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Diginova

Summary

The project Diginova is examining the status and development of Digital Fabrication. Over the last two years a lot of roadmaps have been analysed and condensed in order to establish the current status of Digital Fabrication in Europe and to recommend steps for further development. The research revealed that in addition to Digital Fabrication challenges, there are also a number of good examples illustrating how specific challenges can be overcome by employing Digital Fabrication methods. In this deliverable we describe four case studies that demonstrate the benefits of Digital Fabrication in different market areas. The following listing is in alphabetical order.

Ceramic tile industry

The décor of ceramic tiles can be modified easily and in short periods of time by employing inkjet technology.

Medical support

Splints can be manufactured by additive manufacturing (AM) methods after having determined the patient's individual measurements.

Printed Optics

Lenses can be manufactured employing AM technology, enabling the production of individual eyeglasses.

Textile industry

Reduced run lengths and fast collection changes can be handled by changing from screen to inkjet printing technology.

Specific descriptions of these four cases are given in the appendix.

DIGINOVA WHITE PAPER

The challenges of ceramic tile digital decoration and how Xaar has overcome them

Digital inkjet printing has revolutionised ceramic tile manufacturing in a very short time. Just over a decade ago, the only way to decorate ceramic tiles was using traditional printing methods, the most common of which was screen printing. This was a mature technology with little scope for innovation; it was difficult for ceramic tile manufacturers to make their products stand out from the competition and differentiation was mostly down to price. The process had other disadvantages, including high set-up costs, long production runs, and the difficulty of exactly matching tile colours on repeat orders.

Today, digital inkjet is the “must have” technology for ceramic tile manufacturers. It is no longer a case of offering digital tiles as an “optional extra”; digital capability is expected, and digital inkjet is the only viable option. In Europe the majority of ceramic tile manufacturers in the major producing countries, Spain and Italy, have already converted to digital inkjet printing. By doing so, they have cut production costs, reduced waste, cut work-in-progress and stocks of finished products, and slashed turnaround times. These ceramic tile manufacturers are also producing higher-quality tiles that offer more realistic reproduction of marble and other natural materials. They are doing so in the short runs that buyers demand – using digital, a single ceramic tile can be produced cost-effectively. Instead of competing on price, these manufacturers can compete on creativity and innovation, and do so in new markets.

The change from traditional to digital ceramic tile decoration is gathering momentum around the world. As worldwide production of ceramic tiles grows it is creating huge opportunities for suppliers of digital inkjet ceramic tile printers and ceramic inks.

The market and production process
In 2012, the global production of ceramic tiles was 11.1 billion m^2 – a rise of 6.2% over 2011. China is responsible for the biggest volume (46.5%), followed by Central & South America (11.7%), MEA (11.5%) and the European Union (9.7%).

The sheer scale of ceramic tile production facilities is also impressive. They occupy significant areas of land, situated close to the raw materials they consume. Large manufacturing facilities are needed to house the large-scale mechanical equipment the process employs – hydraulic presses, ceramic tile kilns, etc. Traditional manufacturing sites also need large areas in which to store work-in-progress and finished tiles.

The large ceramic tile manufacturing plants house a capital-intensive process that uses enormous amounts of water, hydraulic pressure and heat, among other resources, to power the huge presses and kilns that turn the raw materials into finished tiles. Due to the drawbacks of traditional printing methods, considerable space is also needed to store work-in-progress and finished tiles.

How tiles are made
The first step in manufacturing ceramic tiles is to quarry and refine the various sands, clays and other raw materials used. These are then transported to the ceramic tile plant, where they are stored until required.

The materials are dry and in powder form when they arrive. The powders must be milled into finer powders before they are mixed in the right proportions and fed into tanks where water is added. The liquid material this creates is called “slurry”. The next stage is to return the slurry to a powder form, which is done by spraying it into a large tank and feeding in a current of hot air. As the slurry becomes airborne it rapidly dries to form a fine, atomised powder.

The powder is then ready to be moulded into a ceramic tile body. Large hydraulic presses are used to compact the powder under extremely high pressure — up to 400 kg/cm^2 — which generates a lot of heat. The combination of the heat and pressure from the press, forms the unbaked tile, or “biscuit”. The press also gives the ceramic tile its size, shape and, in the case of digitally-decorated ceramic tiles, its texture. The tile may then be dried further to remove more moisture and ensure it remains stable on its way to the kiln.

The residual moisture in the powder gives the “biscuit” some strength, but as the name suggests, it is still very fragile. After applying the glaze, a glass-like matt or gloss liquid coating, the tile is now ready to be decorated. As we explained in the Introduction, screen printing (flat or roller) has traditionally been used, applying each of the colours in the pattern using a separate roller. (We will look more closely at what the printing process involves in a moment.) As well as enhancing the aesthetic appeal of the tile, glazing and printing add features such as water repellency, durability and hygienic properties to the product.

The final stage in production is to fire the tile in a kiln. This process solidifies the body of the tile and fuses the glaze and the decorative inks to generate the final pattern on the tile. The kiln is usually the most expensive piece of equipment in the manufacturing plant and it is therefore optimal to keep the kiln running 24 hours a day, 7 days a week, avoiding wasting energy each time it has to be ramped up to the correct temperature. As a result, there will often be more than one ceramic tile production line feeding each kiln with tiles ready for firing.

Kilns come in different designs, but a roller hearth kiln — the most efficient — can be several hundred metres long. As the tiles pass through the kiln — which can take over an hour — the temperature gradually increases until at the centre of the kiln it reaches around 1200ºC. After this, the tiles cool down before they leave the kiln. They are then sorted into batches and large stacks of identical finished tiles are stored ready for distribution.

The limitations of the traditional process
The traditional production process has several disadvantages. For one thing, the kiln is most efficient when handling large batches of tiles — yet consumers and retailers increasingly demand short runs and "Just in Time" deliveries. The most serious weakness, however, is in the decorating process, because roller screen printing is a contact printing technology. This has a negative impact on ceramic tile manufacturing in a number of important ways. For example:

● **Long set-up times:** The biggest disadvantage of conventional decoration is the amount of time needed to set up the printing jobs. It can take as much as 30 minutes to change the rollers and wash down the printer.

● **Patterns repeat frequently.** The circumference of the roller determines the length of the image it can print, and therefore how frequently the pattern repeats. This limits design options and makes tiles less life-like.

● **Only flat tiles can be decorated.** A contact technology cannot print on textured tiles, but only on flat tiles. In addition, screen printing cannot print right up to the edge of the tile, so tiles have a white, unprinted border.

● **Tile breakage is more common.** Printing takes place while the tile is still fragile, and the pressure of the roller on the "biscuit" can easily fracture it. Each time a tile is broken, not only is the biscuit wasted, but also the glaze and the inks. Combine this with the reduced output and it is clear that there are significant cost penalties.

● **Colour management is difficult:** Ensuring consistent, repeatable colour is important in all print applications, but especially so in ceramic tile decoration. The problem is that the colour of the tile when it leaves the decoration printer is different from the colour after firing. The extremely high temperatures in the kiln fuse the frits in the glaze with the pigments in the inks and reveal the true colours of the tile. Each roller change has to be followed by at least one test-firing of the printed tile to check colour, which can bring the total changeover time to two hours, and cause more waste and extra costs.

● **Inflexible production planning:** The inflexibility we have described makes production planning very difficult. For example, the combination of long set-up times and tricky colour management works against those short runs and "Just In Time" supply chains that the market demands. Also, consider what happens in the decorating department at the end of a typical two-shift working day, when the manager receives the patterns for the next day. First, the operator changes the roller sleeves. Next, he prints some sample tiles and takes them to the kiln for firing. This takes at least an hour and a half. If the colour is right, his job is done. If it isn't, he has to start the process all over again. And all the time materials are being wasted and costs incurred.

- **High stocks of finished goods and work-in-progress:** The need to operate the kiln 24/7 and the difficulty of matching colours encourage long runs and the holding of substantial stocks of finished goods. If a repeat order comes in, it is easier to meet it from existing stocks than to try to reproduce exactly the same colours and take the risk problems caused by poor batch control or a slight change in the glaze. (We are all familiar with checking batch numbers when we buy ceramic tiles.) The same is true of work-in-progress, large batches of which are often stacked around the factory awaiting test firings to verify the colour consistency. Furthermore, space must also be found to store the screen drums needed to produce repeat print runs.

THE DIGITAL SOLUTION

Clearly the ceramic tile manufacturing industry needed a decorating solution that overcomes the very considerable challenges described above. What's needed is a printing technology that, among other things, doesn't break tiles, has minimal job changeover and set-up times, offers effective colour management, and can produce short runs. If it can also apply much more life-like patterns, including textures, expand creative design opportunities, even better. Finally, we want it to do all these things reliably, shift after shift, be straightforward to integrate into the existing production line, and pay for itself in just six months.

The benefits of digital inkjet

Digital printing, using various technologies, has been around for some time. Digital printing's history in ceramic tile manufacture is shorter, however. The first digital printer to use inkjet technology to decorate tiles was launched in 1999 by KeraJet with very limited success, and it wasn't until 2008 that digital tile decoration really broke through and became the "must have" process it is today. The catalyst was the launch of the Xaar 1001 printhead and its integrated ink recirculation technology.

Non-contact

For ceramic tile decoration, the first major advantage of digital inkjet is that it is a non-contact process. The distance between the substrate (the ceramic tile) and the printhead is generally 3-5 mm. This means that, unlike in the rotary screen process, no mechanical pressure is put on the ceramic tile, which, as we know, is fragile. As a result, breakages are minimised.

Non-contact also means that digital inkjet printers can print on uneven surfaces to create textured tiles. The texture is added to the ceramic tile biscuit during the pressing process, and the printhead is then able to jet ink into the recesses that rotary screen printing cannot reach. Digital inkjet printers can also decorate right to the edge of the tiles, eliminating white edges and creating seamless expanses of tile.

Ceramic tiles printed using Xaar 1001 and Colorobbia inks

Creative benefits
Digital inkjet printing has a number of creative benefits. There is no roller, so there is no forced limit to the pattern size. With digital inkjet printing the size of the pattern is only limited by the size of the memory of the printer control electronics. Xaar's next generation of printhead electronics, for example, can store enough data to reproduce a pattern of 40 m^2 with no repeats.

Inkjet printing can also apply designs of the highest quality and in the finest detail, creating extremely life-like ceramic tiles that are very difficult to distinguish from real marble and stone. The 360 dpi resolution and greyscale technology used in the Xaar 1001 printheads can reproduce an effective resolution of around 1000 dpi, which is as much as a good human eye can distinguish.

Inkjet printing used to create ceramic tiles that are very difficult to distinguish from real marble and stone.

Faster set-up
On a digital inkjet printing line the set-up is handled by the print control software, so there is no need to physically change the rotary drums to print a new pattern. It is therefore easy to print short runs. The operator can even interrupt a production run to test-print a number of different patterns in preparation for the next day's production; there is no need to wait until the end of the shift. The minimum print run with digital inkjet printing is just one tile, which is ideal for producing test tiles and also perfect for the short print runs required today.

Colour management, too, is software-controlled and is a more sophisticated and predictable process than on a traditional printing line. This has led to reductions in the number of glazes and ink sets used, further improving the efficiency and reducing the costs of ceramic tile manufacturing. Taken together, these factors make it easier to replicate patterns and colours, and have a significant positive impact on the stocks of work-in-progress and finished products that have to be held. Being able to fulfil a repeat order, for example, only depends on having the pattern stored digitally and the ink vendors supplying the same ink.

Rapid payback — in less than six months
The final argument in favour of digital ceramic tile printing is that, thanks to all the above benefits, a digital inkjet ceramic tile printer can pay for itself in less than six months.

The non-contact digital process enables printing on uneven surfaces to create textured tiles.

This is because costs are lower, due to reduced tile breakages, less ink consumption, and the lower ink prices from the open ink model. Faster, simpler set-up enables the short production runs that the market demands, and makes the production line much more flexible. Reliable software-driven colour management reduces stocks of finished tiles and work-in-progress, freeing up capital. Digital storage enables patterns of almost infinite size. Lastly, profit margins are higher, because the final products are of higher quality, closely resemble real marble and stone, and exhibit greater creativity than traditionally-printed tiles.

Digital inkjet technology

The reason why almost a decade passed between the launch of the first digital inkjet printer and the real start of the digital revolution in the industry in 2008 is because it took time to develop printhead technology to print tiles consistently, to the right quality, and reliably.

Digital ceramics printheads use drop-on-demand (DOD) inkjet to image tiles. The active components in the printheads are made from a ceramic material (PZT) that flexes when a voltage is applied to it. The Xaar 1001 printhead family employ PZT material in a unique Hybrid Side Shooter™ architecture.

Piezoelectric printheads can work in two ways: direct (bend) mode or shear mode. In direct mode, the electrical field (voltage) is applied to the PZT material in the same direction as it is polarised which causes it to change in height and width (becomes longer and thinner). It is this expansion that is used to push or bend a membrane and force a drop of ink out from the nozzle in direct-mode end-shooter printhead architectures.

Xaar printheads work in shear mode. The Xaar 1001 uses Xaar's patented Hybrid Side Shooter™ architecture and so the electrical field is applied perpendicular to the polarisation of the material. This causes the piezoelectric crystal to shear, rather than lengthen or shrink. Using two pieces of ceramic material for the wall of the ink chambers, and then applying the voltage, causes the composite material to flex in the middle: the effect resembles a chevron. The chevron flexing is done at a very high frequency which creates an acoustic pressure wave that travels through the ink chamber. It is the pressure wave that forces the ink out through the nozzle in a droplet. This chevron structure is very energy-efficient, reducing the driving voltage required and so reducing power consumption and heat generation. For example, the Xaar 1001 uses less than 1/3 voltage compared to direct mode DoD digital inkjet printheads.

Two chevrons are used to create the walls of each firing chamber, the top of the chamber is also PZT, and the bottom is formed with Xaar's patented nozzle plate. The nozzle is therefore perpendicular to the flow of ink through the firing chamber and hence we have Xaar's unique Hybrid Side Shooter™ architecture (HSS™).

The Xaar 1001 printhead

All this takes place on a micro scale. Inside a typical printhead, the ink channels are only a few tens of microns across and the nozzles are typically 20-50 microns (μm). A 1 picolitre (pL) ink droplet is typically 13 μm in diameter. Compare this with the width of a human hair, which is approximately 80 μm.

The ceramic decoration environment is challenging

Ceramic decoration presents several challenges. Firstly, the manufacturing process generates a lot of dust and debris, because the raw materials are powders. In addition, after leaving the press the unfired ceramic tiles are fragile, hot and steaming. Secondly, to produce vibrant colour, ceramic inks contain large, insoluble particles of pigment, packed tightly together and held in suspension. This makes the ink very viscous and liable to settle, causing sedimentation.

The first digital inkjet tile printers could not cope with these challenges. The early printheads required regular maintenance to clear the nozzles of ink and other debris. This meant printing had to be stopped after only a short time to clean the printheads.

There were other problems as well: the print quality was poor, due to the low resolution produced by the binary printheads; replacement parts were expensive; and inks had a limited colour range and were expensive. The major drawback, however, was the unreliability of the printers, which led to excessive production downtime. As the printing has to be single-pass to achieve the throughput required for industrial-scale decoration, all the nozzles must be working to their full potential all the time.

The major reason for the problems with early piezoelectric printheads was their design: most were based on what is called the “end-shooter architecture”. In an end-shooter printhead the firing chamber has one ink inlet and one outlet (the firing nozzle), and the ink flow is from inlet to outlet. The potential “Achilles heel” with all end-shooter designs is that nozzles can fail, either because they are blocked by particles in the firing chamber, caused by agglomeration of the ink or the ink settling in the chamber, or by air bubbles forming, which also blocks the nozzles. Such a failure then requires a “purge/wipe” maintenance routine before printing can resume.

These issues with end-shooter printheads held back the adoption of digital decoration until 2008, when Xaar launched the Xaar 1001 printhead. The Xaar 1001 features a number of major innovations that have transformed the market’s perception and experience of digital decoration. The Xaar 1001’s most important new features were its Hybrid Side Shooter™ (HSS™) architecture and patented TF Technology™ ink recirculation; complementary technologies that work together to deliver unrivalled reliability and maximum production uptime. As described earlier, as well as an inlet and an outlet for ink flow, HSS™ has a separate nozzle in the side of the ink channel – not at the end – through which the drop of ink is fired perpendicular to the flow of the ink. Added to this, the unique TF Technology™ – the only true ink recirculation system – ensures the highest ink flow across the back of the nozzle during drop ejection, which carries any particles or trapped air bubbles away in the ink path, not forcing them into the nozzle. This means nozzles are continuously primed and kept blockage-free, ensuring that the printhead is fully operational for the maximum length of time. The Xaar 1001 is self-priming, so self-recovery is fast after, for example, a mechanical shock. Only one tile will be lost and there is no need to stop the whole production line.

Ink recirculation is vital

The importance of TF Technology™ ink recirculation cannot be stressed too much. Ink recirculation keeps the ink in constant motion, preventing sedimentation and nozzle blocking. This is essential when printing heavily-pigmented, highly-viscous ceramic decoration inks, and the Xaar 1001 can jet inks with a much wider viscosity range than can other printheads.

TF Technology™ solution to ink recirculation, where high volumes of ink are circulated past the back of the nozzle during printing – at a higher flow rate than any other printhead – is unique to Xaar piezoelectric printheads. Other manufacturers offer what they call "recirculation" but they use different methods. For example, in many other printheads ink circulates in an upper chamber of the printhead but not in the lower chamber; i.e. there is no recirculation past the back of the nozzles in the lower chamber.

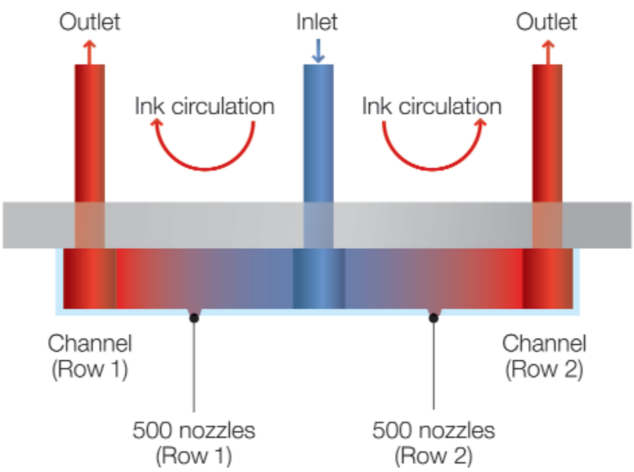


Illustration of TF Technology™ (ink recirculating past the back of the nozzle) in a Xaar 1001 printhead.

The piezoelectric material sits on the roof of the lower chamber and presses downwards to push the ink down and out of the nozzles. This creates a vacuum and ink is sucked into the lower chamber from the upper chamber. Any debris or air bubbles that enter, or accumulate in the lower chamber can still only be removed by pushing them out through the nozzles, which can cause the nozzle to block.

Therefore, printheads without TF Technology™ are less reliable, leading to longer and more frequent maintenance cycles, increased downtime and a higher cost of ownership.

Outstanding print quality

The Xaar 1001 drove major advances in digital inkjet decoration in other ways as well, particularly in delivering outstanding print quality using XaarDOT™ greyscale technology. XaarDOT™ allows variable-sized drops of ink to be placed on the tile. There are several advantages in variable drop size. The high native nozzles per inch (360 npi) of the Xaar 1001 printheads enables pin-sharp patterns to be achieved using the smaller drop sizes; and drop size selection allows printing on tile types of different absorbency and into different glazes, enabling a much wider gamut of colour to be added to the tile.

To print variable drop sizes — described as "greyscale printing" — small droplets are fired very rapidly, one after the other. These "sub-drops" coalesce as they leave the nozzles. In the Xaar 1001 GS6, each sub drop is 6 pL, which creates seven final drop sizes from 6 to 42 pL. Drop sizes can be chosen dynamically. In fact, combining the high native resolution with greyscale means that the Xaar 1001 printheads have an effective resolution of over

1000 dpi, which is at the limit of what the human eye can perceive. In other words, the image appears perfect at normal viewing distances. This results in amazingly life-like images and sharp text with the Xaar 1001 GS6.

The Xaar 1001 GS12 printhead jets larger 12-84 pL drops, delivering even more ink for bolder tile colours and effects. Alternatively, the Xaar 1001 GS12 can deliver the same ink coverage as the Xaar 1001 GS6, but at double the print speed. With both printheads the improvement in the quality of print is significant compared to what can be achieved with binary printheads, where the drop size is always the same. This enables ceramic tile manufacturers to achieve a stunning replication of natural materials like marble and granite, as well as highly decorative creative new designs.

Continuing developments in printhead technology will further advance digital decoration. Xaar is working on delivering higher speeds, more colour and more special effects – enhancements that will enable innovative manufacturers to create tiles for even more applications. Digital is freeing the ceramic tile industry to explore new frontiers in a market with almost limitless potential.

XAAR®

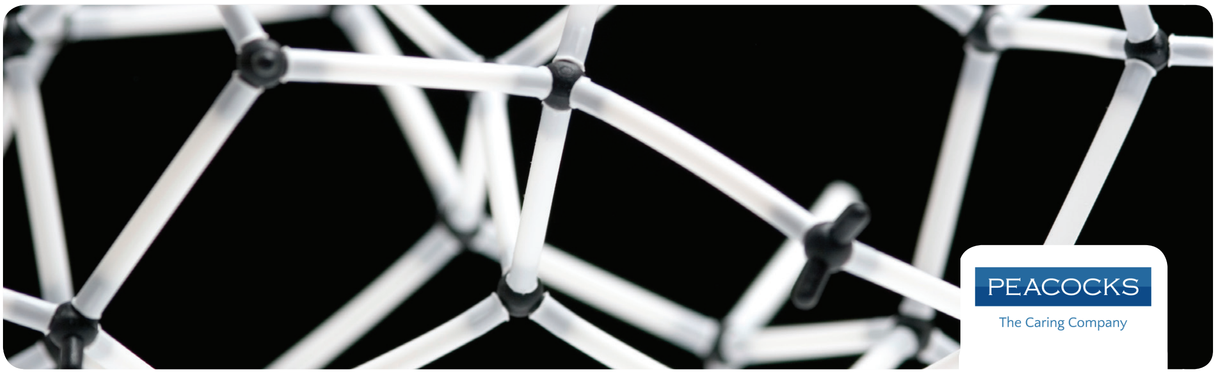
Prepared for Diginova by Xaar

Xaar is the world's leading independent supplier of industrial inkjet printheads, inks and systems components to commercial printing and industrial manufacturing markets. Xaar's innovative technology offers OEM customers and licensees commercial advantage through product differentiation, productivity, and faster time-to-market. Additional information about Xaar is available at www.xaar.com

Diginova

cpi ...the future inspired

Additive Manufacturing for Medical Applications

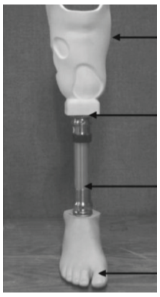


Medical Applications

The Medical industry is one of the three fastest growing sectors for additive manufacturing alongside automotive and aerospace. The technology's success in the medical sector rests with its ability to create orthotics, prosthetic and personalised implants.

Orthotics are external devices that support the body, realign it or redistribute pressure. Prosthetics are replacements for part of the anatomy and can be internal or external.


Orthotics


Prosthetics

Peacock's Medical Group

Established in 1903, Peacocks Medical Group has been supplying medical equipment and services for over 100 years. A multi-award winning family-run group based in the North East of England, Peacocks provide outstanding care in the delivery of both services and equipment to the NHS and private sector on a national and international scale.

Traditional Manufacturing: The Industry Needs to Change

The traditional approach for creating orthotic and prosthetic solutions for patients is outdated, with a need for more sophisticated working methods:


(Pallari, 2013)

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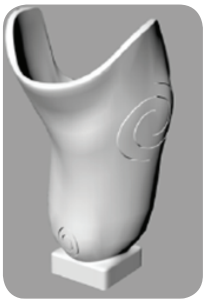
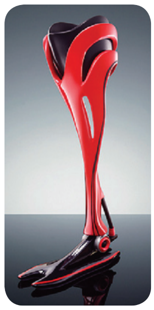
The Advantages of Additive Manufacturing

Unlike most conventional manufacturing techniques, additive manufacturing creates 3D objects by building matter up rather than removing it. Enabled through computer-aided design (CAD) software, and 3D printers the technique is used to create new, innovative models with unique material properties.

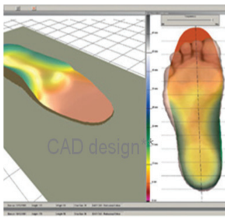
- Easy to manufacture bespoke parts
- Digital design
- Automatic manufacturing
- Functional integration
- The potential for innovation and personalisation is huge

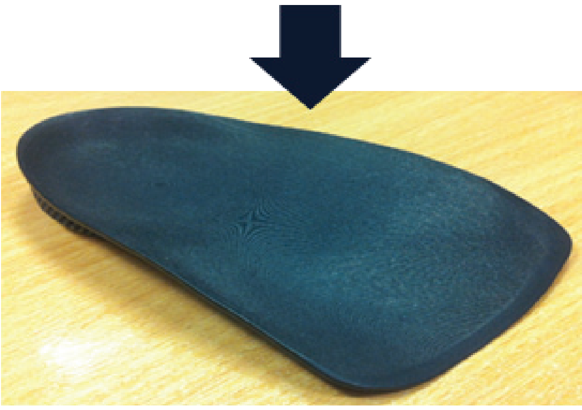




Peacocks Medical Group are currently working with a number of academic and industrial partners regarding commercialising additive manufacturing for customised orthotics. They were an active partner in the recently completed A-Footprint project. This was a joint research and innovation initiative with the objective to develop novel ankle/foot and foot orthoses for common disabling conditions, which are cost effective, high-speed to market, and personalised for form and function.

The Additive Manufacturing Process



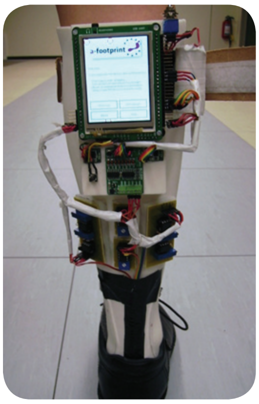


(Pallari, 2013)

Functional Integration in Additive Manufacturing

The technology has great potential to change the lives of many disabled people. So far the potential is largely untapped because of factors such as unfamiliar materials, a lack of knowledge in CAD/CAM and cost. Nevertheless, engineering principles and methods are changing through functional integration.

Functional Integration is imitating the functionality of separate parts/materials in a single part through "clever" design. Within additive manufacturing the actual making of complex parts is not an issue. The innovation lies within the design. Functional integration is important because as it is a digital design environment, the procedure can be controlled very precisely, optimised, automated and repeated. The technology allows the precise placement of external components such as reinforcements, hinges, sensors and activity monitors. All of this adds value and differentiates products.



(Pallari, 2013)

www.bespokeinnovations.com

Personalised Foot Orthoses with Embedded Temperature Sensing

Peacocks Medical in conjunction with Glasgow Caledonian University and Newcastle University conducted a study to test novel designs for foot orthotics with embedded sensing (produced using additive manufacturing techniques) to determine if foot temperature measurements could be used to detect periods of increased activity. The foot orthotics produced were developed and tested in 10 healthy participants over four day wear periods. Activity monitoring was used to estimate energy expenditure during testing. A threshold based algorithm was developed to identify time periods of high activity from foot temperature data.

Achievements

All foot orthotics and their temperature sensors used in the study performed in a reliable manner over each test period. The study demonstrated that foot orthotics with embedded sensing technology can be used to monitor foot temperatures in healthy subjects over extended time periods. Temperatures measured at the plantar surface of the foot were on average higher than the ambient in-shoe temperature.

The nature of the additive manufacture process used to fabricate the devices meant that the additional complexity associated with including sensor holders in the design did not add additional costs to the manufacturing process.

For more information:

Telfer S, et al. Personalized foot orthoses with embedded temperature sensing: Proof of concept and relationship with activity. Med Eng Phys (2013), http://dx.doi.org/10.1016/j.medengphy.2013.08.002

Pallari 2013, 3D Printing, Additive Manufacturing and P&O – Where are we now?, PowerPoint presentation, presented at Biomedical Applications for Digital Fabrication, Peacocks Medical Group, Newcastle. Available at: http://www.diginova-eu.org/content/dam/diginova/en/documents/1311_Pallari_Peacocks_Medical.pdf

The LUXeXCeL® Story

The LUXeXceL Story, As Told by the Founder And CEO Richard Van De Vrie

Back in 1991, I was one of the founders and CEO of an innovative family-owned lighting company designing and manufacturing private label fixtures for several of the larger European OEMs. As an early manufacturer of LED lighting products, we learned that it was very difficult to make money in a fast changing environment. Before we could start the manufacture of a new product, we had to make huge upfront investments in molds and buy large inventories of LED engines and optics. In most cases, the period of development, from idea to product launch took over a year. In particular, the optics were often the most time-consuming part of the product development process.

Also, once a configuration of LED engine and optics were decided on, we became dependent on our chosen part suppliers -- all flexibility to buy it from alternative vendors was gone. If the supplier had a problem with those key components, we could not ship finished products, could not bring in revenue and our inventory of part-built products piled up, waiting for that back-ordered component.

Sourcing prototypes and tooling for optics was expensive and often a surprise. New, better LED diodes are introduced every month and our customers asked for better performance using those newest components. To keep up with these rapid changes, we wasted huge inventories of engines, optics and molds.

By 2008, we had built up distribution in 45 countries and counted some of the world's major lighting companies as our customers. We successfully sold the company to Lighting Science Group (www.lsgc.com). However, along the way we learned the hard way, the difficulty of making profitable products in the fast-changing LED Lighting Industry.

From Frustration to Innovation

With a group of friends, we discussed and investigated how to make the manufacture of optics more flexible and less capital intensive. We looked for a process that didn't need expensive and inflexible tooling like injection molding. We looked at 3D printing technologies but all printed layer-on-layer and printing smooth, clear surfaces was not possible. In particular, we wanted to have a process that supported volume manufacture, as well as Rapid Prototyping. That led us to research fast wide-format printers and after much experimentation and several breakthroughs, which we patented, we developed a new process that enabled us to make optically smooth surfaces directly from the printer.

Foundation of LUXeXceL

From the moment we saw that we could change the direction of light and could make magnifying structures, we knew that we could create change. I gathered an experienced team of friends and advisors and formed LUXeXceL. From day one, we sought to build the company with international vision, potential and reach, and with a global structure.

As inventors of a new process technology, we focused for the first years on further building the capabilities of the "Printoptical" printing process, protecting the IP we had and continue to develop. We also focused on building an experienced team. Many of the leaders, staff and advisors of LUXeXceL are lighting industry veterans. They know the challenges of manufacturing lighting fixtures, understand the changes that the rapid shift to LEDs as a light source are bringing. They have many great contacts globally. The prime focus of LUXeXceL today is the printing of non-imaging optics, optical structures and diffusers for LED lighting fixtures.

Printoptical Technology - A New Digital Future for the Optical Industry

The LUXeXceL Printoptical technology releases Optics Designers from the limitation of molds and tools, from huge upfront investment and costly modifications and limitations of what can be tooled, as well as eliminating high minimum order quantities that cause much financial stress and result in large parts inventory.

Our printing process works directly from a CAD file and enables Optics Designers to test their designs in an affordable way. It also allows experimentation with and production of more complex free-form designs directly. This "Printoptical Liberation" sets them free to think of and create new complex designs, combinations of textures and optics, test different ideas and finally to make new customized products.

Instead of settling for a limited range of round or oval beam angles, it now even becomes possible to customize a fixture to have the ideal optic customized and optimized for each project or application so a perfect lighting distribution can be achieved on every location. For example a square painting asks for a square light distribution outlining the painting exactly, not the wall or the ceiling. Street lights are not installed to illuminate gardens or shine into bedroom windows, now with Printoptical each fixture can light up only the road and sidewalk, saving both energy and light pollution. These new capabilities we offer will change the way lighting designers and architects work and will reduce the R&D lighting fixture development time while increasing the OEM's range of possibilities and customized offerings.

These digital design and digital additive manufacture printing process also will become used for many more applications in several optical industries. We are convinced that with the Printoptical Technology a new future has started, digitizing the optics manufacturing. A "next big thing" that will have significant impact in future optical landscape!

Recognition of Technology

After all the work our team has done, it is fantastic to see so many people understand the possibilities and advantages of printing optics. In 2012 just before the Frankfurt Light & Building fair, we started talking about printed optics to the LED Lighting Industry.

In May 2012, Terry Wohlers, a leading analyst covering the world of 3D Printer, recognized LUXeXceL's Printoptical process as a key emerging technology as we are able to print smooth optical surfaces on fast wide-format printers and combine that with full color textures. Terry is the author of the annual State of the Additive Manufacturing Industry (www.luxexcel.com/news/wohlers-report-2012/).

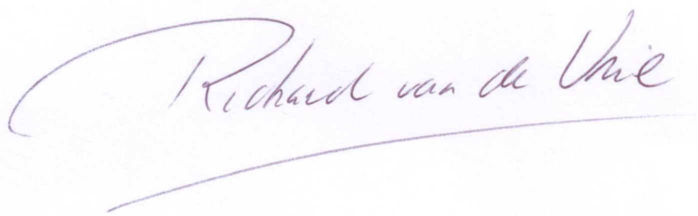
In September 2012, Frost & Sullivan recognized us for our pioneering manufacturing process that addresses the key challenges to large scale adaption of LEDs in general lighting (http://www.luxexcel.com/news/frost-sullivan-award/).

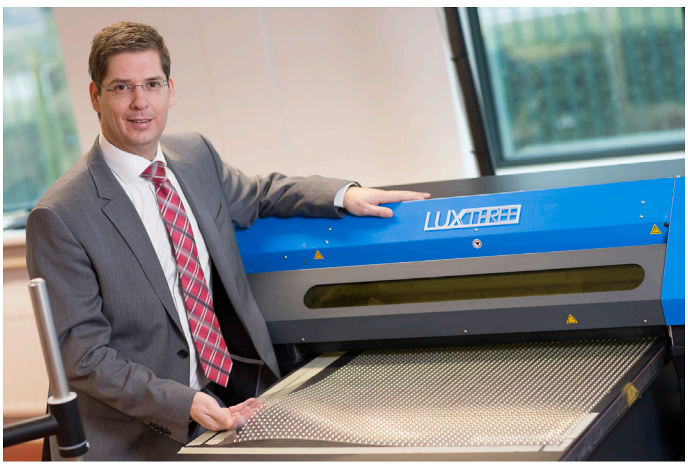
However, we are most excited by talking with our customers and partners at many lighting companies, universities, chemical and printing companies about ideas to use or further improve our printing process and products.

What LUXeXceL Is About

Our goals are to help lighting, product and optics designers and engineers to develop new optics, optical and diffusing structures faster, cheaper and in more flexible ways. We aim to offer competitive advantages to industries reducing upfront investments in tooling and inventories. Also, we help companies reduce waste and capital intensive upfront investments by offering the possibility to order "On Demand" lower volumes of optical components (e.g. 1, 100, 500, 1000 or 10,000 pieces). Modifications in the optics they buy are as easily as changing a design in a CAD file.

With such a great team of employees, advisors and strategic investors and with help of our customers, suppliers and partners, I have full confidence that LUXeXceL will continue to lead the path of digitizing the optical future. You will hear more from us!





LUXeXceL®

LED Lighting Optics

PRINT OPTICAL CAPABILITIES *version 5, April 2013*

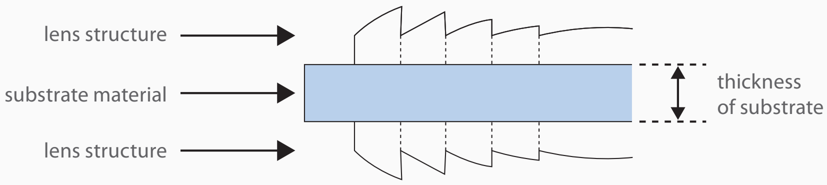
LED engine specifications — We can work with any LED engine or LED diode.

Geometrical specifications substrate

Print area	700 x 1400 mm
Thickness of substrate	Sheet: 1.50 mm; 2.00 mm; 3.00 mm
	Film: 300 microns; 500 microns[1]
Substrate material	Sheet: Acrylics (PMMA) or Polycarbonate (PC)
	Film: Poly-Ethylene Terephthalate Glycol (PET-G) or Polycarbonate (PC)
Temperature Range	-18° C / + 60° C (-0.4° F / + 140° F)[2]
UV-Stability	LUXeXceL optics can be used for indoor applications
Flame rating	PC: UL94 V0 Din 4102 B1
For sheet material, not for foils. (PC foil only has UL94 HB)	PMMA: UL94 HB Din 4102 B2 BS476 Pt. 7 class 3

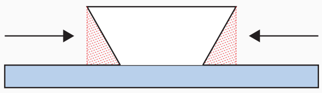
Larger printed areas, other and/or thicker materials on request.

[1] On film a limited lens height of 0.50 mm.
[2] Avoid rapid temp. changes to minimize stress.

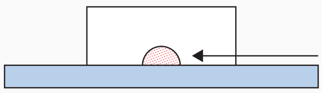


Geometrical specifications optics

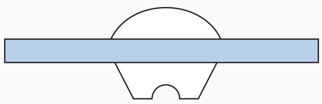
No overhang or undercuts



No Hollows

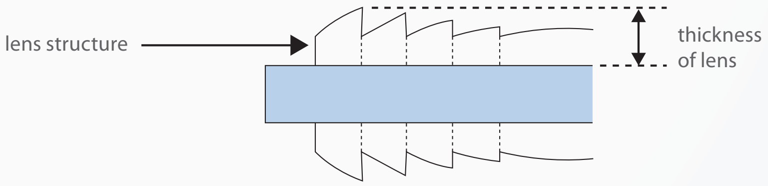


Possible

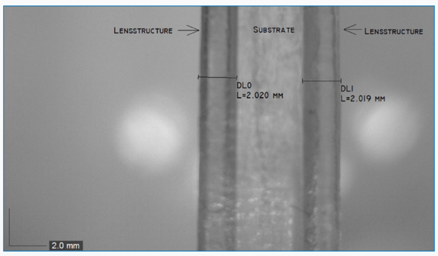


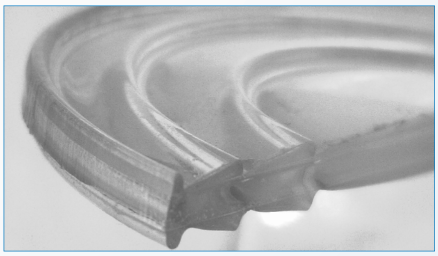
Thickness of the lens
Minimum height: 0,15 mm
Maximum height: 2,0 mm

Note: It is possible to print on both sides of the sheet material



Examples





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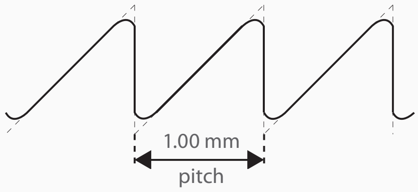
LUXeXceL

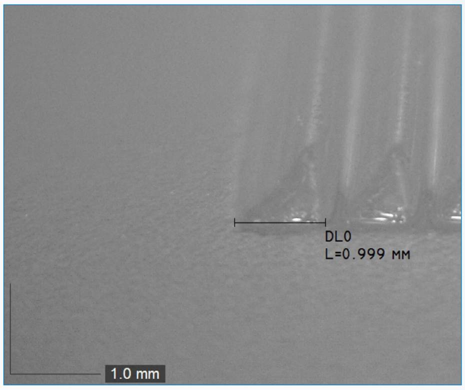
LED Lighting Optics

Geometrical specifications optics

Pitch

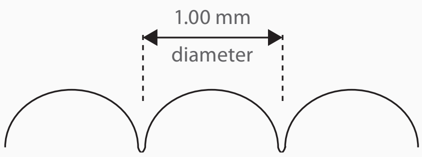
Minimum 1.00 mm (prism, fresnel, spherical)

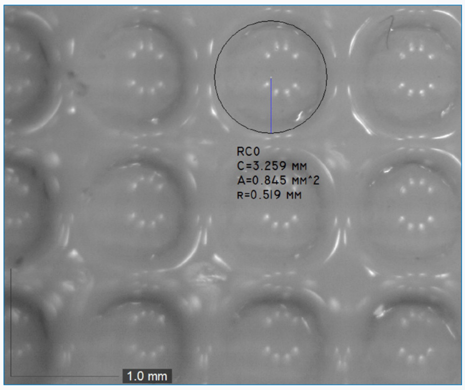




Diameter

Minimum 1.00 mm (micro optics)

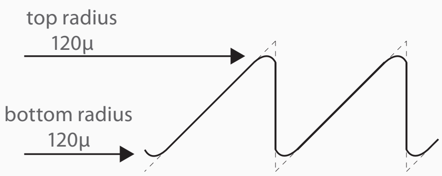


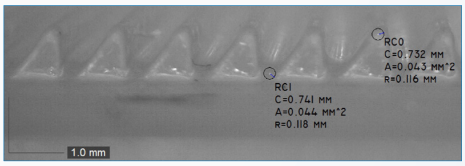


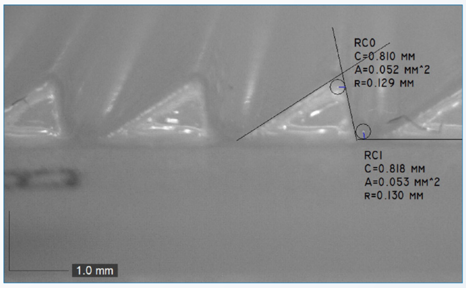
Precision

Top radius: 120 micron

Bottom radius: 120 micron







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LUXeXceL

LED Lighting Optics

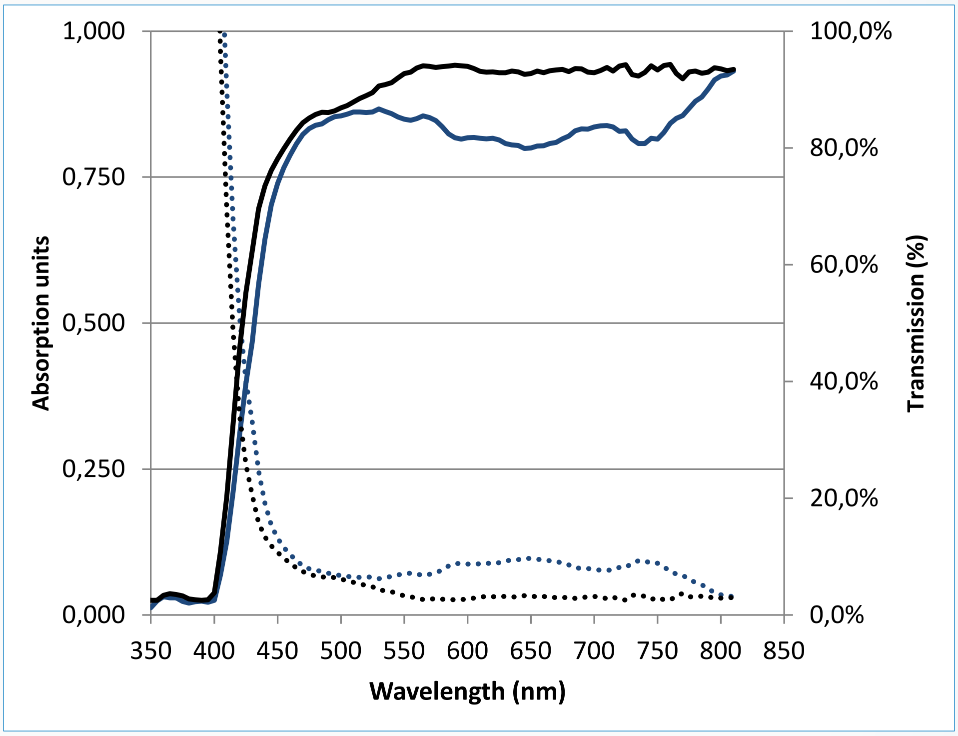
Optical specifications material

Refractive index	LUXeXceL printed optical structure: N=1.54 PMMA: N=1.4914 PC: N=1.5849
Reflection	3-4%
Total transmission	Max. 90%, incl. reflection and scattering (Depending on lens design)
Internal transmission	Transmission of 98.8% per mm, in visible light spectrum (400-800nm)
CIE	x 0.318 y 0.338
Haze	2.6%
Clarity	98.1%

Transmission and absorpsion graph

at 1 mm sample thickness

The solid line represents the trans-mission curve, the dotted line the absorption curve
The black line represents the traditional ink, the blue line represents the (alternative) visibly clear ink.



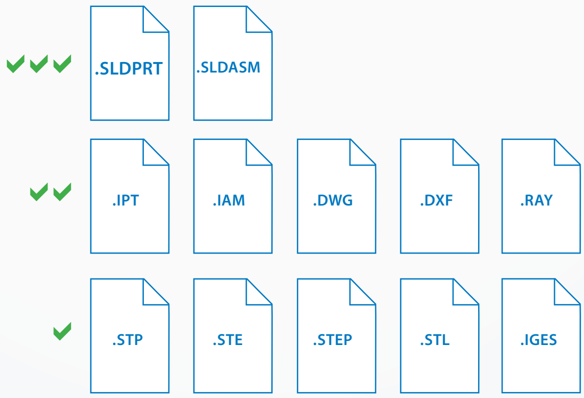
Preffered file extension

Preferred	.SLDPRT; .SLDASM (SolidWorks)
Good	.IPT; .IAM (Inventor), .DWG; .DXF (AutoCAD), .RAY (Photopia)
Possible	.STP; .STE; .STEP, .STL , .IGES

The specifications in this document indicate our current capabilities, they are constantly subject to change.

Designs outside these capabilities could fit into our development roadmap.

Please contact our sales department if you have any technical queries, our technical sales controllers can advice you reaching your optical goals.



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Case Study – Digital Textile Printing

Digital printing of textiles for fashion, signage and soft furnishings is becoming an established and fast growing market. The early adoption of the technology was slow and focussed in key geographical areas such as Italy but has now become a worldwide industry with new equipment and ink manufacturers entering the market place every year. This is borne out by the adoption rates for digital printing equipment and consumables which show a CAGR of 24% per year. In 2010 the value of textiles sold that were decorated digitally using roll to roll systems was already $1.3Bn.

Traditionally inkjet printing has been perceived as slow and expensive which had limited the adoption to proofing rather than production printing for textiles. Whilst this can be considered true for some of the early systems available, new releases in the last 5 years have changed the landscape and allowed adoption of larger volume textile mills traditionally focussed on rotary screen printing. Such systems are varied in width and set-up flexibility and can have an output from 100-800m^2/hour. Inks are now supplied in bulk rather than expensive pre-filled cartridges and other factors such as the up-time and printing only what is needed without wasting ink allows a much closer comparison in terms of cost per metre to analogue techniques. This narrowing the gap in terms of speed combined with the other known benefits of digital printing makes digital printing a more compelling choice for many print houses from low to high volume production. Such benefits of digital printing include reduction in time and cost to introduce new designs, faster set up of print runs, economical set up for shorter run printing with costs per metre similar for printing 10m or 10,000m, reduced inventory requirements (for printing equipment such as screen cylinders and for finished goods) and much greater flexibility of image and ability to offer personalised designs. Ability to react to such jobs is difficult when only traditional analogue printing is used. Figure 1 outlines the processes involved in screen versus digital printing and figure 2 outline some of the key differences that offer digital printing a competitive advantage. In addition one of the key benefits of digital printing lies in the image variations that can be achieved with very accurate detailing and a wider gamut of colours achievable in a single image. Typically a screen set-up will involve 8 colour ways (sometimes up to twelve) so a limitation to that number of pre-mixed spot colours. Inkjet printing allows colour mixing in-situ and so a conventional CMYK set of four colours can create potentially thousands of colours in a single image. Many companies now offer additional colours such as red, orange, blue and grey to allow designers and manufacturers to further expand the colour pallet that can be achieved.

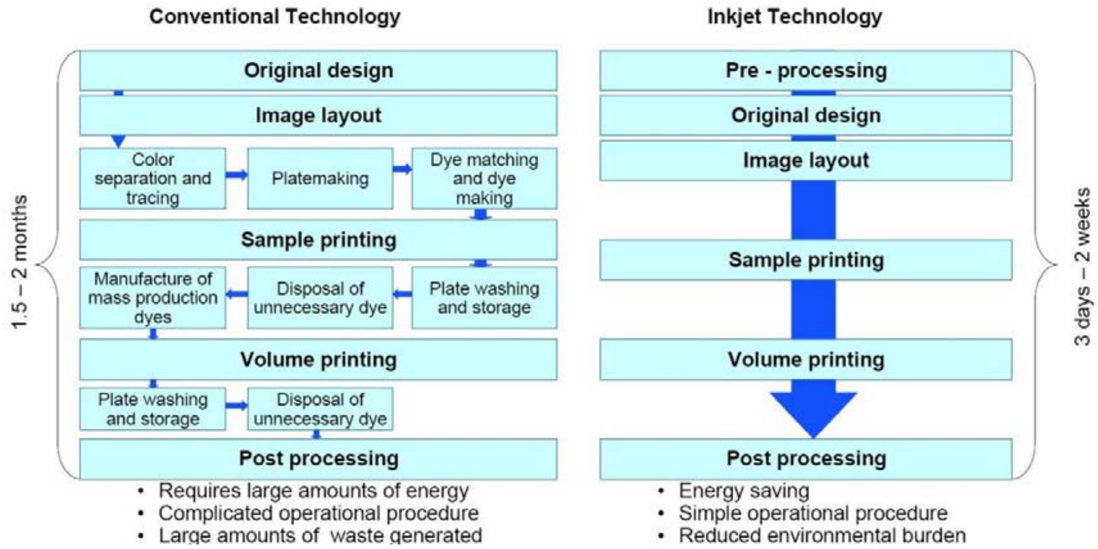

Figure 1 Overview of set-up requirements for Screen vs. Digital Printing

Factor	Ink Jet	Screen Printing
Setting time (design to print)	Few hours	Several days
Energy consumption	low	medium
Waste water production	Ø 2 liters per m fabric	Ø 25 liters per m fabric
Consumption of Chemicals	Depending on substrate type and ink type in use	Ø 300g per m fabric
Style preparation cost	Low, however depending on design data format (100 - 500€ per design)	Ø 350 Euro per screen rotary (av. 8 screens) Ø 85 Euro per screen flatbed
Flexibility	high	Limited since cost and time consuming

Source: Gherzi Research

Figure 2 Key differences between screen and digital printing for textile jobs

Adoption of digital printing is justified by the increase in quality and performance of the systems and inks allowing high efficiency in terms of up-time of printing combined with a cost effective way to print shorter run lengths as demanded by the wider market. The fashion industry in particular is seeing a transition towards "fast fashion" where goods are printed locally and in short runs to minimise over stocking and allow a more exclusive nature to the product. Traditional 2 or 4 season collections are being superseded by brands offering 12-24 collections per year making fast turnaround time and high flexibility a necessity. This has led to average run length decreasing from 4000m in 1995 to 1400m in 2011. By bringing in digital printing technology capable of efficiently decorating such run lengths with rapid design change overs has allowed larger traditional print houses to react more efficiently to all customer requirements using a more cost effective process. Before the adoption of digital printing, many companies had to find other ways to satisfy customers from outsourcing jobs to reduced margins on screen print runs.

Adopters of digital printing also benefit from reduced waste in terms of materials, water and energy consumption (highlighted in Figure 2). One customer based in South America has observed a big change in respect to the environmental benefits of switching to digital printing. They have observed a reduction in the consumption of water, energy and the creation of effluents that require chemical treatment before safe release back into the rivers. Such impacts are very marked when compared to the same requirements for the regular screen printing process. The same customer also reports that the environment for the operators of the machines is greatly improved with a conditioned environment removing any residues and chemical odours.

With the transition to digital comes a challenge to adapt to the new technology and associated requirements. As the colour pallet is extended and the design possibilities increased, creative teams and machine users require educating to maximize efficiency and benefit of the new processes. Many new users of digital have to invest significant time in turning existing designs into appropriate digital formats and in training the designers to "design for digital" rather than for screen where colour separations are required. Designing for digital is very different from the traditional screen images and digital printing should be able to offer more than just printing older screen designs in a different way and so training can be required to ensure customers also reap the benefits of digital output. Digital designs also offer a greater potential to offer exclusive lines and collections. Machine operators also require educating in the day to day running of a digital printer and how to operate the software, how to profile colours for the different substrates and how to spot defects in the print in a different way to techniques used in analogue systems. The necessity for multiple operators per system is reduced allowing for streamlined processing. Selling digital prints and the benefits for customers in terms of the reduced design limitations, run lengths and costs can also be a challenge. Adopters tend to take a measured approach to each challenge and from a start point of digitally printing less than 50.000 linear metres/month, one customer reports to be printing over 300.000 metres/month within a short time of adoption.

Outlook

Digital printing technologies may have a number of other benefits for the textile industry outside of traditional product decoration. There has been investment and investigation into using inkjet printing as a deposition method for applying functional or high value fluids. Much like switching from screen printing to inkjet for decoration, inkjet offers the advantage of applying materials in a very controlled and precise way without wasting often expensive ingredients. Materials can be applied with very exact coating weights and in very precise areas allowing for a greater level of control within the process as outlined in Figure 3.

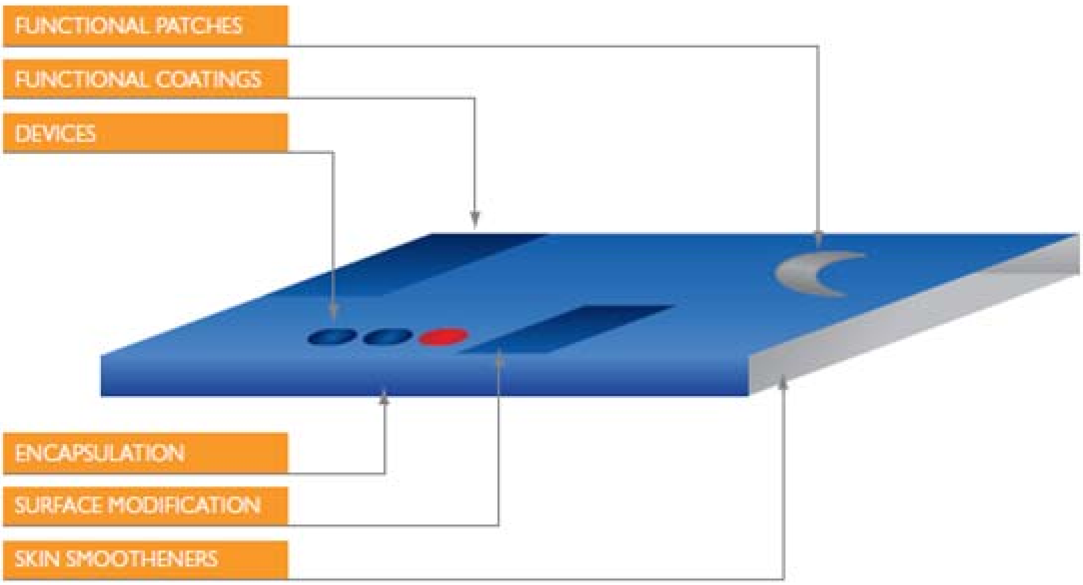

Figure 3 Application of functional materials in precise areas using inkjet printing

Due to the thin layer deposition and ability to limit fabric penetration it is even conceivable to have different functional coatings on either side of a fabric. This could be particularly interesting in areas such as sportswear and some medical devices to allow a hydrophilic coating on one side to allow moisture wicking with a hydrophobic layer on the other side to prevent liquid transfer in the opposite direction. Work has already been done to assess feasibility in a number of other potentially beneficial areas. Such applications include:

- Deposition of fragrances
- Slow release biofluids (using micro encapsulation)
- Application of flame retardant coatings
- UV and IR blockers

- Self-cleaning technologies for outdoor textiles
- Pressure sensitive switches
- Solar harvesting materials
- Printed electronics

All these applications will require further research before becoming a commercial reality but it can be envisaged that in the future production lines may consist of digital printing and finishing processes in-line to allow for maximum efficiency and value add. An example of how such a finishing process may look is shown in Figure 4.

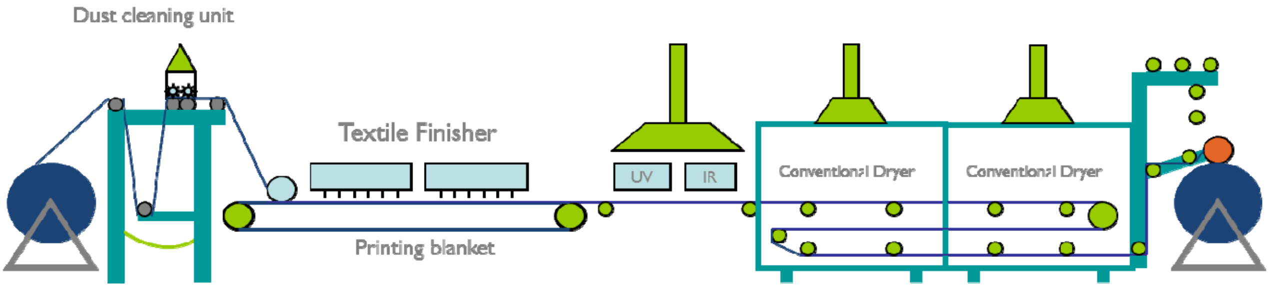

Figure 4 Digital textile finishing line