How Paper-based 3D Printing Works

The Technology and Advantages

mcor technologies
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Introduction

3D printers have been with us for decades, routinely turning 3D computer designs into detailed physical objects for product design, education, architecture, healthcare, mapping, historic preservation and other applications. These devices create models in a range of materials, including plastic, plaster, photopolymers, metal and sometimes even food. Each of these materials brings inherent advantages and disadvantages, depending upon your application. There's one more to consider: paper.

Selective Deposition Lamination (SDL) or paper 3D printing was invented by Dr. Conor and Fintan MacCormack in 2003. Dr. MacCormack first discovered 3D printing in 1986, when he was a secondary student in Ireland watching a BBC special. The technology captured his imagination in the same way that motorbikes, rockets, computers and space travel already had. He initially saw the technology in person when he was earning his doctorate degree at Trinity College. Unfortunately, the school's 3D printer was only a tease: because of the high cost of the material, only one or two students could print a model at the end of the year, defeating the whole purpose of having the technology. When he started working with Airbus as an engineer, he had ample access to a 3D printer – access he knew most students and engineers were denied. It just wasn't right.

Although 3D printer prices were declining, the cost of their materials was soaring. So Dr. MacCormack and his older brother, Fintan, a qualified aircraft mechanic and electrical engineer, set out to invent a 3D printer with an operating cost so low that the technology would be accessible to everyone. It was also important to make the printer robust enough for serious use in commercial settings, yet easy to use and without the toxic chemicals on which so many 3D printers rely.

That vision has become a reality in the company the MacCormacks co-founded, Mcor Technologies, which

Fintan and Conor MacCormack, Co-founders of Mcor Technologies.

manufactures monochrome and full-colour 3D printers that cost a fraction of any other 3D printing technology. The key reason? While most technologies build models from expensive plastic or chemically infused powder, Mcor 3D printers use ordinary, affordable and ubiquitous office paper as the build material.

SDL is not to be confused with the old laminated object manufacturing (LOM) technology. LOM used a laser, laminated paper and glue, so *everything* was glued together, including the support material around the model. Excavating the model was an ordeal, often resulting in 3D part breakage. Mcor uses a blade for the cutting and the 3D printer selectively deposits the adhesive only where it's needed.

This white paper will explain how a paper-based 3D printer creates a physical 3D model using the SDL process, and will document the unique attributes of an Mcor 3D printer that deliver on the MacCormacks' vision.

Selective Deposition Lamination (SDL)

Generating the Digital File

3D printing starts with a 3D data file. Mcor 3D printers support the universal industry standard file format for 3D product designs, STL, as well as OBJ and VRML (for colour 3D printing). All mainstream 3D computer-aided design (CAD) software products, including free programs such as SketchUp, produce STL files. Completed designs offered for download are typically presented in STL, as are files produced by scanning a physical object.

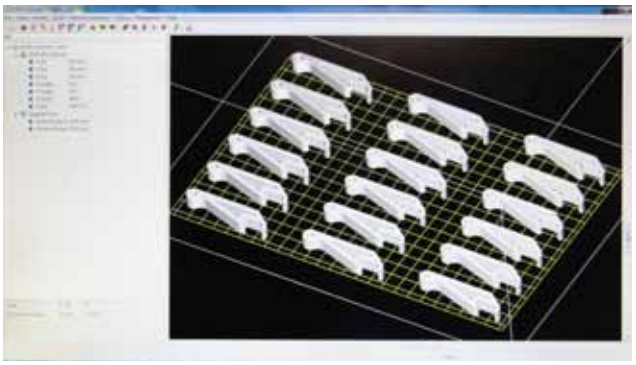


Fig. 1 *Mcor's SliceIT software reads the digital data and slices the computer model into printable layers equivalent in thickness to the paper. Compatible file formats are STL, OBJ and VRML.*

Mcor 3D printers include control software, called SliceIT. *(Fig. 1)* SliceIT reads the digital data and slices the computer model into printable layers equivalent in thickness to the paper. The software also enables you to position the part, or several parts, within the 3D printer's build chamber. SliceIT works on any standard PC running 64bit Windows (2000, XP, Vista or Windows 7) with a dedicated Ethernet card (speed of 10/100 or better) connected directly to the 3D printer.

The IRIS also comes with an additional piece of software, called ColourIT which is used in conjunction with SliceIT to apply colour to the 3D digital files. *(Fig. 2)* ColourIT can open numerous file formats: STL, WRL, OBJ, 3DS, FBX, DAE and PLY. Once the file is within ColourIT it can be checked for integrity to ensure it's a waterproof manifold, however the main function of ColourIT is to apply colours to the digital files prior to slicing in SliceIT.

Fig. 2 *ColourIT applies colour to the 3D digital files prior to slicing in SliceIT.*

Once the colour has been applied, the model is exported as an WRL file which is then imported into SliceIT for preparation for building.

Printing the Object

The first sheet is manually attached to the build plate. The placement of the first sheet is not important, as the first couple of pages are attached as a base layer before the actual part cutting begins. *(Fig. 3.1)*

Once the blade depth and the adhesive levels are correct, the doors are closed and the machine is ready to accept data from SliceIT.

From the PC and within SliceIT, the user selects print and the 3D printer starts to make the part.

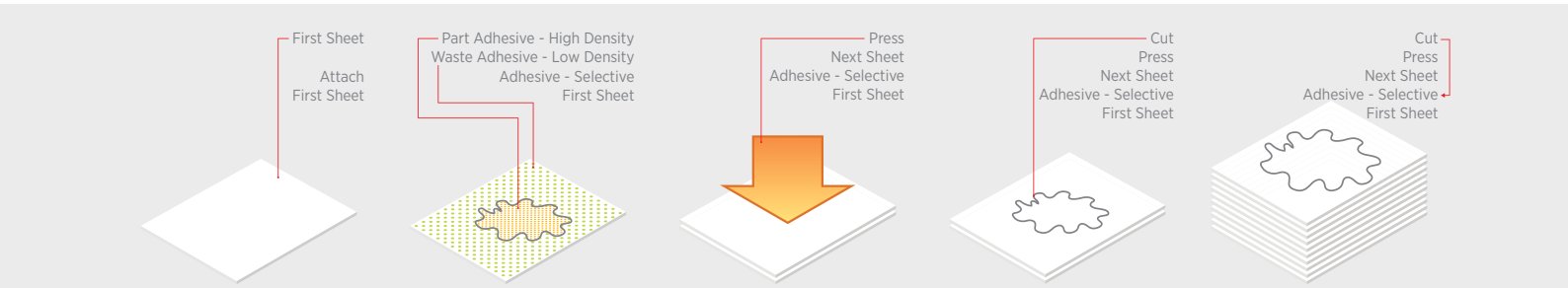
The first thing that happens is that a layer of adhesive is applied on top of the first manually-placed sheet. The adhesive is applied selectively – hence the name SDL – "Selective." This means that a much higher density of adhesive is deposited in the area that will become the part, and a much lower density of adhesive is applied in the surrounding area that will serve as the support. *(Fig. 3.2)*

A new sheet of paper is fed into the printer from the paper feed mechanism and placed precisely on top of the freshly applied adhesive. The build plate is moved up to a heat plate and pressure is applied. This pressure ensures a positive bond between the two sheets of paper. *(Fig. 3.3)*

When the build plate returns to the build height, an adjustable Tungsten carbide blade cuts one sheet of paper at a time, tracing the object outline to create the edges of the part. *(Fig. 3.4)*

When this cutting sequence is complete, the machine starts to deposit the next layer of adhesive and the whole process continues until all the sheets of paper are stuck together and cut and the model is finished. After the last layer is complete, the part can be removed from the build chamber. *(Fig. 3.5)*

Fig. 3 - How SDL Works



3.1 The first sheet is attached to the build plate.

3.2 The machine deposits drops of adhesive on the first sheet of paper, more in the area of the part and less in the surrounding area that will become the supporting material.

3.3 A new sheet of paper slides in, and the machine applies pressure to bond the first and second sheets together.

3.4 An adjustable Tungsten carbide blade cuts one sheet of paper at a time, tracing the object outline to create the edges of the part.

3.5 The process continues for each layer until the model is finished. After the last layer is complete, the part can be removed from the build chamber.

Weeding the Object

The main benefit of the SDL process becomes evident when the removal of the waste occurs. This process is called “weeding.” Because the adhesive is applied selectively, there is a greater bond between the layers of paper which constitute the model and less bond between the layers making the support material. Also, to aid ease of weeding, the support material is “diced” so that small portions of support material can be removed to ensure that delicate 3D models survive. *(Fig. 4)*

Fig. 4 *Quickly and easily peel the supporting paper away from the part. This can be accomplished with your hands and ordinary tweezers; no need for chemicals. The head model emerges.*

Unlike other technologies, Mcor 3D printers do not require dipping of parts in toxic chemicals or sharp instruments to remove support structures, vacuuming powder, or infiltration. An Mcor model will not crumble or shatter. It emerges from the 3D printer as a tough, durable model. *(Fig. 5)* When you consider that it’s made of tightly compressed sheets of paper, it essentially is reconstituted wood. As such, it generates a warm, tactile response that is uniquely pleasing to the touch.

If you want to make parts that can be drilled, threaded, tapped or water resistant, you can give them a quick dip and they’re ready to go. The model will also accept a variety of optional common finishes to suit your application needs.

Fig. 5 *An Mcor model emerges from the 3D printer as a tough, durable model; no need for infiltration.*

Colour Printing

If you're using the Mcor IRIS full-colour 3D printer, there's one more step. Before any cutting, the Mcor IRIS pre-prints the colour outline of the part on each page in the appropriate colour combinations using a modified 2D colour inkjet printer that sits in the IRIS stand. *(Fig. 6)* Mcor's patented water-based ink permeates the paper, preventing any white edges on the part. A barcode is also printed on each page to ensure the pages are in the right sequence. The pre-printed stack is then inserted into the 3D printer, which initiates the process described above in "How SDL Works." If a page is missing, the IRIS will pause to let you print a replacement. This process also fully colours the undersides, overhangs and sidewalls of models, which means you could recreate the ceiling and roof of the Sistene Chapel (at scale) in a single build.

Fig. 6 *The Mcor IRIS pre-prints the colour outline of the part on each page using a modified 2D colour inkjet printer that sits in the IRIS stand.*

Fig. 7 *Three reams of paper are placed in the paper feed door. Finished parts are removed from the front door.*

Mcor 3D Printer System Overview

Although an Mcor 3D printer is clearly a sophisticated system, it was designed to be as easy to use as an ordinary document printer and requires little training. Essentially, three reams of paper are placed in the paper feed door. Finished parts are removed from the front door. These doors open vertically for easy access. *(Fig. 7)* The LCD panel also offers simple instructions for operating the machine.

Technology Designed to Deliver Accessible 3D Printing

This remarkably simple process results from careful technology decisions focused on making 3D printing more accessible, including cost, ease of use, safety and eco-friendliness.

Cost

In order to be fully accessible, 3D printing must be affordable to use on an ongoing basis. Mcor's decision to use ordinary sheets of business A4 and letter paper as the build material was a careful, yet easy, decision. Paper offers a tremendous affordability advantage over other materials. Paper is a ubiquitous, stably-priced commodity, and Mcor printers can consume previously used paper. Whether you choose new or used paper, Mcor part costs are the lowest in the industry – approximately 5 percent of other technologies' costs. The total cost of Mcor IRIS ownership over five years is one-fifth that of competing technologies. A selection of Mcor parts and their production costs can be found on the following page.

These claims are bold, but here's why they're true. Other 3D printers lock you into proprietary technologies and make large profits on the consumable build materials, adhesives and infiltrants. So the more models you make, the higher your cost of ownership. Mcor 3D printers use paper that can be purchased from any office supply store and water-based adhesive; infiltrants are entirely optional.

Moreover, many of Mcor's pricing options include unlimited consumables to encourage access to the technology. The more models you make, the lower your per-part cost. Specific cost differentials depend on the technology you're comparing against Mcor, ranging from do-it-yourself kit devices to the most expensive technology.

Despite using low-tech paper as the build material, Mcor 3D printed models are strictly professional class. They are cut to a precision of 0.00047in (0.012mm) and a dimensional accuracy of 0.004in (0.1mm), and they are incredibly tough and durable. *(Fig. 8)*

Fig. 8 *Mcor models are cut to a precision of 0.00047in (0.012mm) and a dimensional accuracy of 0.004in (0.1mm).*

Architecture
47.1in³ (773cm³) $3.18 (€ 2.45)

Entertainment
8.9in³ (146cm³) $1.07 (€ 0.83)

Casting
11.4in³ (187cm³) $1.17 (€ 0.90)

GIS
18.4in³ (302cm³) $14.27 (€ 10.98)

Medical
6.6in³ (108cm³) $1.12 (€ 0.86)

Archaeology
18.6in³ (304cm³) $13.06 (€ 10.05)

MCAD
34.4in³ (564cm³) $4.07 (€ 3.13)

Consumer
5.7in³ (93cm³) $2.81 (€ 2.16)

Art and Culture
20.4in³ (334cm³) $2.29 (€ 1.77)

Education
11.4in³ (187cm³) $10.50 (€ 8.08)

Green, Safe and Easy to Use

Another aspect of accessibility is the ability to use your 3D printer in non-industrial settings such as schools, medical labs and professional design offices. That means no toxic chemicals, fumes, or dust and no dangerous heat or light.

Accordingly, Mcor's liquid materials – the adhesive and ink – are water-based and non-toxic. Mcor models require no infiltrants. Other technologies produce models of petroleum-based plastic, which is difficult to recycle, or require cyanoacrylate (e.g., Super Glue and Krazy Glue) infiltrants to prevent the models from crumbling. Other models also require chemicals to remove support materials.

In addition to being safe, the Mcor process is green: when you're finished using the model, it can go directly into the paper recycling bin.

Fig. 9 *The Mcor IRIS prints in more than one million colours simultaneously (CMYK, including black), delivering truly photorealistic 3D printed models.*

Colour

Colour 3D printing enables infinitely more possibilities – new applications that simply aren't possible with monochrome 3D printers.

While most "colour" 3D printers print only a handful of colours – one at a time in solid patches – the Mcor IRIS delivers True Colour, printing in more than one million colours simultaneously (CMYK, including black) from a palette more than twice the size of its nearest competitor.

Mcor takes its unique 5760 x 1440 x 508 dpi colour capability a major step further by rendering – on all surfaces of the part – colour as rich, vibrant and complex as it appears on a computer screen. Mcor colours are bolder and truer because the build material is paper, the intended medium for coloured ink. Mcor colour is consistent from computer screen to part and from part to part.

Mcor's high-fidelity colour and photorealistic resolution are critical for organisations that require lifelike models, colour coding, part labeling or other attributes that a mono-chrome 3D printer can't deliver. *(Fig. 9)* With the IRIS, what you see on your screen is what you ultimately hold in your hand, and that's limited only by your imagination.

Applications

The lost-cost, eco-friendly and full-colour capabilities of Mcor's paper-based 3D printers make them ideally suited for a wide variety of 3D printing and rapid prototyping applications.

Manufacturing

For manufacturers who need to develop better products faster, Mcor concept prototypes help designers quickly and thoroughly refine new designs. Concept models also ferret out potential manufacturing issues before they get expensive. SDL is also ideal for investment and sand casting, FEA studies, living hinges, packaging development and more.

Education

For educators, who want to safely and affordably improve learning in engineering, architecture, the arts and more, Mcor makes 3D printing accessible at an affordable cost.

Architecture

For architects who need to collaborate closely with teams and clients, 3D printed pure white massing or full-colour design models are more accurate than handmade alternatives, and easier, faster and more affordable to create. As with product designers, architects can make more refinements in a shorter period of time, resulting in better creations.

Medical

For surgeons, dentists and other healthcare professionals, lifelike anatomical 3D models help deliver better outcomes by improving preparation for procedures and fabrication of medical appliances for the individual patient.

Geospatial

For rescue teams, law enforcement, developers and the military, detailed, colourful 3D maps make achieving objectives quicker and easier than with traditional paper maps.

Entertainment

For the entertainment industry, full-colour 3D printing is a way to bring characters, settings and adventures into the third dimension for maximum impact.

Marketing

For salespeople and marketers who want to show customers and prospects new products before they hit the market, realistic 3D printed prototypes are far more powerful than brochures. There's more understanding and more impact, when customers can hold a new product in their hands.

Service Bureaus

For service bureaus that use 3D printing to make unique toys, jewelry, collectibles and other gifts and household products, in colour and at a price point consumers will accept.

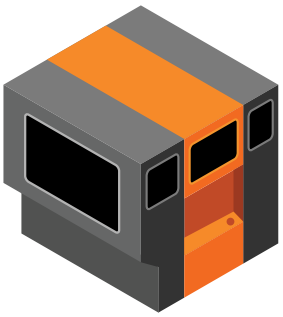
Archaeology

For preservationists, 3D printing offers a wide range of benefits for replicating, repairing and restoring priceless, one-of-a-kind artifacts.

These are just a few of the applications for professional-grade 3D printing, which, thanks to the vision of the MacCormacks, is becoming truly accessible to most everyone who can benefit from the capability.

Conclusion

Paper, as we've seen, is an eminently viable build material and offers distinct advantages in terms of enabling widely accessible, professional-quality 3D printing. There is no more affordable, safe or colour-rich approach. And Mcor's SDL technology is suitable for any office, school, healthcare laboratory or setting where people are learning, working or healing. This accessibility delivers what 3D printing has promised, yet struggled to deliver, for years – the ability for virtually everyone to improve their designs, shorten design cycles and win more business.



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About Mcor Technologies Ltd

Mcor Technologies Ltd is an innovative manufacturer of the world's most affordable, full-colour and eco-friendly 3D printers. They are the only 3D printers to use ordinary business letter and A4 paper as the build material, a choice that renders durable, stable and tactile models. Established in 2004 with a talented team of specialists in the area of 3D printing, software and CAD/CAM, Mcor's vision is to make 3D printing more accessible to everyone. The company operates internationally from offices in Ireland, the UK and America.

www.mcortechnologies.com