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3D PRINTING AND WOOD

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Abstract

Interest in 3D printing has greatly increased since 2013. With 3D printing high part complexity at no additional costs can be achieved, beside of efficiently using the raw material. This article reviews recent developments in 3D printing, with respect to the use of wood. Three examples are given on how wood could come to 3D printing: development of bio-based filaments, printing wood-like 3D objects, and perform „self-replication" of wood by combining 3D printing with microtomography. Bio-based printing filaments require extremely fine wood powder, to ensure a homogenious printing process without nozzle-blocking. The wood-like appearance seems to be of higher priority than the wood-based content as such. The wood „self-replication" is a new approach fostering bio-inspired materials research and biomimetics. Wood-related 3D will certainly have a future, but will most likely occupy „niche market" for e.g. complex-shaped wood products.

Key words: *3D printer; templating; additive manufacturing; filament; biomimetics; bio-inspired materials; biopolymer; self-replication.*

INTRODUCTION

Subtractive manufacturing technologies are well established and they are characterized by the removal of undesired materials to obtain prescribed product shapes. Many woodworking tools are based on substractive manufacturing, examples are CNC milling and turning, wood carving, moulding or grinding. The obtained wood components are usually assembled for e.g. furniture. In contrast, in additive manufacturing such as stereolithography and *fused deposition modelling*^{TM} (FDG$^{®}$, Stratasys), material components are created by depositing or fusing the material layer-by-layer (Conner et al. 2014). The advantages of additive manufacturing, i.e. 3D printing, are evident: unlike subtractive manufacturing incredibly complex products can be produced, making 3D printing ideal for developing prototypes of low-volume customized products. The higher the part complexity, the greater advantage 3D printing has over subtractive manufacturing. In addition, 3D printing is efficiently using the raw material, leading to low or zero waste (Berman 2012). Fig. 1 illustrates conventional manufacturing with respect to increasing complexity and customization, which is ultimately leading to increased cost. The break-even point in cost is shown when comparing costs per part and complexity. For complexity levels greater than that of the break-even point, it is more cost effective to use additive manufacturing.

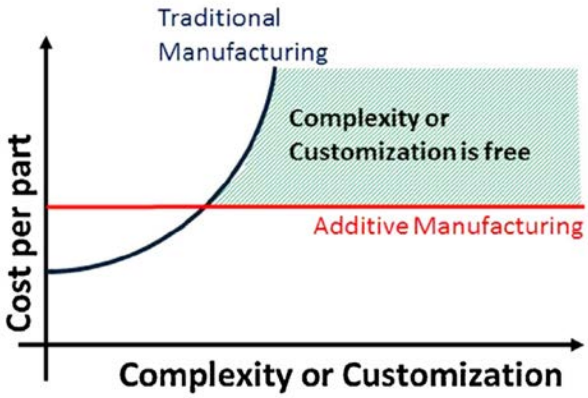


Fig. 1.
Costs per part vs. complexity or customization. With increasing complexity and customization the costs increase with traditional manufacturing. With additive manufacturing, complexity or customization becomes „free" (from Conner et al. 2014)

Fig. 2 illustrates search trends on Google for „3D printing" since 2008. The number of searches in March 2015 is set 100, January 2015 was the second most searches month (index=99). Between 2008 and 2011 the monthly search index was as low as 8, the first peak year was 2013. Since March 2015 the monthly searches have dropped to 72. Peaks mostly associate with published headlines issued by companies or electronic media (e.g. CNET), which relate to 3D printing.

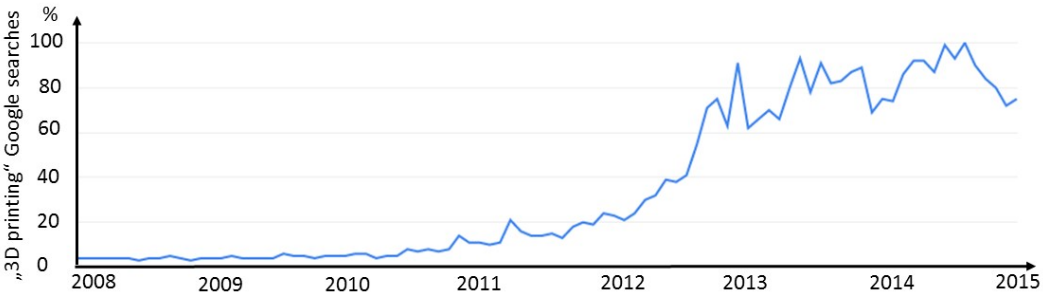
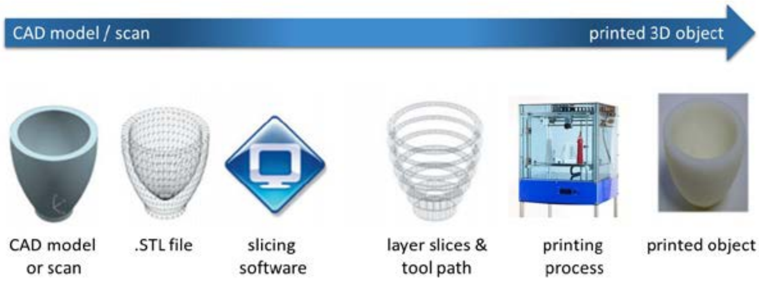


Fig. 2.
Google searches for „3D printing" since 2008; March 2015 searches are set 100%

3D printing designs could move around the world as digital files to be printed anywhere by any printer that can meet the design parameters. A given manufacturing facility would be capable of printing a huge range of types of products without retooling and each printing could be customized without additional cost. Consequently, production and distribution of products might become de-globalized, since production takes place close to the consumer. The carbon footprint of manufacturing and transport as well as overall energy use in manufacturing would be reduced substantially and thus global "resource productivity" greatly enhance and carbon emissions reduce.

Additive manufacturing starts with a 3D model of an object, which is usually created by computer-aided design (CAD) software, or a scan of an existing object. With a slicing software the 3D objects can be separated into cross-sectional layers, resulting in a suitable computer file that can be transferred to a 3D printer (Fig. 3). Then the printer creates the object by depositing layer by layer via selective forming (Fig. 4).



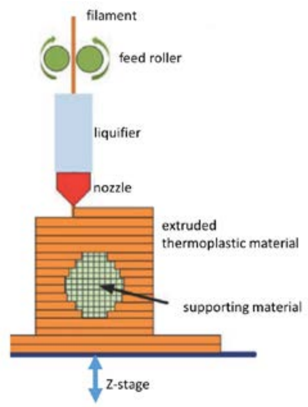


Fig. 4.
Fused-filament-fabrication technique
(after Campbell et al. 2011)

Fig. 3.
The 3D printing process
(after Campbell et al. 2011

There are several additive manufacturing processes that are differentiated by the way of how the individual layers are created. The term „fused filament fabrication (FFF)" was first introduced by the RepRap project (replicating rapid prototyper), a British initiative to develop a 3D printer that can print most of its own components. FFF is an open design, meaning all of the designs produced by RepRap are released under the free GNU General Public License. In FFF, an extrusion of thermoplastic material through heated nozzles is performend (Campbell et al. 2011). A polymer-based filament is guided by a roller into a liquefier that is then heated to a temperature above the melting point of the filament material. The material will then flow freely through the nozzle. The material cools and hardens as soon it is deposited. Once the layer is complete the build platform is lowered one layer-thickness by the Z-stage and deposition of the next layer begins (Fig. 4).

The various additive manufacturing technologies use different ways for creating the individual layers. For example, a binder could be injected into a a variety of powdered materials (e.g. polymers, wood, gypsum), using a UV laser to harden a photosensitive polymer (stereolithography). Another type is using a laser to selectively melt metal or polymeric powder, which is referred to as laser sintering (Gross et al. 2014).

BRINGING WOOD TO 3D PRINTING

There are at least three ways to bring wood to 3D printing: (A) wood-filled (lignocellulosic) filaments (B) 3D printed wood-like products, (C) micro-tomography and 3D printing for wood „self-replicating".

A) Wood-filled (lignocellulosic) filaments

A major interest exists in biodegradable 3D printing, including development and testing of ecofriendly and recycled materials. This refers not only to wood, but also to cellulose, sugars, or lignin. A 3D printer can utilize basically anything that can be powdered to an appropriate particle size. The key therefore is to grind a powder down to the appropriate fineness and texture, to allow it to be mixed into an polymer. Currently, standard polymers used for 3D printing are acrylnitrile butadiene styrene (ABS), polylactic acid (PLA), and different blends such as PLA with polyhydroxyalkanoates (PHA). These filaments are available in either 1.75 or 3.00mm diameters and they are sold in spools at prices of 30-45 Euro per kilogram. An increasing number of filament types are becoming available. There are different wood species compounded with polyethylene, polypropylene, or PLA. In the study by Tisserat et al. (2015) it is shown that if PLA biocomposites can be utilized in 3D printing, with a good interfacial binding necessary between the biomaterial and the PLA matrix.

In own research different lignocellulosic materials were tested for quality filaments. Different PLA types were prepared, which are blended / mixed with a variety of materials, including PHA, modifyers, lignin, cellulose, wood powder, talcum, nanocellulose, and color masterbatches (Steyrer

2015). The material components were processed to filaments on a Collin ZK25, a counter-rotating twin-screw laboratory extruder, equipped with a 3mm single-hole nozzle. Prior to processing, the PLA and PHA granulates were dried at 70°C for 24h, likewise the different bio-based fillers at 105°C for 24 hours. One kilogram of material was delivered to the volumetric dosing device for a continuous influx at the hopper. The screw was operated at 50rpm, with temperatures at the different zones between 145°C and 175°C. The obtained filaments were permanently monitored for thickness constancy, and also for constant polymer properties (melt flow indices measurements). An essential result was the necessity of using ultra-fine wood powder. Even a sieved <250μm particle fraction filled in PLA delivered frequent nozzle-blocking during printing. A produced cellulose pulp-filled PLA/PHA filament delivered low object warping, at reduced mechanical properties. A nanocellulose-filled PLA filament showed improved mechanical properites over the cellulose pulp-filled filament. Scanning electron microscopy (SEM) images of fracture surfaces revealed a cavity-rich inner structure (Fig. 5).

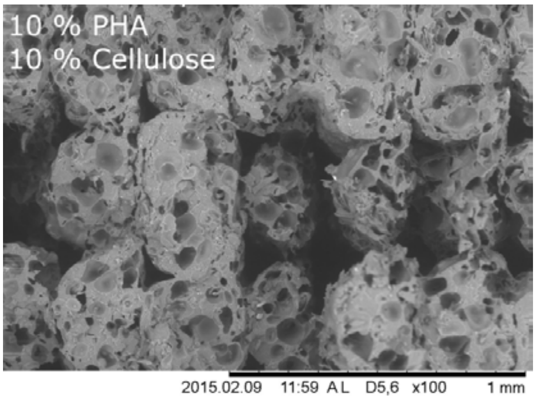


Fig. 5.
Fracture surface SEM image of a printed test bar using a cellulose-PHA-filled PLA filament

Overall, own research has shown that bio-based filaments can be designed for a variety of product properties, showing good printability. Good wood-type haptic was achieved, along with good mechanical properties and low warping. A PLA-type filament, blended with 15% PHA, and filled with 15 % cellulose (pulp), has delivered reproducible results.

B) 3D printed wood-like products

As mentioned, the asset of additive manufacturing is the high part-complexity that can be achieved. Any complex objects that should appear „wooden", or is printed superficially onto wood, can be seen as a potential future application. This could be e.g. ornamentations on wood panels for furniture, printed-on handholds, tool handles, artwork on wood surfaces, wood watches, and generally other special complex-shaped products (Fig. 6). Customers appreciate the warm appearance of "wood like" materials as they are printed with wood-based filaments.

Fig. 6.
Jelwek watches (http://www.3ders.org/), a 3D printed - wood filament watch collection - left; wood-like 3D-printed designer object (Rinkak Marketplace) - right

C) Wood self-replication

As 3D printing is *per se* a self-replicating technology this concept can be extended to wood. Here, 3D printing is combined with another emerging technology, i.e. x-ray computed microtomography. This technology has been already used for 3D-structural characterization of wood and related materials (e.g. Mayo et al. 2010). Recently, tomographic methods have greatly improved in resolution and computation capacity (Mayo et al. 2010). Commercially available scanning systems (e.g. phoenix|x-ray, GE Sensing & Inspection Technologies GmbH, Wunstorf, Germany) are now able to resolve at submicron level. Using such systems different genuine wood structures can be scanned tomographically and then 3D-printed. The 3D printing is used here to facilitate self-replication of wooden cell-structures at different scales of magnification. The self-replication of plant-based materials offers a new approach for structural-functional assessement, and for mechanical characterization towards biomimetic material design (Fig. 7). Printed „real" wood structures have also high potential to be used for teaching purposes, by manufacturing something like a „3D wood-anatomical atlas".

Fig. 7.
3D printed softwood (pine) tracheids, scanned with the Phoenix nanotom® (nanofocus-computer tomograph), with resolution at submicron level

In the field of mechanical assessment of materials and constructions, the digital-image-correlation (DIC) methods have been playing a significant role due to its field character returning displacement and strain data. It is an optical method that employs tracking and image registration techniques for accurate 2D and 3D measurements of changes in images. They are used to measure deformation, displacement or strain. DIC has become an important source of verification for finite element analyses (FEA) and important technique also for (bio-based) composites that deal with anisotropic and heterogeneous materials (Muszyński and Launey 2010, Feraboli et al. 2010, Sebera et al. 2014). Fig. 8 shows data from single cell deformation tests, carried out at the Mendel University in Brno (Kunecký et al. 2015). The images are showing the horizontal pixel movements, with the right image showing the bending of the left cell walls, as the right cell wall part is buckling.

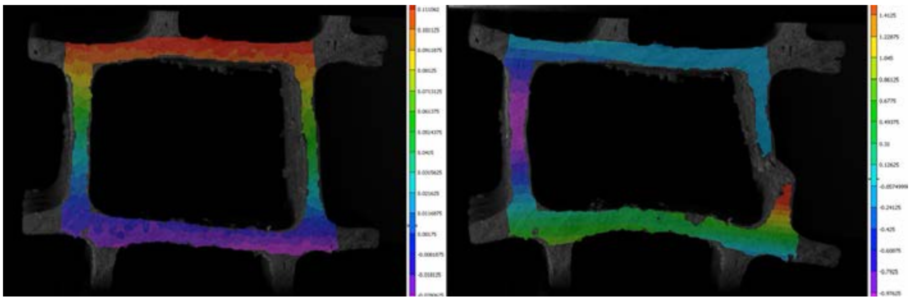


Fig. 8.
Deformation measurement using digital image correlation (DIC) on a 3D-printed single tracheid cell of pine: Initial load (compression) phase (left), and during cell collapse phase (right). Full field-strain and (horizontal) displacement were recorded (colours refer to horizontal shifting – positive values to the right, negative values to the left)

CONCLUSIONS

3D printing as an additive manufacturing technology has the important argument that it is inherently "green." Since material is added layer by layer, only the material needed for the part is used in the production. Consequently, there is virtually zero waste. The other significant feature of 3D printing is that a high part complexity at no additional costs can be achieved. 3D printing of wood has opportunities such as producing wood-like products, and printing complex wooden objects in combination with wood, or directly onto wood. However, 3D printing has also the potential as a novel research tool, to better understand structural features of wood and assess mechanical properties by using finite element modeling and digital image correlation. Through „self-replication", which can be achieved by a combination of 3D printing and microtomography, research in bio-inspired materials and biomimetics can be moved forward.

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