

3D printing has become an increasingly widespread and fashionable topic of discussion as more and more people begin to appreciate its potential. Having said that, few know much about the remarkable technology involved. The fact that it perfectly matches the concept of digital manufacturing, an approach that looks at digital technologies from the very first step of product development with 3D CAD systems to the direct manufacturing of the object, executed by machines that can understand digital data and then transform it into physical artefacts, can seem rather like magic to the uninformed.

In this, the first of two articles on 3D printing, World Footwear outlines the current state of the technology, how it works and the results that can be achieved. A second part that will be published in the near future will examine its potential for applications in footwear manufacture and how it might radically change the industry in the future.

Advances in 3D printing

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We have already mentioned this '3D revolution' in previous issues of *World Footwear*, one that is considered by some commentators as an enabler of a possible forthcoming industrial revolution, highlighting the enormous democratisation of power it would bring with it. Potentially, every designer could become a 'maker' provided they had access to the right design and manufacturing tools that enabled them to completely bypass traditional pipelines and thus force manufacturing companies into reinventing their role.

This is what is happening in the so

called FabLabs (fabrication labs), facilities where inventors with a design skill and products they want to develop clearly in mind, have access to a wide range of manufacturing technologies that would normally be confined between the well-guarded walls of a factory, on a time-share or service charge basis to bring their concept to reality. While in the past these kinds of labs were relatively large structures, with technologies ranging from NC milling to water jet cutting of metal, they are now becoming smaller and are increasingly equipped with just one kind of machine: 3D printers.

A shoe from the Heavy Metal Series, designed by Bryan Oknyansky amply demonstrates the complex structures that can be produced.

CREDIT: BRYAN OKNYANSKY

ADDITIVE MANUFACTURING

Let us therefore focus on these machines and the correct terminology involved as the description '3D printers' is itself an imprecise and generic definition. The proper name that should be used for them is 'additive manufacturing machines' and, in general, the process they perform is called either 'direct' or 'digital' manufacturing.

It is also essential to remember that what all these technologies have in common is that, rather than creating the final object by removing material from a raw block of metal or plastic, they add-layer by layer-only the exact amount of material that is needed to produce the finished object. They are therefore inherently more efficient and 'lean' than any other manufacturing approach that we know of. Keeping this in mind, it is easy to understand how all these machines work because the fundamental steps of the creative process are basically the same for all different vendors and producers. What does change from system to system, however, is the way the material is added or, more specifically, solidified one slice after the other and the nature and range of materials they can deal with.

Incidentally, the one and only prerequisite these machines ask of the object they must produce is that the 2D contour of each slice to be added (solidified) is geometrically defined. This, in turn, again implies that a complete digital 3D model of the same object is available. Additive manufacturing calls for digital modelling and the latter finds in these technologies a perfect match in exactly the same way that a laser or ink jet printer is the ideal match for any Word document or spread sheet.

So this is what makes additive manufacturing (AM) unique and

potentially disruptive for traditional manufacturing concepts. However, not all AM technologies are the same, so it is worth analysing in more detail what the market offers today. To do this, we must consider several relevant factors, among which three are of great importance: the application target, the process technology and the materials involved, highlighting in each one of these areas the most recent advances.

APPLICATION TARGET

AM machines have different application targets and, in relation to that, different costs. We can identify three main classes of system: desktop, office and production.

Desktop machines are a relatively new category that appeared only recently, following the expiration of the patent rights filed by the first pioneering companies in the sector more than a decade ago. This has fostered the proliferation of a number of producers of small machines such as the MakerBot that connect to any laptop and cost anywhere between €1,000 to around €10,000 for the most expensive models. They are ideal for home or small office use, where the most important requirement is obtaining rapidly and inexpensively a solid, conceptual prototype of the object to be later produced. Printing time is normally the driving factor, while accuracy and quality of finish and the size of the

objects that can be produced (normally small) are not so relevant for the specific application.

Office systems address a different category of user and are more suited to professional applications. Typically designed from every angle to be installed in office environments, these machines are bigger, can deal with a much wider range of materials and produce parts with very high dimensional accuracy and a good level of finishing. It is not unlikely that the components they manufacture can be used in production, since the final quality these parts can have is very similar to what is achievable with other production means. Their cost ranges between €30,000 and €100,000 depending on the additive technology involved, the size of the working area and the type and variety of materials they can process. These machines are ideal for exploring new technologies, prototypes and unique component manufacturing and for producing small runs of special parts that would be either uneconomical or impossible to build by any other means.

Finally, we have production systems. The investment required to purchase one of these is very similar to buying a top of the range CNC multi-axis milling machine or equivalent piece of manufacturing equipment, with purchase prices ranging from a minimum of €200,000 to well in excess



Fashion clogs produced on a 3D Systems machine showing the design and colour potential that is possible with additive manufacturing systems. CREDIT: 3D SYSTEMS

of €500,000 for the most expensive models. A large working volume, high accuracy and surface finishing are the most important features of these machines. They can also be regarded as true alternatives to traditional manufacturing systems as many models in this category can solidify metals as well as plastic powders.

There are specific sectors in which AM systems are becoming the main manufacturing approach, allowing the manufacture of specially featured parts that cannot be made in other ways. For instance, turbine blades and other parts of jet engines for aircraft are increasingly produced using AM machines.

PROCESS TECHNOLOGY

This refers to the way in which each single layer of material is solidified in order to create step-by-step the final object. In the twenty and more years these machines have been in development since the time when they were referred to as rapid prototyping systems, many different solidification processes were conceived, patented and implemented. The very early devices were called stereo lithographers and used a laser source selectively beamed onto a photosensitive polymer that then solidified when hit by the laser light.

These are now part of history, their memory being found in the STL (stereo lithography) format used today to describe the data to be sent to all different kinds of AM machines. In the past LOM (laminated object manufacturing) was also popular as a relatively simple way of creating digital objects but lacked the accuracy and finishing needed to move from prototyping applications to production objects.

The term 3D printers was originally coined for the reason that machines actually existed (some still survive) that, instead of spraying inks onto a sheet of paper, sprayed coloured glue onto a layer of powder of varying kinds and gluing the particles together. These first generation machines suffered from a number of limitations, the most relevant being the fragility of parts obtained with a process that required several steps of post-treatment in order to be able to handle the parts safely.

The situation today is one where three main process approaches dominate the market: fused deposition



EOS M290 metal additive system can be used to produce complex structures such as the ladies heel in the title image. CREDIT: EOS

modelling (FDM), PolyJet or MultiJet Printing, and selective laser sintering (SLS). Others exist such as wax deposition modelling (WDM) that produces extremely precise wax-ups with incredibly fine detail and smooth surfaces in a casting material which is subsequently burnt away. It is most commonly used in dental surgery.

3D printers that run on FDM technology build parts layer-by-layer by heating thermoplastic material to a semi-liquid state and extruding it according to computer-controlled paths. Although the simplest models only work with one material, FDM normally uses two materials to execute a print job, a modelling material, which forms the finished piece and a support material that acts as scaffolding. Material filaments are fed from the printer's material bays to the print head which moves in X and Y coordinates (the 2D coordinates of the plane each layer is drawn on), depositing material to complete each layer before the base moves down the Z axis (the vertical axis of the machine that provides the third coordinate) and the next layer begins. Once the printer has finished building, the user breaks the support material away or dissolves it in detergent and water leaving the part ready for use.

PolyJet or MultiJet 3D printing is similar to inkjet document printing but, instead of jetting drops of ink onto paper, these special printers jet layers of liquid photopolymer onto a build tray

and instantly cure them with UV light. The fine layers build up to create a precise 3D model or prototype. Models are ready to handle and use straight out of the printer, with no post-curing needed. Together with the selected model materials, the printer also jets a gel-like support material specially designed to uphold overhangs and complicated structures. This second material is later removed by hand or water. This technology offers many advantages, including fine detail, smooth surfaces, speed and precision. It works with a vast array of materials, in hundreds of colours including clear and tinted translucent shades and also with rubber-like materials, simulated polypropylene and specialised photopolymers for 3D printing in the dental and medical industries.

SLS is very different and uses high power carbon dioxide (CO₂) lasers to fuse plastic, metal or ceramic powder particles together, layer-by-layer, to form a solid model. The system consists of a laser, part chamber and control system. The part chamber consists of a build platform, powder cartridge and levelling roller. A thin layer of build material is spread across the platform where the laser traces a two-dimensional cross-section of the part, sintering the material together. The platform then descends a single layer thickness and the levelling roller pushes material from the powder cartridge across the build platform, where the

next cross-section is sintered to the previous. This process is repeated one slice at a time until the part build height is completed. Once the model is done, it is removed from the part chamber and finished by removing any loose material and smoothing the visible surfaces. The unsintered powder that surrounds the part during processing provides support.

This technology portfolio can be found in the product ranges of all the most important producers and vendors of AM machines. As stated, with the liberalisation of patents rights, a plethora of small manufacturers has appeared. Despite that fact, the market is dominated by three major players: the American companies 3D Systems and Stratasys and the German company EOS. All three offer a large number of different machine families, covering a range of fields, technologies and materials.

MATERIALS

Materials form an important ingredient in the success of 3D printing. When these technologies were first developed, the materials that could be solidified were only opaque and rigid. Nowadays they range from metals to plastics, rigid to flexible and transparent to opaque. In the rigid plastic families we find materials such as ABS (acrylonitrile butadiene styrene), PC (polycarbonate) and nylon, all of which are well suited to FDM machines.

If we are looking for flexible products, we must move to PolyJet or Multijet technologies (these are the names employed by the two main market competitors, 3D Systems and Stratasys to identify what is basically the same technology) that use ABS-based materials specifically prepared to be compatible with the jetting/solidification process. Here we find simulated polypropylene, rubber-like or even bio-compatible substances that can be used in a variety of applications to produce both rigid objects and flexible ones with different grades of flexibility.

A very important feature of this category of machine is their capability of producing parts that combine different materials to achieve rigidity with differing strengths, rigidity and flexibility or multiple colours, thus opening an incredible range of possibilities in regard to manufacturing objects that are as close as possible to production ones. A special mention needs to be made here

of transparent materials (sometimes used in shoe accessories) and high temperature materials, capable of resisting the temperatures that can normally be found in the shoe manufacturing process.

To complete this survey we must mention powders of various kinds that are processed by SLS machines. The choice here includes nylon powders, high performance polymers to obtain both rigid and flexible parts, metals such as aluminium, steel, titanium, gold and several others. The websites of the major vendors offer a very valuable source of information on the many relevant features of the standard and proprietary materials (all these companies are heavily involved in material science research to constantly enhance the properties of the substances they can process with their machines) that are available, each one described in very detailed data sheets that contain all their most relevant chemical and physical properties. These are useful guides for regular users as well as for beginners to select the most appropriate combination of AM technology and materials.

CONCLUSIONS

It is becoming increasingly clear that these technologies are developing at a rapid pace and gaining increasing popularity in many industries. In the footwear sector, they are no longer seen simply as prototyping systems but as

possible alternatives to other manufacturing approaches. In such an evaluation there are three main process or machine parameters that should be taken into consideration.

First, there is the accuracy with which a geometry is reproduced from its digital model. This is typically around a tenth of a millimetre for office machines and even better for production ones. Second, is the quality of finishing which is determined by the thickness of the layer deposited at each step and can range from 0.015mm to 0.3mm. And finally, the working volume that should be big enough to accommodate a large shoe, i.e. a minimum 300mm x 200mm x 150mm.

With these basic parameters in mind we can start to think about the possible applications for these promising technologies in the manufacture of components, tools and, possibly, even finished shoes. Many experiments have been carried out in the past in these areas and a few industrial implementations mostly led by big brands in the sportshoe sector are on the verge of appearing on the market. Nevertheless, a great deal more still needs to be understood and clearly assessed through a carefully designed set of manufacturing benchmarks. This will form the content of the second part of our review of this important topic and will provide an analytical and quantitative assessment of the possibilities for applying AM to modern shoe making. 🔗



*StratasysS Eden
260v office printer
for rapid prototyping.*

CREDIT: STRATASYS