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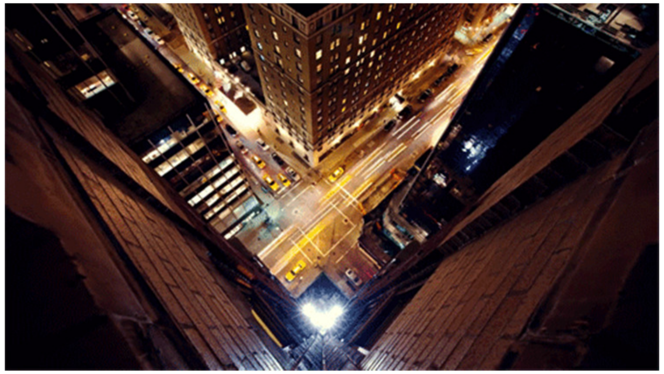
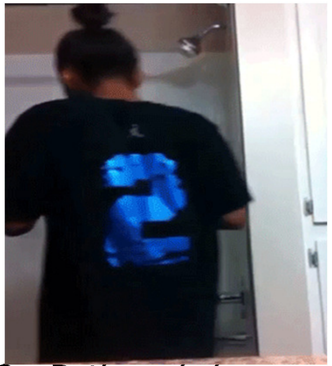
Additive Manufacturing – Standards.

Alex Price, Lead Programme Manager.

So how many standards are there?



PAS 181:2014 - Smart city Framework. Guide to establishing strategies for smart cities and communities



BS 8445:2012 - Bath and shower mats. Testing. Assessment of slip resistance properties safety signs

BS 185-6:1970 - Glossary of aeronautical and astronautical terms. Ballistic and guided missiles

BS 8888:2011 - Technical product documentation and specification

Who sets all these standards?

- Someone has an idea?

National Standards Body

Why adopt a standard/s:

- **Required:**
  - The standard may form part of a contract,
  - The Standard may be part of obligation to CE or some other quality mark,
  - The Standard may be referred to in legislation,
  - The Standard may be required within the supply chain.
- **Recommended:**
  - A good rationale would be presented, adoption of the standard may improve business performance,
  - May improve business practice,
  - A very large percentage of export is influenced by the European and international standards business,
  - May form part training potentially for employees,
  - Interoperability with other standardised products or components.
- **Information:**
  - Elements from a standard could be taken into company best practise without full adoption,
  - May form part training potentially for employees,
  - Could form guidance to day to day business.

Additive Manufacturing – where's the hype

The Economist

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DIY gun project misfires as 3D printer is seized

- 10:31 02 October 2012 by Paul Marks
- Magazine issue 2885. Subscribe and save
- For similar stories, visit the Weapons Technology and US national issues Topic Guides

PRINT SEND SHARE

Who would have thought it? Printing guns is frowned upon. Even in the US.

Cody Wilson, a law student at the University of Texas at Austin, found this out last week when Stratasys, the company that made the uPrint SE 3D printer he was leasing, got wind of his plans to design a 3D-printable handgun and took back their equipment.

"The company is less than thrilled with what we're doing. They're trying to prevent me from breaking any laws with their product," Wilson told New Scientist. With several friends, he has founded a group called Defense Distributed to promote ideas about universal gun ownership.

Image new scientist July 2012.

Why Standardisation?

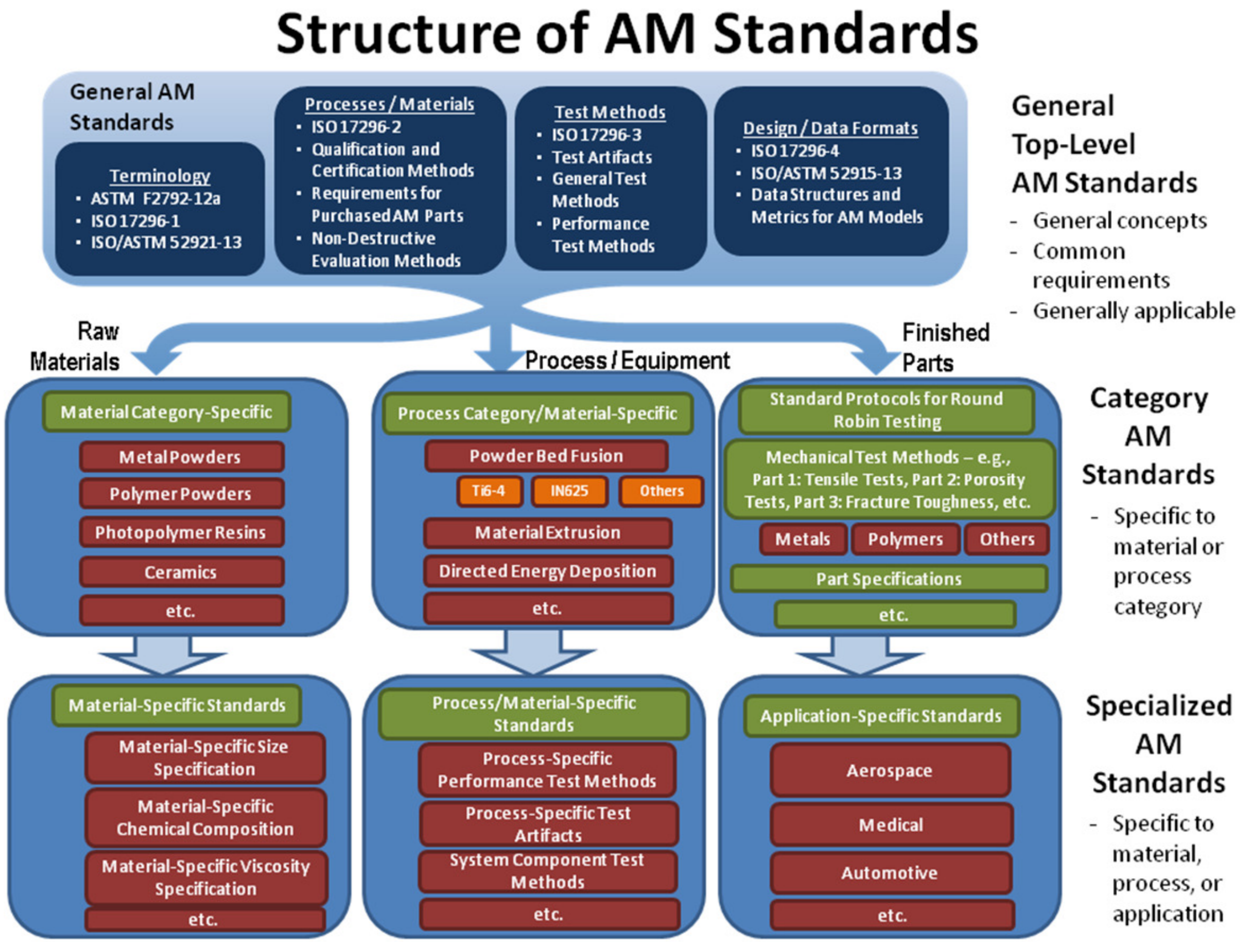
- Any number of reports have highlighted the need.
- Industry request.
- Key Challenged hindering advancement of AM over the next ten years.
  - Report by the IQPC
    - 76% of respondents highlighted certification of finished parts and products.
    - 48% Quality & standardisation of material inputs
    - 36% Questionable quality of finished parts

So many processes, materials and outputs under the additive manufacturing banner.

- There are a number of processes which fall under the Additive Manufacturing label. Which vary in material, process, final shape, surface finish, geometrical shape required. The American Society for Testing and Materials (ASTM) group "ASTM F42 – Additive Manufacturing", formulated terminology defining range of Additive Manufacturing processes into 7 categories ISO/ASTM52900-15 Standard Terminology for Additive Manufacturing – General Principles – Terminology:

  - **VAT Photopolymerisation**
  - **Binder Jetting**
  - **Material Jetting**
  - **Material Extrusion**
  - **Powder Bed Fusion**
  - **Sheet Lamination**
  - **Directed Energy Deposition**

Top level overview of the development of standards.



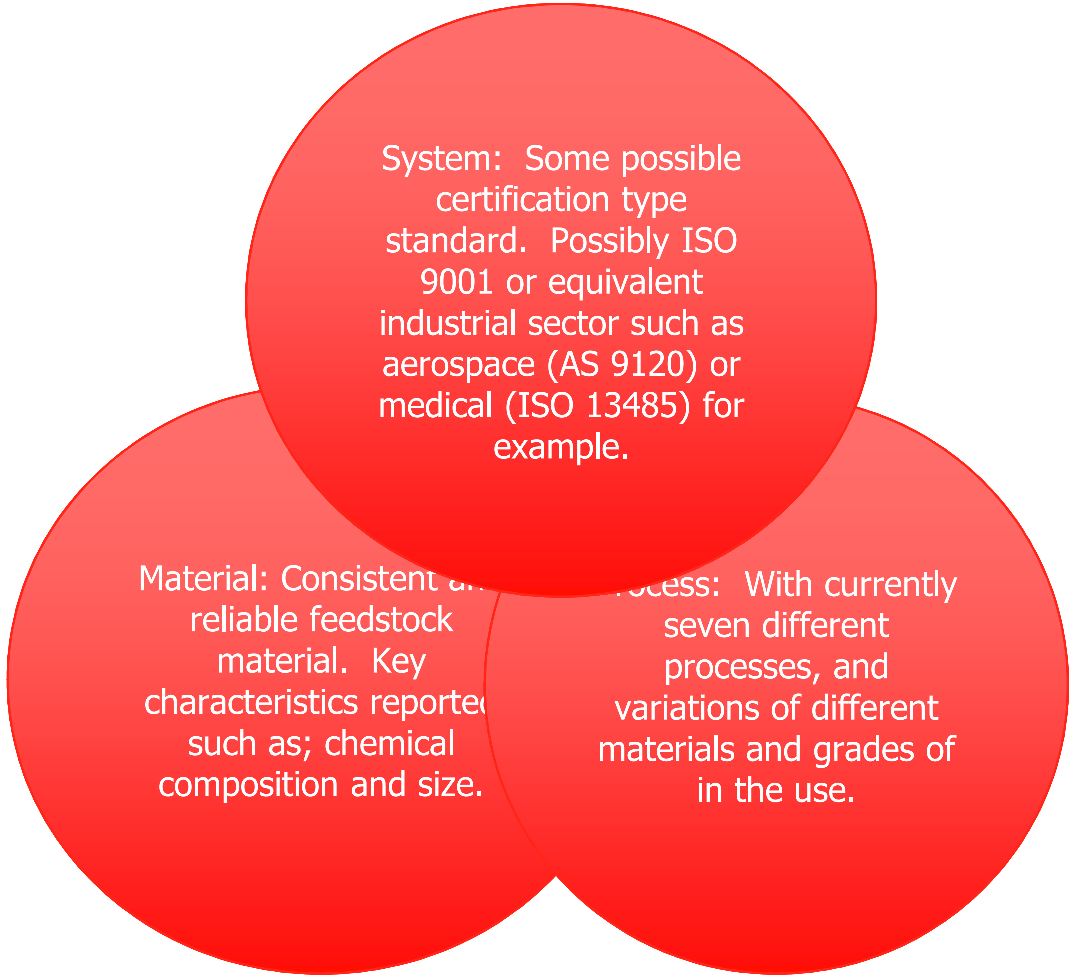
NIST publication on AM.

What new areas is Additive manufacturing linked to?

- Machine Safety
  - Laser safety
  - Contained atmospheres
- Metrology:
  - Both established mechanical properties
  - state of the art ultra-high accuracy
  - multi-sensory coordinate measurement machines.
- Non Destructive Evaluation in-process and post process:
  - For post build inspection for both surface and sub-surface monitoring, digital x-ray, X-ray CT ultrasound. Eddy current may be used for surface and close to surface monitoring.
  - For in-process sensors, thermal and optical imaging.
- Intelligent automation:
  - Complex automation
  - Robotics
  - Sensor technology, embedded.

What is Quality management for AM?

- System:
  - Level of assurance of part.
    - Aerospace
  - Robust systems of traceability.
    - Standards
  - Training and
    - New technology requires it
- Process:
  - What AM process is the most appropriate for your task.
  - Choice of materials.
  - Knowing your key parameters.
    - In process monitoring.
  - Post processing.
    - What needs to be done to get the part up to required levels.
  - Next process consideration.
- Materials:
  - What AM material can be used.
    - Is it the most appropriate for your task.
  - Choice of materials.

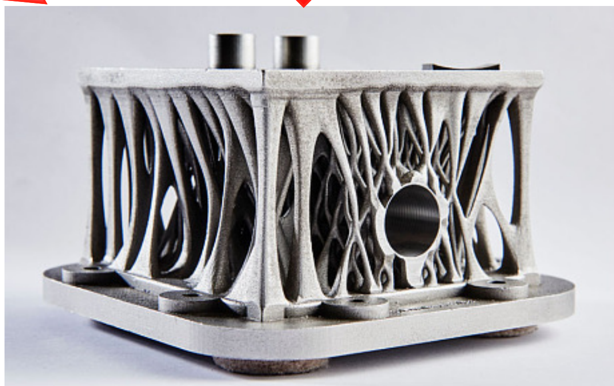


So what are the standards program currently?

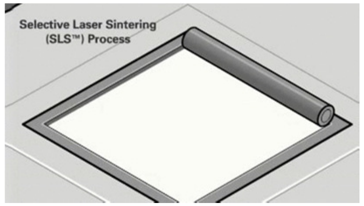
- ISO 17296-2:2015 Additive manufacturing -- General principles -- Part 2: Overview of process categories and feedstock
- ISO 17296-3:2014 Additive manufacturing -- General principles -- Part 3: Main characteristics and corresponding test methods
- ISO 17296-4:2014 Additive manufacturing -- General principles -- Part 4: Overview of data processing
- ISO/ASTM 52900:2015 Additive manufacturing -- General principles -- Terminology 60.60
- ISO/ASTM DIS 52901.2 Additive manufacturing -- General principles -- Requirements for purchased AM parts
- ISO/ASTM NP 52902
- Additive manufacturing -- General principles -- Standard test artifacts
- ISO/ASTM DIS 52903-1 Additive manufacturing -- Standard specification for material extrusion based additive manufacturing of plastic materials -- Part 1: Feedstock materials
- ISO/ASTM CD 52903-2 Additive manufacturing -- Standard specification for material extrusion based additive manufacturing of plastic materials -- Part 2: Process -- Equipment
- ISO/ASTM NP 52905 Additive manufacturing -- General principles -- Non-destructive testing of additive manufactured products
- ISO/ASTM DIS 52910.2 Guidelines for additive manufacturing design
- ISO/NP TR 52912 Design of functionally graded additive manufactured parts
- ISO/ASTM 52915:2016 Specification for additive manufacturing file format (AMF) Version
- ISO/ASTM 52921:2013 Standard terminology for additive manufacturing -- Coordinate systems and test methodologies

How can standards support the development?

- In process monitoring
- Post-process monitoring
- Machinery Safety
- Mechanical, thermal, etc Testing
- Types of AM processes and calibration
- Dimensional metrology
- Guidance and best practise
- Data formats and retention
- Consistent raw materials

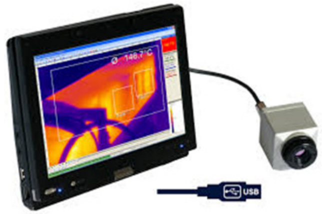


Types of AM process



- Material extrusion
  - ISO/ASTM CD 52903-2Additive manufacturing -- Standard specification for material extrusion based additive manufacturing of plastic materials -- Part 2: Process -- Equipment
- Powder bed fusion
  - Draft DIN 35224: Welding for aerospace applications – Acceptance inspection of powder bed based laser beam welding machines for additive manufacturing"
  - Draft DIN TBD: Aerospace — Powder for additive manufacturing with powder bed process – Technical specification
- Material jetting
- Binder jetting
- Directed Energy deposition
- Sheet lamination
- Vat polymerisation
  - Draft DIN TBD: "Welding for aerospace applications – Qualification of operators for additive manufacturing equipment"
  - Draft DIN TBD: "Testing and Inspection of additively manufactured products"
  - ISO 17296-2:2015 Additive manufacturing -- General principles -- Part 2: Overview of process categories and feedstock

In process monitoring



- AM NDT standards will require consideration of particular number of defects and assessment of the surface monitoring during the build, where thermal monitoring, optical imaging and geometrical monitoring would be useful. For in-process sensors to provide non-destructive evaluation and allow for early detection of flaws/defects, also modelling on residual stresses based on work at the STFC, neutron source.
  - Thermography:
    - BS ISO 18434-1:2008 Condition monitoring and diagnostics of machines. Thermography. General procedures
    - ASTM E1311-14 Standard Practice for Minimum Detectable Temperature Difference for Thermal Imaging Systems
  - Visual inspection:
    - Very much an objective method based human experience and hence virtually impossible to standardise.
  - Ultrasonic:
    - BS EN 583-1:1999 Non-destructive testing. Ultrasonic examination. General principles
  - Computer tomography (CT):
    - BS EN 16016-3:2011 Non destructive testing. Radiation methods. Computed Tomography. Operation and interpretation

Post processing monitoring

- AM NDT standards will require consideration of particular number of defects and assessment of the surface monitoring during the build, where thermal monitoring, optical imaging and geometrical monitoring would be useful. For post build inspection the following techniques may be used for both surface and sub-surface monitoring, digital x-ray, X-ray CT ultrasound. Eddy current may be used for surface and close to surface monitoring.

- Generate best practice guide showing NDT methods potential to inspect AM defects not covered by current standards.

- Current Work Item: WK49798 – Standard Guide for Intentionally Seeding Flaws in AM Parts

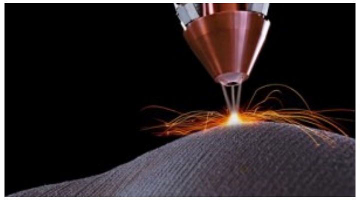
- WK47031 – Standard Guide for Nondestructive Testing of AM Metal Parts Used in Aerospace Applications

Machine Safety

- Many of the Additive machines are on the market, so obviously comply with the machinery directive 2006/42/EC, making use of the standards below:
- Some considerations on machinery safety:
  - Laser
  - Explosive atmospheres
  - Hot melt flow of materials
  - Residual powders

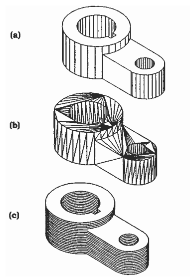
- **EC Directive 2006/42/EC standards dealing with the essential requirements.**
  - BS EN ISO 12100:2010 Safety of machinery. General principles for design. Risk assessment and risk reduction
  - BS EN ISO 13849-1:2015 Safety of machinery. Safety-related parts of control systems. General principles for design

Consistent raw materials



- The raw materials are often in the form of powders or wires that can be melted and shaped by a laser.
- Consistent raw materials.
  - Goes someway to consistent outputs.
  - Guarantees process consistency.
- Characterization of Additive Manufacturing Materials involves developing measurements and standards for characterizing powdered metals—raw materials for additive manufacturing—in terms of particle size and shape, chemical consistency and size consistency.
- Work undertaken by NIST.
    - ISO 17296-2:2015 Additive manufacturing -- General principles -- Part 2: Overview of process categories and feedstock
    - ISO/ASTM DIS 52903-1 Additive Manufacturing -- Standard Specification for Material Extrusion Based Additive Manufacturing of Plastic Materials -- Part 1: Feedstock materials

Data formats and retention



- 3D printing uses digital chain of information
- Many CAD formats extant, only some used for data transfer.
  - Information
  - Process
  - Geometry

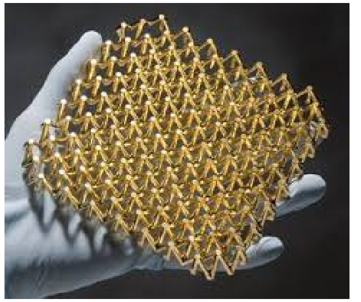
- Additive manufacturing file formats:
  - STL: proprietary, but de-facto standard through frequent adoption by CAD software providers
  - STEP: ISO 10303-242:2014 Industrial automation systems and integration -- Product data representation and exchange -- Part 242: Application protocol: Managed model-based 3D engineering
  - STEP-NC: ISO 14649-1:2003 Industrial automation systems and integration -- Physical device control -- Data model for computerized numerical controllers -- Part 1: Overview and fundamental principles
  - AMF: BS ISO/ASTM 52915:2016 Specification for Additive Manufacturing File Format (AMF) Version 1.2
  - 3MF:industry consortium including Microsoft, HP, Fit, formLabs, etc.

Guidance and best practise

Additive manufacturing

- With the number of processes out there to choose from which one is the best?
  - Considerations (Design for manufacturer/Design for testing):
    - Distinguishing Intermittent Stages of AM
    - Processing
    - Geometry Characteristics Specific to Additive
    - Material Definition
    - Datum/s
    - Functional Requirements
    - Post and pre Inspection

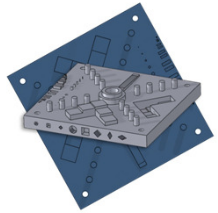
Why a standards is needed.



Technical Report for the Design of Functionally Graded Additive Manufactured Parts:

- Ensuring interoperability
  - The report will review of current capabilities and limitations of existing CAD and Finite Element Method (FEM) software that can support the production of Functionally Graded Additive Manufactured parts and existing software has been used to simulate FG materials that have variation of mechanical properties such as varying elastic modulus of the FGM piece.
- Creating market access
  - It will be relevant for those directly involved in the process of product design development and for those responsible for the material formulation and engineering.
- Provide source of knowledge
  - The report is aimed at all those involved in Additive Manufacturing industry to describe the concept of functionally Graded Additive Manufacturing.
- Creating market acceptance
  - The report will discuss existing gaps in knowledge, the current limitations and suggesting areas for future work. In particular, the report will recommend how future guidelines or standards could be developed from this study.

Dimensional metrology



- The principal check in manufacturing.

- Dimensional metrology instrumentation and post-measurement analysis techniques that will allow them to keep processes under tight control.

  - Why are checking?
    - Reducing scrap rate and therefore enhancing environmental sustainability.
  - What are checking for?
    - Quality.
- 378 published standards:
    - BS 8888 Technical product documentation and specification
    - BS 8887-1:2006 Design for manufacture, assembly, disassembly and end-of-life processing (MADE) - General concepts, process and requirements
    - BS 6808-3:1989 Coordinate measuring machines - Code of practice

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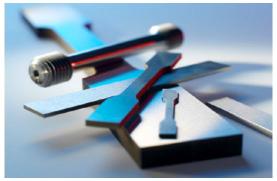
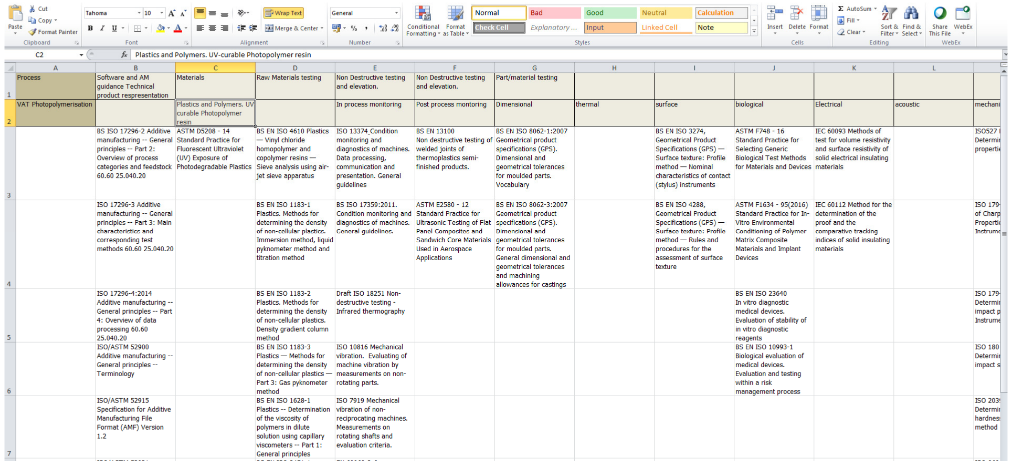
Mechanical, thermal, chemical Testing-AM matrix.



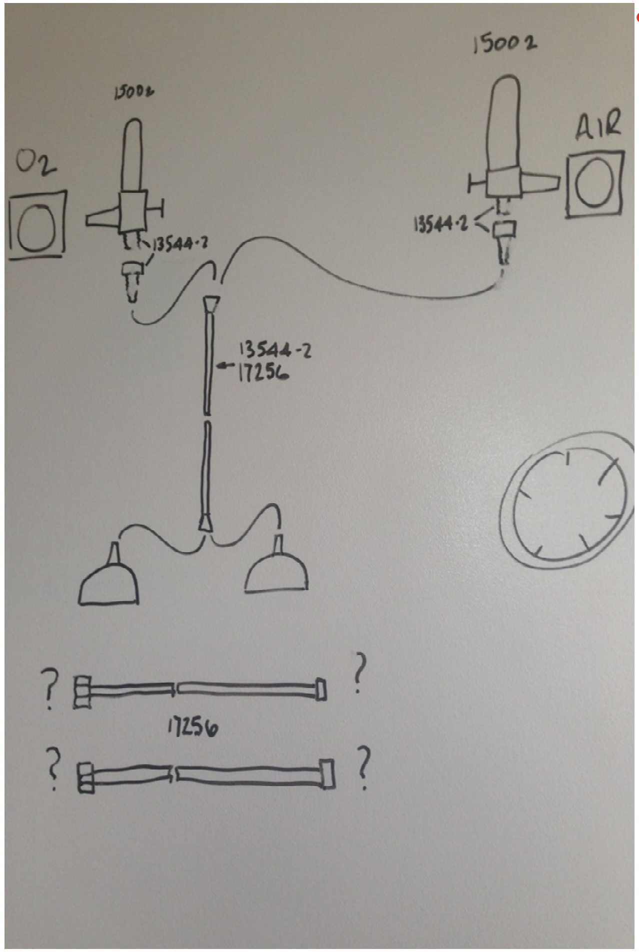
- List of materials properties:
  - Anelasticity
  - Ductility
  - Elastic deformation
  - Elastic recovery
  - Strain
  - Stress
  - Hardness
  - Modulus of elasticity
  - Plastic deformation
  - Poisson’s ratio
  - Proportional limit
  - ShearTensile s
  - trengthToughness
  - YieldingYield strength



C2 — Plastics and Polymers. UV-curable Photopolymer resin

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Process	Software and AM guidance Technical product respresentation	Materials	Raw Materials testing	Non Destructive testing and elevation.	Non Destructive testing and elevation.	Part/material testing						
2	VAT Photopolymerisation		Plastics and Polymers. UV curable Photopolymer resin		In process monitoring	Post process montoring	Dimensional	thermal	surface	biological	Electrical	acoustic	mechani
3		BS ISO 17296-2 Additive manufacturing -- General principles -- Part 2: Overview of process categories and feedstock 60.60 25.040.20	ASTM D5208 - 14 Standard Practice for Fluorescent Ultraviolet (UV) Exposure of Photodegradable Plastics	BS EN ISO 4610 Plastics — Vinyl chloride homopolymer and copolymer resins — Sieve analysis using air-jet sieve apparatus	ISO 13374_Condition monitoring and diagnostics of machines. Data processing, communication and presentation. General guidelines	BS EN 13100 Non destructive testing of welded joints of thermoplastics semi-finished products.	BS EN ISO 8062-1:2007 Geometrical product specifications (GPS). Dimensional and geometrical tolerances for moulded parts. Vocabulary		BS EN ISO 3274, Geometrical Product Specifications (GPS) — Surface texture: Profile method — Nominal characteristics of contact (stylus) instruments	ASTM F748 - 16 Standard Practice for Selecting Generic Biological Test Methods for Materials and Devices	IEC 60093 Methods of test for volume resistivity and surface resistivity of solid electrical insulating materials		ISO527 Determi properti
4		ISO 17296-3 Additive manufacturing -- General principles -- Part 3: Main characteristics and corresponding test methods 60.60 25.040.20		BS EN ISO 1183-1 Plastics. Methods for determining the density of non-cellular plastics. Immersion method, liquid pyknometer method and titration method	BS ISO 17359:2011. Condition monitoring and diagnostics of machines. General guidelines.	ASTM E2580 - 12 Standard Practice for Ultrasonic Testing of Flat Panel Composites and Sandwich Core Materials Used in Aerospace Applications	BS EN ISO 8062-3:2007 Geometrical product specifications (GPS). Dimensional and geometrical tolerances for moulded parts. General dimensional and geometrical tolerances and machining allowances for castings		BS EN ISO 4288, Geometrical Product Specifications (GPS) — Surface texture: Profile method — Rules and procedures for the assessment of surface texture	ASTM F1634 - 95(2016) Standard Practice for In-Vitro Environmental Conditioning of Polymer Matrix Composite Materials and Implant Devices	IEC 60112 Method for the determination of the proof and the comparative tracking indices of solid insulating materials		ISO 179- of Charp Properti Instrume
5		ISO 17296-4:2014 Additive manufacturing -- General principles -- Part 4: Overview of data processing 60.60 25.040.20		BS EN ISO 1183-2 Plastics. Methods for determining the density of non-cellular plastics. Density gradient column method	Draft ISO 18251 Non-destructive testing - Infrared thermography					BS EN ISO 23640 In vitro diagnostic medical devices. Evaluation of stability of in vitro diagnostic reagents			ISO 179- Determi impact p Instrume
6		ISO/ASTM 52900 Additive manufacturing -- General principles -- Terminology		BS EN ISO 1183-3 Plastics — Methods for determining the density of non-cellular plastics — Part 3: Gas pyknometer method	ISO 10816 Mechanical vibration. Evaluating of machine vibration by measurements on non-rotating parts.					BS EN ISO 10993-1 Biological evaluation of medical devices. Evaluation and testing within a risk management process			ISO 180 Determi impact s
7		ISO/ASTM 52915 Specification for Additive Manufacturing File Format (AMF) Version 1.2		BS EN ISO 1628-1 Plastics -- Determination of the viscosity of polymers in dilute solution using capillary viscometers -- Part 1: General principles	ISO 7919 Mechanical vibration of non-reciprocating machines. Measurements on rotating shafts and evaluation criteria.								ISO 203 Determi hardnes method

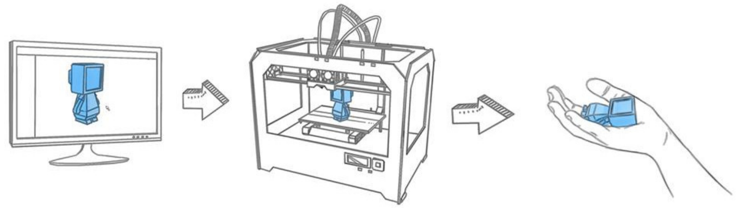
Standards in systems



- The final guidance also includes recommendations for standards in systems.
  - Connector materials
    - BS EN 13544-2:2002+A1:2009 Respiratory therapy equipment. Tubing and connectors
    - BS ISO 17256. Anaesthetic and respiratory equipment. Respiratory therapy tubing and connectors
    - ISO 80369-2:2012, Small-bore connectors for liquids and gases in healthcare applications — Part 2: 62 Respiratory small-bore connectors
  - Flow
    - BS EN ISO 15002:2008 Flow-metering devices for connection to terminal units of medical gas pipeline systems
  - Inadequacy of color-coded and labelled connectors
    - ISO 7000:2004, Graphical symbols for use on equipment – index and synopsis.
  - Labelling
    - EN 980, Symbols for use in the labelling of medical devices
  - Usability and human factors testing
    - BS EN 1041 Information supplied by the manufacturer of medical devices

Additive manufacturing Standard systems

So where else are AM/3DP standards heading



- Legacy parts
  - Reverse engineering
  - Documents retention
  - Comparison testing
- 3D Hubs
  - 27 813 printers on the network
  - 90% are not fully utilized
  - At least of one of these printers chocolate
- Printing at scale
  - Nano scale printing
- Functional materials printing
  - Embedded electronics
  - Printed electronics

Definition of Digital Manufacturing: e-Enablement of value chain optimisation

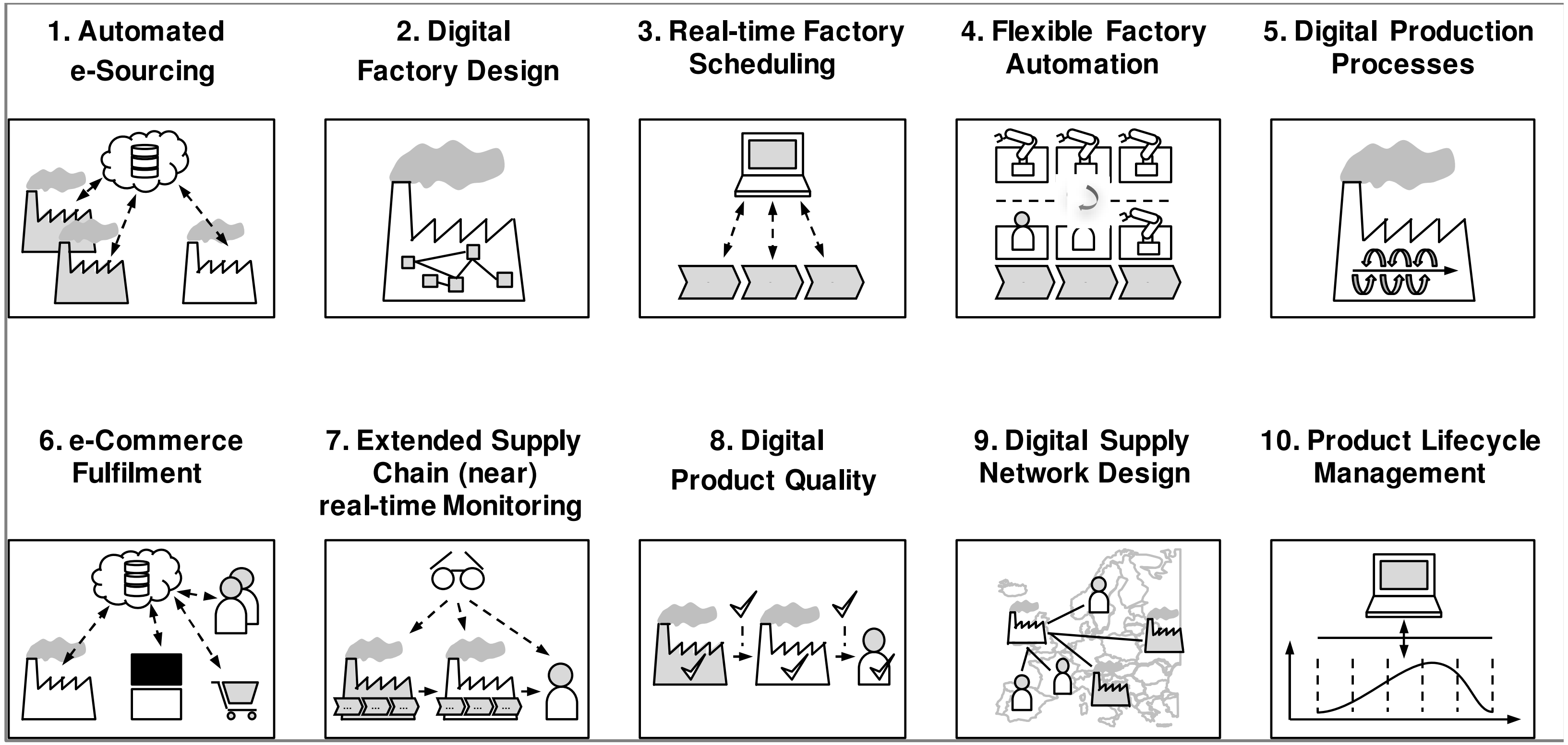
- Digital manufacturing is the **collaborative** transformation of manufacturing through the exploitation of advances in ICT

- Digital manufacturing transformation enables new supply chain and operations capabilities (scenarios) to emerge that exploit advances in digital technologies, devices, data analytics, data integration and management across the value chain in many sectors

- Digital manufacturing requires the development of new systems engineering competencies (systems modeling, simulation and interface design) and skills (attitudes) across the manufacturing value chain (R&D, design, supply, production, distribution, in service, disposal

- Digital manufacturing offers significant national and corporate competitive advantage through affordable flexibility, personalisation and product/service tailoring

10 scenarios for digital adoption by manufacturing supply chains

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