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Study Group Report on 3D Printing and Scanning

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Prepared by the ISO/IEC JTC 1 Study Group on

3D Printing and Scanning

Executive Summary

The purpose of this report is to assess the possible contributions of JTC 1 to the global market enabled by 3D Printing and Scanning.

3D printing, also known as additive manufacturing, is considered by many sources as a truly disruptive technology. 3D printers range presently from small table units to room size and can handle simple plastics, metals, biomaterials, concrete or a mix of materials. They can be used in making simple toys, airplane engine components, custom pills, large buildings components or human organs. Depending on process, materials and precision, 3D printer costs range from hundreds to millions of dollars.

3D printing makes possible the manufacturing of devices and components that cannot be constructed cost-effectively with other manufacturing techniques (injection molding, computerized milling, etc.). It also makes possible the fabrications of customized devices, or individual (instead of identical mass-manufactured) units.

3D printing is expected to have a large impact on the economics of global manufacturing. 3D printing, coupled with 3D scanning, also raises significant issues related to international copyright laws.

The data that drive a 3D printer can be generated either by a CAD system or a 3D scanner, or both. These data are machine interpretable and can use open-source or proprietary formalism. They need to be stored, exchanged, indexed, secured, etc. The integrity of the data, especially for safety or mission critical components or devices, must also be ensured.

Together these developments show that many standards and projects on 3D Printing and Scanning are relevant to JTC 1 and other ISO and IEC Committees and show the need for close collaborations.

Another aspect concerns the accessibility of the devices in both 3D printing and scanning. Just as computers have become available to many people, first in the form of PCs then in telephones and even watches, so will the necessary technology for 3D printing and scanning become cheaper and more widely available. However, in the meantime, it is felt that 3D print service bureaus and platforms will play an important role.

This report was produced to support further development on this topic by JTC 1. Given the potential impact of this IT intensive technology on global commerce, JTC 1 should create and mandate a Working Group to further increase its potential contribution in the area of 3D Printing and Scanning in cooperation with relevant existing ISO and IEC activities. Two New Work Items identified during the study should be progressed via this working group, once endorsed by JTC1.

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1. Introduction

1.1 Purpose and Scope

The purpose of this report is to assess the possible contributions of JTC 1 to the global markets enabled by 3D Printing and Scanning.

3D printing, also known as additive manufacturing (AM), refers to various processes used to synthetically produce a physical three-dimensional (3D) object. In 3D printing, successive layers of material are formed under computer control to create an object. These objects can be of almost any shape or geometry using designs that originate from a 3D model, a 3D scan, or other electronic data source. Since it produces physical objects from digital data, a 3D printer is thus a type of industrial robot [1].

Futurologists such as Jeremy Rifkin believe that 3D printing signals the beginning of a third industrial revolution, succeeding the production line assembly that dominated manufacturing starting in the late 19th century. Using the power of the Internet, it may eventually be possible to send a blueprint of any product to any place in the world to be replicated by a 3D printer, using "elemental inks" capable of being combined into any material substance of any desired form [1].

This document provides an overall review of 3D Printing and Scanning in terms of exploring IT standardization opportunities from the perspective of JTC 1. The JTC 1 Study Group on 3D Printing and Scanning is making this report based on these review results. Contributions of this report include:

- An overview of 3D Printing and Scanning;
- An analysis of active standardization activities in relevant Standards Development Organizations (SDOs) with an emphasis on information technology (IT);
- The identification of potential standardization areas and topics relevant to JTC 1 Terms of Reference;
- Recommendations for continued work by JTC 1.

1.2 Methodology

This report was elaborated by analyzing publicly available information from ISO and IEC Committees, various Web resources, and cooperating SDOs. The Technology Trend Report on 3D Printing and Scanning (ISO/IEC JTC 1 N13177) was used as basis document for this report. This report was finalized through both teleconferences from January to September 2017 and two face-to-face meetings in Seoul, Korea and in Montreal, Canada, where experts from the following NBs participated: Canada, China, Finland, France, Ireland, Japan, Korea, UK and US.

2. Terms and Definitions

3D printing or Additive Manufacturing (AM): any of various processes for making a three-dimensional object of almost any shape from a 3D model or other electronic data source primarily through additive processes in which successive layers of materials are laid down under computer control [2]. A 3D printer is a type of industrial robot [1].

3D scanning: process using a device that analyzes a real-world object or environment to collect data on its shape and possibly its appearance (i.e. color). The collected data can then be used to construct digital three-dimensional models [2].

According to ISO/ASTM 52900:2015, “Additive manufacturing is the general term for those technologies that, based on a geometrical representation, create physical objects by successive addition of material. These technologies are presently used for various applications in engineering industry as well as other areas of society, such as medicine, education, architecture, cartography, toys and entertainment.”

Using the terms and definitions of ISO/ASTM 52900:2015, the following terms are defined more precisely:

Additive Manufacturing (AM): process of joining materials to make **parts** (2.6.1) from 3D model data, usually layer (2.3.10) upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies.

Note 1 to entry: Historical terms: additive fabrication, additive processes, additive techniques, additive layer manufacturing, layer manufacturing, solid freeform fabrication and freeform fabrication.

Note 2 to entry: The meaning of “additive-”, “subtractive-” and “formative-” manufacturing methodologies are further discussed in Annex A of ISO/ASTM 52900:2015.

3D printing: fabrication of objects through the deposition of a material using a print head, nozzle, or other printer technology.

Note 1 to entry: Term often used in a non-technical context synonymously with **additive manufacturing** (2.1.2); until the present time this term has in particular been associated with machines that are low end in price and/or overall capability.

3D scanning / 3D digitizing: method of acquiring the shape and size of an object as a three-dimensional representation by recording x, y, z coordinates on the object’s surface and through software the collection of points converted into digital data.

Note 1 to entry: Typical methods use some amount of automation, coupled with a touch probe, optical sensor, or other device.

Additive Manufacturing processes are defined as: “processes of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing fabrication methodologies.” [ASTM 2792-12]

Additive Manufacturing is also referred to as [9]:

- Generative Manufacturing – Germany
- eManufacturing – Germany
- Constructive Manufacturing – Germany
- Additive Layer Manufacturing (ALM) – Scandinavia & EADS
- Direct Digital Manufacture (DDM) – USA
- Freeform Fabrication (FFF) – USA
- Solid Freeform Fabrication (SFF) – USA
- 3D Printing (3DP) – Global
- Rapid Manufacturing – Global (historic)

Digital Thread is a corresponding global area of interest, which considers changes to overall manufacturing processes and logistics that occur as a result of Additive Manufacturing and related capabilities refactoring of global supply chains.

3. 3D Printing and Scanning

3.1 Introduction

Additive Manufacturing (AM) is defined as the direct production of finished goods using additive processes from digital data (EU, SASAM, 2016). It is a process of making a three-dimensional solid object of virtually any shape from a digital model. It uses an additive process, where materials are applied in successive layers. In contrast, subtractive manufacturing processes usually start with larger sources and successively remove unwanted materials.

A key advantage is that AM typically eliminates the need for tooling, such as molds and dies, which can make the introduction of new products prohibitively expensive, both in time and money. AM enables the production of forms that have been long considered impossible by conventional series production, in fact, they can be created fast, flexibly, and with fewer machines.

Figure 1 Comparing traditional and additive manufacture of a specific part[1]

3D printing, also known as additive manufacturing, is considered by many sources as a truly disruptive technology. 3D printers range presently from small table units to room size and can handle simple plastics, metals, biomaterials, drugs, concrete or a mix of material. They can be used in making simple toys, pills with custom drug mixtures and dosage, airplane engine components, large building components or even human organs. 3D printer costs range from a few hundred to a few million dollars.

3D printing makes possible the manufacturing of devices and components that are not possible to construct with traditional manufacturing techniques. It also makes possible the fabrications of customized devices, or individual (instead of identical mass-manufactured) units. Occasionally 3D printing is used to create custom molds that are subsequently applied to traditional construction processes using alternative materials that themselves might not be suitable for 3D printing.

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[1] SASAM Standardization in Additive Manufacturing, product diagram courtesy of COMPOLIGHT project (http://www.smartlam.eu/index.php/related-projects.html)

The 3D printing market has the potential to significantly improve and refactor supply chain efficiency, reducing time to market, enabling mass customization, and supporting environmental sustainability [10].

3D printing capabilities have the potential to reduce the costs of storing, moving, and distributing raw materials, mid-process parts and end-usable parts. The ability to produce parts on demand without the need for expensive specialty tooling and setup can become a basis for new solutions in supply chain management.

Time-to-market durations are expected to shrink in the 3D printing applications due to faster design and prototyping cycles, more predictable factory loading, and the elimination of special tooling and factory setup times for new products. Increased freedom to design and redesign prototypes and parts without slowing down or adding to production costs also enables a more fluid product development process. Similarly, the ability of machines to read CAD files improves production planning. Systems can accurately predict the time and material requirements necessary to build a part before it is on a machine, and then can measure volume and track excess capacity at any moment.

3D printing's flexibility to employ multiple designs on the same machine can enable the manufacturing industry to move from mass production in factories to mass customization with distributed manufacturing. Using materials ranging from plastic to titanium to human cells, additive manufacturing creates intricate products of a near-infinite variety that can be made to exact customer specifications.

3D printing can further become a multifaceted tool for mitigating environmental impact by replacing many of the casting, molding and other manufacturing processes that consume significant amounts of energy and produce expensive (or hazardous) industrial waste. The technology also imposes few constraints on product design, enabling previously separate parts to be consolidated into a single object with increased functionality while reducing the amount of energy and natural resources. 3D printing thus enables significant impacts on the economics of global manufacturing. 3D printing, coupled with 3D scanning, also raises issues related to international copyright laws.

The data that drive a 3D printer can be generated by a CAD system, a 3D scanner, or both together. These data are machine interpretable and may include open or proprietary formalisms. Indeed either the printable model or the data format itself might be open source or proprietary. Such data are often sensitive and needs to be carefully stored, exchanged, indexed, secured, etc. The integrity of the original data must also be ensured, especially for mission-critical components and safety devices.

The 3D printing process starts with the development of a digital 3D model or data set containing the complete geometrical information. A 3D printer continues with the transformation of such data into a physical model, layer by layer. Thus the 3D printing process begins several steps before the 3D printer actually kicks into action.

The whole process is initiated when a user has an abstract image of an object in mind that he intends to 3D print. The next step is to find appropriate software that can model the particular object in digital form in 3D and will provide the 3D printer's built-in software (also called firmware) with the required input data. Computer-aided design (CAD) software or the scan of an existing artifact can be used to create a 3D model of an object. Alternatively, the user can search various extensive databases online for a suitable existing design file.

Once a design is ready, in current practice, the user typically translates the design file into a special geometric file format such as STL[2], which the control software of the printer can read and work with. When a design file is converted to STL, the software transforms the entire surface of the digital model into a mesh of connected triangles. When the STL conversion is complete, the volume of the newly wrapped object is completely enclosed by the generated mesh. Conversion to STL is not necessary from a technical viewpoint but derives from graphics practice when additive manufacturing first started.

In the next step, a software program known as a slicer, converts the mesh into a series of commands to create the model layer by layer. Depending on the printing technology, these commands may activate a light source to harden or fuse target material or command a print head to extrude material while moving to a given location. These commands are what are transmitted to the printer and interpreted by the printers firmware. For stereolithography and fused deposition modeling, the most common of these command sets is known as G-code. The G-code language originated in the 1950s for controlling CNC machines and Pen plotters. While there is an existing standard (EIA Standard RS-274) for G-code machine tool developers, the hobbyist and consumer markets have extended the language in occasionally incompatible ways. Therefore, a new control standard (ISO 14649) has been developed to replace G-codes for control (https://en.wikipedia.org/wiki/G-code).

ISO 17296-4:2014 shows the general overview of traditional data flow from product idea to actual part, as illustrated below.

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[2]Alternative file formats exist such as AMF(ISO/ASTM 52915:2016), 3MF (proprietary format) or VRML/X3D (ISO/IEC 14772-1:1997 and ISO/IEC IS 19775-1:2013) cf. ISO 17296:2014 Figure 1 – General overview of traditional data flow from product idea to actual part (terminology).

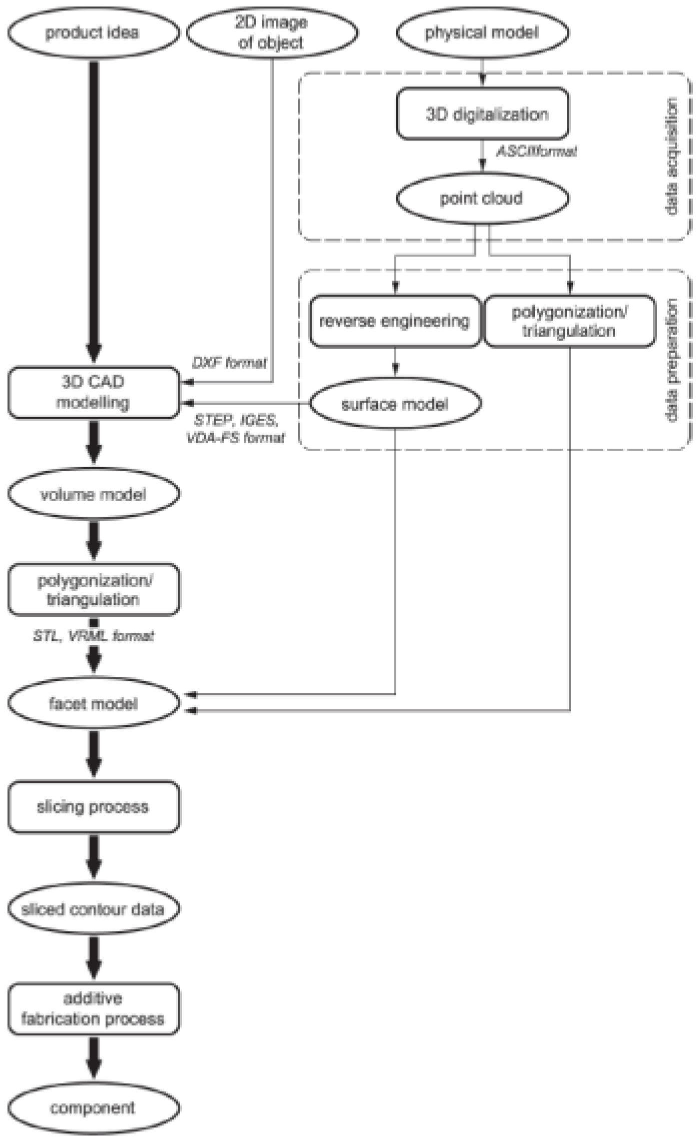

Figure 2 Traditional data flow from product idea to actual part

3D scanning is an accurate and fast method which determines the shape of an entity's surface or its volume in a three-dimensional space. 3D scanners are the devices which capture 3D information about the real-world objects, thereby helping in 3D visualization and measurement. The 3D models can be used extensively to perform comparative and dimensional analysis of a product or can be used to make changes in design to give rise to a new product. 3D scanning is an emerging technology and is expected to show promising outgrowth in the near future [12].

Some 3D scanners capture and measure geometry of physical object or environment by using lasers or structured light. Physical sensing of parts using probes to touch surfaces are also used (CMM machines). Due to high volume and approximation of surfaces, data captured by these 3D scanners are often called "point clouds." Such large datasets are used by software to create 3D representations of the scanned object or physical environment for in-depth analysis, inspection, and modification.

Precision and accuracy both vary widely and depend on sensor fidelity, scanning procedures and the ability of software to correlate numerous point approximations into smooth meshes. 3D scanners find wide application across several industries, currently with varying product quality [13].

3.2 Technology

A large number of additive processes are now available. The main differences between processes are in the way layers are deposited to create parts and in the materials that are used. Some methods melt or soften the material to produce the layers, for example, selective laser melting (SLM) or direct metal laser sintering (DMLS), selective laser sintering (SLS), fused deposition modeling (FDM), or fused filament fabrication (FFF), while others cure liquid materials using different sophisticated technologies, such as stereolithography (SLA). With laminated object manufacturing (LOM), thin layers are cut to shape and joined together (e.g. paper, polymer, metal). Each method has its own advantages and drawbacks, which is why some companies offer a choice of powder and polymer for the material used to build the object [1].

Additional details about 3D printing technology are provided in Table 1.

Table 1 3D printing technologies

Type	Technologies	Materials
Extrusion	Fused deposition modeling (FDM) or Fused Filament Fabrication (FFF)	Thermoplastics, eutectic metals, edible materials, Rubbers, Modeling clay, Plasticine, Metal clay (including Precious Metal Clay)
	Robocasting or Direct Ink Writing (DIW)	Ceramic materials, Metal alloy, cermet, metal matrix composite, ceramic matrix composite
Light polymerized	Stereolithography (SLA)	Photopolymer
	Digital Light Processing (DLP)	Photopolymer
	Solid Ground Curing (SGC)	Photopolymer
	Polyjet	Photopolymer
Powder Bed	Powder bed and inkjet head 3D printing (3DP)	Almost any metal alloy, powdered polymers, Plaster
	Electron-beam melting (EBM)	Almost any metal alloy including Titanium alloys
	Selective laser melting (SLM)	Titanium alloys, Cobalt Chrome alloys, Stainless Steel, Aluminum
	Selective heat sintering (SHS)	Thermoplastic powder
	Selective laser sintering (SLS)	Thermoplastics, metal powders, ceramic powders
	Direct metal laser sintering (DMLS)	Almost any metal alloy
Laminated	Laminated object manufacturing (LOM)	Paper, metal foil, plastic film
Powder Fed	Directed Energy Deposition	Almost any metal alloy
Wire	Electron beam freeform fabrication (EBF)	Almost any metal alloy

Some 3D scanner types are classified as laser and structured light 3D scanners. Product segmentation covers tripod mounted, automated and coordinate measuring machine (CMM) based, and handheld/desktop/stationary 3D scanners. 3D scanning technologies include laser scanners, white light scanning devices, photogrammetry devices, machine vision devices, X-ray computed tomography (CT) or magnetic resonance imaging (MRI) scanners, and others. The various kinds of scanners used are primarily based on the varied sensing technologies available. Optical 3D scanners and CMMs measure the outside of a part only, while CT and MRI also measure the inside, giving more complete data.

3D scanners can be put to extensive use across a varied range of applications such as reverse engineering, inspection, digital archiving, rapid prototyping, topographical surveys and so on. Well-established fields such as automotive, aerospace, education, architecture, medical, dental and others are among the various end-user industries that employ 3D scanning for topological visualizations.

3.3 Market

As seen in Figure 3, Gartner in 2015 was considering Enterprise 3D Printing as fairly mature while Consumer 3D Printing and 3D Bioprinting Systems are not yet mature.

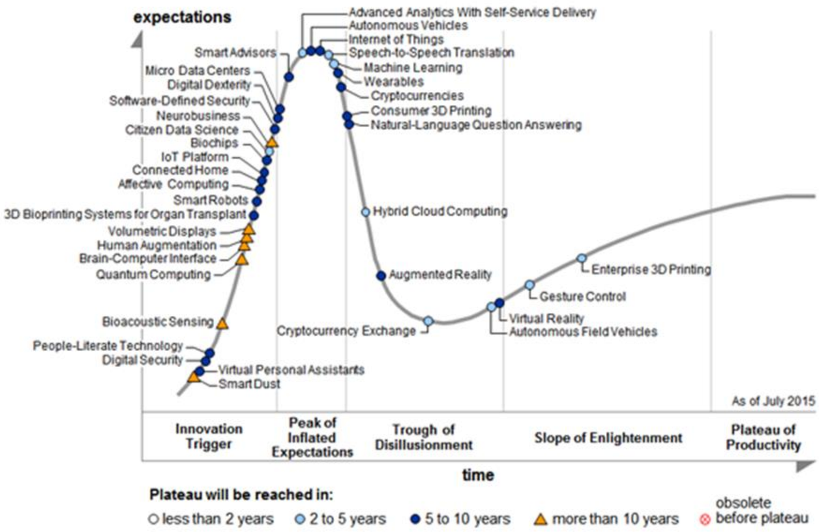

Figure 3 General maturity of 3D Printing and 3D Scanning on 2015 Gartner Hype Cycle[3]

As mentioned, 3D printing has a wide range of applications. The Gartner diagram of Figure 4 is interesting in this regard since it places various applications of 3D printing at different levels of maturity on its "hype cycle." According to Gartner, many applications are at early stages of innovation while others have already reached the plateau of productivity.

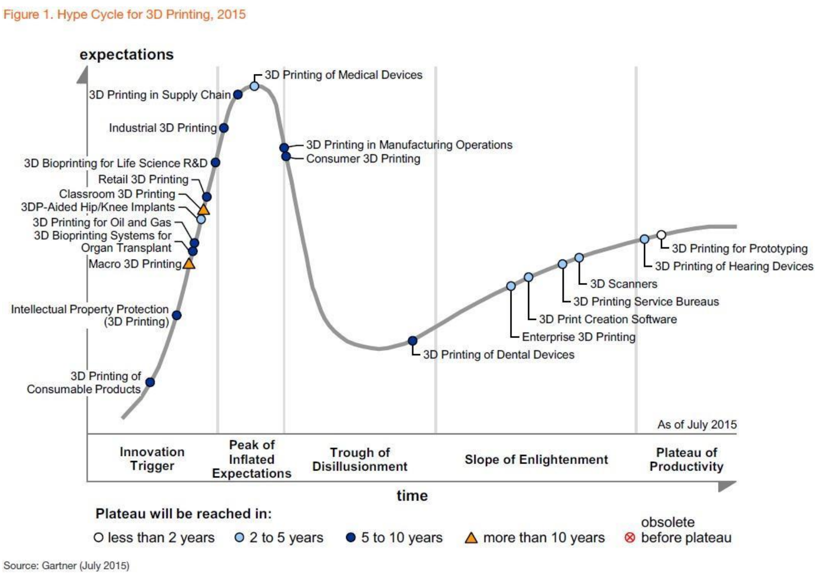

Figure 4 Gartner 2015 Hype Cycle for 3D Printing[4]

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[3]http://www.gartner.com/smarterwithgartner/whats-new-in-gartners-hype-cycle-for-emerging-technologies-2015

[4]http://www.gartner.com/newsroom/id/3117917

Many estimates of the potential size of the 3D printing market are available in the open online literature. Figure 5 summarizes some of them.

RESEARCH FIRM	YEAR ($ Billions) 2013	2014E	2015E	2017E	2018E	2020E	CAGR	CAGR Period
AMR	$2.3					$8.6	20.6%	2013-2020
Canalys	$2.5	$3.8			$16.7		45.7%	2013-2018
CCS Insight	$1.2				$4.8		33.0%	2013-2018
Freedonia				$5.0				
Gartner			$1.6		$13.4		103.1%	2015-2018
IBISWorld *		$1.4					15.7%	2014-2019
IDC							29.0%	2012-2017
Wohler	$3.1				$12.8	$21.0	33.0%	2013-2018

* U.S. market only

Figure 5 Comparative table of Global 3D Printing market estimations[5]

This shows a market that appears to be growing at a fast pace. Figure 6 shows one of these market estimates in more detail, while also illustrating the complexity of the technology for both materials as well as the different 'printing' processes used.

Figure 6 Estimation of the Global 3D printing market[6]

The consumer market is changing rapidly. On the growth side consumer grade 3D printers have accounted for over $10M in crowdfunded startups and they are becoming prolific in libraries and schools. On the down side many companies are struggling to identify a segment for profitability with two of the early consumer printer startups having ceased operation.

[5] http://sophiccapital.com/3d-printing-the-education-sector-is-on-the-cusp-of-adoption/

[6] https://www.forbes.com/sites/louiscolumbus/2015/03/31/2015-roundup-of-3d-printing-market-forecasts-and-estimates/#6dda5fe01b30

Potential impact of 3D printing on different markets is further illustrated in Figure 7.

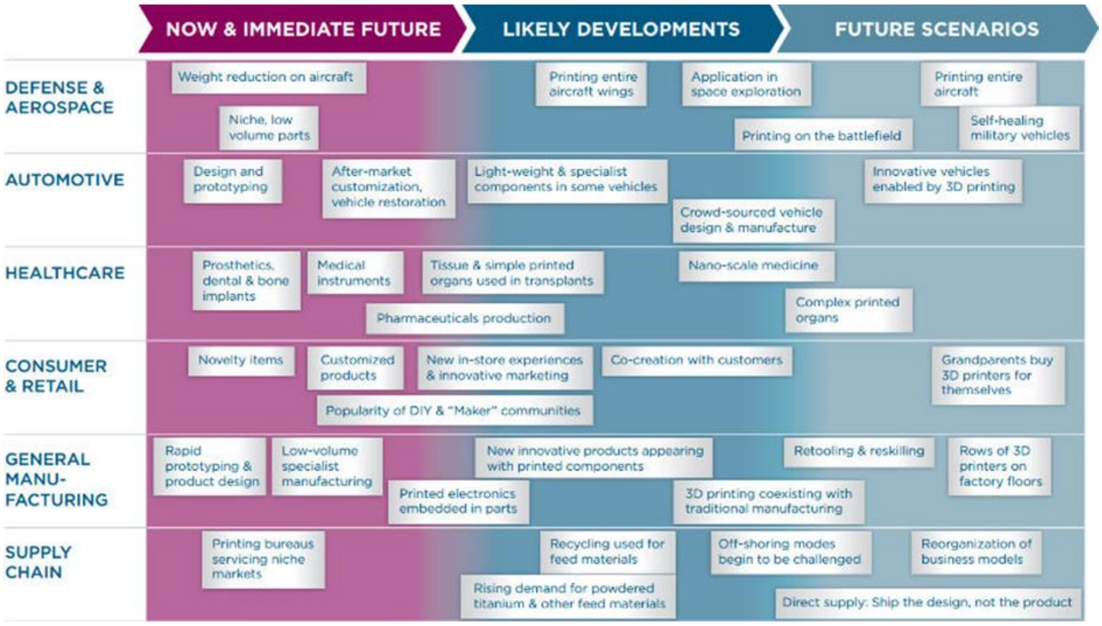

Figure 7 3D printing impact on various industries[7]

Figure 8 shows that the global 3D scanner and printer market is actually quite fragmented, with industry players that are very different from the traditional office and commercial printing markets.

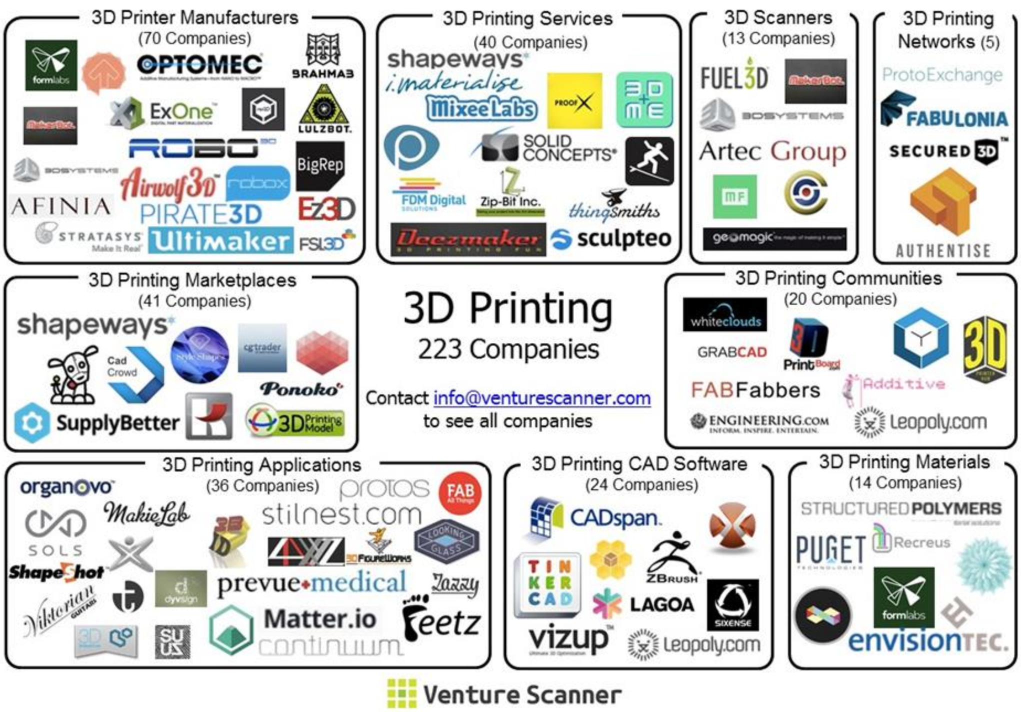

Figure 8 3D scanner and printer companies[8]

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[7] http://www.cellular3d.com/index.php/market-research

[8] http://insights.venturescanner.com/category/3d-printing/

While 3D printing is beginning to be used for a range of different manufacturing functions, it has not yet reached a mass market. At present, only serious enthusiasts or highly specialized manufacturers use 3D printers. Given the rapid pace of progress, everyone may soon find himself consuming products created by 3D printers.

In practice, 3D printing will not create a single, homogenous market; it will most likely be used in a variety of different ways, giving rise to different types of businesses and different approaches to manufacturing. The most significant likely markets involved in 3D printing include [11]:

- *Design* – 3D printing will likely create a global market for digital designs, both for generic blueprints and bespoke (custom) design services.
- *Bespoke manufacturing services* – 3D printing may well place increased emphasis on the service aspect of manufacturing, with retail and production being fused into customized services, including 3D print service bureaus (Fig 4 lists such bureaus on the hype cycle & Fig 8 identifies 40 companies already operating in this sector)
- *Home 3D printing* – Some 3D printing is likely to take place within the home, while some will take place within shops or factories; these domestic and commercial markets will look very different.
- *Manufacture of 3D printers* – Producing and servicing 3D printers themselves are likely to be a big money industry.
- *Materials* – Creating and sourcing materials for use in 3D printers will also become a significant market.

So far, this report has mainly looked at the market for 3D printing that is quite closely related to the 3D scanning but there are other markets for 3D scanning that are not necessarily related to 3D printing.

Because of its usefulness in making dummy parts and prototypes for manufacturing, 3D scanning will continue to be in high demand for the automotive and similar mechanical sectors, while quality control, cultural heritage and reverse engineering will become major growth applications for the technology in the years to come [14].

The 3D scanning market is also being driven by the fact that it is being widely adopted by the medical industry for surgical applications, diagnosis via MRI, CT scan and others, while it is also being used in dentistry. Moreover, a recent story revealed how a 3D scanner is being used by Australian police to map crime scenes without disturbing evidence [14].

Finally, there have been developments in the area of 3D/AM service platforms. Such platforms enable users, via an online service (web and app-based), to specify and procure customized AM objects & parts without incurring the cost of investing in expert AM designers, or purchasing and maintaining expensive AM printers, or holding inventories of feedstock materials.[9]

9 http://www.manufacturingtomorrow.com/story/2017/05/link3d-launches-largest-platform-to-connect-engineers-with-global-additive-manufacturing-services/9601/

4. Use Case and Standardization Requirements

Among other fields of businesses also 3D printing and scanning industry has grown a vital business ecosystem through several areas of industry. In some industries the ecosystem seems to be more mature while in others ecosystems are still evolving at an early stage. Some future businesses or not invented yet services are still to come. Nevertheless the 3D printing and scanning market is growing and will certainly become an important future business ecosystem.

The following table lists prospective areas where 3D printing and scanning could play a big role.

Medical Industry	Health & Wellness	Gaming & Animation
Cranial 3D scanning and printing Dental industry Decease recognition (mixed) Prosthesis creation Manufacturing of surgical practice dummies	Fitness Body wellness Artificial Intelligence Healthcare	3D gaming Movie animation Personal animation and personalization
AR & VR Activities	**Manufacturing**	**Apparel & Fashion**
Leisure and business use cases	Aerospace Automobile Electronics Consumer goods	Fitting / online clothes sale Made to measure clothes Fashion design
Urbanization	**Transportation**	**Industry R&D**
Building industry City / environment planning Road and railway design and manufacturing	Land Air Sea Space	Personal data used for Big Data analyses (clothing and fashion) 3D scanning and printing used to fasten product development cycles

The Gartner's Hype Cycle (Figure 3) and the 3D printing impact on various industries (Figure 7) described that manufacturing and medical applications would be most relevant for 3D printing and scanning. We propose the following use cases.

4.1 Use Cases in General Manufacturing

The following use cases in general manufacturing are considered:

- Manufacturing for production parts
- Manufacturing for multi-process parts
- Mold making

- Part repair, remanufacturing
- Manufacturing for amateur users
- Manufacturing archiving
- Cloud services for additive manufacturing

The basis for the shape models is assumed to be exact models created using CAD or other exact modeling systems, not from measured data such as the ones delivered by measurement systems in medical applications, for example. This excludes single individualized prostheses, for example, where it is easier to use approximate shapes rather than fit complex surfaces to measured points. However, individual parts made from calculated geometry where there is an exact model would be included.

Manufacturing for Production Parts

For many parts with relatively simple shape, production based on milling, turning, etc. is more efficient than additive manufacturing. However, for small, flat parts, parts with complex internal structures or for complex shapes additive manufacturing becomes more competitive. For small, flat parts, many parts can be made in one build run, thus reducing the individual production time per part.

However, the smaller the part, the greater the significance of discrepancies introduced by early approximation of the shape. Turbine blades are a practical example of this use case, as reported by Rolls Royce and General Electric, for example. Prof. Hascoet, Dean of Research at Ecole Centrale de Nantes and member of ISO/TC 184/SC 4/WG 7 has also much experience with suppliers for AIRBUS. Figure 9 shows the information pipeline through the set of production machines of milling, turning, forming and additive manufacturing [22].

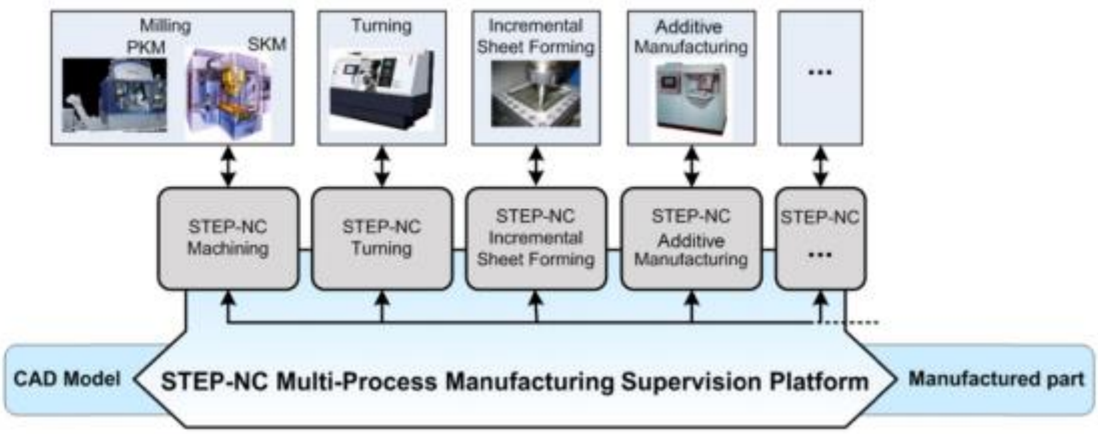


Figure 9 Production information pipeline

Manufacturing for Multi-process Parts

Manufacturing using several processes requires a single model for all processes rather than a set of linked models where there is room for inconsistencies between models. The use of approximate models with the current approximation means that the delivered physical part will be inside the real geometry in convex areas and outside the real shape in concave areas. For processes such as milling, turning and grinding (polishing) it is better to have excess material. For a process such as infiltration it may be preferable to have less material than needed, but this is not certain.

Additive manufacturing can also be used to make raw parts for a technique called 'near net-shape manufacturing', which needs excess material. There is a commercially available machine which combines additive manufacturing and milling in the same workspace. Figure 10 shows a part composed of an additive feature and subtractive features [21].

Figure 10 Part composed of an additive feature and subtractive features

Mold Making

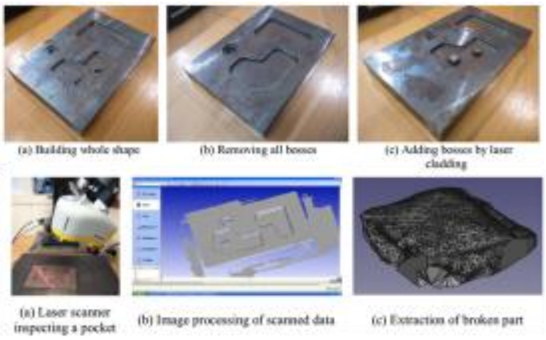
Mold making with additive manufacturing, or rapid tooling, has an important role in production. Mold making means that parts made of a wider range of materials than those used for additive manufacturing can be produced. Normal mold manufacture takes a long time so rapid tooling allows production to start quicker. However, there is an added advantage with rapid tooling that conformal cooling channels can be built into the mold. Cooling channels are used to preheat the mold to allow material to flow into the mold cavity more easily and to cool the mold so that parts can be extracted more quickly.

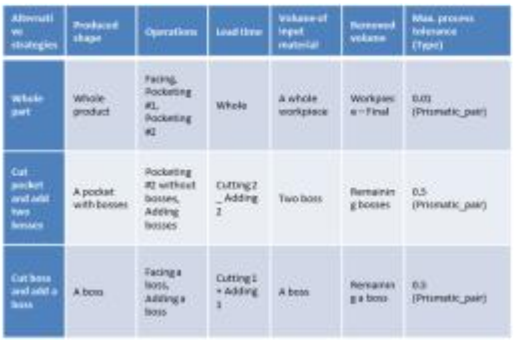
In conventional molds these cooling channels can only be made with simple shapes, usually cylindrical holes drilled at the end of the mold making process. However, with rapid tooling complex shapes adapted to the mold cavity can be made for more efficient heating and cooling. This reduces the production cycle time and hence increases productivity. One drawback of rapid tools is that they have, in the past, used less dense materials and so been less durable than conventional molds. Experiments at EPFL by Dr. Eric Boillat and his collaborators have examined many aspects of rapid tooling and additive manufacturing. These include post-processing (infiltration) as well as behavior of the melt pool which can be used for advanced control to improve part quality.

Part Repair, Remanufacturing

This use of additive manufacturing is interesting for several reasons. One reason is that material is added to an existing part rather than to a base plate or table. Another reason is that the build direction may well not be constant. A third reason is that the material added may not be in planar sections – cladding, or direct metal deposition (DMD) has been proposed for the repair of turbine blade edges, for example. The same technique may also be used to add manufacturing features where, say, milling cannot be used because there is no tool access.

As well as turbine blade edges, mold repair for car bumper molds and engine blocks is another application of this use case. Especially, the mold of car bumper has tiny shapes which are easily worn out due to tremendous heat during the molding process. By removing tiny inserts and cladding them again, the mold can be reused without expensive work to reproduce a large metal shape. The most important knowledge for this case comes from accurate scanning of the broken shape including very small complex geometry and balancing the ratio between the shape removed before cladding and the shape filled by the additive process. Figure 11 compares the performance of various strategies of remanufacturing plans combining subtractive processes and additive processes [22].





Alternative strategies	Produced shape	Operations	Lead time	Volume of input material	Removed volume	Max. process tolerance (Type)
Whole part	Whole product	Facing, Pocketing #1, Pocketing #2	Whole	A whole workpiece	Workpiece − Final	0.01 (Prismatic_pair)
Cut pocket and add two bosses	A pocket with bosses	Pocketing #2 without bosses, Adding bosses	Cutting2 _ Adding 2	Two boss	Remaining bosses	0.5 (Prismatic_pair)
Cut boss and add a boss	A boss	Facing a boss, Adding a boss	Cutting1 + Adding 1	A boss	Remaining a boss	0.3 (Prismatic_pair)

Figure 11 Part remanufacturing

Manufacturing for Amateur Users

Because of the prevalence of home systems for amateur users it is necessary to consider manufacturing by users unaware of the exact nature of the process being used. For such plug-and-play systems it is necessary to have intelligent controllers that can be adapted to provide the desired output to current and future processes.

Although the common, low-priced machines usually work in plastics it is to be expected that the use of metals in hobby machines will increase. It is also to be expected that such machines will be used for the manufacture of spare parts for small home repairs by good DIY people who are unaware of manufacturing technology. Figure 12 shows the comparison of two use cases where the left side is manual works without the knowledge guide system while the right side describes the automatic chain of geometric process along the non-linear plan shown in the right graph [22].

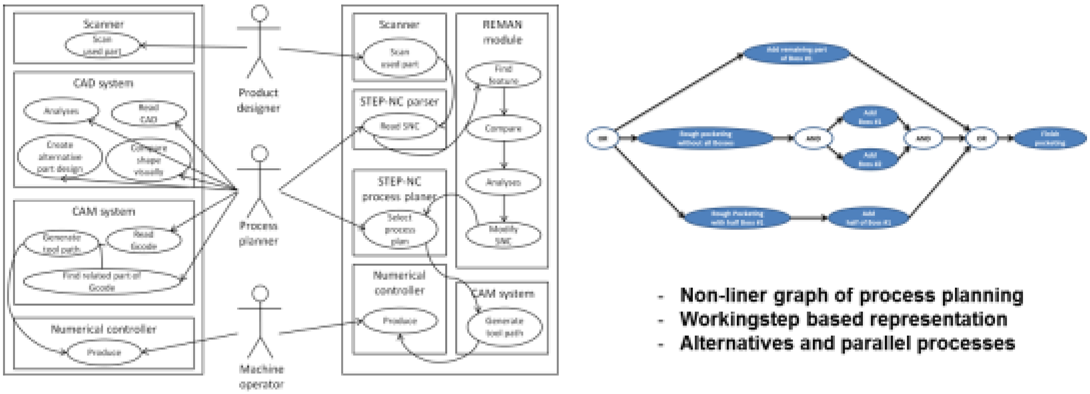


Figure 12 Comparison of two use cases

Manufacturing Archiving

In manufacturing product lifecycles can last for a long time. For aircraft this can be fifty years or more, for example. Cars also have a relatively long lifetime. Manufacturing data have to be preserved over the lifetime of the product. STEP-NC is a micro process plan, containing data about how to make a part rather than just simple geometric movements. This means that it is easier to move manufacture between machines and adapt to new machines as well. With a dynamic manufacturing method such as additive manufacturing this flexibility is important.

Cloud Manufacturing

Cloud services are another possible method for accelerating the revolution of manufacturing industry of 3D printing and scanning. Users need only the hardware for 3D printing and scanning and receive all engineering support through cloud services such as CAD/CAM/PLM/Point cloud analysis/Data conversion/FEM analysis. Many use cases relevant to this application have been developed in European projects funded within the EU Framework FP7 and Horizon 2020. EU H2020 CAxMan project has already finished and reported two industrial use cases of gear parts and mold injection. The description can be found in [23]. The cloud services were developed by the earlier EU FP7 CloudFlow project. Twenty industrial use cases were developed and are described in [24].

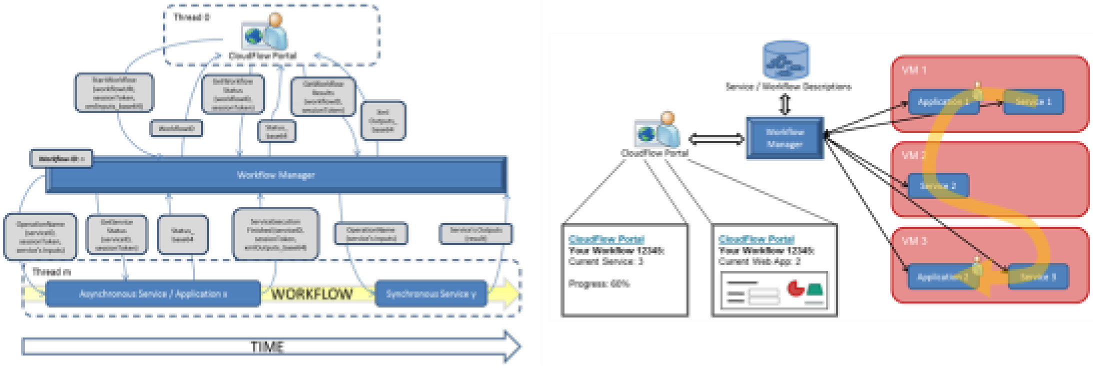


Figure 13 CloudFlow illustration

Figure 14 CloudFlow workflows

Four obvious use cases of 3D scanning in industry are:

- Industrial design
- Raw part scanning
- Remanufacturing
- Quality control

Industrial Design

Scanning for industrial design is one area where measured points are parts of the production chain. It has been common in the car industry to use CAD to get close to the desired shape, then use the CAD model to mill a clay prototype, do hand finishing to get the final shape, and then scan that to get a numerical model. A development at ETH Zürich [20], called TangibleCAD or TCAD, also followed this line. Both the auto scanning and the TCAD method were concerned with the external shape of the part, not the internal shape. The external shape would then be used together with CAD tools to create the final part and molds or dies for production.

Raw Part Scanning

Scanning of parts before or during manufacture is used to assess variations. Sheet metal parts can vary in terms of thickness so that pressed shapes show variations in degree of bending. Car door components, for example, have been scanned visually before subjecting to laser welding, a process without physical contact between the welding tool and the part to overcome part deviations.

Remanufacturing

As described above, remanufacturing requires information about the state of the part to be repaired. This is done by scanning the part or relevant features, comparing them with the CAD part and then determining relevant manufacturing repair operations.

Quality Control

Quality control is another area where scanning may be useful. However, one difference is that certain critical parts, or features, may need to be measured rather than whole objects. Touch probing is an option for this because, even though the technique is slower than optical scanning, it is only needed in limited object parts.

4.2 Use Cases in Medical Applications

Two examples 3D scanning and printing use cases are:

- Cranial implants
- Dental prostheses

These are described below and provide important and practical illustrations of the utility of these techniques. Both descriptions have been provided by experts in their own fields.

Cranial Implants

There will always be a need for cranioplasty in neurosurgery. Many situations, including skull tumors, bone resorption in various circumstances, infection, and traumatic loss, can result in skull defects. The reconstruction of large skull defects is a challenging task. Skull reconstruction should provide not only biomechanical stability, but also cerebral protection.

The main indications for cranioplasty are skull defects resulting from decompressive craniectomy, used increasingly for the treatment of intractable intracranial hypertension caused by a range of conditions. The rationales for cranial reconstruction are protection, cosmetic restoration, and improvement of neurological function.

Workflow for 3D Cranial Implant from Additive Manufacturing

At the very beginning, the cranial defect is assessed by CT (Computed Tomography) or MRI (Magnetic Resonance Imaging) when a skull defect patient visits the neurosurgical clinic. CT has been known as gold standard for investigating bone related problems. As Figure 15 shows CT transports patient data as DICOM file format to a medical imaging system. DICOM images have been used to reconstruct 3D images through segmentation and 3D modeling. This 3D modeled image is transformed and exported to a designing software as an STL (Surface Tessellation Language) file. After completion and confirmation of the 3D cranial implant, a metal additive manufacturing machine prints this implant as designed. Post-processes such as cleaning, sanding, and washing, have been performed. Reverse engineering is made to confirm the completeness of the implant before delivery. After quality control, the implant is packed, sterilized, and delivered. The operation is performed to recover the defect with the 3D cranial implant.

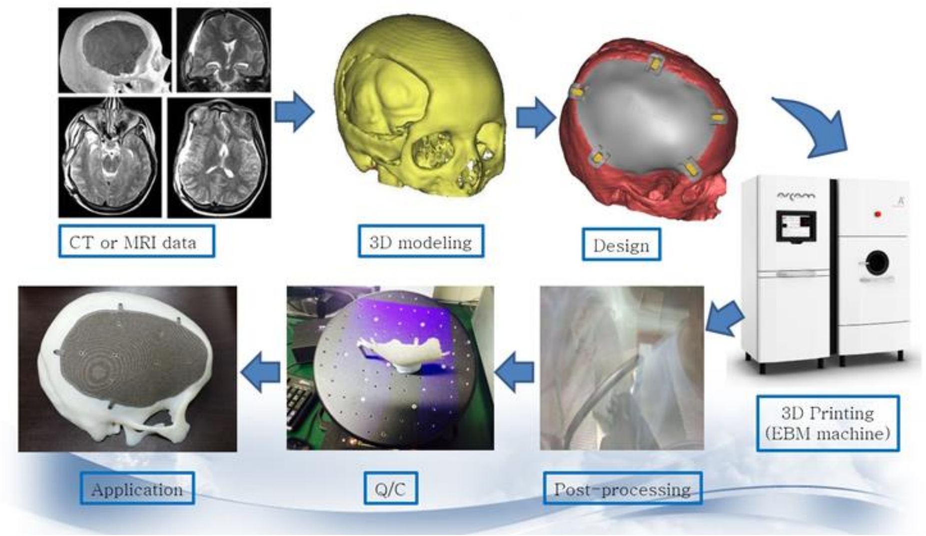


Figure 15 Workflow for cranioplasty with 3D cranial implant by additive manufacturing

Materials

Materials used are Ti-6Al-4V-ELI (extra low interstitial) medical grade powders from Arcam AB®. These chemicals were used without any further purification.

Electron Beam Melting Process

An Arcam A1 electron beam melting (EBM) system is used for the manufacturing the orthopedic implants. Using this system, a focused electron beam is rastered over successive layers of powder which are gravity-fed from cassettes and then raked into layers roughly 50 µm thick. The melt scan process is controlled using a 3D CAD program, allowing only selected areas to be melted when adding metal to the build. One of the major advantages of the AM–EBM process is that it allows for digital CAD protocols to be developed using systematic scanning.

In the workflow shown in Figure 15, DICOM files were transferred to 3D modeling software (MIMICS®; Materialise's Interactive Medical Image Control System) in which 2D masking was performed. The skull is delineated and extracted by segmentation methods and a 3D skull model is built from this segmentation, as illustrated in Figure 16. Because several critical issues for this segmentation have been known, a verification process has been performed before proceeding further, such as pre-surgical planning, CAD (for surgical implant or guide) and CAE (Computer Aided Engineering), e.g. FEA (Finite Element Analysis).

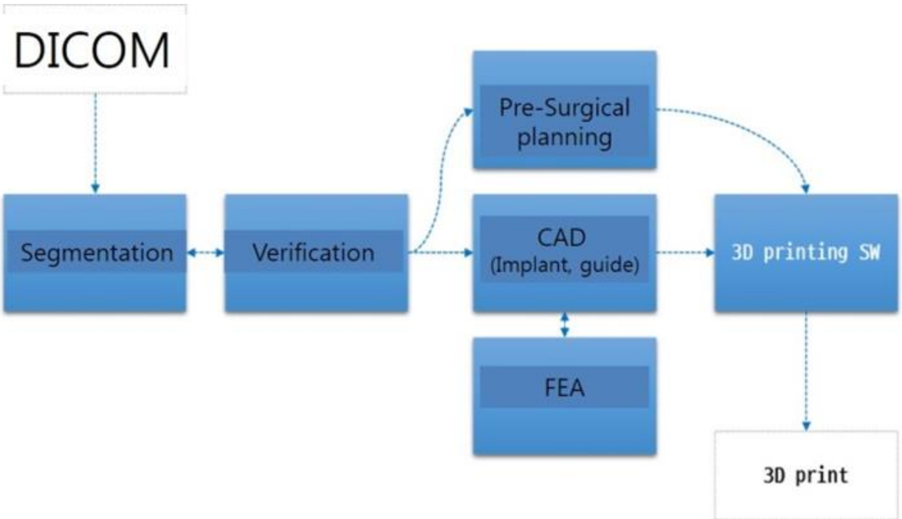


Figure 16 Schematic flow chart for 3D printing from DICOM to printing

Segmentation

To identify and isolate voxels that represent any anatomy of interest. Two implementations of segmentation are: a) assigning a mask to a dataset indicating active voxels; or b) deletion/removal of voxels not included in segmentation. Methods of segmentation are both automatic and manual. Automatic segmentation can be threshold- or atlas-based. Threshold-based segmentation uses pixel brightness and patterns throughout the DICOM data to isolate or remove structures (Figure 17). Atlas-based segmentation uses a database of anatomic structure shapes and attempts to find similar patterns in the current DICOM dataset. For CT scans, brightness measures are standard for various structures across most scanners, but many factors can affect whether the image accurately reflects such brightness with the correct patterns.

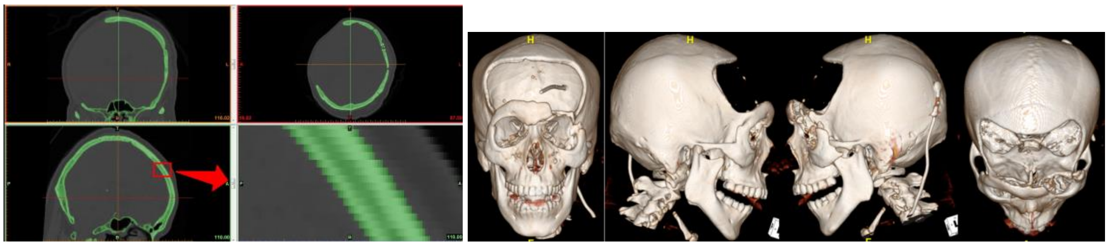


Figure 17 Segmentation and 3D modeling of skull from DICOM 2D CT images

Validation of segmentation / Verification of 3D model

There are several critical issues about segmentation, and 3D modeling validation and/or verification of these processes are far more important. However, this may be far-fetched but it would be nice to have an independent set of DICOM data from which 3D software can be applied to and potentially scored. Segmentation could be a single category of analyses, with subcategories of vendor, CT, and even further subcategories of artifact, image noise, and so on.

Design of cranial implant

The STL file format has been commonly used and formed for this job in the field of medicine. Linear object dimensions within these files could be altered, resulting in a porosity increase or decrease. For this, Materialise's 3-Matic® and MAGICS® are used to create reticulated mesh arrays. These structure generators were used to build mesh arrays with geometries based on structural elements. The STL file format is known as ideal for anatomical geometry because of its simple file structure and flexibility to match any contour desired. Because an STL file is a triangulated surface mesh file, this file has its own limitation to describe geographical and amorphous human body.

The 3-Matic® software creates cranioplasty prosthesis for skull defect in two ways, manually and automatically. The first step indicates the outlines of the defect. Then, a guiding curve for the cranioplasty prosthesis is created. After this step, the prosthesis is created by automatic creation function or manual operation using CAD option in the software (Figure 18). Mostly mirroring of the 'healthy' side is used to restore the defect. Then, the basic design is made with mesh parts and solid parts of prosthesis. On this basic design of prosthesis flanged for fixation and suture holes are made.

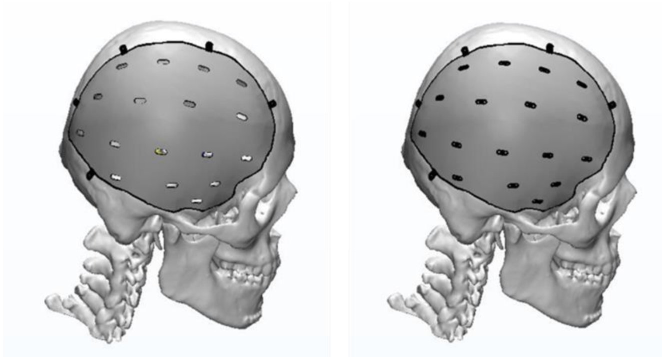


Figure 18 Basic design of cranioplasty prosthesis (flanges for fixation and suture holes)

The 3-Matic® software uses a unit cell or lattice structure unit similar in concept to crystal lattice unit cells, but more complex in some instances. By changing the unit cell or lattice structure unit dimensions, the mesh geometry is correspondingly adjusted for both software programs. After finalization of all these procedures the final product has come out as in Figure 19. Figure 19 demonstrates the implantation of 3D printed titanium cranial implants on rapid prototyped skull model prior to actual operation for pre-surgical simulation and real application.

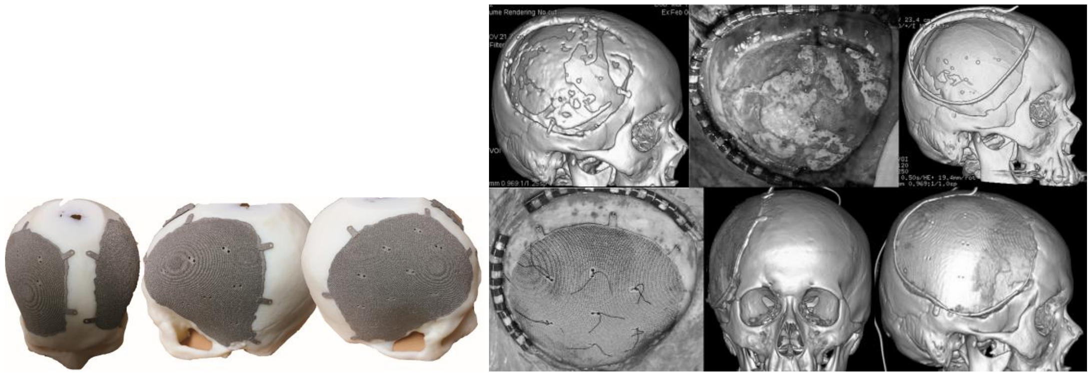


Figure 19 Application of cranioplasty prosthesis
(left: rapid prototyping of skull implant; right: real application for patient)

Dental prosthesis

An 83-year old woman suffering from oral cancer received a new artificial jawbone. In 2012, a medical team from Belgium and Netherlands replaced her mandible with the artificial mandible made with a 3D printer. Within a few hours after surgery, the patient was able to speak and eat the soup. This news was advertised within newspapers around the world. This case is the first one which used a 3D printer for medical purposes. In addition to the reconstruction surgery, 3D printing technology has been utilized actively in the dental restorative area. The intra-oral scanner which acquires the 3D structure data of a patient's mouth with imaging technology is popular now. The 3D printed dental model from intra-oral scan data is utilized for the adaptation of the prosthesis. Also, 3D printing technology is widely applied from the implant surgical template, sacrifice pattern for metal or ceramic casting, to provisional restoration.

Figure 20 First mandible reconstruction with 3D mandibular implant by additive manufacturing

In the field of dentistry, additive manufacturing is utilized for both surgery and restoration. The application for dental surgery includes implant surgical template, rapid prototyped skull for simulation operation, and artificial jaw implants inserted into the human body. In the restorative area, dentists replace destroyed or lost teeth by dental caries or periodontal diseases. If the tooth loss is extensive, a fixed prosthesis will be placed with the help of adjacent teeth, but if the number of residual teeth is limited, a removable prosthesis or a denture will be used. In addition, dental implants can be placed in the area of tooth loss instead of the aforementioned conventional prostheses. Additive manufacturing is applied in most areas of dental field.

Characteristically in the field of restorative dentistry, the prosthesis is fabricated to accurately fit on the prepared teeth which were reproduced by taking an impression of the patient’s mouth. Recently, optical impression techniques with the help of 3D intra-oral scanner have been introduced instead of using conventional impression material. Additive manufacturing is utilized for the purpose of printing out digital data from the actual mouth. Provisional restoration or temporary teeth is now fabricated by additive manufacturing to protect the prepared teeth from thermal irritation while waiting for the final prosthesis production. Final metal restoration is directly produced from PBF (Powder Bed Fusion) technology or wax coping is firstly printed and then invested and cast into metal. In addition, transparent material is used for the fabrication of surgical template or orthodontic appliance. Polymer 3D printing technologies, such as DLP, SLA and Polyjet, are most commonly used in dentistry.

Figure 21 3D printing machines of various additive manufacturing principles

Jaw damage and temporomandibular joint dysfunction due to an accident or a tumor cause considerable disruption to mastication and swallowing of food. The purpose of mandibular reconstruction is to reconstitute the mandibular arch and enable dental rehabilitation. Among many options, reconstruction with a titanium plate and a bone-containing free flap transfer has been the most common procedure for patients with mandibular defects. A computer-assisted surgical simulation of concurrent orthognathic surgery to align the maxilla and mandible and mandibular reconstructive surgery using 3D printed titanium can be performed to achieve functional and esthetic outcomes.

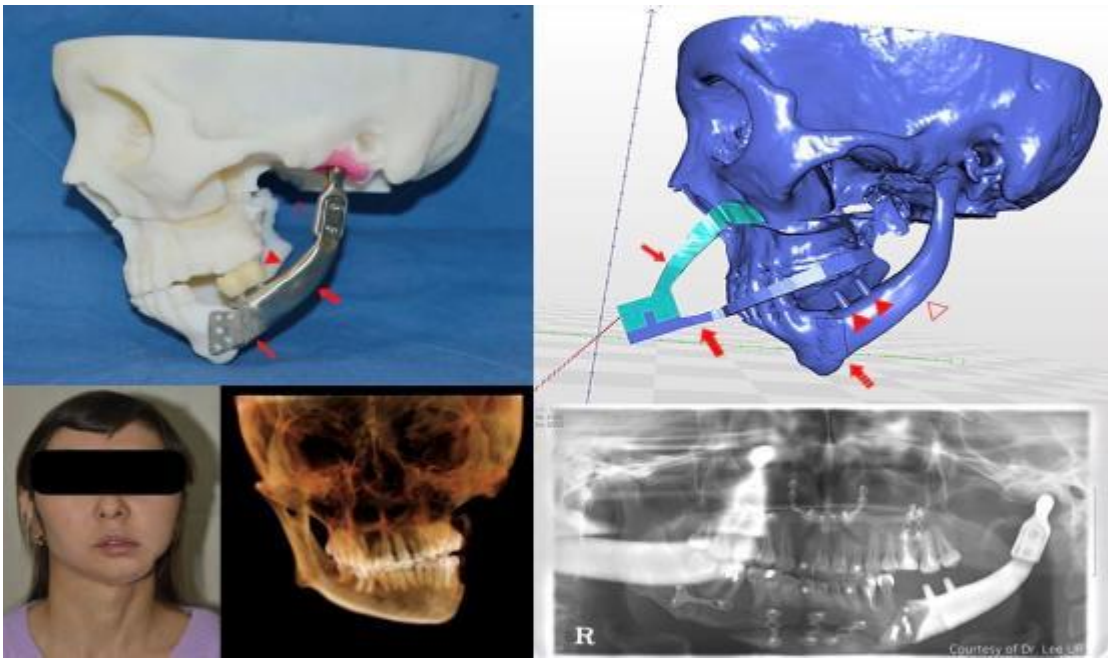


Figure 22 Mandibular reconstructive surgery using 3D printed titanium

The most common treatment in dental clinics is the production of fixed prosthesis. 3D data are acquired from an intra-oral scanner, processed into solid model, and produced into a model by additive manufacturing. This model is used for the purpose of trying in the final prosthesis before setting it in the patient's mouth, and identifying the relationship between the final crown and the adjacent or opposing teeth during the process of porcelain add-on. When the final restoration is not completed on the same day and then referred to the dental laboratory, the temporary restoration is simply printed out by copying the tooth shape of preoperational scan data.

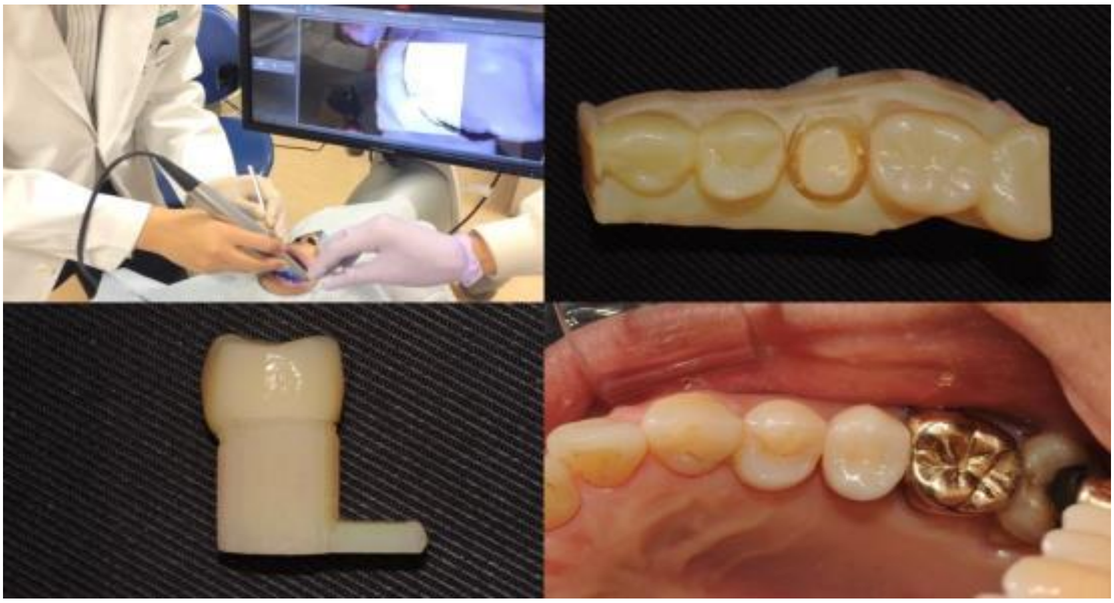


Figure 23 Dental model fabricated from optical impression data by additive manufacturing

Figure 24 Provisional prosthesis and model can be manufactured on the day of tooth preparation at the dental clinic

It the tooth loss area is large, denture is fabricated for this patient. Because it is difficult to precisely mill large and complicated objects like dentures with CNC machines, additive manufacturing is utilized. After scanning the dental model, a metal framework is designed with CAD software, and produced directly into metal or castable resin first, then cast into metal.

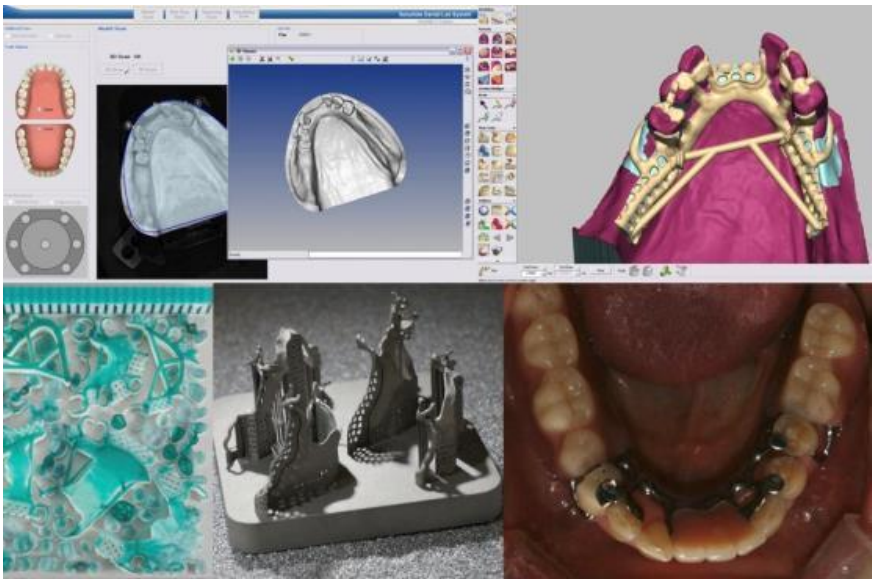


Figure 25 Metal framework for removable partial denture is designed virtually and printed by additive manufacturing technology

Additive manufacturing is frequently utilized for the fabrication of implant surgical template before implant surgery. The customized abutment and crown are CAD/CAM produced after osseointegration of dental implant. The model is 3D printed on the basis of optical impression data from an intra-oral scanner.

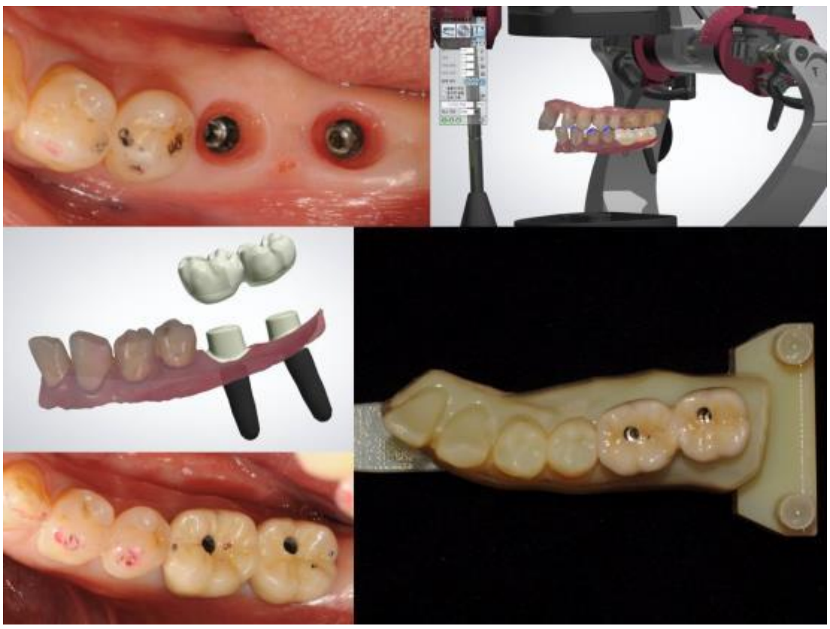


Figure 26 Model for implant restoration designed from optical scan data

5. IT Standardization Activities

Currently, 3D printing and scanning standardization activities occur in the following committees and organizations:

- ISO TC 261 (Additive Manufacturing)
- ISO TC 61 (Plastics)
- ISO TC 106 (Dentistry)
- ISO TC 119 (Powder Metallurgy)
- ISO TC 171/SC 2 (Document File Format)
- ISO TC 172/SC 9 (Electro–optical Systems)
- ISO TC 184/SC 1 (Industrial Cyber and Physical Manufacturing Systems)
- ISO TC 184/SC 4 (Industrial Data)
- IEC TC 62 (Electrical Equipment in Medical Practice)
- IEC TC 76 (Optical Radiation Safety and Laser Equipment)
- IEC TC 108 (Safety of Electronic Equipment within the Field of Audio/Video, Information Technology and Communication Technology)
- IEC TC 119 (Printed Electronics)
- IEEE-ISTO Printer Working Group (PWG)
- IEEE C3DP (Consumer 3D Printing Working Group)
- IEEE 3DMA (3D Based Medical Application Working Group)
- ASTM Committee F42 on Additive Manufacturing Technologies
- ASTM Committee E57 on 3D Imaging Systems
- 3MF Consortium
- DICOM (Digital Imaging and Communications in Medicine)
- Khronos 3D Format Working Group
- CIE (International Commission on Illumination) Division 8 (Image Technology)[10]
- Web3D Consortium
- JTC 1/SC 24
- JTC 1/SC 28
- JTC 1/SC 29/WG 11
- AMSC

5.1 ISO TC 261

ISO TC 261 covers standardization in the field of Additive Manufacturing (AM) concerning processes, terms and definitions, process chains (hardware and software), test procedures, quality parameters, supply agreements and all kind of fundamentals.

It has the following groups that might be of interest to JTC 1:

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[10]CIE Division 8 is proposing a new TC to define a comprehensive method for the evaluation of color differences between 3D objects and color reproduction by 3D printing, using both subjective and objective methods.

- ISO TC 261/WG 1 (Terminology)
- ISO TC 261/WG 4 (Data and Design)
- ISO TC 261 – ASTM F42 Steering Group on JWG activities
- ISO TC 261/AHG 3 (Monitoring of Data Representation Standards)
- ISO TC 261/AHG 4 (Medical Requirements on AM)

Six standards have been published by ISO TC 261:

- ISO 17296-2:2015: Additive manufacturing -- General principles -- Part 2: Overview of process categories and feedstock
- ISO 17296-3:2014: Additive manufacturing -- General principles -- Part 3: Main characteristics and corresponding test methods
- ISO 17296-4:2014: Additive manufacturing -- General principles -- Part 4: Overview of data processing
- ISO/ASTM 52900:2015: Additive manufacturing -- General principles -- Terminology
- ISO/ASTM 52915:2016: Specification for additive manufacturing file format (AMF) Version 1.2
- ISO/ASTM 52921:2013: Standard terminology for additive manufacturing -- Coordinate systems and test methodologies

Noteworthy and pertinent to this report topic is standard ISO 17296-4:2014: Additive manufacturing -- General principles -- Part 4: Overview of data processing listed above. Its content, extracted from ISO/IEC JTC 1/SG 3 N14, is summarized as follows:

ISO 17296-4:2014 covers the principal considerations which apply to data exchange for additive manufacturing. It specifies terms and definitions which enable information to be exchanged describing geometries or parts such that they can be additively manufactured. The data exchange method outlines file type, data enclosed formatting of such data and what this can be used for.

ISO 17296-4:2014 enables a suitable format for data exchange to be specified, describes the existing developments for additive manufacturing of 3D geometries, outlines existing file formats used as part of the existing developments, and enables understanding of necessary features for data exchange for adopters of the International Standard.

ISO 17296-4:2014 is aimed at users and producers of additive manufacturing processes and associated software systems. It applies wherever additive processes are used, and to the following fields in particular: production of additive manufacturing systems and equipment including software; software engineers involved in CAD/CAE systems; reverse-engineering systems developers; and test bodies wishing to compare requested and actual geometries.

Specifically, section 4.1.2.2 on 3D digitalization (reverse engineering) describes this as a process in which the surface geometry of a physical object is measured using appropriate hardware and software and recorded in a digital point cloud model. The objects may be manually produced or finished models which need to be copied in digital form. The use of 3D digitalization is particularly efficient if the model has empirically drafted freeform surface areas since these are difficult to reproduce through direct 3D CAD modeling.

ISO/ASTM 52915:2016: Specification for additive manufacturing file format (AMF) Version 1.2 provides the specification for the Additive Manufacturing File Format (AMF), an interchange format to address the current and future needs of additive manufacturing technology (refer to ISO/IEC JTC 1/SG 3 N14). As additive manufacturing technology is quickly evolving from producing primarily single material, homogeneous objects to producing geometries in full color with functionally defined gradation of materials and microstructures, there is a growing need for a standard interchange file format that can support these features. The additive manufacturing file (AMF) may be prepared, displayed, and transmitted provided the requirements of this specification are met. When prepared in a structured electronic format, strict adherence to an extensible markup language (XML)(1)2 schema is required to support standards compliant interoperability. To be successful across the field of additive manufacturing, this file format is designed to address the following concerns:

- **Technology independence**. The AMF format describes an object in such a general way that any machine can build it to the best of its ability. It is resolution and layer thickness independent and does not contain information specific to any one manufacturing process or technique. This does not negate the inclusion of features that describe capabilities only certain advanced machines support (for example, color, multiple materials), but these are defined in such a way as to avoid exclusivity.

- **Simplicity**. The AMF format is easy to implement and understand. The format can be read and debugged in a simple text viewer to encourage comprehension and adoption. Identical information is not stored in multiple places.

- **Scalability**. The file size and processing time scales well with increase in part complexity and with the improving resolution and accuracy of manufacturing equipment. This includes being able to handle large arrays of identical objects, complex periodic internal features (for example, meshes and lattices), and smooth curved surfaces when fabricated with very high resolution.

- **Performance**. The AMF format enables reasonable duration (interactive time) for read-and write operations and reasonable file sizes for a typical large object.

- **Backwards compatibility**. Any existing STL file can be converted directly into a valid AMF file without any loss of information and without requiring any additional information. AMF files are also easily converted back to STL for use on legacy systems, although advanced features will be lost. This format maintains the triangle-mesh geometry representation to take advantage of existing optimized slicing algorithm and code infrastructure already in existence.

- **Future compatibility**. To remain useful in a rapidly changing industry, this file format is easily extensible while remaining compatible with earlier versions and technologies. This allows new features to be added as advances in technology warrant, while still working flawlessly for simple homogeneous geometries on the oldest hardware.

ISO/ASTM DIS 52910 Standard Practice – Guide for Design for Additive Manufacturing (previously known as ISO/DIS 20195) indicates in section 7.10 File Source — CAD vs. CT — There are a number of file sources used to generate STL and AMF files including scanned data and CAD. Errors can occur due to CT slice scan thickness and resolution, point cloud quality from scanners, and similar resolution limitations from other sources of scanned data. Designers need to understand the quality of files being used to design components intended for AM.

ISO TC 261/WG 4 published a document "**Investigating the Impact of CAD Data Transfer Standards for 3DP**" (refer to ISO/IEC JTC 1/SG 3 N9) which outlined five different types of file formats that were recognized to be suitable and appropriate for a redistributed manufacturing scenario in the UK. The document compared aspects of STL, STEP, STEP-NC, AMF, 3MF; and also discussed data interface problems of current 3DP methods. The current de facto standard of using STL to describe surfaces has some shortcomings due to its inability to describe the properties of the object such as material gradation and color. As there is an increased demand for such features to be used in 3DP, the use of STL is less capable to meet the demands of the next generation of 3DP systems. Second, while some of these issues have been addressed by newer file formats such as AMF and STEP-NC, the formats are usually software or hardware dependent and the build files are sometimes difficult to be translated across different printer systems. Third, 3DP as an industrial process should be capable of going beyond the mere volumetric and geometric description of an artefact to be manufactured. Some production parameters have relevance to artefact integrity and need to be contained in the file for production such as built orientation or the melt pool size. Fourth, the majority of current models favor tessellated descriptions of volumes. Accordingly, a model with originally round surfaces will be represented as a number of edges and vertices. Through the tessellation process, it is inevitable that some precision is lost. Originally, tessellation seems to have been required to simplify the necessary calculations for slicing. However, processing power available in modern computing should now allow for the processing of geometric models. Future requirements for AM file formats based on the hypothetical RDM scenario would include support for intellectual property, quality assurance, and product liability. An RDM scenario where the end user can modify parts might also take into account limited 3D modelling and engineering skill as well as capturing the knowledge between end users and conventional artefact modelers. As such, an RDM compatible 3DP data transfer standard might have features that can be modified and other features such as the minimum and maximum wall strengths in artefacts that will be locked and cannot be edited. This work was carried out by Dr Eujin Pei and Dr Malte Ressin which ended in 2016.

ISO TC 261/WG 4 also presented a report of activity carried out by the ad hoc group on "**Monitoring of data representation standards**" on 20 January 2017 (refer to ISO/IEC JTC 1/SG 3 N11 and ISO/IEC JTC 1/SG 3 N12). This work was carried out by Professor Alain Bernard. Key questions were: Do we have sufficient information from design to manufacturing to control? Should we concentrate on real parts or on prototypes? Should we make a difference between both? How to deal with intermediary steps of the part? Do we have to manage all these steps in the files? What is the information needed at what step of the process? Do we have to take into account the solid format but also the process plan and distribution of tasks? Or do we need to generate as many files as steps of manufacturing? The group agreed that a first action is to identify what are the industrial needs by analyzing case studies known by the members of the group (medical, aeronautics, consumer products). There is a need to provide a link between features defined in standards and features used in industry. It was decided to ask the members of the group to provide complements to the matrix and case studies in order, for each case, to study the necessary steps from design to control and to be able to identify the gaps and propose orientations. This is still an ongoing work.

5.2 ISO TC 184/SC 1

ISO TC 184/SC 1 deals with "Industrial Cyber and Physical Manufacturing Systems" with the scope "standardization of the control, the interface, the interoperability, the definition and the integration in the area of industrial cyber and physical manufacturing systems covering all manufacturing technologies. This includes but is not limited to symbols, codes, formats, axis and motion nomenclature, command languages and related system aspects, programming methods, simulation, information and data exchange, definition and integration of data and definition of data models for manufacturing systems". It has two WGs: WG7 dealing with data modeling for integration of physical devices; and WG 9 dealing with interfaces between manufacturing systems. The main involvement with additive manufacturing comes through the work of WG 7 on the modern control standard, STEP-NC.

SC 1/WG 7 has worked on and produced a number of standards in the area of machine tool control. Machine tool control was first standardized as ISO 6983, which dealt with numerical control in the early days of computer development. Originally developed in the 1960s, various control developers added non-standardized extensions which has led to the current state where part programs became specific for controllers rather than being standard. In view of this, as well as the advances in computing power and general sophistication of machine tools, various interested stakeholders, led by Siemens, developed a new philosophy for machine tool control, called STEP-NC and standardized as ISO 14649. This new philosophy involves moving CAD data to the machine tool controller and enables a whole new generation of advanced, intelligent control. Since the methods for tool movement are well-known, it is possible to compute the movements on the machine itself, allowing the control developer to adapt control to the machine. The standard file format includes information about what is to be made rather than how to make it, as with ISO 6983. STEP-NC is also characterized as a “micro process plan”. The standard has been published for milling, turning, wire EDM and sink EDM. A draft of the additive manufacturing part has been developed and is currently being revised for publication. The STEP-NC standards have been used by ISO TC184/SC 4 Digital Manufacturing WG as what is termed the “Application Reference Model” to define the STEP equivalents for milling and turning.

Although the standard provides many advantages for traditional machining processes such as milling and turning, it offers many more for innovative processes such as EDM and even more for very dynamic process areas such as additive manufacturing. Specifically for additive machining, new processes, new machines and new materials are arriving on the market relatively quickly. The price of the machines has fallen, putting them within reach of naïve users not readily familiar with manufacturing techniques. This requires a high level of intelligent control to support the market flux. The STEP-NC part includes the common information, such as the exact shape, information on materials and such like that are known and allows the detailed control information to be determined. At a simple level the additive process plan can be post-processed by a manufacturer to produce the more traditional formats to meet the requirements of their machine and process. It also allows development of intelligent controllers to allow additive manufacturing to move into the ‘plug-and-play’ market for unsophisticated users. Perhaps more importantly it allows developers of new machines and materials to optimize control for their processes.

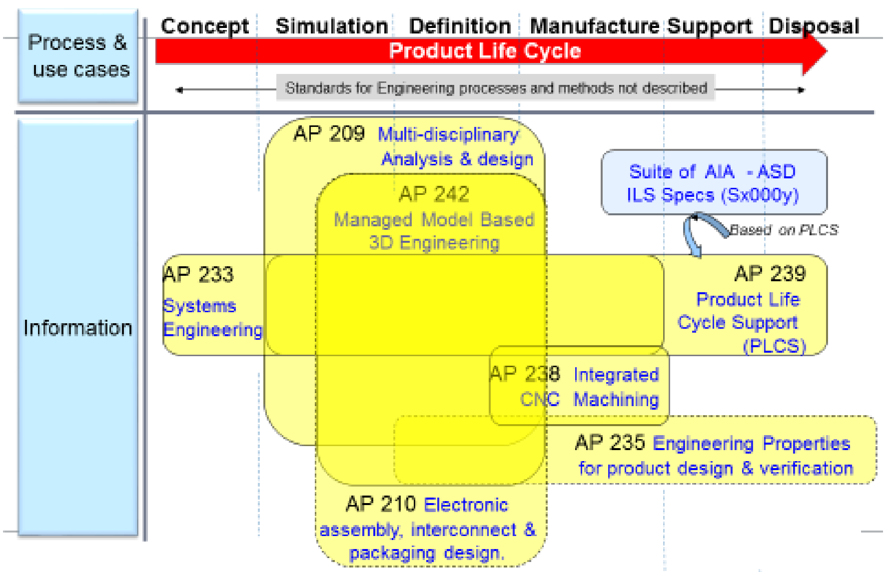
The work of SC 1 in the development of new control platforms, in WG 7 combined with WG 9, is an important step in the use of additive manufacturing as part of the general process chain.

5.3 ISO TC 184/SC 4

ISO/TC 184/SC 4 develops and maintains ISO standards that describe and manage industrial data throughout the life of the product. Its work includes modeling of industrial, technical and scientific data to support the exchange, sharing and long term archiving of product data. Among them, ISO 10303 is a standard for the computer-interpretable representation and exchange of product manufacturing information. Its title is “Automation systems and integration – Product data representation and exchange.” It is known informally as "STEP", which stands for "Standard for the Exchange of Product model data" and has been in industrial use since 1997. ISO 10303 can represent 3D objects in CAD and related PLM and support information throughout the entire product lifecycle, and is under continuous extension to support growing industry requirements for increased functionality, including systems engineering, simulation and electronics. It is delivered as a series of application protocols, each of which provides a consistent information model to address a particular industrial data requirement.

The design information in STEP provides the basic definition for multiple manufacturing processes, including 3D printing. The latest versions of the design application protocols include the option to deliver tessellated geometry as an option for manufacturing, although the direct use of the exact geometry held in STEP along with the associated manufacturing information and tolerances is obviously preferred.

Since 2007 STEP Part 238 has provided the capability to drive digital manufacturing systems direct from the design model into the control system of the machine tool. Other STEP parts provide production planning functions. Based on operational experience and innovation, a new edition of AP 238 is now under development to support new classes of manufacturing tools, such as additive manufacturing and combined additive/subtractive manufacturing devices.



According to [18], ISO TC 184/SC 4 Plenary made the resolution to establish a new working group on "Digital Manufacturing" to ensure a fully integrated approach to digital manufacturing, based on the standardized design model and the experience with AP 238. This obviously includes 3D printing and scanning as one possible manufacturing method. The scope of the new WG is to identify and where necessary develop a coherent set of Industrial Data Standards maximizing efficiency for the realization of digital products including the areas of digital control, digital planning, digital monitoring, digital simulation, digital validation and digital inspection, in full cooperation with other standards development organizations.

This will include interfaces to groups such as ISO TC 29/WG 3 for cutting tools, ISO TC 261 on additive manufacturing and ISO TC 299 on robotics. Other groups may be added as appropriate.

Currently ISO TC 184/SC 4 has liaisons with many ISO/IEC JTC 1/SCs such as SC 7, SC 24, SC 31, SC 32 and SC 34. Among these, only SC 24 for its X3D visualization format and SC 31 for RFID identifiers would seem to have relevance for 3D printing and scanning.

SC 4 is also responsible for a variety of standardized options for 3D visualization of geometry and other product characteristics, including COLLADA (PAS 17506) and ISO 14306, based on the JT specification. These also provide tessellated approximations to exact geometry. It is planned to create a new JWG to manage these standards and the interface from STEP to other 3D formats suitable for consumption by tools for visualization, 3D printing and other functions that do not require a full CAD model or toolset.

The ISO 8000 series of data quality standards provide a clear and pragmatic approach to ensuring that digital information can be trusted for downstream use such as manufacture.

5.4 IEC TC 62

IEC TC 62 (Electrical Equipment in Medical Practice) prepares international standards and other publications concerning electrical equipment, electrical systems and software used in healthcare and their effects on patients, operators, other persons and the environment. They cover the use of 3D printing for medical applications such as the preparation of anatomical models, customized implants and bio-printing.

SC 62B (Diagnostic Imaging Equipment) and SC 62C (Equipment for Radiotherapy, Nuclear Medicine and Radiation Dosimetry) have a close relationship with DICOM for medical imaging file formats.

5.5 IEC TC 76

IEC TC 76 (Optical Radiation Safety and Laser Equipment) is the leading body on laser standardization, including the high-power lasers used in industrial and research applications as well as in 3D printers.

TC 76/JWG 10 is the joint ISO/IEC working group on safety of lasers and laser equipment in industrial materials processing environments, responsible for maintaining the ISO 11553 series jointly with ISO TC 172/SC 9.

5.6 IEC TC 108

IEC TC 108 (Safety of Electronic Equipment within the Field of Audio/Video, Information Technology and Communication Technology) addresses safety aspects of a large range of IT equipment, including 3D printing and additive manufacturing.

IEC 60950-1 (Safety of IT equipment) and IEC 62368-1 (Safety of audio-visual, information and communication technology equipment) are the main applicable standards series.

5.7 IEC TC 119

IEC TC 119 (Printed Electronics) addresses standardization of terminology, materials, processes, equipment, products as well as health, safety and environmental aspects in the field of printed electronics.

5.8 IEEE-ISTO Printer Working Group (PWG)

The IEEE-ISTO PWG presents itself as follows:

> The IEEE Industry Standards and Technology Organization (ISTO) was established in January 1999 as a federation of member alliance programs with the aim of supporting accelerated technology standards development and market adoption for industry. A global, 501(c)(6) not-for-profit corporation, ISTO offers a membership infrastructure and legal umbrella under which member alliances and trade groups can stand themselves up as legal operating entities.
>
> The Printer Working Group (PWG) was established as a Program of the IEEE Industry Standard and Technology Organization (ISTO) in September 1999 with members including printer and multi-function device manufacturers, print server developers, operating system providers, print management application developers, and industry experts.

With its roots in the IETF Network Printing WG founded in 1989, the industry consortium Network Printing Alliance founded in 1991, the IETF Printer MIB WG founded in 1993, and the ISO/IEC JTC 1/SC 18 Document Printing Application (DPA) standards work in the 1990s, the IEEE-ISTO PWG is chartered to make printers, multi-function devices, and the applications and operating systems supporting them work together better.

IETF Printer MIB v1 (RFC 1759, March 1995) and IETF Internet Printing Protocol/1.1 (RFC 2910 and RFC 2911, September 2000) were both based on the semantic elements defined in ISO/IEC 10175-1 (September 1996) Document Printing Application (DPA) -- Part 1 and all shared a common editorial team. See the historical timeline below and the PWG Semantic Model evolution diagram at: http://ftp.pwg.org/pub/pwg/mfd/white/SemanticEvolution-PWG.pdf.

The IEEE-ISTO PWG currently has two active WGs. The Internet Printing Protocol (IPP) WG is focusing on harmonized 2D and 3D printing and the Imaging Device Security (IDS) WG is focusing on collaboration with the international Common Criteria community and other external standards bodies.

PWG Standard 5100.12: IPP 2.0, 2.1, and 2.2 was published in October 2015. PWG Candidate Standard 5100.21: IPP 3D Printing Extensions v1.0, was published in February 2017 and provides a secure and widely implemented network printing protocol and requires support for files in the 3D Manufacturing File Format (3MF) and recommends support for PDF files containing 3D content encoded in U3D or PRC objects.

PWG Best Practices 3D Print Job Ticket and Associated Capabilities v1.0 (PJT3D) was just approved and will be published in early September 2017; PJT3D exposes the same Job Ticket, status, and capability data elements defined in IPP 3D as an XML schema. PWG Best Practices Mapping CIP4 JDF to PWG Print Job Ticket v1.0 (JDFMAP) was just approved and will be published in September 2017.

Historical Printing Standards Timeline:

(1) IETF Network Printing WG published:
    a. RFC 1179, August 1990, Line Printer Daemon Protocol.
(2) ISO/IEC JTC 1/SC 18 published:
    a. ISO/IEC 10175-1, September 1996, Information technology -- Text and office systems -- Document Printing Application (DPA) -- Part 1: Abstract service definition and procedures;
    b. ISO/IEC 10175-2, August 1996, Information technology -- Text and office systems -- Document Printing Application (DPA) -- Part 2: Protocol specification;

c. ISO/IEC 10175-3, December 2000, Information technology -- Text and office systems -- Document Printing Application (DPA) -- Part 3: Management abstract service definitions and procedures.

IEEE POSIX published:

d. IEEE 1387.4 D8, October 1994, Draft Standard for Information Technology – POSIX System Administration – Part 4: Printing Interface;

e. IEEE 1387.4 D9, January 1998, Draft Standard for Information Technology – POSIX System Administration – Part 4: Printing Interface, (technically aligned with ISO/IEC 10175-3).

(3) IETF Printer MIB WG published:

a. RFC 1759, March 1995, Printer MIB v1;

b. RFC 2790, November 1999, the Job Monitoring MIB;

c. RFC 3805, June 2004, Printer MIB v2;

d. RFC 3806, June 2004, Printer Finishing MIB.

(4) IETF Internet Printing Protocol WG published:

a. RFC 2910, September 2000, Internet Printing Protocol/1.1: Encoding and Transport;

b. RFC 2911, September 2000, Internet Printing Protocol/1.1: Model and Semantics;

c. RFC 3510, April 2003, Internet Printing Protocol/1.1: IPP URL Scheme;

d. RFC 3995, March 2005, Internet Printing Protocol (IPP): Event Notifications and Subscriptions;

e. RFC 3998, March 2005, Internet Printing Protocol (IPP): Job and Printer Administrative Operations;

f. RFC 7472, March 2015, Internet Printing Protocol (IPP) over HTTPS Transport Binding and the 'ipps' URI Scheme;

g. Many other IPP standards and reference documents.

(5) IEEE-ISTO Printer Working Group published:

a. RFC 8010, January 2017, Internet Printing Protocol/1.1: Encoding and Transport, (in collaboration with IETF);

b. RFC 8011, January 2017, Internet Printing Protocol/1.1: Model and Semantics, (in collaboration with IETF);

c. PWG Candidate Standard 5100.14, January 2013, IPP Everywhere, (driverless printing);

d. PWG Standard 5100.12, October 2015, IPP 2.0, 2.1, and 2.2;

e. PWG Candidate Standard 5100.17, September 2014, IPP Scan Service (SCAN);

f. PWG 5100.18, June 2015, IPP Shared Infrastructure Extensions (INFRA), (Cloud printing);

g. PWG Candidate Standard 5100.21, February 2017, IPP 3D Printing Extensions v1.0 (3D);

h. PWG Best Practices, August 2017, 3D Print Job Ticket and

Associated Capabilities v1.0 (PJT3D), (publication pending);

i. PWG Best Practices, August 2017, Mapping CIP4 JDF to PWG Print Job Ticket v1.0 (JDFMAP), (publication pending);

j. Many other PWG standards and reference documents.

It is interesting to note that, according to this organization, 'while IPP and the PWG Semantic Model can be easily adapted to 3D printing, adapting the existing 3D file formats is proving to be more of a challenge.'

Four 3D file formats are enumerated on the Web page on 3D printing http://www.pwg.org/3d[11]:

- 3D Manufacturing File Format (3MF): 3MF offers a slightly more compact XML format than AMF with physical dimensions, named materials, and shared vertices. The OPC[12] (ZIP) format it uses may pose resource issues for low-end printer controllers, and little existing 3D software supports the format.

- Additive Manufacturing File Format (AMF): AMF[13] is an ISO standard XML format that supports physical dimensions, named materials, and shared vertices. It is generally considered to be the replacement for STL and is supported by some 3D software.

- Collada (DAE): COLLADA defines an XML Namespace and database schema to make it easy to transport 3D assets between applications without loss of information, enabling diverse 3D authoring and processing tools to be combined into a content production pipeline. COLLADA is standard format defined by Khronos Group and also ISO standard – ISO/PAS 17506[14] (CAD format).

- Stereo Lithography File Format (STL): STL is the current de facto-standard file format with both plain text and binary encodings. While it is the most widely used and supported file format for 3D printing, it lacks support for physical dimensions, materials and colors, metadata, or shared vertices.

The IEEE PWG web site was updated and two formats are now presented as "IPP 3D File Formats": 3MF and PDF with the following description:

- PDF: PDF 1.7 (ISO 32000-1) includes 3D support using the Universal 3D

[11] This information can be found on the "August 13, 2014 BoF slides" link at the bottom of the web page: https://www.pwg.org/bofs.html (accessed on 19/09/2016)

[12] Open Packaging Conventions

[13] AMF(ISO/ASTM 52915:2016)

[14] The Collada Specification was last modified in October 2008 as version 1.5.0 and subsequently approved as ISO/PAS 17506 in March 2013(ISO TC 184 SC 4).

format ("U3D", ECMA-363) and PDF 2.0 (ISO 32000-2) will add support for the Product Representation Compact format ("PRC", ISO 14739-1:2014) format. Both U3D and PRC are binary file formats with named materials. PRC also includes manufacturing tolerance metadata. PDF is a recommended file format for the IPP 3D Printing Extensions.

This information is pertinent to JTC 1 since 3D Scanning is considered as well as 3D printing.

5.9 ASTM Committee F42 on Additive Manufacturing Technologies

The ASTM Committee F42 on Additive Manufacturing Technologies scope is (http://www.astm.org/COMMIT/SCOPES/F42.htm):

The promotion of knowledge, stimulation of research and implementation of technology through the development of standards for additive manufacturing technologies. The work of this Committee will be coordinated with other ASTM technical committees and other national and international organizations having mutual or related interests.

Created in 2009, ASTM F42 has led a number of additive manufacturing standardization initiatives, including the specification of the AMF standard. In 2013, ASTM F42 and ISO Additive Manufacturing Committees agreed on joining efforts under a Partner Standards Developing Organization Agreement (PSDO). As a result, a number of ASTM F42 initiatives are now led in close collaboration with ISO TC 261, such as ISO/ASTM 52915:2016 Specification for additive manufacturing file format (AMF) Version 1.2 or the ISO/ASTM DIS 52910 Standard Practice – Guide for Design for Additive Manufacturing. More information can be found in section 5.1 describing ISO TC 261 activities.

It has the following sub-committees:

- F42.01 (Test Methods)
- F42.04 (Design)
- F42.05 (Materials and Processes)
- F42.06 (Environment, Health and Safety)
- F42.90 (Executive)
- F42.91 (Terminology)
- F42.94 (Strategic Planning)
- F42.95 (US TAG to ISO TC 261)

Of possible interest is the following project:

WK48549: AMF Support for Solid Modeling: This work item, which is now supervised by ASTM/ISO Joint Group 64 in collaboration with ISO TC 261, focuses on providing Guidelines and identifying possible areas of development in a Technical Report to further Solid Modeling support for the AMF standard. The work currently covers existing features and extension opportunities for the following modalities: Voxel Information, Constructive Solid Geometry Representations and Solid Texturing. Because such solid modeling features can support datasets acquired by scanning parts produced by Additive Manufacturing, this group is interacting with ASTM/ISO Joint Group 59 on Non Destructive Testing.

5.10 ASTM Committee E57 on 3D Imaging Systems

The ASTM Committee E57 on 3D Imaging Systems scope is (http://www.astm.org/COMMIT/SCOPES/E57.htm):

The development of standards for 3D imaging systems, which include, but are not limited to laser scanners (also known as LADAR or laser radars) and optical range cameras (also known as flash LADAR or 3D range camera).

The initial focus will be on standards for 3D imaging system specification and performance evaluation for applications including, but not limited to:

- Construction and Maintenance
- Surveying
- Mapping and Terrain Characterization
- Manufacturing (e.g. aerospace, shipbuilding)
- Transportation
- Mining
- Mobility
- Historic preservation
- Forensics

It has the following sub-committees:

- F57.01 (Terminology)
- F57.02 (Test Methods)
- F57.03 (Guidelines)
- F57.04 (Data Interoperability)
- F57.90 (Executive)
- F57.91 (Strategic Planning and Marketing)

Of possible interest to is the following standard:

E2807-11 Standard Specification for 3D Imaging Data Exchange, Version 1.0

5.11 3MF Consortium

The 3MF Consortium presents itself as follows (http://www.3mf.io/about-us/overview):

Launched in 2015, the 3MF Consortium, a Joint Development Project, is an industry consortium working to define a 3D printing format that will allow design applications to send full-fidelity 3D models to a mix of other applications, platforms, services and printers. Its goal is to quickly release and then maintain a specification that allows companies to focus on innovation, rather than on basic interoperability issues.

3D printing has many failure points, some of which arise from a tangle of different and inadequate file formats. 3MF can address this problem. The 3MF consortium came into being to deliver to the 3D printing industry a file format called 3MF (3D Manufacturing Format) that is:

- Rich enough to fully describe a model, retaining internal information, color, and other characteristics
- Extensible so that it supports new innovations in 3D printing
- Interoperable
- Useful and broadly adopted
- Free of the issues besetting other widely used file formats

This consortium, founded by Microsoft, has eleven industrial members including HP, Siemens, Dassault Systèmes and Autodesk. It has published a 3MF Specification document that is available online at http://www.3mf.io/specification.

5.12 Web3D Consortium

The Web3D Consortium presents itself as follows (http://www.web3d.org):

Founded in 1997, it is an International, non-profit, member-funded, industry standards development organization. It develops and maintains royalty-free ISO standards for web-based 3D graphics. Its standard X3D (Extensible 3D) originated from VRML and is available in XML, JSON, Compressed Binary, and classic VRML formats. X3D is open, royalty free, extensible, interoperable, and runs on all platforms including desktops, tablets, and phones.

The X3D standard is currently in use in the consumer 3D printing market through its adoption in online tools and archives aimed at 3D printing. 3D printing services offer online uploading of user design files to be printed in a variety of materials. Several of these services, including Shapeways, support submitting user designs as X3D files. X3D offers multiple advantages over STL format. In addition to metadata representations and geometric efficiencies, X3D supports multiple colors on a single model; and multiple color printing is now being offered in the consumer market. Online solid modelers now allow consumer users to prepare 3D printing designs using browser-based application, and several of these including TinkerCAD and Clara.io, support exporting a user's design file in X3D format for submission to a 3D printing service. A third component of the 3D printing market is online archives of design files; popular archives such as Thingiverse and NIH Print Exchange support X3D format files.

Among the WGs in Web3D Consortium, the following are identified as relevant for 3D printing and scanning:

- Design Printing and Scanning WG (http://www.web3d.org/working-groups/design-printing-and-scanning)
- Medical WG (http://www.web3d.org/wiki/index.php/X3D_Medical)
- X3D Graphics WG (http://www.web3d.org/working-groups/x3d)

A broad range of X3D activity is under way to achieve integrated support for CAD, 3D printing and 3D scanning. The X3D Graphics standards include full functional capabilities of the Virtual Reality Modeling Language (VRML) 97 International Standard, ISO/IEC 14772-1:1997 and ISO/IEC 14772-2:2004. Backwards compatibility with VRML syntax is also maintained for all versions of X3D through the X3D Classic VRML Encoding, ISO/IEC 19776-2. A great many tools and applications continue to support VRML import/export and modification, so X3D/VRML consistency provides valuable capabilities for printing 3D models.

The X3D standard includes a CADGeometry Component which supports representation of product assembly structure and face features in X3D scenes. The CADInterchange Profile defined in the X3D standard supports distillation of computer-aided design (CAD) data to downstream applications. Multiple conversions routes from STEP (ISO 10303) exchange files to X3D scenes have been identified, including standalone translation software and web based applications. Commercial CAD applications commonly support export to VRML file format which is a subset of X3D and readily converted to X3D files in Classic VRML or XML encoding. Broad X3D support for Web-based CAD usage continues to be reported regularly during SC24 liaison efforts with ISO/TC 184/SC4.

A pair of workshops at the Web3D 2016 and 2017 Conferences have demonstrated consensus and progress regarding the suitability of creating a combined X3D Profile for CAD, 3D Printing and Scanning. Functional compatibility with other related formats (such as STL, PLY, AMF, and 3MF) provides important design guidelines for this work. Building converters to demonstrate full compatibility is an important part of this work, with many tools already available (e.g. Blender, Okino NuGraf and dozens of other software resources). Current estimates indicate that well over 80% coverage is already available for use, and that most additions are refinements to existing capabilities.

Given the broad capabilities of X3D, we are finding that a number of other related technologies are pertinent. Brief descriptions follow.

- Two distinct types of compression are being established for X3D models. The Shape Resource Container (SRC) work by Fraunhofer IGD provides a variety of geometric compression schemes (polygonization efficiencies, quantization, etc.). Through cooperative work between Web3D Consortium and the Khronos Group, SRC has been fully aligned with the recently released glTF version 2.0. The X3D Working Group is now reviewing additional X3D requirements unmet by glTF version 2.0 to determine next-step activities.
- Additionally, cooperative work with the World Wide Web Consortium (W3C) is applying the Efficient XML Interchange (EXI) schema-based compression standard to the X3D XML Encoding. Together these composable approaches are expected to provide unprecedented levels of data compaction and decompression performance, in turn minimizing memory requirements and maximizing processor performance.
- Additional cooperative work with W3C has already applied XML Security capabilities to X3D, including both XML Encryption for privacy and XML Digital Signature for authentication. Of interest is that these standards can each be applied either in whole or in part to an X3D scene document. Current EXI working group efforts include consideration of compatibly applying XML Security standards to X3D scenes that are first reduced using SRC and then compressed using EXI. Such comprehensive capabilities appear feasible and are expected to support a wide range of use cases for secure 3D printing of X3D models.
- X3D includes a document metadata model matching HTML, and also includes a Metadata component which enables embedding of strongly typed metadata anywhere within an X3D scene graph. Current working group efforts are examining addition of a potential Annotation component to facilitate sharable markup and situated display of user metadata annotations. Implementation efforts are especially keen to demonstrate effective integration of ISO metadata libraries suitable for 3D printing, CAD and medical applications.
- Web3D Conference workshops continue to clearly demonstrate the applicability of 3D printing to medical applications, with many models and illustrative examples online as part of the U.S. National Institutes of Health (NIH) 3D Print Exchange (http://3dprint.nih.gov). Current work, performed in part with the DICOM medical imaging standards organization, includes investigation into the suitability of including printable medical X3D models as part of patient electronic health records. Additional related work is being considered with the IEEE 3D Body Processing (3DBP) technical group.
- Of interest is that joint work between SC 29 and SC 24 Working Group 9 on the ISO/IEC JTC1 Joint Ad hoc Group (JAhG) Mixed Augmented Reality (MAR) Reference Model, draft ISO/IEC 18039, which includes the possible use of 3D printed markers and physical objects within MAR spaces.
- The X3D standard is currently in use in the consumer 3D printing market

through its adoption in online tools and archives aimed at 3D Printing. 3D printing services offer online uploading of user design files to be printed in a variety of materials. Several of these services, including Shapeways, support submitting user designs as X3D files. X3D offers the advantage over STL format in that it supports multiple colors on a single model; and multiple color printing is now being offered in the consumer market. Online solid modellers now allow consumer users to prepare 3D printing designs using browser-based application, and several of these including TinkerCAD and Clara.io, support exporting a user's design file in X3D format for submission to a 3D printing service. A third component of the 3D printing market is online archives of design files; one popular archive, Thingiverse, directly supports X3D format files.

- The X3D Specifications include language bindings for JavaScript and Java, as well as a newly demonstrated X3D Encoding for JavaScript Object Notation (JSON). Formalization of further language bindings for C++ and Python are under consideration. Current work includes autogeneration of exemplar open-source code for the X3D Scene Access Interface (SAI). We expect that such production of strongly typed application programming interfaces (APIs) for X3D across multiple programming languages, with the likelihood of tuning for small-footprint applications like printers and scanners, is likely to further facilitate the use and interoperability of X3D for printers and scanners.

The Web3D Consortium, through its working groups, public meetings, and open publication of the X3D standards documents, is supporting development of workflows and software conversion and authoring tools to increase adoption of X3D as a standard allowing interchange of 3D content for visualization on desktop and mobile device screens and for connections with the physical world with 3D Printing and Scanning.

The work of newly recharted Design, Printing and Scanning Working Group recognizes that no single standard or format can satisfy all the needs of all applications. Even so, X3D acts as a central hub that can route engineering information between diverse engineering applications. To this end a central focus of the group is to develop workflows and tools to import and export data between X3D and other international standards or, when feasible, proprietary formats. When data is presented in an X3D file it can be visualized with X3D players available over all platforms and the geometric data and metadata can be written and read with open, non-proprietary tools. The Working Group will also aid in documenting and clarifying the current X3D standard, in particular the CAD Geometry Component, and will lead efforts to develop extensions to the standard to further support design, printing, and scanning.

The Web3D Consortium is an international non-profit SDO supported by a Category A liaison with JTC 1. The Virtual Reality Modeling Language (VRML97) is the still compatible predecessor to X3D and the first JTC 1 approved standard to be freely published publicly on the Web. Web3D also has formal liaison relationships with the World Wide Web Consortium (W3C), the Open Geospatial Consortium (OGC), Digital Imaging and Communications in Medicine (DICOM) and other groups in order to maximize Web interoperability (http://www.web3d.org/about/liaisons). An active community supports these efforts. Primarily focused on the X3D and Humanoid Animation (H-Anim) standards, all Web3D Consortium standardization efforts are presented to JTC 1/SC 24 for formal review and ratification.

5.13 JTC 1/SC 24

JTC 1/SC 24 Terms of References are:

Standardization of interfaces for information technology based applications relating to:

- Computer graphics
- Image processing
- Environmental data representation
- Support for the augmented reality continuum (ARC)
- Interaction with, and visual presentation of, information

It has currently the following structure:

- WG 6 (Mixed and augmented reality (MAR) presentation and interchange)
- WG 7 (Image processing and interchange)
- WG 8 (Environmental data representation)
- WG 9 (Mixed and augmented reality (MAR) concepts and reference model)

JTC 1/SC 24/WG 6 started the standardization of Extensible 3D (X3D) that is related to 3D printing and scanning in collaboration with the Web3D consortium more than 10 years ago. The ISO/IEC 19775 (Extensible 3D) standard is already used in 3D printing as a 3D file format allowing some printing services by Shapeways, Thingiverse and browser-based 3D design and modeling tool by an online modeler such as TinkerCad. There are converters available from ISO 10303-203 and 10303-214 STEP files to X3D for lightweight visualization and printing.

According to the SC 24 Business Plan [17], the revision of the X3D standards, ISO/IEC 19775, 19776 and 19777 are under way.

Table 2 shows up-to-date information on X3D standards, all of which are ongoing work. Each standard for file format encoding and programming language binding remains harmonized with the technology neutral functionality defined in the X3D abstract specification ISO/IEC 19775-1.

Table 2 X3D related International Standards[15]

Number	Name	Version	Common Name	Status / Date	Link
19775-1	ISO/IEC 19775-1:2013	V3.3	X3D Architecture and Base Components V3	IS 2013-11-04	HTML ZIP
19775-2	ISO/IEC 19775-2:2015	V3.3	X3D Abstract Scene Access Interface (SAI)	IS 2015-04-24	HTML ZIP
19776-1	ISO/IEC 19776-1:2015	V3.3	X3D XML Encodings	IS 2015-06-15	HTML ZIP
19776-2	ISO/IEC 19776-2:2015	V3.3	X3D ClassicVRML Encoding	IS 2015-05-28	HTML ZIP
19776-3	ISO/IEC 19776-3:2015	V3.3	X3D Compressed Binary Encoding	IS 2015-05-28	HTML ZIP
19777-1	ISO/IEC 19777-1:201x	V3.3	X3D Language Bindings: ECMAScript	CD 2014-09-05	HTML ZIP
19777-2	ISO/IEC 19777-2:2006	V3.0	X3D Language Bindings: Java	IS 2006-05-01	HTML ZIP

Historically, SC 24 has expressed concerns about absence of coordination regarding the harmonization of the following standards within its functional mandate [16]:

- JT (ISO 14306:2012)
- Collada (ISO/PAS 17506:2012)
- ISO/ASTM 52915:2013 – Additive Manufacturing File Format
- ISO/ASTM 52921 – Standard Terminology for Additive Manufacturing – Coordinate Systems and Test Methodologies

Coordinated work with other standards committees and SDOs focused on CAD, 3D printing and 3D scanning technologies is expected to help improve the coherence, capabilities and interoperability of multiple international standards.

5.14 JTC 1/SC 28

JTC1/SC28 Terms of References are:

Standardization of basic characteristics, test methods and other related items of products such as 2D and 3D printers/scanners, copiers, projectors, fax and systems composed of their combinations, excluding such interfaces as user system interfaces, communication interfaces and protocols.

[15] http://www.web3d.org/standards. The Web3D Consortium provides free access to the X3D related International Standards as allowed by the Cooperative Agreement with JTC 1

It has currently the following structure:

- AG (Advisory Group)
- WG 2 (Consumables)
- WG 3 (Productivity)
- WG 4 (Image quality assessment)
- WG 5 (Office color)
- ISO TC 130/JWG 14 (Print quality measurement methods)

JTC 1/SC 28 is currently investigating consumer/office areas for 3D standardization, but as of now there are no active projects.

5.15 JTC 1/SC 29/WG 11

JTC 1/SC 29/WG 11 (MPEG) started working on the standardization of 3D printing couples of years ago, and reached approval stage. MPEG is updating its 3D graphics representation to support printing of 3D assets that contain the associating printing material information with material texture which is very familiar to the 3D graphics designers and its set of user preference, device characteristic and device command to support the 3D cloud printing services [15].

The following documents have been developed for cloud printing with MPEG Tools: a file format standard defined in MPEG-4, which was published as amendment of MPEG-4 Part 16, and a set of metadata defined in MPEG-V, which is at DIS stage:

- Text of ISO/IEC DIS 23005-1 4th Edition Architecture (w17083)
- Text of ISO/IEC DIS 23005-2 4th Edition Control Information(w17084)
- Text of ISO/IEC DIS 23005-3 4th Edition Sensory Information (w17085)
- Text of ISO/IEC DIS 23005-5 4th Edition Data Formats for Interaction Devices (w17088)
- Text of ISO/IEC DIS 23005-6 4th Edition Common types and tools (w17090)
- ISO/IEC 14496-16:2011/Amd 3:2016 Printing material and 3D graphics coding for browsers

The usage scenario of 3D printing service under the variety of printing technologies and materials is as follows:

- Set the user's preference: A user said "I don't like a glass printed stuff because a glass is fragile". This is "User Sensory Preference: ISO/IEC DIS 23005-2".
- Set the capability of his/her 3D printer: it is said that "I can print with glass, plastic and metal". This is "Sensory Device Capability: ISO/IEC DIS 23005-2".
- A user watches the video stream which has a coffee dripper 3D model inside the video stream package. The 3D object attached in the video stream has information saying that "I am a coffee Dripper. I must be heat-proof: ISO/IEC 14496-16".
- When a user watches the specific scene, the STB (set-top box) activates the "PrintMe" button on the screen.

- The user clicks the “PrintMe” button and the 3D model with corresponding metadata, “Print with heat-proof material” is downloaded to STB.
- Now the STB choose which 3D printer is best for this case among the available cloud printers and makes a command (ISO/IEC 23005-5) for the user’s printer based on the all information. The command could be “Print with heat-proof plastic”, because the user does not want the glass.

One of the large advantages of MPEG standards for the 3D printing industry is the access to the large MPEG ecosystem that can provide additional functionality to 3D printing services. MPEG has defined methods for compression and transport of 3D asset, technology which can drastically reduce the bandwidth and sharing time when printing 3D objects in a network environment. With the MPEG standards, one click cloud printing service could be implemented under the various printing materials and technologies environment.

5.16 AMSC

In March, 2016, America Makes and the American National Standards Institute (ANSI) launched the America Makes & ANSI Additive Manufacturing Standardization Collaborative (AMSC). The AMSC was established to coordinate and accelerate the development of industry-wide additive manufacturing standards and specifications consistent with stakeholder needs and thereby facilitate the growth of the additive manufacturing (AM) industry. The AMSC was not chartered to write standards.

America Makes is the National Additive Manufacturing Innovation Institute. Established in 2012 as the flagship Institute for Manufacturing USA, America Makes is the nation’s leading and collaborative partner in additive manufacturing and 3D printing technology research, discovery, creation, and innovation. It is driven by the National Center for Defense Manufacturing and Machining.

Founded in 1918, ANSI serves as the administrator and coordinator of the United States private-sector voluntary standardization system. The Institute has a track record of convening stakeholders to define standardization needs that address national and global priorities in a variety of areas.

The catalyst for the AMSC was the recognition that a number of standards developing organizations are engaged in standards-setting for various aspects of additive manufacturing, prompting the need for coordination to maintain a consistent, harmonized, and non-contradictory set of additive manufacturing standards.

This Standardization Roadmap for Additive Manufacturing, Version 1.0 (“roadmap”) represents the culmination of the AMSC’s work over the past year to identify existing standards and standards in development, assess gaps, and make recommendations for priority areas where there is a perceived need for additional standardization and/or pre-standardization research and development. The focus is the industrial additive manufacturing market, especially for aerospace, defense, and medical applications.

The roadmap has identified a total of 89 gaps and corresponding recommendations across the topical areas of design, process and materials (precursor materials, process control, post-processing, and finished material properties), qualification and certification, nondestructive evaluation, and maintenance. Of that total, 19 gaps/recommendations have been identified as high priority, 51 as medium priority, and 19 as low priority. A “gap” means no published standard or specification exists that covers the particular issue in question. In 58 cases, additional research and development (R&D) is needed.

The hope is that the roadmap will be broadly adopted by the standards community and that it will facilitate a more coherent and coordinated approach to the future development of standards and specifications for additive manufacturing.

6. Gap Analysis and Identification of Opportunities

The survey of standardization activities has shown that:

- Most activities are focused on the industrial market
- Most activities are focused on material and industrial processes
- Additional activities continue to gain broad interest
- Coordination and cooperation with various stakeholders are needed

The following table lists ongoing and future activities with regards to different application domains.

Application Domains	**Maturity Level**	
	Ongoing Activities	Future Activities
Medical Industry	**ISO TC 261/WG 4: NWIP (Medical Data for Additive Manufacturing)** **ISO/IEC JTC 1/SC 24:** ISO/IEC 19775 - X3D Medical Interchange Profile	**IEC TC 62** **ISO/IEC JTC 1** **ISO/IEC JTC 1/SC 24**
Health & Wellness		**ISO TC 261/WG 4** **IEC TC 124**
Gaming & Animation	**ISO/IEC JTC 1/SC 24:** ISO/IEC 14772 - VRML, ISO/IEC 19774 H-Anim, ISO/IEC 19775 – X3D	**ISO TC 261/WG 4** **ISO/IEC JTC 1/SC 24**
AR & VR Activities	**ISO/IEC JTC 1/SC 24:** ISO/IEC 14772 - VRML, ISO/IEC 19775 – X3D Immersive Profile	**ISO TC 261/WG 4** **ISO/IEC JTC 1/SC 24**
Manufacturing	**ISO TC 184/SC 4:** draft 10303-242ed 2, 10303-238, ISO 14306	**ISO TC 261/WG 4** **ISO TC 184/SC 1**

	ISO TC 261/WG 4: ISO 17296-4:2014, ISO/ASTM 52915:2016 **ISO TC 184/SC 1:** draft ISO/AWI 14649-17 (20.00) **ISO TC 171/SC 2 :** PDF/E **ISO/IEC JTC 1/SC 24:** ISO/IEC 14772 - VRML, ISO/IEC 19775 – X3D CAD	**ISO TC 184/SC 1/WG 7** **ISO TC 184/SC 4** **ISO TC 184/SC 4/WG 15** **ISO TC 184/SC 4/WG 16** **ISO SMCC** **IEC TC 65** **IEC SEG 7** **ISO/IEC JTC 1/SC 24**
Apparel & Fashion		**ISO TC 261/WG 4**
Urbanization	**ISO/IEC JTC 1/SC 24 :** ISO/IEC 14772 GeoVRML, ISO/IEC 19775 - X3D Geospatial	**ISO TC 261/WG 4** **ISO/IEC JTC 1/SC 24**
Transportation		**ISO TC 261/WG 4**
Industry R&D	**ISO TC 261/AHG 3** **ISO TC 261/JG 64** **ISO TC 261**: draft ISO/NP TR 52912 (10.99) **ISO TC 184/SC 1** **ISO TC 184/SC 4: draft** 10303-242ed 2 **ISO/IEC JTC 1/SC 24 :** ISO/IEC 14772 - VRML, ISO/IEC 19774 H-Anim, ISO/IEC 19775 – X3D	**IEC TC 119** **ISO/IEC JTC 1/SC 24**

There appears to be opportunities for JTC 1 to work on the following:

- Harmonization of 3D file formats to describe 3D objects in a form suitable for printing and 3D print files, coordinated with ISO TC 261 and ISO TC 184
- 3D file standardization through fast track of work done by industrial consortia
- Standardization to support a consumer 3D printing market

Regarding the harmonization of 3D file formats, ISO TC 261 has a major role of “harmonization of 3D file formats to describe 3D objects and 3D print file” but there would be still the role of JTC 1/SC 24 and SC 29 to contribute to “harmonization of 3D file formats to describe 3D objects and 3D print file”. The recent study on “3DP-RDM and the Impact of CAD Data Transfer Standards” (EPSRC in UK) might draw attention to JTC 1.

The study reports that many CAD formats exist but only some are used for data transfer. For the question “What data interface problems exist with current 3DP methods?” the report indicated that there were four key issues:

1. Surface vs. volume description
2. No established common standard
3. Industrial manufacturing data requirements beyond geometry
4. Tessellated vs. geometric models

It also reviewed existing standards:

- STL: proprietary but de facto standard through frequent adoption
- STEP: ISO standard through ISO 10303 (AP 242)
- STEP-NC: ISO standard through ISO 14649
- AMF: ISO standard through ISO 52915
- 3MF: industry consortium including Microsoft, HP, Fit, formLabs, etc.

What we have seen with control is that industry and suppliers have difficulty knowing how to apply the standards, even though they would provide significant advantages. There is a problem of information overload where there is too much information of a general nature for people to find out what they need to know. Some possible gaps are:

1. Single point of reference for user community to find out information about 3D printing and scanning implementation
2. Coordination of aims within standardization activities
3. Information collection point for contact between user community and standardization bodies
4. Knowledge of how and where to apply standards
5. Possibility to evaluate standards in different circumstances
6. Links to education and professional bodies to further lifelong learning

Manufacturing patterns are changing with the introduction of additive machines and it is to be expected that there will be a period of hesitancy by companies to avoid committing to new technology with which they are unfamiliar. Large firms with established production chains would be less affected but smaller firms will have more difficulty to move additive into production and hence would need support. At the same time, smaller companies do not have time to invest in extensive research and so need a more efficient method of getting information. Standardization in this context means that user communities are created which can provide mutual help and real practical problems from user groups provide important input to standardization efforts. Mutual help is natural within amateur and enthusiast groups but for potential competitors a neutral standardization body becomes more important. With the trend towards customization and personalization short series production, including molded parts bring environmental concerns about recycling or disposal of additive parts. Remanufacturing also has a role to play and this relates 3D printing and scanning as well as CAD modeling. The development of 3D/AM service platforms can help smaller companies and consumers to bridge this gap (see also section 3.3 Market), and therefore the SG will recommend a New Work Item in this area (see Annex 2).

In terms of individual standardization efforts by particular committees it is easier to focus on particular areas and cover the gaps, but overall coordination is needed where there are several groups working in the same general area.

Some general opportunities provided are:

1. Increased use of standards in manufacturing
2. Lower production costs because of greater efficiency
3. Improved support for complex tasks
4. Increased flexibility for localized and distributed production, including via print service bureaus
5. New technical solutions because of greater understanding and ease of use of systems

Some of these lead to obvious business cases which can be taken advantage of directly by entrepreneurs, others will require government support. In either case, though, standardization leads to a common pool of knowledge which can be created and exploited.

There are many points which existing standards do not match the requirement of medical industry. As Figure 27 shows there are many points for requiring standardization for the manufacturing of cranial implants. At the very beginning there should be accurate and consistent images. There are currently no standard best practices for creation of protocols and validation procedures to ensure that medical imaging data can be consistently and accurately transformed into a 3D printed object. For medical image segmentation techniques should be optimized and combined according to the characteristics of image modalities and body parts to get the ideal 3D visualization. Currently none of the existing file format does contain ideal information for medical 3D printing. This issue will grow further as in-progress and novel applications for 3D printing make the transition from medical laboratory to clinical practice.

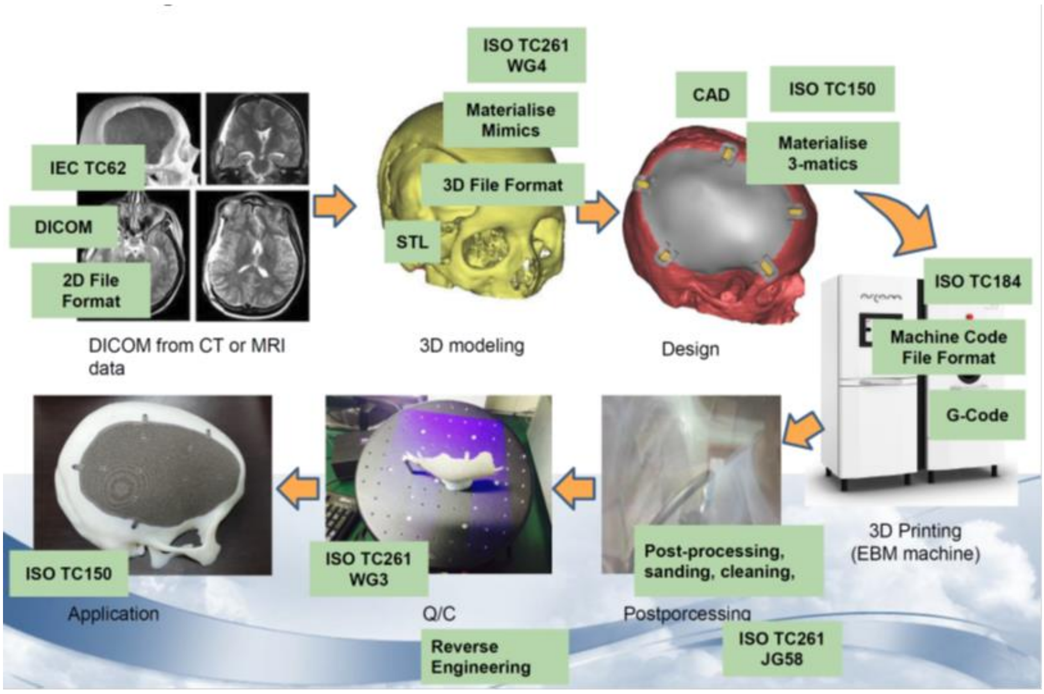


Figure 27 Overview for cranioplasty prosthesis manufacturing through additive manufacturing and possibly associated standards organizations and committees

There are several critical issues for medical 3D printing and related standardization groups:

1. Optimization of segmentation; minimization of the error while segmentation of interesting body parts; IEC TC 62, DICOM WG 17, ISO TC 261/WG 4
2. Optimization of 2D to 3D conversion; reduce step ladder, ideal and consistent smoothing and averaging; ISO TC 261/WG 4, ISO TC 261/AHG 3, JTC 1/SC 24
3. Calibration and validation of 2D to 3D conversion; set the scale and units, development of proper phantom; ISO TC 261/WG 4, JTC 1/SC 24, JTC 1/SC 25, JTC 1/SC 28/WG 4, JTC 1/SC 38, IEC TC 62
4. File format renewal; revision of STL or renewal of AMF or 3MF; ISO TC 261/WG 4, 3MF Consortium, AMSC

Recognizing the need for ICT standardization in this area of medical 3D printing, the SG will propose a New Work Item on image processing for cranial defects for JTC1 to consider (see Annex 2)

7. Conclusions and Recommendations

This report provided an overview of ICT related standardization opportunities in the field of 3D Printing and Scanning. Based on an in-depth analysis of ongoing technology and market developments, together with the description of several use cases and the assessment of the current standardization landscape, SG 3 identified gaps and opportunities that could be adequately addressed by JTC 1.

Because 3D Printing and Scanning covers a very wide range of potential application domains and involves a diverse set of technologies and ICT protocols, there is a strong need for cooperation and coordination between different standards development entities, whether part of ISO, IEC or external organizations. Following its systems integration focus and its experience in collaborating with a broad set of stakeholders and organizations, JTC 1 is in a unique position to fulfil this role. There was a clear consensus among SG 3 members that JTC 1 should become the driving force for the development and promotion of foundational ICT standards related to 3D Printing and Scanning. With this in mind the SG proposes two new work items for JTC1 to consider (see Annex 2).

As two New Work Item Proposals are being put forward as part of this report, SG 3 also recommends the creation of a Working Group to progress this work and to address the gaps and opportunities in 3D Printing and Scanning standardization. The Terms of Reference of the proposed WG are provided in Annex 1.

8. References

This document refers to the following standards, specifications, articles and papers:

[1] 3D printing http://en.wikipedia.org/wiki/3D_printing

[2] 3D scanner http://en.wikipedia.org/wiki/3D_scanner

[3] ISO/IEC JTC 1/SC 28 Business Plan (ISO/IEC JTC 1/SC 28 N1952)

[4] ISO TC 261 Business Plan http://isotc.iso.org/livelink/livelink/fetch/2000/2122/687806/ISO_TC_261__Additive_manufacturing_.pdf?nodeid=14655650&vernum=-2

[5] IEEE Printer Working Group http://www.pwg.org/about.html

[6] Open3DP http://open3dp.me.washington.edu

[7] ASTM Committee F42 on Additive Manufacturing Technologies http://www.astm.org/COMMITTEE/F42.htm

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[11] Big Innovation Centre (The Work Foundation and Lancaster University), Three Dimensional Policy: Why Britain needs a policy framework for 3D printing, 2012.

[12] IndustryARC http://industryarc.com/Report/10614/3d-scanning-market.html

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[14] TCT http://www.tctmagazine.com/metrology-3d-scanning-imagine-inspection-news/3d-scanning-market-to-exceed-4bn-by-2018/

[15] ISO/IEC JTC 1/SC 29/WG 11 N15303 (Investigation on 3D Printing) http://mpeg.chiariglione.org/standards/exploration/3d-printing

[16] ISO/IEC JTC 1/SC 24 N3754 (SC 24 Draft Resolutions London 2015)

[17] ISO/IEC JTC 1 N12727 (SC 24 Business Plan for the period August 2015 - July 2016)

[18] ISO TC 184/SC 4 N3044 (Final Resolutions 70th Plenary, 2015 Baltimore)

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[21] Rauch, Matthieu, Raphael Laguionie, and Jean-Yves Hascoët. "A STEP-NC approach for multi-process manufacturing, simulation and optimisation." International Journal of Product Development 20 19.1-3 (2014): 21-38.

[22] Um, Jumyung, et al. "STEP-NC compliant process planning of additive manufacturing: remanufacturing." The International Journal of Advanced Manufacturing Technology 88.5-8 (2017): 1215-1230.
[23] https://www.caxman.eu/en/technology/use-case-1/
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[25] AMSC Standardization Roadmap for Additive Manufacturing, https://www.ansi.org/standards_activities/standards_boards_panels/amsc/
[26] DICOM WG 17; 3D manufacturing, http://dicom.nema.org/dicom/geninfo/Strategy.pdf

Annex 1 Proposed Terms of Reference for a JTC 1 Working Group

Resolution xx – Creation of a Working Group on 3D Printing and Scanning

Contingent upon approval of a relevant NWIP, JTC 1 establishes JTC 1 Working Group on 3D Printing and Scanning with the following Terms of Reference:

1. Serve as a focus of and proponent for JTC 1's standardization program on 3D Printing and Scanning.
2. Develop ICT related foundational standards for 3D Printing and Scanning upon which other standards can be developed.
3. Develop other 3D Printing and Scanning standards that are built upon the foundational standards when relevant ISO and IEC committees that could address these standards do not exist or are unable to develop them.
4. Identify gaps and opportunities in 3D Printing and Scanning standardization.
5. Develop and maintain liaisons with all relevant ISO and IEC committees as well as with external organizations that already have or may propose work related to 3D Printing and Scanning.
6. Engage with 3D Printing and Scanning communities to raise awareness of JTC 1 standardization efforts and provide an open platform for discussion and further cooperation.

JTC 1 appoints xxx to serve as Convenor of the JTC 1 Working Group on 3D Printing and Scanning. To continue to progress the topic of 3D Printing and Scanning in a timely manner, the Study Group on 3D Printing and Scanning will remain in place, with Mr. Byoung Nam Lee as Convenor, pending the approval of an NWIP. Once an NWIP has been approved, JTC 1 instructs the JTC 1 WG (3D Printing and Scanning) Convenor to work with ITTF to formally establish WG (3D Printing and Scanning).

Annex 2 Draft NWIP(s)

See Attachments (Zip files)

1. Information technology — Framework for Additive Manufacturing Service Platform (AMSP)
2. Information Technology— Requirements of Image Processing for covering cranial defect

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This report is open to the ISO/IEC JTC 1 community for review in order that all relevant stakeholders have the opportunity to express their suggestions for JTC 1 future work on 3D Printing and Scanning. This input will be used together with this report for the decision of the October 2017 ISO/IEC JTC 1 Plenary Vladivostok, Russia.