axes of 3D printing machines.

Zuzanna Weiss

optimising the yarns (using only natural cotton for the moment) or the binders. Possible end-uses for these materials include shoe soles and shock protecting materials for fencing, taekwondo or American football. The small size of the current prototype machine limits research into larger structures, he says.

These new machines may one day produce one-off fabrics for specific end-uses, and shapes not possible with other manufacturing methods, just like rapid prototyping machines do in many high-tech industries today. Selective laser sintering is one such technique that produces objects no other machine can, said Karsten Bleymehl, owner of Materials Research & Consulting (MR&C), at the 3D printing and textiles talk at Performance Days.

3D printing in fashion

3D printed plastic elements have made various appearances in fashion, most notably in the couture collections of Dutch fashion designer Iris van Herpen. Some of the more flexible and possibly wearable dresses (like the Voltage 3D dress) were developed with Julia Körner, a designer who was voted most promising rising star by the Global 3D PrintShow in 2014. For her graduation collection, Tel Aviv-based Noa Raviv presented a series of garments combining 3D-printed elements and traditional textiles.

Like Oluwaseyi Sosanya, Noa Raviv was intrigued by the disconnection "between the two-dimensional nature of fabrics used to make three-dimensional wearable objects. Fashion is, in that respect, not logical," she says, and 3D printing can be considered more "straightforward". But that is not how she ended up using 3D printed elements in her collection. In her early attempts at preparing the computer files to send to a 3D printer, the coding contained errors that the machine somehow managed to produce. "The object was the result of a computer-generated mistake, but how could a computer possibly make a mistake?" she wondered.

In addition to the new language of 3D printing, the young designer was also excited to be able to create shapes that are "barely imaginable, and quite different from drawing and draping". The 3D-printed elements in her collection, called Hard Copy, integrate some of the computer glitches of her first (mis)steps in coding, and were made on a Stratasys Objet500 Connex3 Multi-Material 3D printer. She attached them to intricately pleated and shaped textiles. The two manufacturing methods are cleverly merged so that it is not immediately clear which one is fabric and which one is plastic. "I find it interesting to combine the two techniques, the hand-made and the computer-made. As a designer I think it's important to keep traditional manufacturing methods alive while seeking to modernise them," she says.

Knitting fab labs

There is yet another field in which new approaches to manufacturing are converging with traditional textile techniques. Within the vast maker movement, there is a trend to "hack" home flat-knitting machines to use them like 3D printers. Tricodeur, an art project residency organised by Sew & Laine, an association specialising in fashion and digital arts based in Bordeaux, France, invited French designer Louis Eveillard to a "knit hacking" session last autumn. The project was based on retrieving open-source internet data, such as Facebook profiles or Twitter feeds, to design patterns reproduced by the knitting machine. "It is a way to help people visualise the information they leave on the web by representing it graphically in a knitted object," says Mr Eveillard, who has studied both computer coding and knitting. Eugénie da Rocha, Sew & Laine founder, now plans to create the first knit fab lab in France. Across Europe, similar projects are under way, such as the Knitic project in Spain.

As 3D printing shops are expected to become part of the urban landscape, the prospect of seeing 3D knitting shops open around the corner may also be forthcoming. Such a project is actually currently in operation in London, at Somerset House, where Knyttan, a start up, has installed a Stoll flat-bed knitting machine. This "Factory of the Future" allows consumers to create personalised designs and have them knitted into merino wool scarves or jumpers on site. Joerg Hartmann, from Stoll, helped the team, headed by Ben Alun-Jones, set up the machine and learn how to programme it. Examples of knitting-to-measure shops have existed in the past, says Mr Hartmann, but with little success. That was before the maker movement emerged promoting a very 21st century ethos of empowering individuals to make their own products. The concept of manufacturing to shape, with little or no waste, and the countless customisation options of 3D printers may yield novel products and manufacturing techniques in both sportswear and performance materials.



The Kinametics Dress by Nervous System is one of the first 3D printed dresses to move with the body utilising its 2,279 triangular panels interconnected by 3,316 hinges, all 3D printed as a single piece in nylon. It was recently acquired by MoMA, the New York Museum of Modern Art.

Steve Marsel