Digital inkjet ceramics – Where do we go from here?

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Inkjet printing has revolutionised ceramic tile decoration over a relatively short period of time. This is an amazing achievement for an industry that for many years traditionally produced either plain or very unsophisticated patterned tiles using screen printing and had little use even for computers. Inkjet printing has of course been used successfully in many other industries over the years, including graphics (advertising), packaging and textiles. In the packaging and textiles industries over the same period, the penetration of inkjet has risen to only around 2%, compared to the ceramics sector where it has reached around 50%.

We will first look into why there is such a difference in the take up between ceramics and these other industries and then we shall look at what are the next challenges in ceramics.

TF TECHNOLOGY®

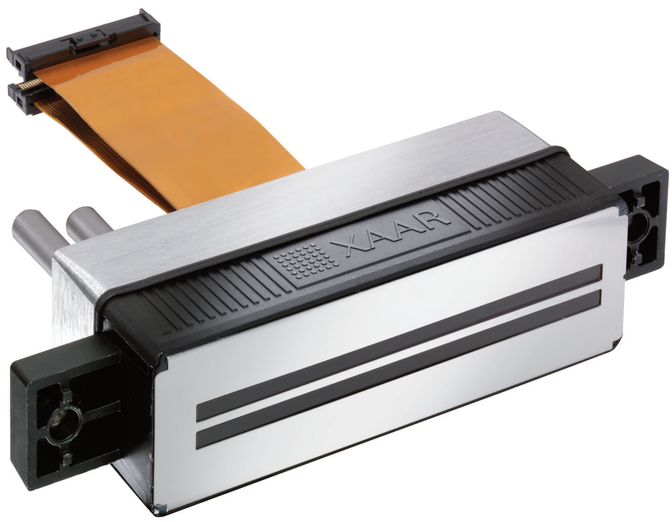

Figure 1: Xaar 1003 printhead with its unique TF Technology®

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XAAR INNOVATIVE TECHNOLOGY THROUGH AND THROUGH

The past to the present

Digital printing was not an instant hit in ceramics even though the potential was recognised. The first inkjet ceramic decoration printers appeared around the year 2000, and these early printers suffered from poor reliability with blocked or deviant nozzles causing unwanted white and dark lines on the tiles. The printers required frequent maintenance to clear blocked nozzles making them unsuitable for full-scale production and printheads had to be replaced repeatedly at high costs. In addition the images were very grainy and not very attractive.

It was in 2007 when Xaar released the Xaar 1001 that the market really began to take off. The unique, patented TF Technology® in the Xaar 1001 meant that the printers could run for extended periods of time because the high flow rate of ink past the back of the nozzle during drop ejection ensured that any unwanted particles or air were removed from the printing nozzle and the ink was jetted reliably. Now ceramic tile producers could take advantage of the benefits of digital printing which were so significant that the printer could pay for itself in around six months.

One immediate advantage was the reduction in waste – digital printing is a non-contact decoration technique (compared to roller or flat screen printing which press on the delicate tile) so there is no tile breakage. The next advantage is that the minimum batch size became one, so that the changeover or set up of new designs had no waste of materials or time, therefore zero cost. In comparison, traditional methods require new silk screens, or roller sleeves, for each design changeover, plus the time and effort to check the colour consistency. The fact that a computer was now in control of the colour also meant it was easier to reproduce patterns time and time again, which lead to a reduction in inventory. All these changes reduced costs and the amount of money tied up in stock, major financial drivers for mass conversion to digital.

Figure 2: Digital inkjet decorated tiles

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The next digital advantage was the increase in creativity it gave tile designers. Before digital inkjet printing took over, a great level of skill was required to produce the most attractive and highest quality tiles. The Italians and Spanish were held up as the specialists who could create fantastic designs, but the cost of producing these tiles was very high. The Xaar 1001 introduced greyscale printing to the industry (early printers offered only large drop binary printing). With its small drop size of 6 pL*, high native resolution of 360 npi (nozzles per inch) and eight grey levels, the apparent resolution of the Xaar 1001 was equivalent to more than 1000 dpi, which appears lifelike to the human eye. Digital printing also removed the high level of pattern repetition, which had previously been dictated by the size of the roller sleeve or screen. Now designs are only limited to the size of memory in the printer's electronic sub-system; a whole room could be laid with individually patterned tiles. In addition, as digital inkjet printing was non-contact, relief or texture could be added to individual tiles, giving them a profile just like with the materials they were trying to look like. Digital inkjet printing with the Xaar 1001 meant that tiles became indistinguishable from natural materials, for example marbles and stone. All these advances were available to everyone who had a digital inkjet printer; everyone could produce "Italian tiles" time and time again – the process was repeatable.

None of this would have happened without one other element – the open ink model used in the ceramic tile market. This means that the ink is bought independently of the printer manufacturer. In most other digital inkjet markets, ink is purchased from the manufacturer of the printer who often likes to keeps the price of their ink high as it produces a good revenue stream. This has been the major contributor to keeping the price per label high, for example in the packaging segment. In contrast, as the ceramic tile decoration has an unregulated ink market, manufacturers are free to purchase their ink from the most competitive source and change that ink as often as is commercially attractive. Xaar supports this open ink model by working directly with ink partners to ensure their inks work to maximum capability in the printheads. In addition, Xaar engineers provide carefully tuned waveforms that jet the ink reliably and accurately. The open ink model has provided sufficient competitive pressure to reduce the price of digital inks in the ceramic market and this has been a significant contributor to the adoption of digital printing in ceramic tile production.

So with all these positive factors, we have seen a rapid take up of digital inkjet tile decoration since 2007, reaching now, as noted earlier, approximately 50%. The revolution began in Europe where the majority of production lines are now converted to digital, but it rapidly spread to other large production areas, such as China, India and now Brazil, Iran and Turkey.

During this time Xaar has expanded its printhead family, by offering the Xaar 1001 GS12 in 2012, which is a larger drop version (12 pL smallest drop) of the original Xaar 1001 GS6 (6 pL smallest drop). The larger drop increased the amount of colour that could be achieved and has been perfect for floor tiles, where deep, rich browns or dark stone colours are preferred. Alternatively the Xaar 1001 GS12 can be used to increase the speed of printing whilst still achieving the same level of colour as the Xaar 1001 GS6. In 2014 Xaar released the Xaar 1002 and more recently, in March 2016 it launched the latest generation Xaar 1003 family of printheads. All printheads incorporate multiple innovative technology features, drawing on Xaar's many years in the ceramics industry to improve reliability, performance and ease of use, so that Xaar remains the printhead manufacturer of choice for ceramics.

* All drop sizes are measured with Xaar's test fluid, the final drop size achieved will be dependent upon the ink.

The Xaar 1003 printheads feature 1000 Optimised Geometry nozzles that can jet and place drops with the highest precision on the market. As a result the new printheads produce the smooth tones and solid areas needed to replicate natural materials that are stunning replications of the real thing.

At Xaar we expect that the conversion of production lines to digital decoration will continue as it offers such great rewards, and in fact it is business critical for the tile manufacturers to remain in the industry. In parallel we have also been thinking about what else could happen in the ceramic tile industry, what are the next challenges? Where else can digital inkjet technology provide benefits? Leading ceramic tile manufacturers are also looking for ways in which they can add differentiation to their products again; since as everyone is able to decorate digitally, they can all learn to manufacture the same patterned tiles.

Figure 3: Digital inkjet decorated tiles and Xaar 1003 printhead

The future

In Xaar we see a future where the whole of the production line is digital – with multiple printers linked to a common command and control centre.

Structure and relief

The first of these printers will be used to add the structure to a flat tile body. The present technique to achieve the relief on a tile is to use a mould attached to the press. These moulds are created by milling the required pattern on to metal pads, which are then used to stamp the same pattern on to each tile as it is produced. This is an expensive process as it is expensive to design the mould and also to set up, so that once mounted in the press a mould will be used to produce many tiles. If we could do this digitally we could change the pattern of relief on every tile, in the same way that the coloured decorative pattern can be changed on every tile using digital inkjet printing today. The structure and coloured pattern could then be synchronised to improve the realism of the natural material. Bringing digital technology to this area of ceramic tile production would further reduce the set up costs and time and we predict it would increase the number of tiles produced with structure.

This technique is also required in another emerging area of ceramic tile manufacture: that of large, thin tiles. These tiles are manufactured by extruding the base material, rather than by pressing it. Digital inkjet printing could be used to add structure or texture to these tiles as it would be an additive, non-contact process. This would increase the attractiveness and natural look of these tiles at the same time as avoiding breakage of the thinner, less robust tiles.

Such a digital printer would need to be significantly different from the printers used today to add the coloured decoration to tiles. The present digital inkjet printers put down on average up to 20 g/m^2 of coloured ink. To add structure (relief) to a tile would require hundreds of grammes per square metre; in addition the particle size would be significantly larger than that used today. The Xaar 001 printhead will achieve these goals by jetting drops in the nanolitre not picolitre range. It will have a drop size of between 70 and 200 nL, more than 1000x greater than that of the present drop-on-demand printheads.

A printer capable of this level of fluid laydown could also be used in other applications, for example applying the engobe and glaze to the tile body. Using digital technology in these applications could reduce the amount of fluid used and allow further creativity to mix effects on a tile. In the future a large volume digital printing technique could also be used to add technical coatings to tiles, for example non-slip, antibacterial, water repellent or other coatings. Tiles could also become more functional, for example embedding conductive elements to make sensors for alarms, lighting or other systems.

Ceramic inkjet ink colour space

Coming back to adding the decorative pattern to the tile, at Xaar we have also been looking at what can be done to improve this area of digital printing. One of the challenges during the uptake in digital inkjet printing was that a new type of digital ink had to be developed. Previously with screen printing, colour had been applied in pastes with large particle sizes, putting down up to 50 or 100 g/m^2 (rotary and flat screen respectively) of material onto the ceramic tile before firing. The drop-on-demand inkjet printheads have internal dimensions measured in tens of microns, which meant that the pigments for digital printing had to be delivered in a liquid and that the particle size had to be carefully controlled to avoid particles blocking the channels and nozzles in the printheads. The particle size and amount of pigment being deposited had an impact on the range of colours that could be achieved.

The range of colours that can be achieved in printing are usually described using a “Lab” diagram. The Lab colour space is made up of the “L” dimension which represents the lightness of a colour and the “a” and “b” dimensions that represent the colour components. These dimensions are calculated from the colour co-ordinates in a standard specified by the International Commission on Illumination (a French Commission called the Committee Internationale de l'Eclairage, or CIE) and are said to be the closest match to how humans perceive colour and brightness. The full colour space is shown in **Figure 4**.

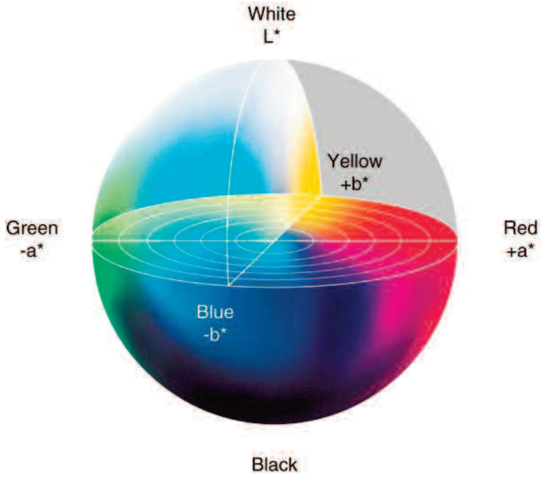

Figure 4: The Lab colour space

If we represent this purely in the 2D colour space, ie not using "L", then we can map out the colour space that can be achieved with the standard colour sets for computer displays (the RGB scale) and for standard digital inkjet printing with CMYK colours (Cyan, Magenta, Yellow and blacK), which are used in desktop, label and other segments.

The three different shaded areas in **Figure 5** show that with the RGB or CMYK colour sets it is not possible to reproduce the complete range of colours that the eye can see. The only point at which this becomes an issue is when you are trying to use the two different mediums to display the same picture or image. It can be clearly seen that if you want the two images to look exactly the same then it is necessary to restrict the range of colours on the computer display to match that of the printer.

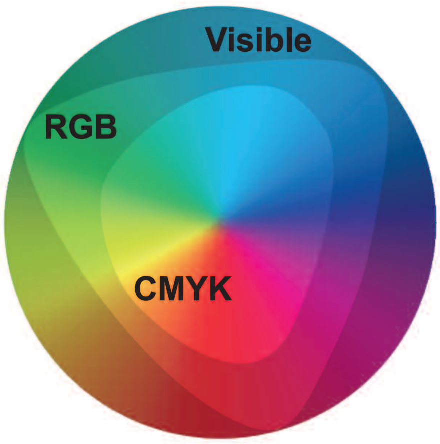

Figure 5: Computer display and standard inkjet CMYK colour space

So what about the ceramic colours? Ceramic inks cannot use the same pigments as those used in other digital inkjet applications – ceramic tiles are subject to very high temperatures during the firing process, up to 1200 °C, in order to fuse the glass frit in the glaze to the body of the tile. Therefore the pigments used in digital inkjet decoration of ceramic tiles have to be capable of withstanding these high temperatures. The only pigments that will not be destroyed by such a process are inorganic ones, for example metal oxides.

The colour set used in the ceramics market is also different from that used in desktop, label or wide-format printing; it generally consists of brown, beige, blue, black, yellow and pink due to the limitations in the type of inorganic pigments used. This is further restricted to avoid pigments made from toxic heavy metals. Although there are techniques to enable encapsulation of these pigments to reduce their effective toxicity, many companies or countries insist on inks that do not utilise these components. The sum of all these constraints is that the colour gamut (or range of colours in a colour space) available from a set of ceramic inks is compromised.

There are no standard colour profiles available. These have to be sought from individual suppliers of ceramic pigments, but in general terms we can say that ceramic pigments used in traditional screen printing inks are challenged in mostly yellow and red colours (greens are not as popular for tiles, roughly in the proportion shown below in **Figure 6**:

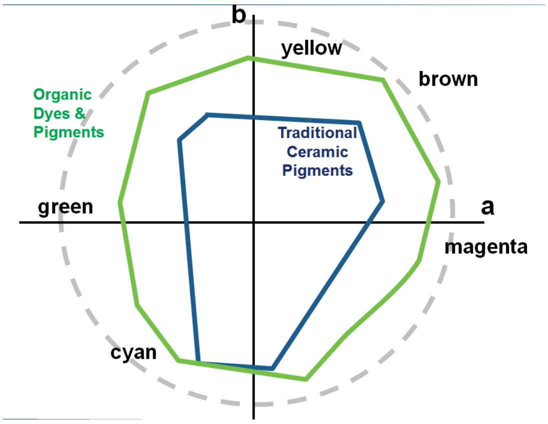

Figure 6: Computer display and standard inkjet CMYK colour space

For the majority of ceramic tiles this is acceptable. We all expect representations of natural materials, which in general have a limited colour space – stone is generally grey with some variation, wood is generally brown/beige.

Traditional roller, or flat, screen printing inks (pastes) contain high concentrations of solids, made up of inorganic pigments and frits, suspended in either mineral oil or glycols. The particle size of these inks has a D90 of approximately 10 to 15 μm. D90 is the standard method of describing pigments and/or inks for many industries, it means that 90% of all particles in that set have a diameter less than that value. D90 is chosen as the level of particles that can accurately be measured by the available equipment. Scientists and experts who manufacture the equipment advise against using D99 or D100 measurements; they state that any slight disturbance during the measurement such as an air bubble or thermal fluctuation can significantly influence those values. Plus the statistical methods that are used to calculate these values are not robust because the actual numbers of particles at these extreme levels is by definition small.

So how does this compare with the inks that were developed for digital inkjet application of pigments to ceramic tiles? Well the carrier fluids are generally the same – oil or glycol – both for traditional and digital inkjet ceramic inks. The choice of carrier fluid enables the surface tension and viscosity of the ceramic ink to be carefully controlled, which is important to ensure reliable printing or jetting of the ink, both for traditional and digital inks.

The significant difference between traditional and digital inks is the particle size allowed and the concentration of solids in the inks. We mentioned before that traditional inks were pastes; the carrier fluid is generally of the order of 10-15% by weight, the pigment 20-40% and the rest is mostly made up by frit, with smaller amounts of other materials to adjust surface tension and inhibit agglomeration, etc. Digital inks are liquids, still with high pigment loadings of over 20% and more by weight, but without the high frit loading.

The particle size in digital inks is dictated by the internal dimensions of the printhead. Drop-on-demand printheads from Xaar and other manufacturers have dimensions that are tens of micro-meters, as they eject drops with volumes from as small as 6 pL. A 6 pL ceramic ink drop will have a diameter of approximately 25 µm so it is easy to see that the particles used in traditional inks with a D90 of 10-15 µm cannot be used with digital inkjet printing as they would block the internal structures and the nozzles. In practice digital inks have particle sizes with a D90 of less than 1 µm. Part of this restriction is also due to the tendency of digital ceramic inks to sediment. Remember, we have a high particle loading kept in suspension. In fact one of the reasons that the Xaar 1001, Xaar 1002 and now the Xaar 1003 is so successful is that its TF Technology™ ensures that the ink is always kept in constant motion through the narrow spaces in the printhead, there are no dead spots where the ink can sit and start to sediment and any unwanted particles due to agglomeration are swept away from the printing nozzle and can be removed by filters in the ink system.

Compare this to traditional inkjet printheads with no recirculation past the back of the nozzle where inks sit in the firing chamber and can start to settle; the only way out of that firing chamber is the nozzle.

The reduction in particle size affects the colour space that can be achieved with digital inks. In some cases when pigments are ground to this small size they lose the majority of their ability to reflect light; alternatively some can be destroyed by the melting process in the kiln. All this makes it a challenge for ink manufacturers to find pigments that have good colour and are non-toxic. The final result is a much reduced colour space for digital inks.

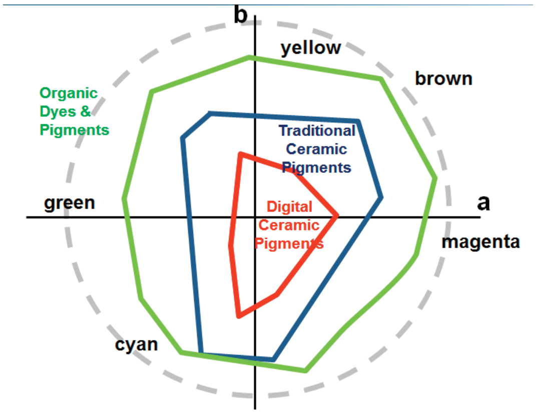

Figure 7: Computer display and standard inkjet CMYK colour space

The diagram in **Figure 7** outlines the main colour challenges with digital ceramic inks versus traditional colours. We can see that again yellow and red colours are the most affected. Better reds can be achieved using cadmium, but as mentioned earlier the use of this is restricted. Reds containing small amounts of gold can also improve the colour, but these are expensive.

More colour with inkjet

So what can be done? The final colour achieved by digital printing can be improved by two methods. The first is increasing the amount of ink that is put down by the printing process. The Xaar 1003 GS6 printhead has 6-42 pL drops and can place these in a 360 x 360 dpi grid when running at approximately 25 m/min.

If we calculate the weight of fluid laid down when running at 100% of the largest available drop size, with an ink of 1.2 g/cm^3 density we can conclude that this will put down approximately 10 g/m^2 per ink colour. So if there are 5 colours used on the tile, the maximum weight will be 50 g/m^2 for this printhead. Needless to say when printing a ceramic image, it is not a 100% full coverage with all colours, so the laydown with a real image will be less than this, but it is all lower than what can be achieved with traditional ceramic screen printing pastes.

This is why Xaar introduced the Xaar 1001 GS12 in 2012. With its 12-84 pL drops it was capable of laying down up to 20 g/m^2 per ink, significantly improving the colour that could be achieved. There is always a trade-off to be made of course, larger drops are more visible to the eye and can make the printed image appear more grainy. This remains a popular printhead when fine detail is required in wall tiles where they are often viewed from a closer range.

This principle was extended even further. Later in 2014, printers were available with the Xaar 1002 GS40 (now Xaar 1003 GS40) which has drop sizes ranging from 40 to 160 pL. This further extends the laydown to up to 40 g/m^2 per colour which is close to the capability of rotary screen printers, significantly impacting on the colour gamut that can be achieved. Again, though this comes with large drops – it does not replace the need for the Xaar 1003 GS6 or GS12, merely complements them, offering enhancements in colour where required.

This large drop printhead is also used to add decorative glazes to the tiles, replacing the single roller printer sometimes used to add these after the decoration stage of the production line. Either this could be added as one or two extra printbars to an existing machine, with perhaps a gloss glaze in one and a matt glaze in the other or as a stand-alone machine in order to allow the colours to dry first. Removing this last roller machine would bring all the usual digital benefits to that area: reduction in set up time and costs, ability to change the glaze effect as often as you want, and of course enhance the range of creative effects that can be achieved on the tile, for example fusion tiles, where natural materials are mixed with modern overprints, or effects such as lustre, sinker, metallic or white.

The other area we are investigating is what can be achieved with particle size. We said that the maximum particle size was limited by the size of the internal printhead structures and the nozzle size, referring to the fact that the diameter of a 6 pL drop is around 25 µm, the diameter of a 12 pL drop is around 35 µm and a 40 pL drop is around 55 µm. What is the relationship between the mechanical dimensions of the printhead and nozzle and the ability to reliably print pigmented inks?

Some conventional pumping experts suggest as a rule of thumb that a ratio of 20:1 aperture: particle is necessary to enable free and uninhibited flow, but others say it is as low as 2:1. There is also reference to the velocity of flow that is required dependent on the size of the pipe and the particle size, so it is not a simple calculation. Is that the same at our microfluidic levels? Probably not. Xaar will be releasing further technical papers on this subject in the coming months.

Xaar worked with Instituto de Tecnología Cerámica in Castellon, Spain, as well as its ink partners, firstly to understand the impact of particle size on colour and cost and secondly on what improvements to the present inks can be attained. The cost of an ink is dependent on many factors including the cost of the carrier medium, the cost of the additives and the cost of preparing the pigments. Again it is not a simple calculation. Changing the carrier medium can have two effects. Firstly it can make the ink harder or easier to prepare; secondly it will impact the additives required. It cannot be assumed that reducing the cost of the carrier will definitively reduce the final cost of the ink. What is true though is that if we can reduce the preparation time of the ink it will help reduce the cost and one way we could do that is to reduce the milling time of the pigment. A large particle size would further improve the colour gamut of the inks on top of that, which can be achieved by increasing the amount of ink laid down.

If it was all so easy, then why hasn't it already happened? Of course it isn't that easy! We know that digital ceramic inks are already heavily loaded and have a tendency to sediment. If we can increase the particle size, then the tendency to sediment also increases. If we then have to reduce the concentration of the pigment in the ink to regain stability, then we could be back to the same point at which we started. There is a significant body of work to do to get the correct balance of particle size, carrier fluid, additives to achieve the viscosity, surface tension and drop velocities required to accomplish stable and reliable jetting of inks. Xaar's TF Technology™ will be vital in all of this. The constant circulation of the inks through the printhead and the ink systems is critical if we increase particle size and ink volumes.

The flow-rate may also have an impact on the fluid behaviour and TF Technology™ delivers not only the highest flow rate, but also the widest range of flow-rates to accommodate techniques such as shear-thinning if required.

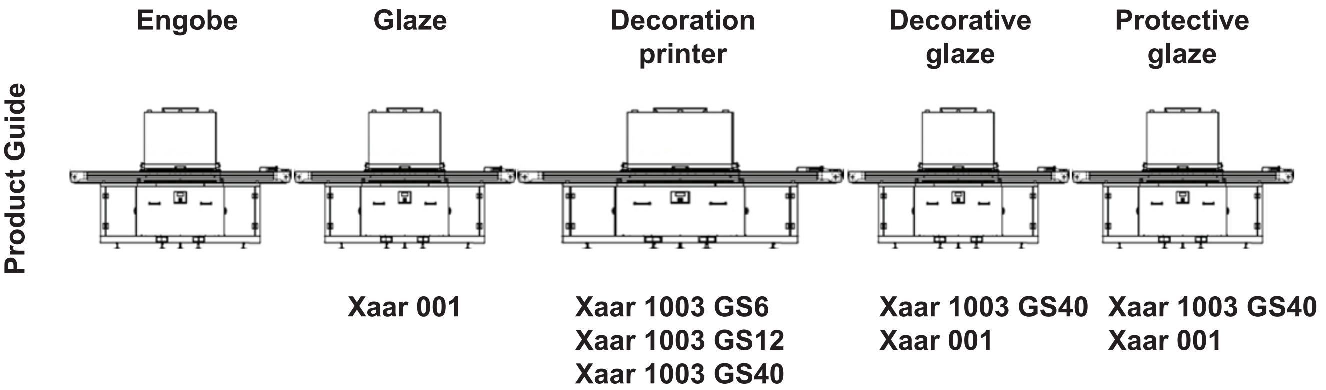

Figure 8: Digitalisation of ceramics production line

Summary

In summary we have outlined the opportunities for the Xaar 1003 family of printheads. How the Xaar 1003 GS40 brought the ability to enhance colour and special effects to make ceramic tiles even more attractive and life-like. The Xaar 1003 is the third iteration of the market leading printhead with TF Technology® and Hybrid Side Shooter® architecture as implemented in the Xaar 1001 and Xaar 1002 printheads and demonstrates Xaar's commitment to continuous improvement. The Xaar 1003 printheads are fully backwards compatible with the previous Xaar 1002 printheads and can therefore be retrofitted into existing printers. These printheads, along with the very large drop Xaar 001, form part of our continuing investment in R&D targeted to moving along our vision of digitalising the entire deposition process in the ceramic tile production line.