Digital Manufacturing:
3D PRINTING AND CNC MACHINING

WORDS | LEX LENNINGS, DELFT SPLINE SYSTEMS, NL



Any reader of this magazine will have noticed that the mainstream media has (at last) discovered 3D printing. Every talkshow seems to have shown a 3D printer with an enthusiastic evangelist user; major newspapers have published full-page stories, even some retail stores are now offering 3D printers to the general public. For us specialists this is of course good news, after many years of first having to explain what 3D printing is about. In addition all this press coverage will help to make engineering more interesting and 'cool' to people who didn't already know that: any engineer would surely welcome that?

In recent years we have seen that the number of 3D printer manufacturers is growing rapidly: almost every month a new supplier enters the market. At the same time prices for these low-cost systems are falling, because of both the larger series and the steeper competition. Altogether there are many factors behind the intense media coverage just mentioned.

Adding Material or Removing Material

Because of all the attention for 3D printing, it may seem that adding material is the only available method for 'Digital Manufacturing', transforming a virtual model to a real model or product. And that is of course not true: removing material (i.e., CNC machining) is a good alternative and for many applications can be far more efficient. This paper will show some of these applications.

The abbreviation CNC stands for Computer Numerical Control, as a contrast to conventional milling machines where the cutter's movements can be controlled by turning a hand-wheel. The complexity of the process depends on the software that is used: for CNC machining as well as for 3D printing. Where traditional CAM software (the software to calculate the CNC toolpaths) was meant to be used by skilled CNC specialists, nowadays a new type of CAM software is available and meant to be used by users without CNC knowhow and experience. This software makes operating a CNC milling machine just as simple as operating a 3D printer. All that is needed to prepare a new job is following a 'wizard', the rest of the process is taken care of by the software.

In order to be complete, a third method of shaping material needs to be mentioned as well: deforming. Deformation is applied in manufacturing technologies like casting (including injection moulding), forging and bending (for instance bending sheet metal). For mass production these technologies offer unrivaled low prices, however for a one-time conversion from CAD model to tangible model they cannot be easily applied. Of course some exceptions can be found where deforming is most efficient also for small numbers (like a programmable CNC bending machine), generally however for small numbers the choice is between adding and removing material.

The old name Rapid Prototyping (RP) made it easy to distinguish between these two methods: Additive RP and Subtractive RP. These names are no longer correct, as 'Digital Manufacturing' is applied for much more than just prototyping.

i **Delft Spline**
www.deskproto.com

Panoramic Predictions

Future visions surrounding 3D printing predict big changes: "Personal fabrication is the next revolution that will impact our lives," says Neil Gershenfeld of the Massachusetts Institute of Technology, the 'father' of all FabLabs. In this vision, digital manufacturing will cause a transition from current mass production (one design for all clients) to custom production (each client gets a unique design). Production can then be done on a small scale: by small and medium-size companies or even in-house by the end-user.

This transition will absolutely follow for some products and will offer important advantages. However, for most products such transition will not come, as the low prices offered by mass production just cannot be beaten. The 3D printing of single products makes these so much more expensive than injection moulding in large numbers that custom manufacturing will be used only when needed.

A useful analogy can be found in 2D printing on paper: 'printing on demand' is perfectly suited for small batches and for personalised prints. However, for the large series that are needed for books, magazines and newspapers, offset printing remains cheapest by far.

My reservations about the idea of having a personal 3D printer in every house are even greater. Here the analogy is the home bread-baking machines that are available: perfect for having fresh bread every morning. However, it is much more efficient to have a specialist bake the bread and just buy it at the local bakery. So these baking machines, despite the advantages they offer, are not commonly used.

Custom manufacturing by selecting from a number of available options is something different, as that can be achieved at normal prices. Key factor here is a tight control of the processes for assembly and logistics; the actual production of the parts is standard mass production.

CENTRALSCANNING

3D digitizing and verification

Central Scanning, established in 2006, use their team of experts in the 3D scanning field to provide high quality scanning related services. They offer Steinbichler and Artec 3D scanning systems for sale as well as using these systems daily.

- 3D Scanning
- Reverse Engineering
- Inspection (part-to-part, part-to-CAD)
- CNC programmable large volume CMM
- 3D Printing
- CNC Machining
- 3D Modelling and Rendering
- ISO 9001 and ISO 14001 accredited
- Temperature Controlled Environment







01527 558 282

info@central-scanning.co.uk

www.central-scanning.co.uk

@CentralScanLtd

Like us on Facebook
facebook.com/centralscanning

- Design
- Engineering
- Electronics
- Software
- Prototype
- Test

crux

PRODUCT DESIGN



+44 (0)117 300 9788

cruxproductdesign.com

DeskProto®

Digital Manufacturing using a CNC milling machine



www.brandeseenmeurs.nl

Product Design

Use your milling machine as a Rapid Prototyping system



www.digital-jeweller.com

Jewelry

Machine very smooth wax models for investment casting



www.deskproto.com

Arts

Sculptures can be machined in any size and in any material



www.epokemodeller.dk

Hobby

Scale models, RC airplanes and boats, figurines, avatars, etc



www.roberts-chocolate.com

Food and sweets

Even the wildest designs can be easily realized



www.protoway.com

Moldmaking

Injection mold cavities, thermoform patterns, composite molds



www.plc.qld.edu.au

Education

Offer students hands-on CNC experience within a short time frame



www.deskproto.com

Woodworking

Reliefs, signs, ornaments, even the most complex designs are possible



www.liftonline.eu

Medical, dental

Machine custom prostheses, insoles, braces, dental crowns



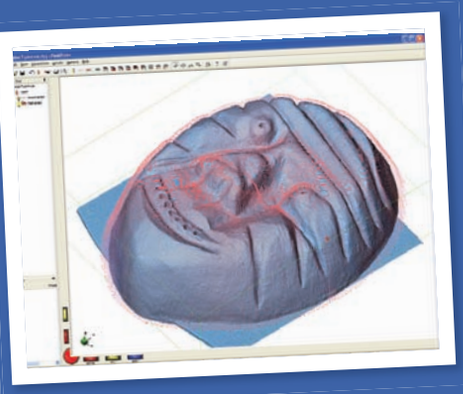
www.deskproto.com

Lithophanes

Artwork that can be seen only when illuminated from the back side

www.deskproto.com





Selection of the optimum process

Being a designer or engineer today you have a 3D CAD model and you need to make (or have made) a model, product or mould. The question is when it is best to 3D print and when it is best to use a CNC machine.

Key factors for this selection are of course the advantages and disadvantages of either method. An advantage for the one method most times also being a disadvantage for the other. In this section for each method a list will be presented of its main advantages. The actual choice however is more than just comparing the scores on advantages: in many cases one of the factors will tip the balance. Some examples will make it clear why for very similar cases the best choice still may be different.

Advantages of 3D printing:

- Easy to use: few required preparations.
- Price independent of part complexity
- No limit on part complexity
- Price per part independent of batch size
- Easy to switch to a next part (flexibility).

Some of these advantages need to be elaborated on.

The preparations that are needed to start a job: 3D printing does require some (so it's more than simply pushing the button '3D print'), like finding the optimal orientation of the part and adding a support structure where needed. And after printing, this support structure again needs to be removed. This is an advantage for 3D printing, as for CNC machining yet more preparations are needed: decide which side(s) need to be machined, which cutter to use, prepare a block of material in the correct dimensions and decide how to fix this block on the machine's working table.

The advantages of few preparations and high flexibility are closely connected, though with an important exception: when all parts to be manufactured are similar, the same preparations can be used for all parts. Then the flexibility advantage no longer applies. Examples of such similar parts are: rings (jewellery), insoles (orthotics), crowns (dental). Each part is different, however from a manufacturing point of view they are all equal. As such the process can use standard material blocks, a standard fixture and standard settings for CAM.

Allowing any level of complexity is a clear advantage of 3D printing. Well-known examples are manufactured by the likes Freedom of Creation, Nervous System and other companies that exploit this advantage of 3D printing to create products that otherwise would have been impossible.

The part price for 3D printing will not rise with the part's complexity. This is a clear contrast with CNC machining, where more details do cause a higher price, as more toolpaths will be needed. And the smaller these details, the smaller the cutter that is needed, and thus the higher the machining time.

Price and batch size being independent (making 10 identical products will cost 10 times as much as making one product) is an advantage for small series, however when large series are needed this becomes a disadvantage.

Advantages of CNC machining:

- Free choice of material
- Free choice of resolution
- High surface quality
- High accuracy
- Lower cost of ownership (both for machine and supplies)

Where for 3D printers the choice of materials is limited to a few materials only (or even one per system in some cases), CNC milling machines can handle a wide range of materials. The most important factor for the resolution of the part is the layer thickness (for 3D printers) or the toolpath distance (for CNC machines). The layer thickness can be set for the whole part, usually within a few pre-set increments. The toolpath distance can be freely chosen so that the same machine can produce both 'quick and dirty' parts and 'slow but perfect' parts. The surface quality (smoothness) for CNC machining is generally much better than for 3D printing. Even when the CNC toolpath distance is much larger than the layer thickness of the printer: the cutter is much wider than this distance and will smooth over the transition between the toolpaths.

For CNC machining the production time is related to the surface area to be machined (and to the volume to be removed, though that can be done quickly in a roughing operation). For 3D printers the production time is related to the volume that needs to be solidified. Though current building software applies smart algorithms to replace a solid volume by a shell with a 3D raster inside, still for large models machining will be much quicker than 3D printing. CNC machining as said can be done in almost any material. This does not only apply to the type of material, it does to the supplier as well, which makes it impossible for the system manufacturer to offer the machine at an artificially low price and have all revenues from the very expensive patented material cartridges.

Special selection cases

In many cases the selection can indeed be done based on the advantages and disadvantages mentioned above. An example from the field of model making: a model is needed of an electric hand drill. When making a styling block model (to show the outside appearance and for ergonomic tests) it will be best to CNC machine a solid model in tooling board: quick, low cost, and a perfect surface quality. When making a functional prototype (one that is capable to actually drill a hole) a model of the thin-walled casing will be needed, including all inside ribs, screw holes and other details. For such a part 3D printing is best (small volume to be printed, high volume to be machined, needing thin cutters).

In many other cases one of these advantages will be the deciding factor, making other factors irrelevant. This will be illustrated by the examples mentioned overpage:

Continues on p47



[AM vs Traditional: Delft Spline]

1/ The functional prototype just mentioned (electric hand drill), needs to be in exactly the same material as the final product for accurate testing.

2/ The products by Freedom of Creation and the like, already mentioned above, that just cannot be manufactured by CNC machining.

3/ A series of unique facade panels in stainless steel (1 m x 1 m) for the computing centre of the Dutch tax administration in Apeldoorn: savage-looking masks designed by Dutch artist Rob Birza. Here the size of the part was decisive, making CNC milling by far the most cost effective. Material was irrelevant, as the part was only used to cast a concrete mold. Production technology for the panels was hydroforming.

CNC machining can be the best process in case of special requirements for the material: dental crowns and bridges will be machined from zirconium, as after sintering (and finishing) that material can be used in the client's mouth.

Jewellers make a personal decision about which process to use: the deciding factor will not be the same for every jeweller. The required parts are jewellery wax models, to be converted to gold via investment casting. Some jewelers prefer CNC machining for its superb surface quality, or because of the lower investment for an in-house system, others use 3D printing for the complexity that can be achieved. Some jewellers subcontract to an outside service bureau for the ease of use, others do not want to go outside for reasons of confidentiality and/or speed.

Finally it will be clear that in many cases the deciding factor simply is the fact that a certain system is available in-house and the alternatives are not.

Example projects

A perfect example of custom manufacturing is the production of insoles, to solve problems with feet and/or posture. A podiatrist or pedorthist can solve such problems by designing a custom insole for the client. This is a sole to be used inside a normal shoe, with different locations with extra support and pressure relief for each client.

Such insoles are made of a flexible foam, in many cases using a different density for the front and the back. Specialised software is used to quickly design the insole, and the product is created using CNC machining. 3D printing cannot produce these flexible foams, and apart from that it would be more expensive.

The milling process can be completely automated. Calculating toolpaths is done by pushing one button (using the default settings). The machinist needs to place two foam blocks in the machine, push the button to start the vacuum pump for fixturing these blocks, and then start the machine. Production time is 10-to-20 minutes per pair. Production can be done either small scale (a lowcost machine for each podiatrist) or at a central location by a service provider using a fast machine.

Another example is an electric driver for the Dutch brand Ferm (www.ferm.com), by Brandes en Meurs industrial design in Bunnik, NL (www.brandesenmeurs.nl). The driver belonged to a complete series of power tools that the company has designed for Ferm. Brandes en Meurs used Creo Elements (Pro/E) for design, presentation renderings and computer simulations. Tangible models (Rapid Prototyping) were used at several stages of the design process: quick and dirty foam models at the start, ergonomic models later, and finally perfect presentation models of the resulting designs. These models will help the designers, and will also facilitate communications with the client and with the manufacturer in China.

Brandes en Meurs have a light CNC milling machine in their in-house modelshop, which makes it easy for them to machine a model when needed.

On another scale entirely is the city model of the Dutch town Maastricht, created by Made by Mistake in Delft (www.madebymistake.nl) and Komplot Mechanics (www.komplotmechanics.com) in Capelle a/d IJssel, both in NL. The model shows a plan ("De Groene Loper") to replace the A2 motorway in this town by a tunnel below the town.

The plan has indeed been selected, and the tunnel is currently being built, see www.avenue2.nl. Dimensions of the model are 3.5 m x 1.7 m. Such a model can be achieved using 3D printing, however machining was chosen as the model was easier to finish and thus cheaper. The model was not only large in size, the file-size for the CAD data (both terrain and buildings) was huge as well. To keep calculation time acceptable, a subdivision into 14 sections was made for the calculations. Details have later been applied manually: colours, roads, water, trees, etc.

In education the creation of tangible models results in an important lesson: the student will realise that his/her design in real life looks rather different from what he/she thought based on computer-generated renderings. This makes the use of models important, made either by 3D printing or by CNC machining.

A special advantage of CNC machining for education is that it forces the student to think about manufacturing issues. Designs with undercuts cannot be easily machined, and not easily produced either. As said before: most products will require a mass production technology like injection molding, where undercuts come with higher cost. In addition most schools will be happy with the low cost of ownership for CNC machining (materials to be machined).





