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Revised JTC 1/WG 12 Business Plan 2020

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Description

This document is circulated for review and consideration at the November 2020 JTC 1 virtual Plenary

International Organization for Standardization
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Международная организация по стандартизации

STRATEGIC BUSINESS PLAN – ISO/IEC JTC 1/WG 12, 3D PRINTING AND SCANNING (November 2019 – November 2020)

Executive summary

The purpose of JTC 1 Working Group 12 (Systems Integration WG) is to develop ICT standards specifically relevant to digitally enabling the prototyping and manufacturing of physical objects. As necessary and when not covered elsewhere, this will include nomenclature, frameworks, interface and protocol specifications, and format specifications required for facilitating the digital control of the production and supply of physical objects including but not limited to additive and subtractive fabrication and automated assembly and distribution.

The scope of this WG as agreed to via Resolution 11 of the 32nd meeting of ISO/IEC JTC 1, October 2-6 in Vladivostok, Russia is:

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 have interests in 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.
7. Develop and maintain a list of existing 3D Printing and Scanning standards produced and standards development projects underway in ISO TCs, IEC TCs and JTC 1.

1 Business Environment of the ISO/IEC JTC 1/WG 12

1.1 Description and Quantitative Indicators of the Business Environment

The following political, economic, technical, regulatory, legal and social dynamics describe the business environment of the industry sector, products, materials, disciplines or practices related to the scope of this ISO/IEC JTC 1/WG 12, and they may significantly influence how the relevant standards development processes are conducted and the content of the resulting standards:

3D Printing

What is 3D Printing?

ISO/ASTM 52900

3D printing

fabrication of objects through the deposition of a material using a print head, nozzle, or another printer technology

Note 1 to entry: Term often used in a non-technical context synonymously with additive manufacturing (2.1.2); until present times this term has in particular been associated with machines that are low end in price and/or overall capability. (5)

Wikipedia

The term "3D printing" covers a variety of processes in which material is joined or solidified under computer control to create a three-dimensional object,[1] with material being added together (such as liquid molecules or powder grains being fused together), typically layer by layer. (6)

Market Size

3D Printing is a multi-billion-dollar business with growth rates in the high teens to low twenties. Forecasts vary widely; presumably due to differing methodologies. Growth is primarily attributed to industrial 3D printing. Desktop 3D printing system sales (< US$5000) are declining. (7)

- Deloitte – 3D printing related sales US$ 2.7 billion in 2019 and US$3 billion in 2020.
- Wohlers (via Forbes) – 3D printing revenues will be US$15.8 billion in 2020, US$23.9 billing in 2022, and US$35.6 billion in 2024.
- Allied Market Research – Market value of approximately US$4.2 billion in 2014 growing to approximately US$44.4 billion in 2025. CAGR of 21.8% from 2019 to 2025.
- Markets and Markets – Market size is estimated at approximately US$9.9 billion in 2018 and is expected to grow to US$34.8 billion in 2024. CAGR for that period is 23.25%
- Grand View Research – Market size of approximately US$7 billion in 2017 with a CAGR of 16.5% from 2018-2025. (8)

Industries addressed

The following industries are addressed by 3D printing. They are sorted roughly by the number of mentions in the sources examined.

- Healthcare (9) (10) (11) (8)
- Automotive (9) (11) (8)
- Industrial (9) (11) (8)
- Consumer Electronics (9) (11) (8)
- Aerospace & Defense (9) (11) (8)

- Education (10) (11) (8)
- Energy (11) (8)
- Fashion & Jewelry (11) (8)
- Food and Culinary (11) (8)
- High-Tech (10)
- Services (10)
- Architecture and Construction (11)
- Printed Electronics (11)
- Household and domestic (8)

Example Applications

The following lists several applications of 3D printing. This list is certainly not comprehensive and is not sorted in any particular way.

- Complex bio printing and personalized prosthetics for healthcare (9) (10)
- Toolmaking (12)
- Weight reduction (9)
- Automotive design (9)
- Product customization (9)
- Functional part manufacturing (11)
- Modeling (8)

Purpose of 3D prints

The Sculpteo survey asked about the use of the prints produced. Uses are sorted by quantity of mention.

- Prototype (10)
- Proof of concept (10)
- Research / Education / R&D (10)
- Production (10)
- Mechanical / Spare Parts (10)
- Personal Interest / Hobby (10)
- Tooling (10)
- Marketing Samples (10)
- Art / Jewelry / Fashion (10)
- Medical / Dental / Prosthesis (10)
- Mass Production (10)
- Retail Sales (10)

Trends

The following lists some of the trends related to 3D printing that the reports mentioned seem to feel were having significant effects on the 3D printing market. These are not sorted in any particular order.

- Growth in the automotive industry (9)
- Partnerships (7)
- Services (11)
- Dominated by powder bed fusion processes (11)
- Prototyping still dominates (11)
- Increasing use of metals (12) (10)

- Increasing print volumes (12)
- Mixed material printers (12) (10)
- Increasing print speeds (12) (10)
- Large companies entering the market (12)
- Powder bed fusion (11)

Challenges

The following lists challenges for the 3D printing market cited in the reports examined. Those mentioned more than once are sorted near the top of the list.

- Cost/Affordability (9) (10)
- Education / Scarcity of skilled laborers (9) (10)
- Efficient logistic management (9) (12)
- Knowledge and skills development (7) (8)
- Materials development (7) (12)
- High energy consumption (9)
- Expensive software (9)
- Cybersecurity (7)
- Post-process automation (7)
- Industry standards (7)
- Mass production (10)
- Software / Generative Design (10)
- Adaptability (10)
- Sustainability (10)
- Standards (8)
- Parts Quality (20)

3D Scanning

What is 3D Scanning?

ISO

3D scanning / 3D digitizing / raw data acquisition
method of acquiring the shape and size of an object as a 3-dimensional representation by recording x,y,z coordinates on the objects surface and through software the collection of points is converted into digital data
Note 1 to entry: This collection of data via the scanning process creates a raw data set (3.1.14).
Note 2 to entry: Typical scanning methods use some amount of automation, coupled with a touch probe or an optical sensor, or other device. (13)

Wikipedia

3D scanning is the process of analyzing a real-world object or environment to collect data on its shape and possibly its appearance (e.g. colour). The collected data can then be used to construct digital 3D models. (14)

Market size

3D scanning market size estimates vary widely. The general conclusion after examining several sources is that it's still relatively small today, but steadily growing. Sample forecasts from various sources are as follows:

- Allied Market Research - Approximately US$8.5 million in 2017, projected to reach approximately US$53 million by 2025. (15)
- Morder Intelligence - Market value of approximately US$1.0 billion in 2018 growing to approximately US$3.3 billion in 2024. US$2019-2024 CAGR of 22.21% (16)
- Grand View Research - Market size is approximately US$4.5 billion in 2018 with an expected CAGR or 8.5% from 2019 to 2025. (17)
- Report Buyer- Market size of approximately US$13.3 billion in 2024 with a CAGR of 18.4%. (18)
- IndustryARC - Market for 3D scanning in 2017 was approximately US$9.0 billion and is expected to reach US$11.6 billion by 2023. The estimated CAGR is 4.39% during 2018-2023. (19)

Industries addressed

Industries addressed by 3D scanning are listed below sorted roughly by frequency of mention in the sources consulted.

- Architecture and Construction (16) (17) (18) (19) (15)
- Healthcare / Medical (15) (16) (17) (19)
- Manufacturing (15) (16) (17) (18)
- Aerospace and Defense (16) (17) (18)
- Automobile (15) (16) (17)
- Movies and entertainment (15) (16)
- Historical preservation (15)
- Civil infrastructure (15)
- Mining (15)

Application areas

Application areas for 3D scanning are listed below sorted roughly by frequency of mention in the sources consulted.

- Reverse engineering (15) (16) (17)
- Quality inspection (15) (16) (17)
- Rapid prototyping (15) (16)
- Face and Body scans (15) (16)
- Digital Modeling (16) (17)
- Diagnosis (15)
- Security and surveillance (15)
- Material processing (17)
- Automotive designing (17)
- Automotive radar (16)
- Plant inspection (17)
- Building design (19)
- Crime investigation (19)

Challenges

- Material dependencies (e.g., subsurface scattering)
- Cybersecurity (anti-counterfeiting)

2 Benefits expected from the work of the ISO/IEC JTC 1/WG 12

3D Printing and 3D Scanning are two distinct industries with significant overlap. These industries are growing rapidly, are being utilized in an increasing array of applications, and are facing many significant challenges. Some of these challenges may be addressed by creating and adopting strategically developed industry standards. Many of these standards opportunities are ICT related in whole or in part.

In addition, the ongoing pandemic exposes the fragility of the current global supply chain. 3D Scanning and 3D Printing are playing an important role in accelerating the product development to scale up the production of medical and personal protective equipment. For example, 3D Scanners are being used to more rapidly develop the moulds for the protective gear and therefore reducing the overall time to produce lifesaving medical equipment. 3D printing allowed rapid design of crucial parts which can be immediately shared around the world for immediate production for local medical staff. The immediacy that is enabled by digital design and transmission, coupled with digital manufacturing, provides emergency solutions that are otherwise unavailable. In addition to that, medical imaging is starting to use 3D scans of COVID-19 patients for modelling and research. Refer to the links provided in references (24 through 43) section for a list of ongoing work as a response to the pandemic.

In order to have a distributed supply chain as could be provided by Additive Manufacturing, it will be important to have tools and standards in place to ensure that customers can be assured of the reliability of parts within the distributed model.

Finally, standards need to be created in areas of current adoption where the existing standards fail to address the differences of Additive Manufacturing. Primary areas of adoption include medical, aerospace, and automotive applications. Enabling success and consistency is critical to the long-term success for all involved parties.

In summary, the shift to the fourth industrial revolution will require the right amount of oversight and commonality to enable broad adoption and usage to prevent surprises on the part of the manufacturer and the end customer.

3 Representation and participation in the ISO/IEC JTC 1/WG 12

3.1 Membership

https://sd.iso.org/documents/ui/#!/browse/iso/iso-iec-jtc-1/iso-iec-jtc-1-wg-12/?p=nuxeo-committee-member-page

3.2 Analysis of the participation

ISO/IEC JTC 1/WG 12 consists of 11 P-members and 2 O-members.

- P-members: Australia, Canada, China, France, Germany, India, Italy, Japan, Korea, Republic of, United Kingdom and United States
- O-members: Israel and Nigeria

4 Objectives of the ISO/IEC JTC 1/WG 12 and strategies for their achievement

4.1 Defined objectives of the ISO/IEC JTC 1/WG 12

Digital Manufacturing, and more specifically, Additive Manufacturing has spent much of its history viewed first and foremost as a prototyping technology. As such, the performance

requirements and associated standards have been less critical to the adoption and use of Digital Manufacturing. This WG will be making efforts to enable Digital Manufacturing as a production-level option for users. To be useful to users, it will need to ingest, move, and provide data in a reliable way across systems and services to enable end customers to spend their time creating parts instead of trying to connect with disparate systems.

The first step and base level is the creation of 23510 – Additive Manufacturing Service Platform, which provides a common framework upon which other standards can build, and to which other standards can connect.

Going forward, the move to production will require quality systems and controls that provide the needed underpinnings to provide verifiable and reliable information regarding the parts being produced.

In addition, digital manufacturing and the transfer and handling of proprietary information will require standardization around the handling of part data to provide security to the part creator regarding their intellectual property.

4.2 Identified strategies to achieve the ISO/IEC JTC 1/WG 12's defined objectives

3D Printing and 3D Scanning are inherently cyber-physical systems. As such, many standardization opportunities cannot be addressed from a strictly ICT point-of-view. Collaboration with other standards bodies with complementary areas of expertise will be required in many cases. For each opportunity, the following approaches will be considered:

1. If the standardization opportunity is clearly a foundational ICT enabler for 3D printing or 3D scanning, then WG 12 will take the initiative and lead in developing that standard. Examples include but are not limited to underlying broadly applicable file formats, protocols, or cyber-security mechanisms.
2. If the standardization opportunity requires both ICT expertise and domain expertise in another area, then WG 12 will investigate collaborative development opportunities with other entities within ISO and/or IEC, and externally with other appropriate standards bodies. Examples include but are not limited to, specific applications of file formats and protocols, information management policies, data quality standards.

For those 3D printing and scanning related standardization activities with significant ICT concerns currently underway, WG 12 will seek a collaborative arrangement with the standards bodies responsible for the work.

5 Factors affecting completion and implementation of the ISO/IEC JTC 1/WG 12 work programme

No negative factors that could negatively impact the completion or business community acceptance and use of the standards developed by this Working Group.

6 Structure, current projects and publications of the ISO/IEC JTC 1/WG 12

Information on ISO online

The link below is to the TC's page on ISO's website:
https://isotc.iso.org/livelink/livelink?func=ll&objId=19905763&objAction=browse

Click on the tabs and links on this page to find the following information:

- About (Secretariat, Committee Manager, Chair, Date of creation, Scope, etc.)
- Contact details
- Structure (Subcommittees and working groups)
- Liaisons
- Meetings

- Tools
- Work programme (published standards and standards under development)

6.1 Structure

At its first meeting in Seoul in August 2018, WG 12 resolved to establish an Ad Hoc Groups (AHG) to progress the WG discussions around 4D Printing, and Overview & Vocabulary requirements at its second meeting in NYC in February 2019.

The current structure of WG 12 is as follows:

- AHG 1 4D Printing (August 2018 - Present)
- (Disbanded) AHG 2 Overview and Vocabulary (February 2019 -August 2019)

6.2 Deliverables

The status of the deliverables planned for this review period are given in Table 1.

Deliverable	Status	Forecast
ISO/IEC CD 23510 Information technology — 3D Printing and Scanning — Framework for Additive Manufacturing Service Platform (AMSP)	30.60(2020-09-28, Current)	30.99(CD approved for registration as DIS) will be made after 5th WG12 meeting.
ISO/IEC PWI 24398 Overview and Vocabulary on 3D Printing & Scanning	00.00(2020-09-28, Current)	10.00(Proposal for New project registered) is expected in 2021.
ISO/IEC WD 3532 -1 Information Technology — 3D Printing and Scanning — Medical Image-Based Modelling – Part 1: General Requirement	30.20(2020-09-28, Current)	30.99(CD approved for registration as DIS) is expected no later than 2022-08-24.
ISO/IEC WD 3532-2 Information Technology – 3D Printing and Scanning – Medical Image-Based Modeling – Part 2: Segmentation	20.00(2020-09-28, Current)	30.99(CD approved for registration as DIS) is expected no later than 2022-08-24.

Table 1 - Deliverables

6.3 Coordination and Collaboration

There are several SDOs and consortia active in the area of 3D printing standardization. WG 12's focus is on the ICT foundational aspects of 3D printing standardization, and, in developing its work programme and deliverables, WG 12 strives to ensure synergy with other standardizing organizations thereby avoiding duplication of effort.

The following tables show the organizations active in the area of 3D printing standardization.

Org	TC	Description
ISO	TC 261	Additive Manufacturing
ISO	TC 106	Dentistry
ISO	TC 150	Implants for surgery
ISO	TC 184/SC 1	Automation systems and integration – physical device control
ISO	TC 184/SC 4	Automation systems and integration – industrial data
ISO	TC 215	Health informatics
IEC	TC 62	Electrical equipment in medical practice
ISO	TC 213	Dimensional and geometrical product specifications and verification
ISO/IEC	JTC 1/SC 24	Information technology - computer graphics, image processing and environmental data representation
ISO/IEC	JTC 1/SC 28	Information technology – office equipment
ISO/IEC	JTC 1/SC 29	Information technology - coding of audio, picture, multimedia and hypermedia information
ISO/IEC	JTC 1/SC 31	Information technology - automatic identification and data capture techniques
ISO/IEC	JTC 1/SC 38	Information technology - Cloud Computing and Distributed Platforms
ISO/IEC	JTC 1/SC 41	Internet of things & related technologies
ISO/IEC	JTC 1/SC 42	Artificial intelligence

Table 2 - ISO/IEC Committees

Organization	Sub-group	Description
Web 3D Consortium (1)	N/A	An international, non-profit, member-funded, industry standards development organization. Utilizes its broad-based industry support to develop the X3D specification, designed for sharing interactive 3D graphics on the Web, between applications and across distributed networks and web services.
3MF Consortium (21)	N/A	3MF 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.
Khronos Group (2) Note: Has a Category C relationship with WG 12	N/A	The Khronos Group is a member-driven consortium developing royalty-free open standards and vibrant ecosystems, to harness silicon acceleration for demanding graphics rendering and computationally intensive applications such as 3D graphics, Virtual and Augmented Reality, Parallel Computing, Neural Networks, and Vision Processing
DICOM	WG 17 (3)	Extend and promote the use of DICOM for the creation, storage and management of virtual reality, augmented reality, and mixed reality models in a healthcare setting, where the model is either (a) derived from medical images, or (b) expected to be compared / composited with medical images.
ASTM	F.42 Additive Manufacturing Technologies	The promotion of knowledge, stimulation of research and implementation of technology through the development of standards for additive manufacturing technologies. The

	(4)	work of this Committee will be coordinated with other ASTM technical committees and other national and international organizations having mutual or related interests.
ASME (22)	Y14	Develop and standardize systems and indications to promote uniform product definition practices for Additive Manufacturing (AM). Create a broadly accepted standard that incorporates, expands, or refines international practices and symbology to enable AM product definition data sets to be created, interpreted, and consumed on a global basis. This standard shall ensure that component parts and component assemblies, produced from such AM product definition data sets, are subject to a single interpretation of engineering specifications and requirements for the purpose of conformance verification. This standard shall supplement the requirements of the Y14 series.
MPIF (23)	N/A	The Metal Powder Industries Federation issues standards to provide the design and materials engineer with the information necessary for specifying powder metallurgy materials which have been developed by the powder metallurgy and metal injection molding parts, powder, and equipment producers. MPIF standards are intended to present and clarify powder metallurgy technology so as to aid in the conduct of business. PM materials specifications and test standards relate to those activities that concern designers and users of PM parts as well as the manufacturer.

Table 3 - External Organizations

7 References

1. Web 3D Consortium. About. *Web3D Consortium.* [Online] [Cited: 07 25, 2019.] https://www.web3d.org/about.

2. Khronos Group. About The Khronos Group. *Khronos Group.* [Online] [Cited: 07 25, 2019.] https://www.khronos.org/about/.

3. Spellman, Lisa, Nordvyk, Allan and Ryan, Justin. WG-17 3D. *DICOM.* [Online] 04 05, 2019. [Cited: 7 25, 2019.] https://www.dicomstandard.org/wgs/wg-17/.

4. Picariello, Pat. Committee F42 on Additive Manufacturing Technologies. *ASTM International.* [Online] [Cited: 07 25, 2019.] https://www.astm.org/COMMITTEE/F42.htm.

5. ISO/ASTM. Online Browsing Platform, search for "3D Printing". *ISO Online Browsing Platform.* [Online] 2015. [Cited: Jul 05, 2019.] https://www.iso.org/obp/ui/. ISO/ASTM 52900 2015(en) 2.3.1.

6. Wikipedia. 3D Printing. *Wikipedia.* [Online] Jul 05, 2019. [Cited: Jul 05, 2019.] https://en.wikipedia.org/wiki/3D_printing.

7. McCue, TJ. Significant 3D Printing Forecast Surges To $35.6 Billion. *Forbes.* [Online] Mar 27, 2019. [Cited: Jul 03, 2019.] https://www.forbes.com/sites/tjmccue/2019/03/27/wohlers-report-2019-forecasts-35-6-billion-in-3d-printing-industry-growth-by-2024/#6a217afd7d8a.

8. Grand View Research. 3D Printing Market Size, Share & Trends Analysis Report By Component, By Printer Type, By Technology (FDM, Stereolithography), By Software, By Application, By Vertical, By Region, And Segment Forecasts, 2018 - 2025. *Grand View Research.* [Online] Oct 2018. [Cited: Jul 05, 2019.] https://www.grandviewresearch.com/industry-analysis/3d-printing-industry-analysis.

9. Allied Market Research. 3D Printing Market by Technology [Stereolithography (SLA), Fused Deposition Modelling (FDM), Selective Laser Sintering (SLS), Electron Beam Melting (EBM), Digital Light Processing (DLP), and Others], Component (Hardware, Software, and Services), and End U. [Online] https://www.alliedmarketresearch.com/3d-printing-market.

10. Sculpteo. Download your State of 3D Printing for free! *Sculpteo.* [Online] 2019. [Cited: Jul 04, 2019.] https://www.sculpteo.com/blog/2019/05/29/download-your-state-of-3d-printing-for-free/.

11. Markets and Markets. 3D Printing Market by Offering (Printer, Material, Software, Service), Process (Binder Jetting, Direct Energy Deposition, Material Extrusion, Material Jetting, Powder Bed Fusion), Application, Vertical, Technology, and Geography - Global Forecast to 2024. *Markets and Markets.* [Online] Feb. 2019. https://www.marketsandmarkets.com/Market-Reports/3d-printing-market-1276.html.

12. Stewart, Duncan. 3D printing growth accelerates again. *Deloitte Insights.* [Online] Dec 11, 2018. [Cited: Jul 03, 2019.] https://www2.deloitte.com/insights/us/en/industry/technology/technology-media-and-telecom-predictions/3d-printing-market.html.

13. ISO. Online Browsing Platform, search for "3D Scanning". *ISO.* [Online] 2015, 2016. [Cited: Jul 05, 2019.] https://www.iso.org/obp/ui/. ISO/ASTM 52900 2015 def 2.4.1 modified, ISO 18739 2016 3.1.3.

14. Wikipedia. 3D Scanning. *Wikipedia.* [Online] Jun 23, 2019. [Cited: Jul 05, 2019.] https://en.wikipedia.org/wiki/3D_scanning.

15. Allied Market Research. 3D Scanning Market by Type (Optical Scanner, Laser Scanner, and Structured Light Scanner), Range (Short Range Scanner, Medium Range Scanner, and Long Range Scanner), Service (Reverse Engineering, Quality Inspection, Rapid Prototyping, and Face Body Scanni. *Allied Market Research.* [Online] Sep 2018. [Cited: Jul 03, 2019.] https://www.alliedmarketresearch.com/3D-scanning-market.

16. Mordor Intelligence. 3D SCANNING MARKET - GROWTH, TRENDS, AND FORECAST (2019 - 2024). *Mordor Intelligence.* [Online] 2018. [Cited: Jul 04, 2019.] https://mordorintelligence.com:81/industry-reports/gloval-3d-scanners-market-industry.

17. Grand View Research. 3D Scanning Market Size, Share & Trends Analysis Report By Product (Optical Scanner, Laser Scanner), By Range, By End-user, By Component, By Type, By Application, By Region, And Segment Forecasts, 2019 - 2025. *Grand View Research.* [Online] 2018. [Cited: Jul 04, 2019.] https://www.grandviewresearch.com/industry-analysis/3d-scanning-industry.

18. Unknown. Global 3D Scanning Market (2018 - 2024). *Report Buyer.* [Online] April 2019. [Cited: Jul 05, 2019.] https://www.reportbuyer.com/product/5774545/global-3d-scanning-market-2018-2024.html?utm_source=PRN.

19. IndustryARC. D Scanning Market: By Build-up system, By Scan Range, By Technology, By S... *IndustryARC.* [Online] [Cited: Jul 05, 2019.] https://www.industryarc.com/Report/10614/3d-scanning-market.html.

20. AMFG. Quality Assurance for Metal 3D Printing: Solving 3 Common Challenges [online] [cited: March 15, 2019] https://amfg.ai/2019/03/15/quality-assurance-for-metal-3d-printing-solving-3-common-challenges/?cn-reloaded=1

21. 3MF Consortium. About Us. [Online] [Cited: July 01, 2020.] https://3mf.io/about-us/

22. ASME. Y14 Subcommittee. [Online] [Cited: July 01, 2020.] https://cstools.asme.org/csconnect/CommitteePages.cfm?Committee=100749850

23. MPIF. Standards. [Online] [Cited: July 01, 2020.] https://www.mpif.org/Resources/Standards.aspx

24. https://www.cnn.com/2020/03/26/health/covid-19-lung-damage-video/index.html

25. https://www.weforum.org/platforms/covid-action-platform/projects/3d-printing-covid-19-rapid-response-initiative

26. - https://www.fda.gov/emergency-preparedness-and-response/coronavirus-disease-2019-covid-19/3d-printing-fdas-rapid-response-covid-19

27. - https://www.canada.ca/en/health-canada/services/drugs-health-products/medical-devices/covid-19-unconventional-manufacturing-personal-protective-equipment.html

28. - https://www.gov.uk/guidance/3d-printing-additive-manufacturing-of-medical-devices-or-component-parts-during-the-coronavirus-covid-19-pandemic

- https://ec.europa.eu/docsroom/documents/40562

29. - https://www.nature.com/articles/s41578-020-00234-3

30. - https://link.springer.com/article/10.1186/s41205-020-00064-7

31. - https://www.liebertpub.com/doi/full/10.1089/3DP.2020.0101

32. - https://www.mdpi.com/2076-3417/10/11/4004

33. - https://threedmedprint.biomedcentral.com/articles/10.1186/s41205-020-00064-7

34. - https://standards.ieee.org/covid-19/index.html

35. - https://www.3dsystems.com/covid-19-response

36. - https://www.nihlibrary.nih.gov/services/3d-printing-service/3d-printing-medical-equipment-response-covid-19-pandemic

37. - https://penntoday.upenn.edu/news/rapid-response-covid-19-puts-power-innovation-test

38. - https://www.manufacturingusa.com/covid-19-response

39. - https://www.3dmednet.com/live-updates-3d-printing-in-a-time-of-coronavirus-the-additive-response-to-covid-19/

40. - https://www.materialise.com/en/3d-printing-response-to-covid-19

41. - https://enable.hp.com/us-en-3dprint-COVID-19-containment-applications/#:~:text=First%20industrialized%20field%203D%20printed,the%20shortage%20of%20medical%20equipment.

42. - https://www.industryweek.com/technology-and-iiot/additive/article/21136038/3d-printing-lessonslearned-from-covid19-and-how-they-will-change-manufacturings-future

43. - https://www.theverge.com/2020/5/25/21264243/face-shields-diy-ppe-3d-printing-coronavirus-covidmaker-response