‘What is in a Word?’—The Use and Background for Terms and Definitions in Additive Manufacturing

Klas Boivie

1 Introduction

Additive manufacturing (AM) is a highly diverse field of technology, with a multitude of commonly used terms and abbreviations that, for the novice could appear as being inconsistent and confusing such that it many times has been compared to an ‘alphabet soup’. In the present context of AM, regarded as an industrial manufacturing process, this impression could certainly be justified; however, the development of terms and abbreviations used in the field of AM has been following the development of the technology, with respect to the different application areas and markets. Nevertheless, all communication, including education relies on being able to share a common, clear understanding of terms used for a specific topic. It is, therefore, important for the educator to not only use terms and definitions correctly, and in the right context, but also to have an understanding of the background and usage of terms and concepts with historical relevance, that can be found in literature and occasionally still be in use.

2 The Origin and Background for Terms and Abbreviations Used in Additive Manufacturing Technology

Albeit fabrication of objects by the successive addition of materials is not uncommon in nature or in human history, what we today call additive manufacturing technology is a relative recent development. The principle of forming objects by materials’

The original version of this chapter was revised: Belated corrections have been incorporated. The erratum to this chapter is available at https://doi.org/10.1007/978-3-319-76084-1_16

K. Boivie (✉)
Department of Production Technology, SINTEF Raufoss Manufacturing AS, S.P. Andersens vei 5, 7465 Trondheim, Norway
e-mail: klas.boivie@sintef.no

E. Pei et al. (eds.), *Additive Manufacturing—Developments in Training and Education*, https://doi.org/10.1007/978-3-319-76084-1_11

addition is demonstrated in nature for example, by the shells of snails and shellfish, that are produced layer by layer, by successive addition of minerals and protein, and also by swallows', and hornets' nests, that are built by successive addition of clay or pulp. Human ingenuity have applied the same principle in, for example, early techniques to make pottery, where coils of clay are successively stacked and joined onto each other. However, even if the principle of materials' addition as such was hardly unknown, the development of the modern AM industry and processes were largely motivated by the needs of the American automotive industry. During the 1980-s American carmakers were facing an increasingly stiff competition from Japan. One of the most important advantages held by the Japanese was their ability for rapid development of new models. At the same time, analysis indicated that a critical bottleneck for the American automotive companies was the time and cost spent on the production of prototypes during the development of new car models. This need created a market for new technologies enabling cheaper and more efficient prototype production. Meanwhile, the development of computer technology and software had reached a level that enabled the generation of three-dimensional (3D) solid models of the products during the design process. This made it possible to bypass several steps in the prototyping process by automating the production of physical models directly based on the 3D solid model. As a result, a number of Rapid Prototyping (RP) processes were brought to the market during the late 1980-s and early 1990-s (Wohlers Report 1996–2005; Gibson et al. 2010).

Even if these new processes in some aspects were principally different, there were also common traits, which still are fundamental in additive manufacturing technology. Typically, the process starts from a 3D solid model generated by a Computer Aided Design (CAD) program. This model is converted into slices, and the physical models are built through the reproduction of these slices by successive addition of material.

The most distinctive difference between the processes is, therefore, the different solutions for the conversion of a generic feedstock material into a solid geometry. These, often patented, solutions for material's addition have also been the inspiration for the different process names and acronyms used for the marketing of each process. Since this technology originally targeted a specific need, and the different solutions were aimed at a distinctive market, the different rapid prototyping process solutions were, therefore, brought to the market as products under their own product names. These names have, since then, been used as process names, and quite often also commonly used as generic names for a type of process, even if they, in reality, have been product names for a process solution from a specific company.

This development of processes and branding for the intended market segment brought process names such as 'Stereo Lithography', where the machine was a 'Stereo Lithography Apparatus' (SLA[1]), 'Selective Laser Sintering' (SLS[2]), 'Fused

[1]Registered trademark: (for a machine) serial number: 75331091, registration number: 2327581.

[2]Registered trademark: (for a service 1990–93) serial number 74063299, (for a service 2003–16) serial number 78232400, registration number: 2980742, (for a rapid prototyping system 1990–2016) serial number 74063, registration number: 1842387.

Deposition Modelling’ (FDM[3]), Laser Engineered Net Shaping (LENS[4]) ‘Laminated Object Manufacturing’ (LOM[5]), ‘Inkjet’ and ‘3D-Printing’[6] (3DP[7]) to the market. As long as these were unique solutions marketed for prototyping purposes by different companies, this was not a problem. However, as new companies entered the market, and brought similar process solutions to market under their own product names, the conditions were set that would develop into the confusing situation for AM terminology that has complicated the understanding of this sector of technology for several years.

3 Process Names, Brand Names and Acronyms

As new processes were patented and introduced to the rapid prototyping market, the names used for branding each process were often inspired by the title of the patent and what the inventors considered distinguishing features of their specific process. The process names were normally trademarked to protect the brand name and market reputation. When other companies introduced similar processes, they had to use different names for their ‘product’. The names for processes that were first to make an impact on a specific customer segment have had a tendency to stick and could for a period be used as a group name for a type of processes. However, the different groups of processes have been identified differently over time, partially with respect to process features and partially with respect to actual or anticipated application areas.

3.1 ‘3D Printing’

The commonly used term ‘3D Printing’ (3DP) was first introduced to the field of additive manufacturing as the name for a specific process developed at Massachusetts’ Institute of Technology (MIT) and filed for a patent in 1989 under the name ‘Three-dimensional printing techniques’ (Sachs et al. 1993). The name comes from that this process is based on conventional printing technique where a printhead is used to selectively deposit adhesive fluid (i.e. a binder or a glue) onto a thin layer of powder that has been spread over a platform that repeatedly can be lowered as new

[3]Registered trademark: (for a process) serial number: 85380733, registration number: 4325106, (for a service 2006–07) serial number: 78849754.

[4]Registered trademark: (for a machine) serial number: 85409708, registration number: 4134993, (for a machine 2002–07) serial number: 76123411, registration number: 2575496, (for a service 2000–09) serial number: 76115922, registration number: 2575471.

[5]Registered trademark: (for a process 1992–93) serial number 74283081, (for a machine and software 1993–2006) serial number: 74428567, registration number: 1892939.

[6]Registered trademark: (for a service 1992–93), serial number: 74285016.

[7]Registered trademark: (for a machine 1992–94), serial number 74292965.

powder layers are applied. The curing of the adhesive binds the powder particles together, thus forming a layer of solid material attached to previously applied layers of powder. This basic patented principle has been licensed to several companies, who are using it for different particulate materials, such as gypsum, foundry sand, metal and ceramic powders, and used for different application areas and industries. Even if these companies sometimes use their own brand name for their variety of the process, they could, clearly, all be considered as '3D Printing processes'.

However, other AM processes have also employed technical solutions used in conventional printing processes. Instead of distributing a binder, the printhead could dispense a liquid material that solidifies after deposition, either by solidification as the liquid's temperature is lowered, or by curing after exposure to ultraviolet light. Such processes have been known under product names such as 'Inkjet', 'Multi-Jet Modelling', 'Thermojet', 'Polyjet' and others, but since they originally were based on conventional printing techniques, also identified as belonging to the group of '3D Printing' processes, together with MIT's process.

Furthermore, since several of the processes that were based on conventional printing technology at a time were comparably low cost and easy to use, they were thought to be likely candidates for a future application where they would be commonly used by smaller companies and in people's homes, similar to a conventional 2D-printer. Thus, they were grouped together with other low-cost AM machines, which not necessarily were based on conventional printing technology, and collectively also called '3D Printers', to distinguish them from the more advanced 'Industrial RP machines' (Wohlers Report 2005).

Then, in 2012, when Chris Anderson, published his book, *'Makers: The New Industrial Revolution'*, he mentioned '3D Printers' as one of several types of low-cost, user friendly, machine tools, that he envisioned, in combination with accessible low-cost CAD software, would be the beginning of a new industrial revolution. When Anderson mentioned '3D Printers' in this context, he was clearly referring to the group of low-cost, easy to use AM machines. However, since this book was the first time mentioning of AM technology reached a wide impact in popular media, '3D Printing' has a bit misleading, become the term for AM technology that is most widely recognized by the general public. Since all of the four different meanings of the term '3D Printing' are currently used in parallel, through publications and documentation, from different times and by different groups, throughout the AM industry, the term is by itself, perhaps the most ambiguous term used in the AM industry. Even if the term '3D Printing' sometimes is used by highly experienced professionals, who recognize the power of its public recognition, the question of how to understand the term and the message that goes with it will still be a question of who is using it, and in which context the term is used. There will clearly be many more results from a web search on '3D Printing' than from a web search on 'additive manufacturing', but the search on '3D Printing' will include results for all different meanings of this term, and therefore also much that has been generated based on the popular hype around '3D Printing' during recent years. This includes a large part that is based mainly on speculations, loosely formed opinions, and much inflated expectations. It is, therefore, advisable to use the term ‘3D Printing’ with great caution in regards to all communication, including education.

3.2 ‘Laser Sintering’

Originally, ‘Laser Sintering’ was the term used to describe a process for joining polymer powder by the heat of a laser, as it was used in one of the early additive manufacturing processes, which had been developed at the University of Texas at Austin. Most commonly, the term ‘sintering’ is used to describe a process to bond and densify metallic and ceramic particulate materials by heating close to, but below the melting point. However, since the feedstock material used in this case was a polymer powder which was not fully melted, ‘sintering’ was the term that closest described how the powder was bonded together to form the parts, and thus the process was patented (Deckard, filed 1986, published 1989; Beaman and Deckard, filed 1986, published 1990), trademarked, and commercialized as ‘Selective Laser Sintering’ (SLS) by DTM Corp. (which later has been purchased by 3D Systems Inc.). When other varieties of this process principle were brought to market, the trademark was avoided by describing the process of consolidation as ‘laser sintering’. However, even if this interpretation of ‘sintering’ is reasonable and many times accepted in regard to polymer powders, in particular for amorphous polymers, it is not quite generally applicable for all powders and particulate materials. Still, when this type of process equipment began to be used for different types of powders, including metal and ceramic powders, it was generally also called ‘laser sintering’, regardless of the actual process of bonding and consolidation of the powder actually did fulfil the normal description of sintering for that particular material.

The first metal powder application of this process principle that was launched on the market by EOS GmbH, was based on a mixed composition of bronze powders with different melting temperatures. The smaller fraction of the powder composition which had lower melting temperature melted during processing while the remaining powder particles stayed intact. The contact between the solid and melted phases enabled the diffusion of material to the boundaries between the solid particles, thus causing densification and thereby fulfilling the conditions for liquid-phase sintering. Since the parts both acquired the geometry and was consolidated to final density directly in the machine, this was a considered as a ‘direct process’ from the Rapid Prototyping perspective, and this made this process being trademarked as ‘Direct Metal Laser Sintering’, DMLS.[8] However, when later models of similar machines with more powerful lasers were launched from the same company, the process was still referred to under the trademarked name, DMLS, even if the metal powder in these cases could be fully melted, and the actual process, thus had no resemblance to conventional sintering of metallic materials. Today (2018), the low melting/high melting—temperature powders have been withdrawn from the market, and the

[8]Registered trademark: (for services) serial number 85592510, registration number 4515227.

alternative term 'Direct Metal Laser Melting' DMLM, has been introduced, all powders marketed for processing by this equipment are fully melted during processing, the process is still sometimes referred to as DMLS, sometimes DMLM and sometimes as DMLS/DMLM.

Another very similar process was developed directly for processing metal powders. The material was fully melted selectively, and the process was following industry conventions patented (Meiners et al., filed 1996, published 1998; Fockele and Schwartze, filed 2001, published 2009) and trademarked as 'Selective Laser Melting' SLM.[9] This name is very easy to understand and explain and is, therefore, often also used for other closely related metal powder-based processes. However, since the name is trademarked by SLM Solutions Group AG, and is used in the names of products from that company, the actual meaning of the term 'SLM' is under control by SLM Solutions. So far SLM Solutions have exclusively worked with lasers melting powders, but in principle, there is nothing that could stop them from changing energy source, or use a different type of feedstock or a different feedstock distribution system, and they still could use their brand name and call that process and machines 'SLM'. Just like EOS have kept on using their trademarked process name DMLS after the powders that actually did sinter had been taken off the market.

For example and comparison, the automotive company name 'Volvo' started as a brand name used by the Swedish ball bearing manufacturing company SKF. The name is derived from Latin: 'volvore'—to roll, thus 'volvo'—I roll. Originally, it was used for a line of bearings aimed at the market for automotive, bicycle and similar typically rolling products. When SKF decided the launch of a new automotive company, they simply took their already registered brand and used it for the new company (Pederson 2005). It was easy to read and easy to pronounce in all languages of the major markets. However, since 'Volvo' means 'I roll', does this mean that everything that rolls is a 'Volvo'? Since the company over time has had several different divisions, and been active on several different markets, including construction equipment, boat engines and aerospace, it would clearly be a mistake to conclude that all things called 'Volvo' would be rolling objects. In this case, as well as the entire field of additive manufacturing, it is very well advised to be aware of which is a generic product name and which is a trademarked product name, and use the terms accordingly.

Other companies that have shared the original development background with SLM Solutions, or have licensed the technology, also use the process name 'SLM'. However, when Concept Laser, a new company entered the market, and launched their version of this process, it was marketed by a different name: 'Laser Cusing' which so far is unique to Concept Laser.

[9]Registered trademark: (for workpieces, shapes, machines, control devices, design, etc.) serial number. 85507057, registration number: 4416715, (for services) serial number 86407585, registration number: 5335733.

3.3 'Fused Deposition Modelling'

'Fused Deposition Modelling', FDM, was one of the first AM processes to be patented and make an impact on the market. Originally developed, patented (Crump, filed 1989, published 1992), trademarked and marketed by Stratasys Ltd. The basic principle for the process is not very complicated; extrusion of thin strings of low-temperature melting plastics, fed from a filament roll. It is fairly user-friendly and does not require processing equipment like lasers, or atmosphere controlled process chambers. It is, therefore, hardly surprising that this principle was among the first to be copied by several initiatives to develop low-cost AM machines after the patent had expired. Perhaps the most influential among these was the RepRap project, which was an open design, low-cost solution developed with the intention to enable continuous evolution of the design over a global community of users (www.reprap.org). Several commercial varieties of RepRap designs have also been brought to the market and sold for use in private homes, smaller companies, and not least important, at different levels of education. Since FDM is a name trademarked by Stratasys, this process is instead often referred to as 'Fused Filament Fabrication' FFF, when other manufacturers apply it in their machines. However, the acronym 'FFF' has also for a long time been referring to 'Free Form Fabrication', and then used as a general term for the entire field of additive manufacturing. Moreover, in addition to this, the company Arcam AB, for a period kept the registered trademark 'FFF[10]' which was used in their international marketing for their, entirely different, AM process. Within the AM community, 'FDM' has only been used for this process, but if correctly used, should only refer to processing in machines by Stratasys. 'FFF' could have several meanings, and what actually is meant by this acronym depends on the context and person who is using it. Moreover, since this is the process that has been most exposed during the recent '3D Printing' hype, and machines based on this process are marketed both to private users and schools as '3D Printers', this is the process that most people associate with the term '3D Printing', even if it has no connection to any traditional printing technology.

3.4 'SLA', 'LOM' and Others

There are several more AM processes and services known by different names and acronyms available on the market. However, many of these have primarily been marketed, and thus known under the product name for the actual machine rather than a trademarked name for a process. For example, the acronym 'SLA' refers to 'Stereo Lithography Apparatus', and thus refer to the machine, which is less of a problem as long as any competitors use their own product names for their machines. Moreover, processes that are mainly directed on the prototyping and service providing industry can still be regarded as working with their customers on an ad hoc and by

[10]Registered trademark: serial number 76111397, registration number 2614068.

agreement—basis, and in these cases, the meaning of the terms used could typically be whatever the vendors and customers agree upon. In regard to education, if a process is used for prototyping and service providing purposes it would be natural just to refer the specific processes name, but in reagards to a more general perspective for industrial production, international standards terminology can bring much clarity and is therefore recommended.

3.5 Describing the Process: As Rapid Prototyping or Industrial Manufacturing?

Besides process, and brand names, the model for describing the actual processes has also been highly influenced by the technology's original application for prototyping purposes. In the market for prototyping services, the actual 'product' delivered is the creation of a physical prototype based on a design provided by the customer. Thus, the prototyping process is the combination of operations that reproduces the shape as designed and the subsequent post-processing operations that make the shape fulfil the requirements for the purpose of the prototype. Since prototyping was the main application area for additive manufacturing processes, the convention was also to describe the Rapid Prototyping process as consisting of a building operation to render the geometry, and subsequent post-processing operations to finish the prototype to customer requirements. Typically, 'post-processing operations' for the Rapid Prototyping process would then by any operations that were performed on the part outside the Rapid Prototyping machine.

An industrial manufacturing process is in reality quite different: while a prototype does not necessarily need to fulfil all functional requirements for the final product, the industrial manufacturing process must be able to reproduce both the product geometry and the material properties in a way such that the quality is both predictable and consistent. It is rare that all the geometric and material requirements for an industrial product can be realized through a single operation or process step, and therefore industrial manufacturing processes are made up of a series of operations and sub-processes, with defined interfaces and specified requirements for each process step. It is also common that one company, or department within a company, have specialized in performing one or a few of these operations before delivering the part to the next agent in the process chain. This makes each agent taking the role of both being a customer that receives the part from the previous agent and a supplier that delivers the part to the following agent. In this situation, it does hardly make sense to regard any operation or sub-process as being the main process and the rest as pre-, or post-processing. In an industrial manufacturing situation, it would be most natural that the AM process would fill a corresponding function as any other manufacturing operation, such as casting injection moulding, forging and milling: to deliver a part produced to a given specification for further processing by subsequent process steps. Even if additive manufacturing can drastically reduce the number of operations needed to create the desired product geometry, any other operations necessary to make the part fulfil the product requirements must still be regarded as additional steps in the manufacturing process chain, rather than post-processing operations.

This does, however, raise the question of which operations and process steps are a part of the AM process and which are to be considered as subsequent process steps. In a Rapid Prototyping process, typical post-processing operations could be post-curing of photo-curable polymer parts, heat treatment of metal parts, sintering and infiltration of parts made from joining powders, and any other operations needed to give the part the required properties, dimensions and appearance. For an industrial manufacturing situation, it is necessary to determine which operations are an indispensable part of the AM process and which operations either are preparations for the AM process, or perform further operation steps on the outcome of the AM process.

By definition, additive manufacturing processes joins material to make parts based on 3D model data. Therefore, the AM process must include the joining of material until the geometry as specified by the 3D model is represented, and since the 'part' constitutes a functional unit of an intended product, this also means that the material should have the fundamental properties as determined by the intended application. This means that the material for an intended metal of ceramic part must be joined so that metallic or ceramic bonding has been established throughout the part.

Many AM processes achieve this in a single process step, thus called single-step processes. But there are others, for example, application of metallic powder in a binder jetting process, that combines one process step to form the geometry, in this example the binder jetting process, with one or more subsequent process steps to consolidate the material to metallic properties, thus called multi-step processes. This type of procedure is typically shared with conventional powder metallurgy and ceramic manufacturing processes which has a separate process step to shape the material into a geometry, called a 'green body', followed by material consolidation by sintering, with, or without infiltration.

3.6 International Standards Development

Since it had become increasingly clear that technology based on successive addition of materials had the potential to bring important benefits to the manufacturing process as well as improving the performance of parts, it was also clear that the development of an international market for products and technology required the development of international standards. The first initiative to begin the development of international standards was the formation of ASTM International Committee F42, inauguration in early 2009. This was also the occasion when 'Additive Manufacturing' (AM) was first defined as the common general term for the 'process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies'. The argument behind this original definition was that the common and key determining feature of the processes targeted by the standardization initiative, was the successive addition of material. This definition was also intended to distinguish the technology from, for example, numerically controlled machining operations, which would also be based on digital data, but created geometries by successive removal of material, hence called subtractive manufacturing methodologies. This definition has undergone some minor modifications over time but the content and argument remains the same. The current definition by ISO/TC261 and ASTM F42 reads: 'additive manufacturing, (noun), AM: process of joining materials to make parts from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies' (ISO/ASTM 52900:2015). In this context, 'formative manufacturing methodologies' refer to processes that shape the geometry by the application of pressure to a raw material, for example, forging, casting, injection moulding, sheet metal forming and others.

The development of international standards for AM created an urgent need for a consistent use of terms and definitions that would be valid for all AM standards, and thus throughout the entire AM industry. This need was defined as a key task for both ASTM F42 and ISO/TC261 (inaugurated 2011), and therefore has been a prioritized topic for workgroups in both organizations. Since ISO and ASTM agreed to work together and jointly develop AM standards, the responsibility for continuously developing and integrating new terms and definitions in a joint international standard for AM terminology is now handled by a joint working group with experts appointed from both organizations. Since all standards' development is based on building a common consensus among the involved stakeholders, the development of an international standard terminology for AM presents an opportunity to disconnect trademarked product names from use as general-purpose terms, and replace them by terms and definitions that are under control by a committed community of stakeholders, rather than the marketing divisions of individual corporations. The present edition of this joint AM terminology standard (ISO/ASTM 52900:2015) has been based on input from the members of both ISO/TC261 and ASTM F42 and been accepted by ballot of more than 120 expert stakeholders in ASTM F42 and more than 20 different national mirror committees through ISO/TC261. In addition to this, it has also been balloted and passed as a European standard through CEN/TC438, and is now one of the very few EN ISO/ASTM approved standards in the world.

With the great diversity of AM process technology and different application areas, the task of developing a consistent international standard terminology for the entire field of additive manufacturing clearly has many challenges. By necessity, this work will include deconstruction of established concepts and terminology, inherited from AM's past as primarily a prototyping process. Since these terms and concepts still are habitually being used in parts of the international AM community, replacing them is clearly hardly possible to achieve without raising controversy. Moreover, since different AM processes share traits with different conventional manufacturing technologies, there are also stakeholders with background from these technology areas that now are getting involved with AM and expects the concepts and terminology used in AM to follow the conventions and terminology of the different related technologies. However, since the field of AM is highly diverse, and share common traits with several different technologies, it would not be possible to adhere different parts of AM terminology to the traditions of all different related conventional manufacturing technologies without losing the consistency of terminology for AM. So far, the policy of the ISO/ASTM Terminology Joint Work Group has been to as far as possible use established terms and definitions from the traditional use within the AM industry as well as using terms and definitions published in available standards from ISO and ASTM International as a source of reference when applicable. However, serving the needs of the AM industry, terms and definitions have been adapted and modified when needed in order to maintain a consistent terminology throughout the field of AM technology. Even if people tend to prefer the terminology they learned first and are used to, and certainly are free to do so in their daily speech, the development of an international standard terminology is at present the only available possibility to create and maintain a consistent and generally accepted terminology for the entire AM field of research and industry.

3.7 Process Categories and Structure of Concepts

One of the first tasks to be addressed through the development of an international terminology standard was to identify a basic structure for different processes that could addressed by the same or very similar standards. Historically, AM processes were identified as sharing the 'type' with a process that had entered the market at an early stage. However, standards development organizations' regulations are highly restrictive with the usage of trademarked names as generic terms in terminology standards. Moreover, in order to accommodate the needs for standards' development, the characteristics' of the process categories to be addressed by similar standards need to be clearly defined. Since, in addition to this, some of the names of the early processes had become obsolete with regards to the actual function of the process, there was a need to identify, define and name generic process categories for the different AM processes. The task was limited to include only the AM processes that could be candidates for development of international standards, meaning that they should be available on the market through several actors, either as machine vendors or as service providers, or both. This means that processes that are still in development or are only available as a service from one specific company have not yet been considered for the process category structure, at least not until they are firmly established on the market. There are presently seven different process categories identified, but this structure is open for revision and new process categories can be included as they are developed and become relevant for manufacturing purposes on the international market. Since trademarked process names should be avoided, the process categories have been named after characteristics in the process design that distinguish them from other comparable processes. These are as follows:

- Binder Jetting: processes in which a liquid bonding agent is selectively deposited to join powder, (or very small particles), the powders or particles would typically be distributed in a powder bed (see Fig. 1)
- Directed Energy Deposition: processes in which a focused thermal energy is used to fuse materials by melting as they are deposited, where the energy source, typically a laser, electron beam or plasma arc, is focussed to provide a melt pool on the substrate where the feedstock material is deposited (see Fig. 2)
- Material Extrusion: processes in which material is selectively dispensed through a nozzle or orifice (see Fig. 3)
- Material jetting: processes in which droplets of build material are selectively deposited, where the build material typically could be a low-temperature melting polymer such as wax or a photo-curable polymer resin (see Fig. 4)
- Powder Bed Fusion: processes in which thermal energy selectively fuses regions of material in a powder bed (see Fig. 5a and b)
- Sheet Lamination: processes in which sheet material are bonded together to form a part (see Fig. 6)
- Vat Photopolymerization: processes in which liquid photo-curable polymer resin in a vat is selectively cured by light-activated polymerization (see Fig. 7a and b)

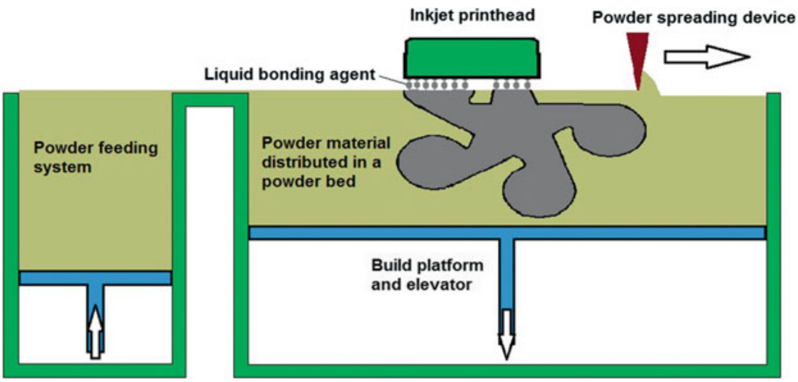

Fig. 1 Binder jetting

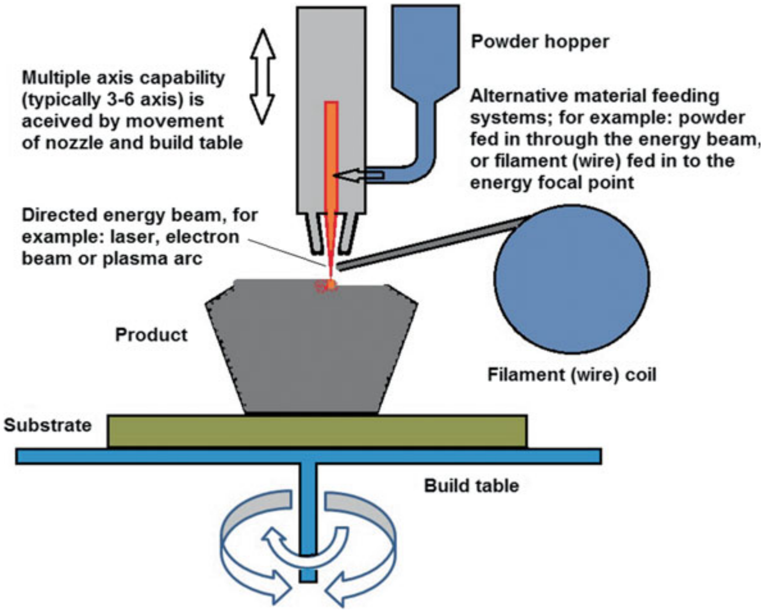

Fig. 2 Directed Energy Deposition, with example of alternatives for feedstock distribution

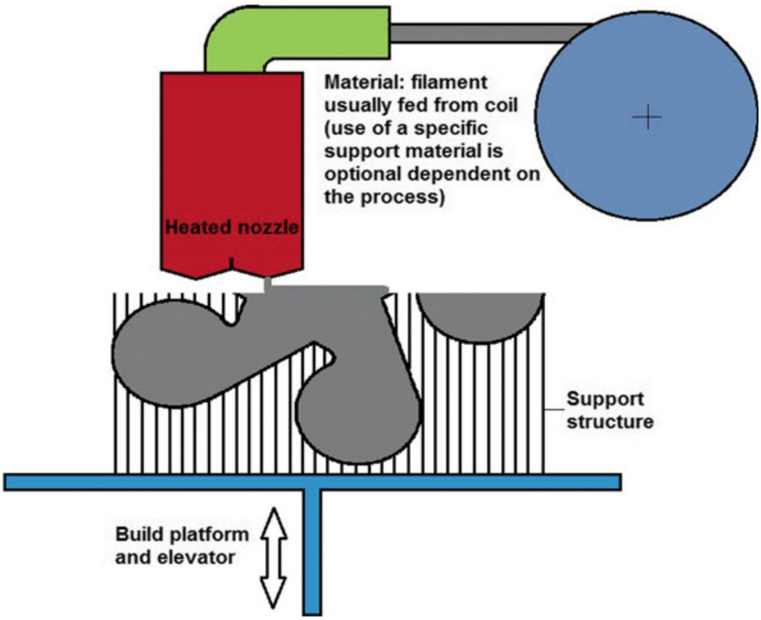

Fig. 3 Material extrusion

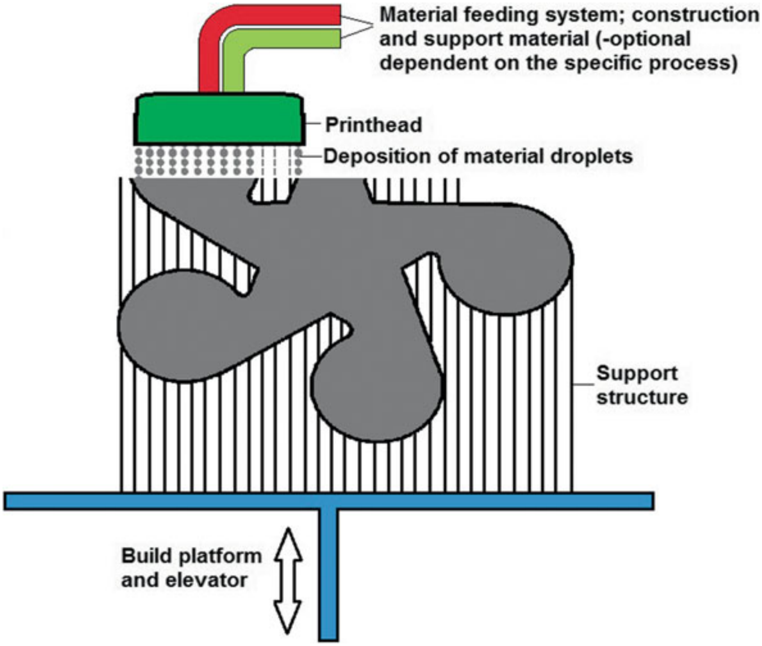

Fig. 4 Material jetting

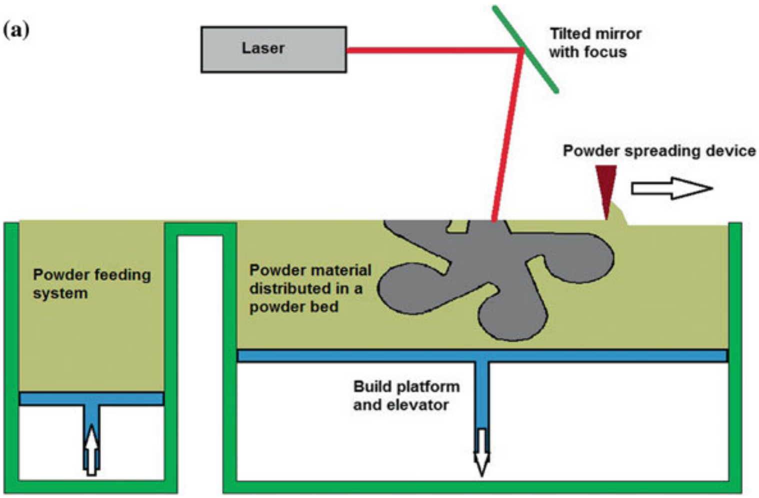

Fig. 5 **a** Powder Bed Fusion, typically using a laser and polymer powders. **b** Powder Bed Fusion, typically using an electron beam and metal powder

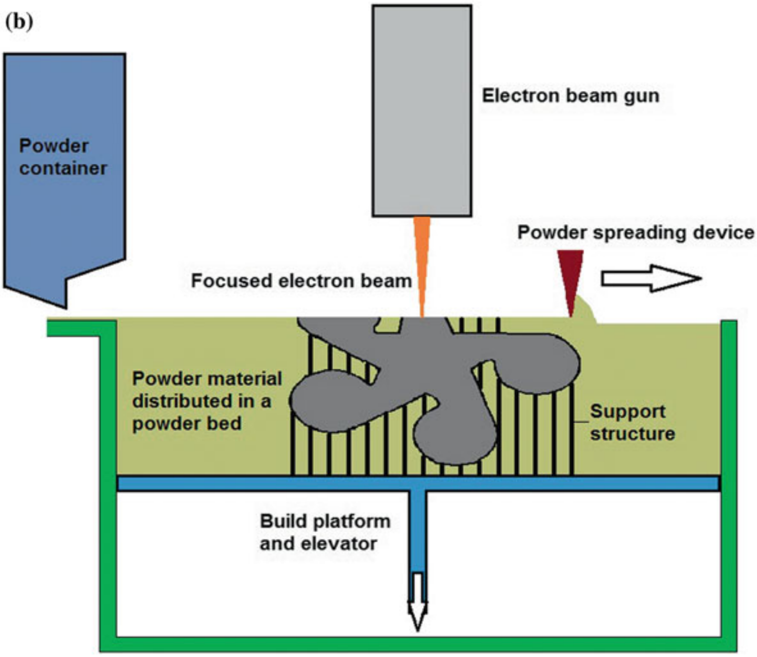

Fig. 5 (continued)

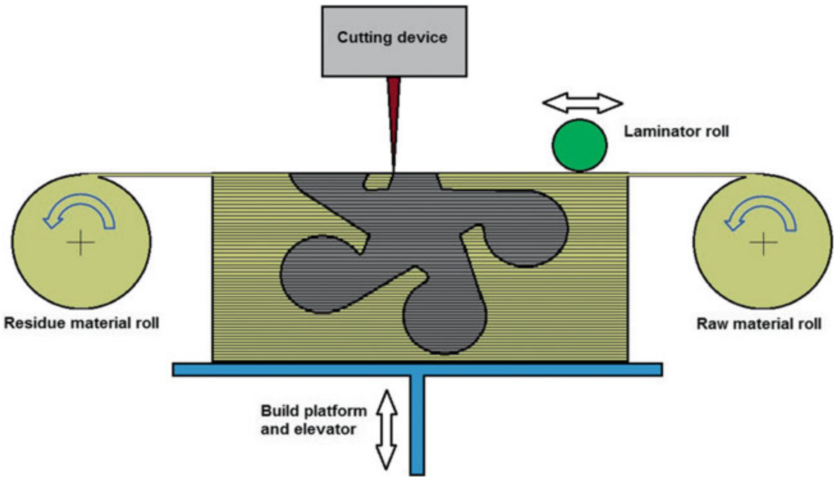

Fig. 6 Sheet Lamination

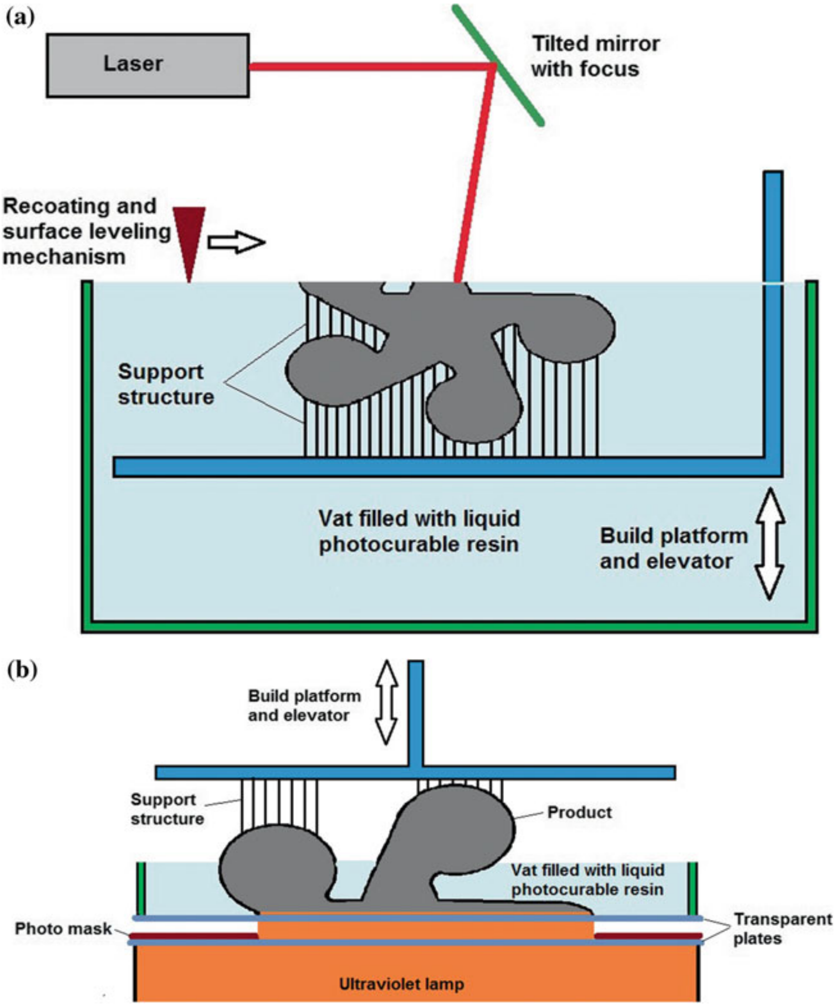

Fig. 7 **a** Vat photopolymerization using a scanning laser. **b** Vat photopolymerization using a photomasking technique

More detailed information about the seven presently defined AM process categories is available in ISO 17296-2:2015, *Additive manufacturing—General principles—Part 2: Overview of process categories and feedstock*. Since the objective for this structure of process categories was to identify basic groups of processes that could be addressed by common standards, it is by intention very basic in nature, and there are many more features and characteristics that could be used to distinguish between processes in further detail. This has been a topic for discussion within the AM standards development community, and a system for further specification of processes based on more detailed process features and materials processed, will be proposed in upcoming revisions of the ISO/ASTM 52900-standard (publication expected during 2018).

4 Summary

The use of different terms and acronyms in the field of AM that has been conventional for many years have largely been based on the needs for the technology's early application for rapid prototyping purposes. Many terms that have been used as generic process names are in reality trademarked brand names under the control of specific companies. Other commonly used terms can have different meanings dependent on who is using them and the context they are used in. This has made the usage of terms, abbreviations and concepts within additive manufacturing become highly ambiguous and inconsistent. In order to address this issue, a joint collaboration effort by ISO/TC261 and ASTM F42 develops and maintains a common international terminology standard for the entire area of additive manufacturing technology. The first issue, *ISO/ASTM 52900:2015, Additive manufacturing—General principles—Terminology*, was published in 2015 and is available for purchase from both organizations. However, since ISO makes all informative parts of their standards, typically including the terminology section, public accessible, free of charge from their online browsing platform, this source of reference is largely available for anyone to use. This international standard will be continuously updated as the new revisions are completed. Next revision is expected to be ready for publication during 2018.

Even if people, in general, tend to prefer to use terms and abbreviations in the context and meaning as they were first learned, and certainly are free to do so in their daily speech, the ISO/ASTM 52900 standards terminology, is the only source of fully defined terms that is consistent for the wide perspective of additive manufacturing technology. It is the prime source of reference for any situation where a clear and unambiguous communication about additive manufacturing is needed. It is therefore important that all people who would be professionally involved with AM should be familiar with the existence and content of this standard and highly recommended that it should be included, or referenced in the education in additive manufacturing.

References

Anderson, C. (2012). *Makers: The new industrial revolution*. Crown Business, ©Chris Anderson 2012. ISBN-13: 978-0307720962, ISBN-10: 0307720969.

Beaman, J. J., & Deckard C. R. (1990). Selective laser sintering with assisted powder handling. Patent US 4938816 A.

Crump, S. S. (1992). Apparatus and method for creating three-dimensional objects. Patent US 5121329 A.

Deckard, C. R. (1989). Method and apparatus for producing parts by selective sintering. Patent US 4863538 A.

Gibson, I., Rosen, D. W., & Stucker, B. (2010). *Additive manufacturing technologies, rapid prototyping to digital manufacturing,* ©Springer 2010. ISBN: 978-1-4419-1119-3.

Fockele, M., & Schwartze, D. (2009). Method and apparatus for producing a shaped article. Patent DE 10208150 B4.

ISO/ASTM 52900:2015. *Additive manufacturing—General principles—Terminology*. Retrieved January 15, 2018, from https://www.iso.org/obp/ui/#iso:std:iso-astm:52900:ed-1:v1:en.

Meiners, W., et al. (1998). Selective laser sintering at melting temperature. Patent WO 1998024574 A1.

Pederson, J. P. (2005). *AB Volvo international directory of company histories*. 67. St. James Press. pp. 378–383. ISBN 978-1-5586-2512-9.

Sachs, E. M., et al. (1993). Three-dimensional printing techniques. Patent US5204055 A.

Wohlers Associates: State of the Industry: World Progress Report, 1996–2005, http://www.wohlersassociates.com/state-of-the-industry-reports.html.

Wohlers Associates: State of the Industry: World Progress Report, 2005, pp. 28–29. ISBN 0-9754429-1-0, http://www.wohlersassociates.com/state-of-the-industry-reports.html.

Klas Boivie works as a Senior Researcher in additive manufacturing (AM) technology at SINTEF Raufoss Manufacturing AS in Trondheim Norway. He started working with AM for metallic materials in 1997 and defended his Ph.D. thesis on the topic in 2004. After completion of a Post-Doc contract at NTNU in Trondheim, 2007 and until the present, Klas has been employed by SINTEF, and SINTEF Raufoss Manufacturing AS, acting as the principal researcher in AM technologies. Over the years, he has been active in multiple research projects covering various aspects of this technology, from new process development to practical solutions for industrial applications. With respect to the ongoing development towards industrialization of AM technology, Klas has taken an active part in the development of international standards for AM, through ASTM F42 as well as ISO/TC261 and CEN/TC438 technical committees. He currently serves as the convener for ISO/TC261 Work Group 1 for Terminology, as well as convener for the ISO/ASTM Joint Working Group 51, which is responsible for development and maintenance of the international terminology standard for Additive Manufacturing: EN ISO/ASTM 52900.

External Resources: National standards for AM in Sweden. https://www.sis.se/standardutveckling/tksidor/tk500599/sistk563.

ISO/TC261 is the International Standardization body in the field of Additive Manufacturing (AM) concerning their processes, terms and definitions, process chains (Hard- and Software), test procedures, quality parameters, supply agreements and all kind of fundamentals. https://www.iso.org/committee/629086.html.

ASTM Technical committee F42 on Additive manufacturing was formed in 2009. F42 members meet twice a year, usually in January and July, with about 100 members attending two days of technical meetings. The Committee, with a current membership of approximately 400, has 6 technical subcommittees; all standards developed by F42 are published in the Annual Book of ASTM Standards, Volume 10.04. https://www.astm.org/COMMITTEE/F42.html.

Informative parts of ISO/ASTM 52900:2015 AM terminology standard made publicly available by ISO. https://www.iso.org/obp/ui/#iso:std:iso-astm:52900:ed-1:v1:en.