| | |
|---|---|
| NEW WORK ITEM PROPOSAL | |
| Date of presentation<br>2010-09-20 | Reference number<br>(to be given by the Secretariat)<br>**ISO/TC -- / SC --** N<br>Not available yet. |
| Proposer<br>DIN-Germany | |
| Secretariat<br>not available yet | |

A proposal for a new work item within the scope of an existing committee shall be submitted to the secretariat of that committee with a copy to the Central Secretariat and, in the case of a subcommittee, a copy to the secretariat of the parent technical committee. Proposals not within the scope of an existing committee shall be submitted to the secretariat of the ISO Technical Management Board.

The proposer of a new work item may be a member body of ISO, the secretariat itself, another technical committee or subcommittee, or organization in liaison, the Technical Management Board or one of the advisory groups, or the Secretary-General.

The proposal will be circulated to the P-members of the technical committee or subcommittee for voting, and to the O-members for information.

See overleaf for guidance on when to use this form.

**IMPORTANT NOTE: Proposals without adequate justification risk rejection or referral to originator**.
Guidelines for proposing and justifying a new work item are given overleaf.

**Proposal** (to be completed by the proposer)

**Title of proposal** (in the case of an amendment, revision or a new part of an existing document, show the reference number and current title)

English title: Additive Manufacturing - Rapid Technologies (Rapid Prototyping) - Fundamentals, terms and definitions, quality parameters, supply agreements

French title (if available): -

**Scope of proposed project**

This International Standard covers the principal considerations which apply to the design, fabrication and assessment of parts produced by additive fabrication and it lists the fields of activity. It specifies terms and definitions, deals with the fundamentals of the processes involved and specifies their requirements and selection criteria. It specifies relevant quality parameters and explains in detail component testing and the drawing up of supply agreements. It also covers safety-related and environmental aspects. This International Standard

☐ differentiates between additive and conventional processes,

☐ facilitates improved assessment of different additive processes,

☐ specifies the quality parameters of different processes,

☐ specifies appropriate test procedures,

☐ recommends the scope and content of test and supply agreements.

This International Standard is aimed at users and producers of additive fabrication processes. It applies wherever additive processes are used, and to the following fields in particular:

☐ production of additive fabrication systems and equipment including software;

☐ material development and distribution;

☐ additive fabrication of parts, tools and end products;

☐ use of the parts, tools and end products.

**Concerns known patented items** (see ISO/IEC Directives Part 1 for important guidance)

☐ Yes ☒ No If "Yes", provide full information as annex

**Envisaged publication type** (indicate one of the following, if possible)

☒ International Standard ☐ Technical Specification ☐ Publicly Available Specification ☐ Technical Report

**Purpose and justification** (attach a separate page as annex, if necessary)

Possibilities of Additive Manufacturing/Rapid Technologies:

Additive Manufacturing (AM) are an inherent part of the product development process. They are used to manufacture prototypes, tools and production parts. In comparison to conventional methods where parts are molded into specified forms or cut from a massive block Additive Manufacturing bases on the principle that liquids, powders, stands and films are layered to build three-dimensional structures without the use of a mold.

In the laser sintering process for example, containers are filled with fine metal, ceramic or plastic powder. A laser located above the powder bed, and precision-guided by CAD software and suitable optics, lights only certain areas of the uppermost particle layer. These areas melt and solidify after cooling. An automatic mechanism then lowers the floor of the powder container by fractions of millimeters, and spreads a fresh layer of particles. The result of this method is a spatial component built of ultra-thin layers, whose complexity is limited by almost nothing but the specified electronic construction data.

This free-form fabrication uses no casting molds, tools or space consuming production plants. With AM, components are created directly from a digital construction plan. This enables the production of forms that have been long considered impossible by conventional series production—in fact, they can be created fast, flexibly, and with fewer machines.

AM will grow appreciably over the next ten years. The advantages are: developers can produce functional hollow structures in small batches, and the structures can be precisely modified to changing stress requirements. The components can be customized with specific porosities or surfaces, and ultra-lightweight components are also duable. Here, the aviation industry is one of the pioneers. There are already about 30 SLSsintered components produced due to AM-processes installed in the Boeing 787. According to estimates by Airbus Industries, an aircraft produced entirely through additive manufacturing would be 30 % lighter and 60 % more cost-effective than current machines.

Need of action:

In the past, development, modification and use of mold-free production processes (AM) has been quite unsystematic. One of the reasons is the lack of availability of International and European Standards. Therefore International and European Standards regarding AM are urgently necessary to promote a widespread use of the process and to regulate evaluation of existing products. Furthermore there is no Technical Committee at ISO or CEN level that deals with the standardization of Additive Manufacturing Technologies.

First step of Implementation:

According to the above identified need of action, it should be the first step to develope an International and European Standard (EN ISO) regarding the fundamentals of AM as described in this NWIP.

Justification of the NWIP as proposed:

During the somewhat turbulent development of AM, different terms and definitions have emerged which are frequently ambiguous and confusing. Moreover, there are various different processes available on the market and it is not always clear which opportunities and limitations they offer in terms of application. This proposed International/European Standard aims to offer fieldtested recommendations and advice to users (customers) and manufactures (both external and internal service providers), to improve communication between customer and supplier and to contribute to an authoritative performance design and a smooth handling of the project.

**Target date for availability** (date by which publication is considered to be necessary) `31.12.2013`

**Proposed development track** ☐ 1 (24 months) ☒ 2 (36 months - default) ☐ 3 (48 months)

**Relevant documents to be considered**

-

**Relationship of project to activities of other international bodies**

not known yet

| | |
|---|---|
| **Liaison organizations** | **Need for coordination with:**<br>☐ IEC ☒ CEN ☐ Other (please specify)<br>**This proposed International Standard should be parallel developed and approved by CEN under Vienna Agreement. Lead organization: ISO.** |

**Preparatory work** (at a minimum an outline should be included with the proposal)

☒ A draft is attached ☐ An outline is attached. It is possible to supply a draft by

The proposer or the proposer's organization is prepared to undertake the preparatory work required ☒ Yes ☐ No

| | |
|---|---|
| **Proposed Project Leader** (name and address)<br>Joerg Lenz<br>Collaborative Projects Coordinator<br>EOS GmbH - Electro Optical Systems<br>Robert-Stirling-Ring 1<br>D-82152 Krailling/Munich, Germany<br>Joerg.Lenz@eos.info<br>Martin Schäfer<br>Siemens AG<br>Siemensdamm 50<br>D-13629 Berlin, Germany<br>martin.schaefer@siemens.com | **Name and signature of the Proposer**<br>(include contact information)<br>Steffen Schneider<br>DIN - German Institute for Standardization<br>Burggrafenstr. 6<br>10787 Berlin - Germany<br>steffen.schneider@din.de |

**Comments of the TC or SC Secretariat**

**Supplementary information relating to the proposal**

☒ This proposal relates to a new ISO document;

☐ This proposal relates to the amendment/revision of an existing ISO document;

☐ This proposal relates to the adoption as an active project of an item currently registered as a Preliminary Work Item;

☐ This proposal relates to the re-establishment of a cancelled project as an active project.

Other:

**Voting information**

The ballot associated with this proposal comprises a vote on:

☒ Adoption of the proposal as a new project

☐ Adoption of the associated draft as a committee draft (CD)

☐ Adoption of the associated draft for submission for the enquiry vote (DIS or equivalent)

Other:

**Annex(es) are included with this proposal** (give details)

☒ Preparatory work

| | | |
|---|---|---|
| Date of circulation | Closing date for voting | Signature of the TC or SC Secretary<br>Mr. Steffen Schneider |

**Use this form to propose:**

**a)** a new ISO document (including a new part to an existing document), or the amendment/revision of an existing ISO document;

**b)** the establishment as an active project of a preliminary work item, or the re-establishment of a cancelled project;

**c)** the change in the type of an existing document, e.g. conversion of a Technical Specification into an International Standard.

This form is not intended for use to propose an action following a systematic review - use ISO Form 21 for that purpose.

Proposals for correction (i.e. proposals for a Technical Corrigendum) should be submitted in writing directly to the secretariat concerned.

**Guidelines on the completion of a proposal for a new work item**
(see also the ISO/IEC Directives Part 1)

**a) Title:** Indicate the subject of the proposed new work item.

**b) Scope:** Give a clear indication of the coverage of the proposed new work item. Indicate, for example, if this is a proposal for a new document, or a proposed change (amendment/revision). It is often helpful to indicate what is not covered (exclusions).

**c) Envisaged publication type:** Details of the types of ISO deliverable available are given in the ISO/IEC Directives, Part 1 and/or the associated ISO Supplement.

**d) Purpose and justification:** Give details based on a critical study of the following elements wherever practicable. *Wherever possible reference should be made to information contained in the related TC Business Plan.*

1) The specific aims and reason for the standardization activity, with particular emphasis on the aspects of standardization to be covered, the problems it is expected to solve or the difficulties it is intended to overcome.

2) The main interests that might benefit from or be affected by the activity, such as industry, consumers, trade, governments, distributors.

3) Feasibility of the activity: Are there factors that could hinder the successful establishment or global application of the standard?

4) Timeliness of the standard to be produced: Is the technology reasonably stabilized? If not, how much time is likely to be available before advances in technology may render the proposed standard outdated? Is the proposed standard required as a basis for the future development of the technology in question?

5) Urgency of the activity, considering the needs of other fields or organizations. Indicate target date and, when a series of standards is proposed, suggest priorities.

6) The benefits to be gained by the implementation of the proposed standard; alternatively, the loss or disadvantage(s) if no standard is established within a reasonable time. Data such as product volume or value of trade should be included and quantified.

7) If the standardization activity is, or is likely to be, the subject of regulations or to require the harmonization of existing regulations, this should be indicated.

If a series of new work items is proposed having a common purpose and justification, a common proposal may be drafted including all elements to be clarified and enumerating the titles and scopes of each individual item.

**e) Relevant documents and their effects on global relevancy:** List any known relevant documents (such as standards and regulations), regardless of their source. When the proposer considers that an existing well-established document may be acceptable as a standard (with or without amendment), indicate this with appropriate justification and attach a copy to the proposal.

**f) Cooperation and liaison:** List relevant organizations or bodies with which cooperation and liaison should exist.

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**ISO/TC XXX/SC  N**

Date:   2010-09-17

**ISO/WD**

ISO/TC XXX/SC /WG

Secretariat:   ---

# Additive Manufacturing — Rapid Technologies (Rapid Prototyping) — Fundamentals, terms and definitions, quality parameters, supply agreements

*Élément introductif — Élément central*

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Document type:   International Standard
Document subtype:
Document stage:   (20) Preparatory
Document language:   E

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# Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO  was prepared by Technical Committee ISO/TC XXX, *Additive Manufacturing*, Subcommittee SC , .

This second/third/... edition cancels and replaces the first/second/... edition (), [clause(s) / subclause(s) / table(s) / figure(s) / annex(es)] of which [has / have] been technically revised.

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# Introduction

Additive manufacturing/rapid technologies are an inherent part of the product development process. They are used to manufacture prototypes, tools and production parts.

In addition to engineering, the scope of this interdisciplinary technology now covers fields ranging from architecture and medicine to archaeology and cartography.

During its somewhat turbulent development, different terms and definitions have emerged which are frequently ambiguous and confusing. Moreover, there are various different processes available on the market and it is not always clear what opportunities and limitations they offer in terms of application.

This International Standard aims to offer fieldtested recommendations and advice to users (customers) and manufactures (both external and internal service providers), to improve communication between customer and supplier and to contribute to an authoritative performance design and a smooth handling of the project.

It assumes that the reader has a basic understanding of the process flow of various different additive processes. It explains the processes used in practice in only much detail as it necessary to understand the statements.

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# Additive Manufacturing — Rapid Technologies (Rapid Prototyping) — Fundamentals, terms and definitions, quality parameters, supply agreements

## 1 Scope

This International Standard covers the principal considerations which apply to the design, fabrication and assessment of parts produced by additive fabrication and it lists the fields of activity. It specifies terms and definitions, deals with the fundamentals of the processes involved and specifies their requirements and selection criteria. It specifies relevant quality parameters and explains in detail component testing and the drawing up of supply agreements. It also covers safety-related and environmental aspects.

This International Standard

- differentiates between additive and conventional processes,
- facilitates improved assessment of different additive processes,
- specifies the quality parameters of different processes,
- specifies appropriate test procedures,
- recommends the scope and content of test and supply agreements.

This International Standard is aimed at users and producers of additive fabrication processes. It applies wherever additive processes are used, and to the following fields in particular:

- production of additive fabrication systems and equipment including software;
- material development and distribution;
- additive fabrication of parts, tools and end products;
- use of the parts, tools and end products.

## 2 Terms and definitions

### 2.1 General

The following two paragraphs describes the use of the wordings "rapid" and "rapiding" within the field of additive fabrication.

Additive processes are often described as "rapid", meaning that they are quicker than competing processes. This has a historical basis, because the first applications were considerably quicker and indeed cheaper than conventional processes, since tooling was unnecessary. Today the focus often lies on other features of additive fabrications, such as geometric freedom. Speed is therefore not the sole determining factor when assessing additive processes.

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Processes that use the appellation suffix "rapiding" may, but need not necessarily be generative. The user has to determine the technology behind each respective determination and if this International Standard needs to be applied.

## 2.2 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

**3.2.1**
**additive fabrication**
manufacturing processes which employ an additive technique whereby successive layers or units are built up to form a model

**3.2.2**
**rapid manufacturing**
additive fabrication of end products (often also described as production parts) which have all the characteristics of end products or is accepted by the customer for "series production readiness" and where the material is identical and furthermore the construction corresponds to that of the end product

**3.2.3**
**rapid prototyping**
additive fabrication of parts with limited functionality (prototypes, test parts) which have selected characteristics (e. g. geometry, surface quality) and where the material can but does not have to be engineering material and furthermore the design can but does not have to be suitable for serial production

**3.2.4**
**rapid technologies**
technology which describes all process chains that manufacture parts using additive fabrication processes

**3.2.5**
**rapid tooling**
use of additive technologies and processes to fabricate tools and moulds

# 3 Component types and intended purpose

## 3.1 General

Additively manufactured parts include both prototypes and serial products. Prototypes are used for different purposes in the various stages of product development, depending on the application and the industry, in order to assess specified characteristics of the product under development. Different processes and materials can be used depending on the type of prototype, application and industry, and this is also reflected in the respective costs and delivery times. It is the responsibility of the developer to design the prototypes and decide on their specification. Close consultation with the prototype manufacturer is advisable, depending on the developer's expertise. Prototypes can be categorised as defined in 3.2 till 3.6[1)]

## 3.2 Concept prototype

Concept prototypes are the earliest possible physical realisation of a product design or product concept (solid image). Material, function and size hereby do not correspond to the product specifications. The most important target parameter is the impression. Scaled, additively manufactured parts (proportional models can be used.

**Application:** testing the aesthetic impression in the field of application

---

1) The terms prototype, model and sample are sometimes used interchangeably depending on the application and industry.

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## 3.3 Geometric prototype

Geometric prototypes are additively manufactured parts designed to assess the size, shape and feel of the product. Material characteristics are of secondary importance.

**Application:** testing the geometry (e.g. installation test)

## 3.4 Functional prototype

Functional prototypes are additively manufactured parts which already embody the defined product functions of the subsequent production part. Some or all of the functions may be tested. The shape and form may differ from the subsequent product.

**Application:** testing (some of) the functions

## 3.5 Technical prototype

The characteristics of technical prototypes do not differ significantly from those of the subsequent production part. However, the manufacturing process may vary from that used for serial production.

**Application:** pilot test of the part

## 3.6 Product (production part)

Marketable product that can be used for the intended purpose. The parts are typically used in specific phases of product development, as shown in Table 1.

**Application:** small batch, rapid manufacturing, individual products

**Table 1 — Use of additively manufactured parts in product development**

| **Component types** | **Stages of product development** | | | | | | |
|---|---|---|---|---|---|---|---|
| | concepts | | prototypes | | | products | |
| Product (production part) | | | | | | ■ | ■ |
| Technical prototype | | | | | ■ | ■ | |
| Functional prototype | | | | ■ | ■ | ■ | |
| Geometric prototype | ■ | ■ | ■ | ■ | ■ | | |
| Concept prototype | ■ | ■ | | | | | |
| **Part type** | concept | design | construction parts | construction tools | preparation production | pilot production | production |

# 4 Process fundamentals

## 4.1 General

Additive fabrication is used to produce physical models. Rather than starting with a solid mass and shaping it using subtractive techniques such as milling, objects are built up with successive layers of material or through phase transition of a material from a liquid or powder to a solid state. The fabrication technique does not require moulds.

In additive fabrication, the general process flow (see 5.3) begins with the generation of manufacturing data (see Figure 1) which is divided into the following steps:

- data preparation: creation of CAD models and export (e. g. in STL file format);
- data conditioning: separation into successive layers (slices);
- data processing: process planning and parameter setting in the system's control computer (material deposition etc.)

The parts (models) are then manufactured using the chosen additive layer manufacturing system. On completion of fabrication, the part undergoes post-processing, for example cleaning, post-curing, coating (fixing) or machining (see 4.4).

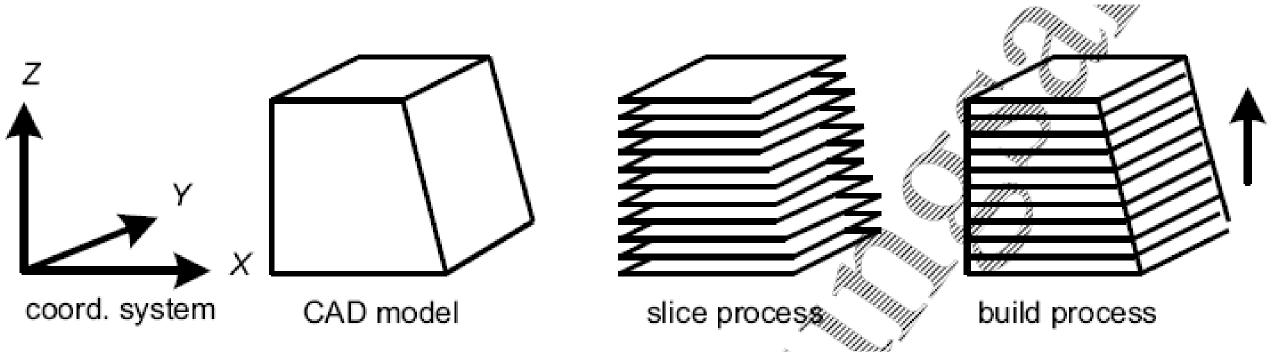


Figure 1 — Generating the manufacturing data

## 4.2 Process chains

### 4.2.1 General

The process chain involved in additive fabrication technologies is characterised by rapid, flexible and direct fabrication from 3D CAD data. Intermediate stages, such as tool manufacturing, are unnecessary.

There are basically three different categories:

- **direct processes** (see 4.2.2): Usable parts are fabricated in the desired material in a single-step process. Removal of the support structure and cleaning may be necessary;
- **direct (multi-stage) processes** (see 4.2.3): Usable parts are fabricated in several stages, in which additive fabrication is followed by one or several secondary processes (e.g. chemical or thermal transformations, infiltration);
- **indirect processes** (see 4.2.4): The additively manufactured parts are used as equipment, models or tools for secondary manufacturing processes such as electrical discharge machining, reshaping or casting rather than the usable part itself.

It may be necessary to finish metal and plastic products produced using additive techniques in order to obtain or improve selected characteristics such as surface quality or mechanical properties. In general it is important to stipulate that this type of post-processing treatment complies with the following requirements:

- reproducibility;
- the shortest possible, simplest and ideally automated process steps;
- minimum error rate/wastage.

The technologies involved are well-known and well documented non-additive processes and therefore it is unnecessary to describe them in further detail at this stage.

### 4.2.2 Direct processes

Direct processes are used to fabricate the desired part directly from 3D CAD data on an RP system (see Figure 2).

Depending on the technology and material availability, these methods generally offer the greatest advantages in terms of function integration, cost and time compared with conventional processes and have considerable potential for the manufacturing of end products. Examples of direct methods are shown in Table 2.

Further examples of direct processes can be found in the relevant literature.

**Figure 2 — Process chain of direct processes**

### 4.2.3 Direct (multi-stage) processes

A part made by a direct (multi-stage) additive process (see Table 3), often referred to as a “green part”, does not exhibit the desired characteristics at this stage. Further secondary operations are required to produce these characteristics (see Figure 3).

These processes can be useful if the actual geometry can be generated very quickly and/or affordably and if they still remain advantageous compared with alternative manufacturing processes even when the cost of secondary operations have been taken into account.

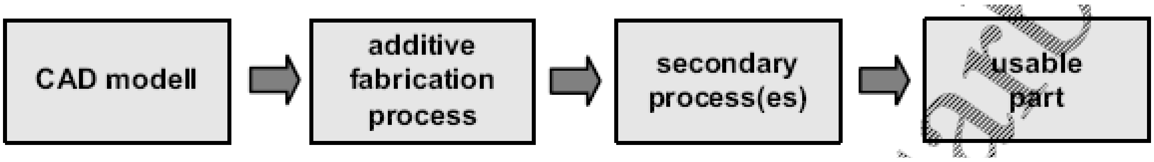


**Figure 3 — Process chain for direct (multi-stage) processes**

**Table 2 — Examples of direct processes**

| **Application example** | **Part type** | **Additive fabrication process** | **Finishing** | **Specific part characteristics** | **Usable part** | **Optional: Post-processing** (see 4.4) |
|---|---|---|---|---|---|---|
| PA 12 cable plug for automotive industry | Functional prototype | Laser sintering (LS) see 4.3.3 | — manual cleaning by blasting | — Durability<br>— Accuracy |  | |
| Acrylate in-the-ear hearing aid | product (production part) | Stereolithography (SL) see section 4.3.2 | — Manual removal of support structure<br>— Automatic washing process (batch)<br>— Post-curing required | — Biocompatibiliy<br>— Good accuracy and surface finish |  | blasting, dipping varnish |
| Aerodynamic functional body in nanofilled epoxy resin | Functional prototype | Stereolithography (SL) see section 4.3.2 | — manual removal of support structure<br>— cleaning by washing<br>— post-curing required | — high stiffness and surface quality<br>— high contour accuracy |  | blasting, assembly accessories |

**Table 2** *(continued)*

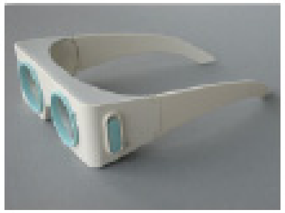
| **Application example** | **Part type** | **Additive fabrication process** | **Finishing** | **Specific part characteristics** | **Usable part** | **Optional: Post-processing** (see 4.4) |
|---|---|---|---|---|---|---|
| CoCr knee implant | Product (production part) | Selective laser melting (SLM) see 4.3.4 | — removal of support structure by milling<br>— manual cleaning by blasting | — high surface quality and accuracy<br>— good material characteristics<br>— biocompatibility<br>— durability |  | e. g. electro-polishing |
| CoCr tooth restoration | Product (production part) | Selective laser melting (SLM) see 4.3.4 | — manual removal of support structure<br>— manual cleaning by blasting | — high accuracy<br>— good material characteristics<br>— biocompatibility<br>— durability |  | Ceramic facing |
| Concept bed | Concept model | Stereolithography (SL) see 4.3.2 | — manual removal of support structure<br>— cleaning by washing<br>— post-curing required | — high-surface quality<br>— high contour accuracy |  | Blasting, grinding |
| Designer glasses | Functional and/or geometric prototype | Stereolithography (SL) see 4.3.2 | — manual removal of support structure<br>— cleaning by washing<br>— post-curing required | — high surface quality<br>— high contour accuracy |  | Blasting, grinding, colouring |

**Table 2** *(continued)*

| **Application example** | **Part type** | **Additive fabrication process** | **Finishing** | **Specific part characteristics** | **Usable part** | **Optional: Post-processing** (see 4.4) |
|---|---|---|---|---|---|---|
| Motorbike luggage rack | Geometric prototype | Laser sintering (LS) see 4.3.3 | — manual cleaning by blasting | — sufficient stiffness to ensure geometry, design and function |  | Blasting, grinding, adhesion |
| Tool insert with conformal cooling | Product | Selective laser melting (SLM) | — manual cleaning by blasting, functional surface milled | — conformal cooling (cannot be manufactured by convention means) |  | Blasting, grinding |
| Motobike throttle valve | Functional prototypy | Selective laser melting (SLM) | — manual cleaning by blasting | — smallest series<br>— several geometries for very rapid functionality check |  | Blasting, grinding |
| Crank shaft | Geometric prototype | Stereolithography | — manual cleaning by blasting (removal of support structure and adherent resin) | — several geometries for very rapid functionality checks |  | Clear varnish seal |

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**Table 3 — Examples of direct (multi-stage) processes**

| **Additively manufactured model/tool** | **Intermediate product characteristics** | **Secondary processes** | **End product characteristics** |
|---|---|---|---|
| Photopolymer resin framework constructed with SL | Open-pored structure with poor mechanical properties | — Ceramic infiltration<br>— Burning out organic resin<br>— Re-infiltration with ceramic and burning | Dense ceramic part with good mechanical properties |
| PE framework will be sintered | Open-pored structure with poor mechanical properties | Infiltration with PU | Dense rubber elastic part, suitable as end product only to a limited extent |

### 4.2.4 Indirect processes

A part made by an indirect additive process is used as a master mould or tool for further manufacturing processes.

These processes also offer advantages in terms of time and costs if the use of these parts results in savings in terms of modelling equipment or tools, assembly and adjustments and/or if a degree of geometric complexity can be obtained that is not achievable through conventional means (see Figure 4).

More detailed information about corresponding conventional manufacturing processes can be found in the relevant documentation and guidelines.

Examples of indirect processes are shown in Table 4.

Figure 4 — Process chain for indirect processes

Table 4 — Examples of indirect processes

| Additively manufactured model/tool | Use of additively manufactured part | Secondary processes | End product materials |
|---|---|---|---|
| Polystyrene, wax, resin with LS, SL, 3DP | Lost master mould for precision casting | Precision casting (compact mould casting, ceramic shell casting) | metal |
| Polystyrene, polyamide, resin with LS, SL, 3DP | Master mould for vacuum casting | 1) Construction of silicone mould<br>2) Casting wax models<br>3) Precision casting | metal |
| Foundry sand with LS, 3DP | Lost moulds and cores for sand or chill casting | Sand casting (gravity, low pressure, etc.) | metal |
| Bronze alloys, steel with SLM | tool | Pressure die casting | metal |
| Photopolymer resin with SL | Master mould for vacuum casting | 1) Construction of an intermediate silicone mould<br>2) Casting a metal binder mix<br>3) Sintering and removal of binder<br>4) Infiltration wit copper | metal |
| Polystyrene, polyamide, resin with LS, SL, 3DP | Master mould for vacuum casting | 1) Construction of silicone mould<br>2) Casting of plastic | plastic |
| Bronze alloys, steel with SLM | tool | Injection moulding | plastic |

## 4.3 Description of processes

### 4.3.1 General

The principal processes on which commercially available technologies are based are described below. Industrial systems often consist of hybrid technologies. The generic names used in Section 4.3.2 to Section 4.3.11 can be used to identify current manufacturers and their products, via the Internet for example. It must be noted that additively manufactured component sizes are approximately 20 % smaller than the build spaces specified by the manufacturer. As a rough guide, Table 5 compares construction materials typically used in the different technologies with the prototypes.

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Table 5 — Overview of typical construction materials associated with the processes

| Process | | Material | | | | |
|---|---|---|---|---|---|---|
| | | Paper | Plastic | Foundry sand | Metal | Ceramic |
| 4.3.2 | Stereolithography (SL) | | x | | | x |
| 4.3.3 | Laser sintering (LS) | | x | x | x | x |
| 4.3.4 | Laser melting | | | | x | |
| 4.3.5 | Fused layer modelling/ manufacturing (FLM) | | x | | | |
| 4.3.6 | Multi-jet modelling (MJM) | | x | | | |
| 4.3.7 | Poly jet modelling (PJM) | | x | | | |
| 4.3.8 | 3D-printing (3DP) | | x | | | |
| 4.3.9 | Layer laminated manufacturing (LLM) | | x | x | x | x |
| 4.3.10 | Mask sintering (MS) | | x | | x | x |
| 4.3.11 | Digital light processing (DLP) | | x | | | |

### 4.3.2 Stereolithography (SL)

**Fabrication process:** additive technique in which photopolymer resins (polymers with photo activators) selectively cure, or solidify, when exposed to a laser beam (see Figure 5)

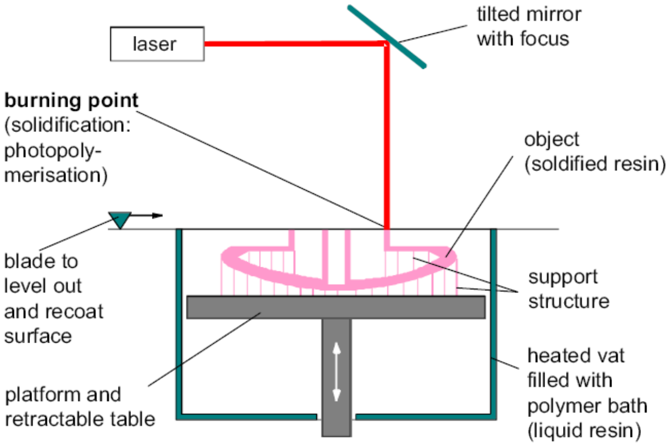

Figure 5 — Schematic diagram of Stereolithography

**Source material:** liquid or paste: synthetic resin with or without filler

**Binding mechanism:** chemical

**Material processing method:** vector-oriented

**Activation energy:** UV radiation from lasers and lamps

**Secondary process:** cleaning, post-curing in UV oven

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### 4.3.3 Laser Sintering (LS)

**Fabrication process:** additive technique in which powdered material is selectively melted, or sintered, when exposed to a laser beam (see Figure 6)

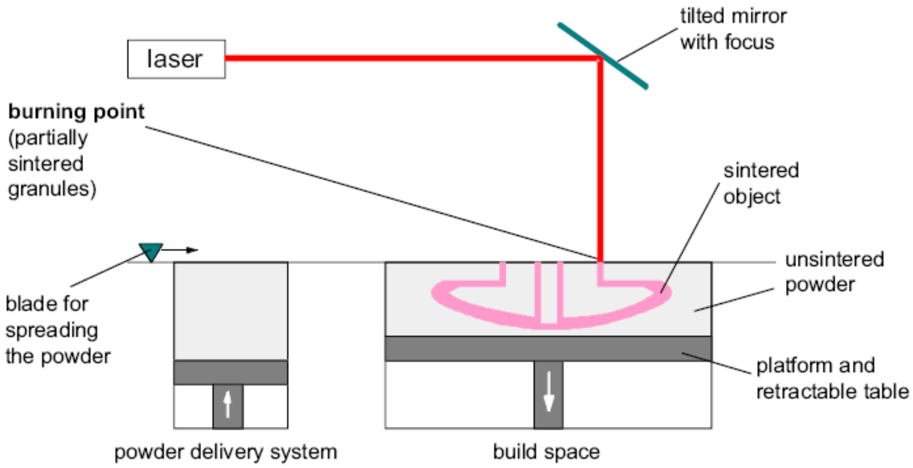

Figure 6 — Schematic diagram of laser sintering

**Source material:** powder: high polymers, metal alloys, ceramics with or without fillers and binders

**Binding mechanism:** thermal

**Material processing method:** vector-oriented

**Activation energy:** thermal radiation from lasers and lamps

**Secondary processes:** compressed air cleaning

NOTE Laser sintering (LS) is also referred to as selective laser sintering (SLS).

### 4.3.4 Laser melting

**Fabrication process:** additive fabrication process which utilises lasers or electron beams to selectively melt powdered materials, which then fuse during solidification (see Figure 7)

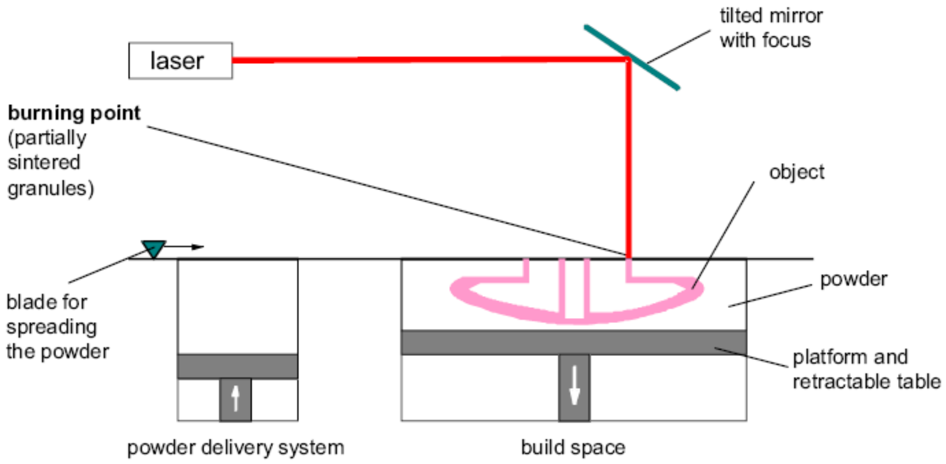

Figure 7 — Schematic diagram of selective laser melting

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**Source material:** powder: metal alloys

**Binding mechanism:** thermal

**Material processing method:** vector-orientated

**Activation energy:** thermal radiation from lasers and lamps

**Secondary processes:** post-processing to improve the surface finish:

- Microblasting;
- laser-assisted material removal;
- laser remelting;
- PVD coating.

NOTE Laser melting is also referred to as laser forming, selective laser melting (SLM), laser cusing, electron beam melting (EBM), direct metal maser sintering (DMLS). A similar process to LS (see 4.3.3.) for fabricating metal components by fully melting the material.

### 4.3.5 Fused layer modelling/manufacturing (FLM[2]

**Fabrication process:** additive technique in which a thermoplastic material is melted and selectively deposited through a heated nozzle or print head; the material hardens immediately after deposition. Each successive layer may be milled or not, depending on the technology (see Figure 8)

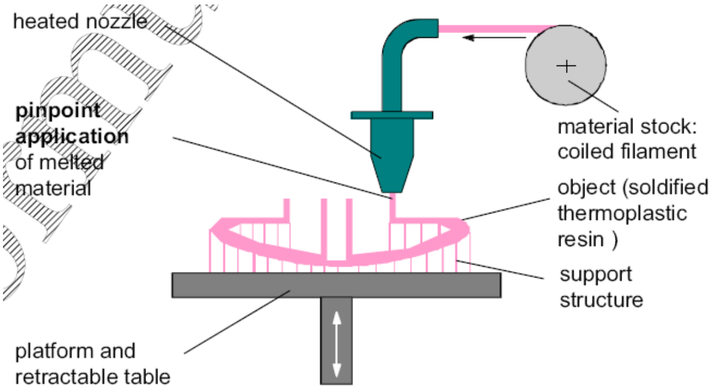

**Figure 8 — Schematic diagram of fused laser modelling**

**Source material:** filament: one or two different high polymers (component material, support material) with or without filler

**Binding mechanism:** thermal

**Material processing method:** vector-oriented

**Activation energy:** heating of the nozzle/print head to melt the source material

**Secondary processes:** cleaning

NOTE Fused layer modelling/manufacturing (FLM) is also referred to as fused deposition modelling (FDM).

---

[2] The "M" stands for "modelling" or "manufacturing" depending on the author.

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### 4.3.6 Multi-jet modelling (MJM)

**Fabrication process:** additive technique in which thermoplastic materials are melted and linearly deposited through heated nozzles; material hardens on impact (see Figure 9)

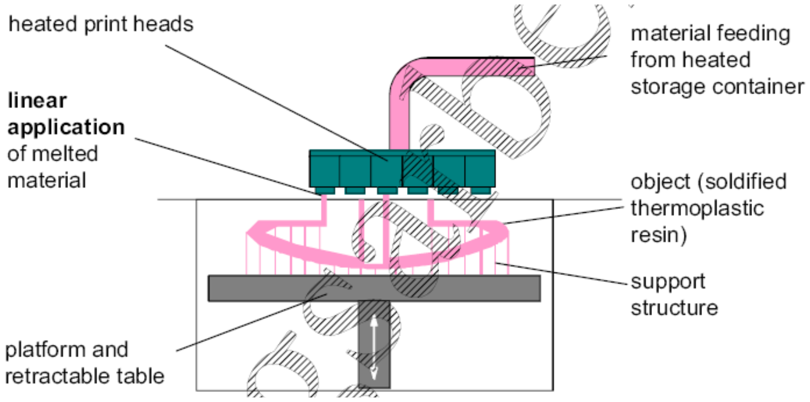

Figure 9 — Schematic diagram of multi-jet modeling

**Source material:** granular high polymers (wax)

**Binding mechanism:** thermal

**Material processing method:** grid-oriented

**Activation energy:** heating of the print heads to melt the source material

**Secondary processes:** mechanical removal of the support structure

### 4.3.7 Polyjet modelling (PJM)

**Fabrication process:** additive technique in which photopolymer liquid resins (polymers with photo activators) are linearly deposited and immediately harden on exposure to UV radiation (see Figure 10)

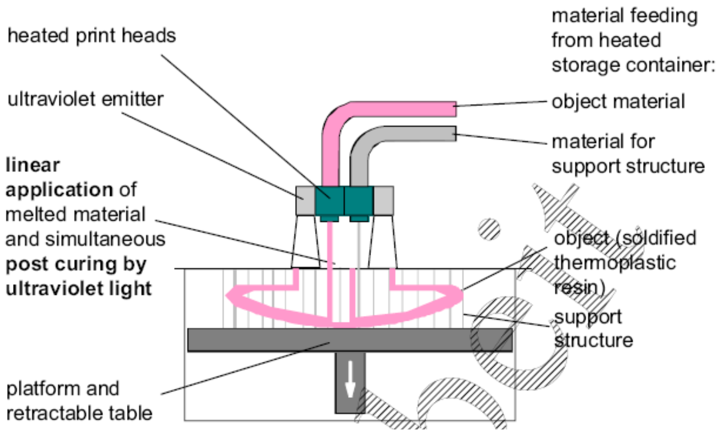

Figure 10 — Schematic diagram of poly-jet modeling

**Source material:** liquid/slurry: two different polymer mixes

**Binding mechanism:** thermo-chemical

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**Material processing method:** grid-oriented

**Activation energy:** heating of the print heads to melt the source material; UV radiation for post-curing

**Secondary processes:** cleaning with water jets to remove support structure

### 4.3.8 3D Printing (3DP)

**Fabrication process:** additive technique in which an adhesive is deposited dot by dot onto a powder bed, causing the powder to bond where the adhesive is deposited (see Figure 11)

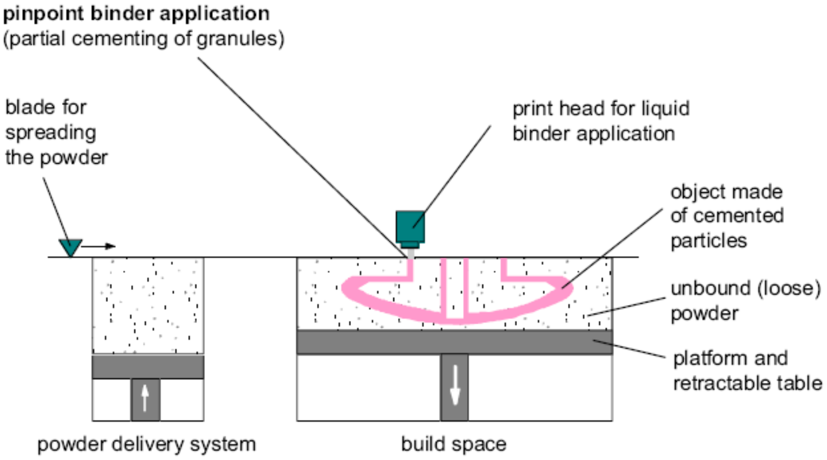

Figure 11 — Schematic diagram of 3D printing

**Source material:** powder: powder mixes (polymers, ceramics, etc.); liquid: adhesive

**Binding mechanism:** thermal and/or chemical

**Material processing method:** vector or grid-oriented

**Activation energy:** none

**Secondary processes:** compressed air cleaning; impregnation with liquid hot wax or infiltration with epoxy resin or adhesive; necessary to increase the mechanical resistance; sintering (ceramics)

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### 4.3.9 Layer laminated manufacturing (LLM)

**Fabrication process:** additive technique in which contoured layers of material are cut out using a laser (see Figure 12), knife (see Figure 13) or water jet, then bonded, or fused by ultrasound

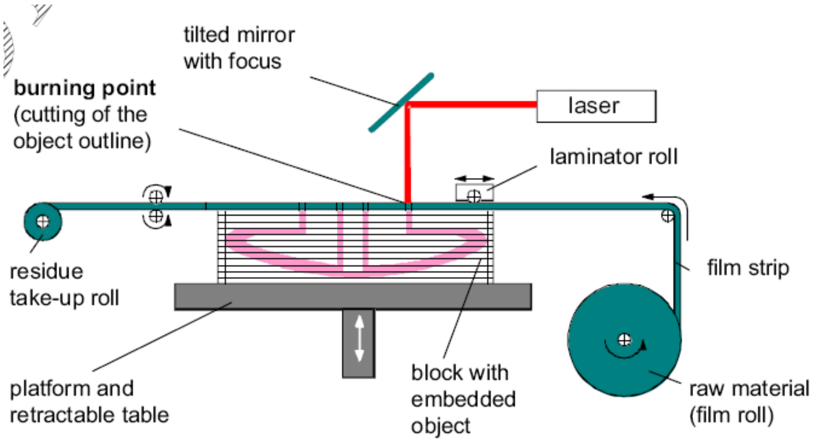

Figure 12 — Schematic diagram of layer laminate manufacturing using a laser

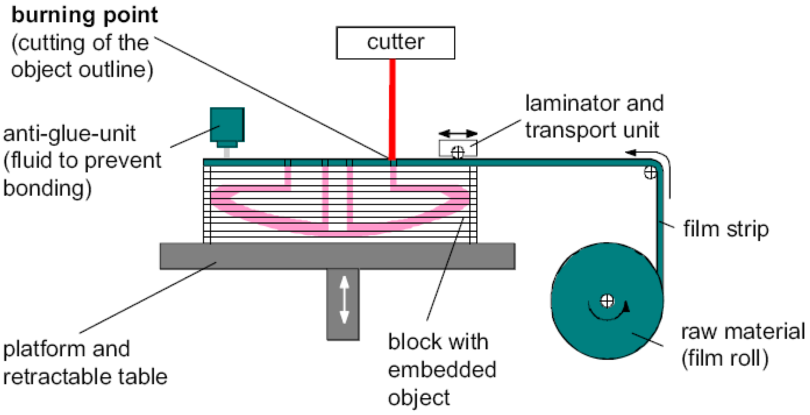

Figure 13 — Schematic diagram of layer laminate manufacturing using a knife

**Source material:** prefabricated sheets of paper, high polymer, metal or ceramic

**Binding mechanism:** thermal or thermochemical

**Material processing method:** vector-oriented

**Activation energy:** application of heat to melt the hot glue to bond the layers; targeted radiation source for cutting when using laser technology

**Secondary processes:** removal of waste non-part area, finishing (painting or coating), sintering if required

**Tools:** laser, knife, water jet

NOTE Layer laminated manufacturing (LLM) is also referred to as laminated object manufacturing (LOM).

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### 4.3.10 Mask sintering (MS)

**Fabrication process:** additive technique in which a toner mask is created (toner on transparent supporting material in areas which are not part of the component) and the powdered material is selectively melted in the transparent (light permeable) and diathermic areas using infrared heating lamps (see Figure 14)

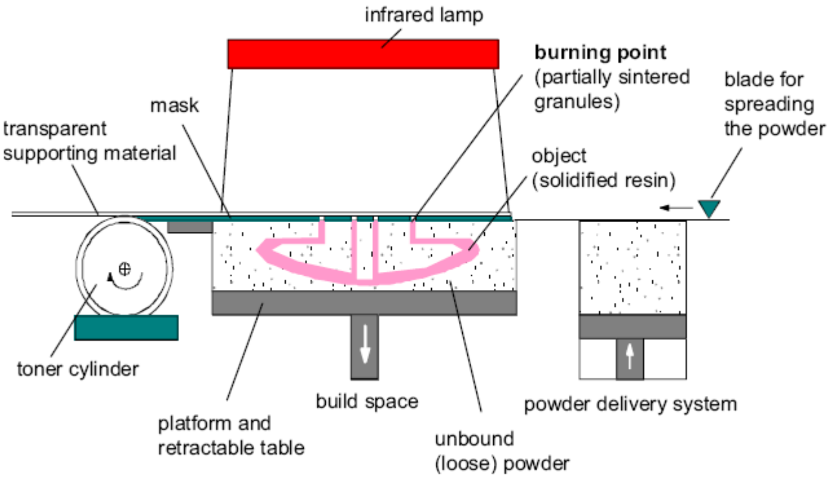

Figure 14 — Schematic diagram of mask sintering

**Source material:** powder: high polymers, metal alloys, ceramics with or without filler or binder

**Binding mechanism:** thermal

**Material processing method:** grid-oriented

**Activation energy:** largescale thermal conduction using infrared lamps to process the material

**Secondary processes:** compressed air cleaning

NOTE A similar process to LS (see 4.3.3) which uses infrared heating lamps.

### 4.3.11 Digital light processing (DLP)

**Fabrication process:** additive fabrication process in which liquid photopolymer resins (polymers with photo-activators) are selectively cured when exposed to a light mask (controlled by micro-mirrors or deflected laser beams) (see Figure 15)

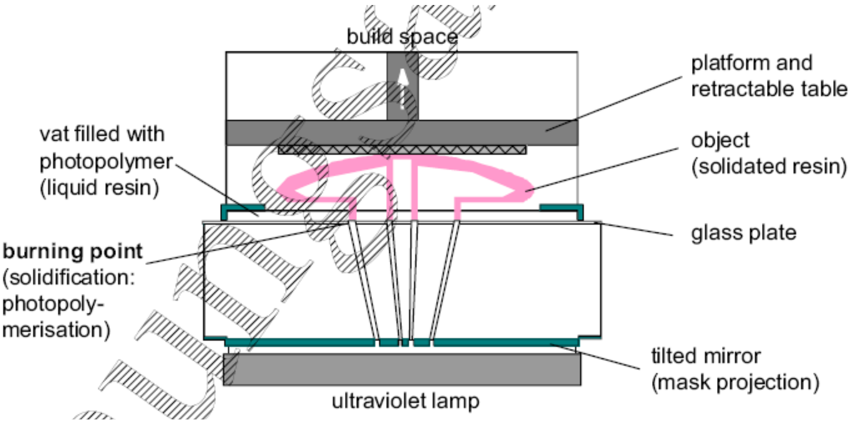

Figure 15 — Schematic diagram of digital light processing

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**Source material:** liquids and pastes: oligomers/monomers with and without fillers

**Binding mechanism:** chemical

**Material processing method:** grid-oriented

**Activation energy:** targeted radiation source to process the material

**Secondary processes:** chemical cleaning

NOTE A similar process to SL (Section 4.3.2) which uses a lamp and mask.

## 4.4 Secondary treatments

### 4.4.1 General

Additively manufactured components can be finished using well-established non-additive fabrication processes to improve the physical characteristics such as surface finish.

### 4.4.2 Plastic products

The processes listed in Table 6 are proven for directly fabricated plastic components.

**Table 6 — Secondary treatment of plastic products from additive processes**

| Target property | Modification |
|---|---|
| Surface quality and geometry | A wide range of common grinding processes can be used (e. g. drum grinding). Modifications are occasionally required. |
| Physical properties | If an additively manufactured plastic product does not have the required mechanical properties, such as density, strength or elongation at break, conventional infiltration processes using various different chemicals can be used. The same applies to the changing of physical properties. |
| Surface as interface | Here too, established processes such as coating, galvanising, etc. can be used to make plastic products resistant to temperature, liquids or gaseous media or other environmental effects. |
| Feel | The look and feel of the surface finish is particularly important in the field of design. Processes such as water transfer printing, painting/varnishing, or coating with leather or flock can be used to enhance the surface finish. |

### 4.4.3 Metal products

The processes listed in Table 7 have become firmly established for directly fabricated metal products.

The main aim of secondary treatments is to improve the surface finish, and in some cases also the structure, density and hardness.

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**Table 7 — Secondary treatment of metal products from additive processes**

| Target property | Modification |
|---|---|
| Surface quality and geometry | The structure of the modern materials now used in direct processes (DMLS, EBM) allows the use of all established metal-cutting finishes. Milling, grinding, polishing and even electrical discharge machining are common techniques for finishing these products without creating visible pores on the surface. |
| Mechanical properties | Infiltration is predominantly used, in addition to the still rather uncommon process of heat treatment. Typically, epoxy resin is used to reduce the porosity of parts made from materials which do not exhibit 100 % density following additive fabrication. |
| Surface as interface | Here too, established processes such as coating (e. g. with boron nitride) can be used to make metal products resistant to acting forces, liquid or gaseous media or influences. |

# 5 Data exchange

## 5.1 Dataflow

### 5.1.1 General

A complete 3D dataset of the component forms the basis of additive fabrication. Most commonly, this is created by direct 3D CAD modelling. The datasets can also be generated by measurements if the components exist in a physical form (see Figure 13).

A facet model is then generated from the volume or area model through polygonisation or triangulation (see Section 5.3.1) and transferred to the additive fabrication process in STL or VRML format (see Section 5.2). This software-assisted process runs automatically as far as possible.

### 5.1.2 Explanation of the key terms used in Figure 16

#### 5.1.2.1 3D CAD modelling (solid modelling)

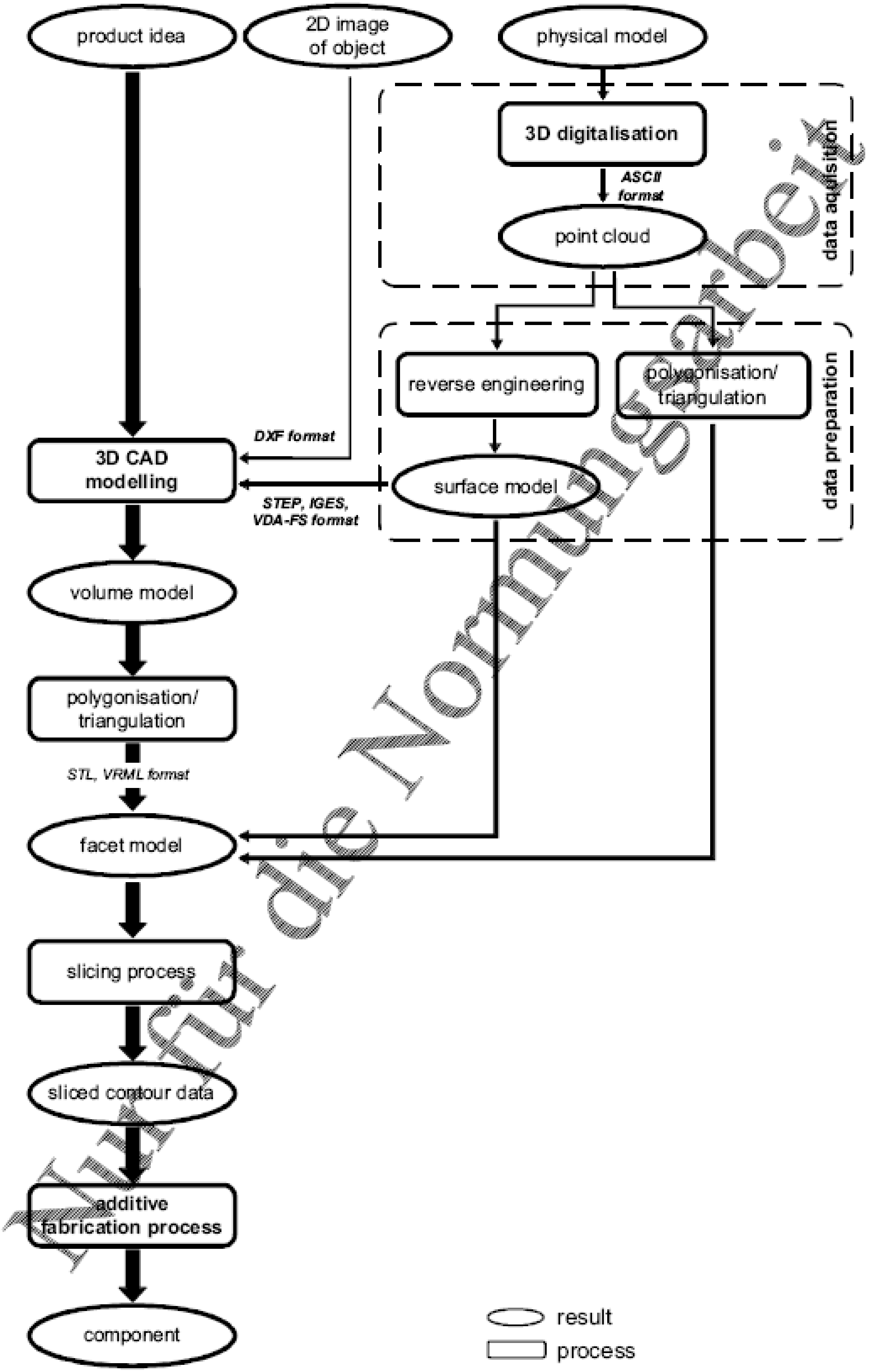
3D CAD modelling is the process most commonly used during design to produce a digital 3D model. The starting point may be an idea for a product, which takes shape and becomes increasingly defined directly on the computer screen during the process, or a previously generated image of the object in the form of sketches, drawings, etc., which are then simply converted to 3D data. Volume can be described using two different techniques, or a combination of both. The object is either composed of basic volumes (shapes) (cuboid, wedge, cylinder, cone, sphere, toroid) which generate the actual object via a sequence of Boolean operations, or the volume is described by its surrounding boundary surfaces and the location of the material relative to the boundary surfaces.

#### 5.1.2.2 3D digitalisation (reverse engineering)

3D digitalisation is the process in which the surface geometry of a physical object is measured using appropriate hardware and software and recorded in a digital point cloud model. The objects may be manually produced or finished models which need to be copied in digital form. The use of 3D digitalisation is particularly efficient if the model has empirically drafted, freeform surface areas, since these are difficult to reproduce through direct 3D CAD modelling.

#### 5.1.2.3 Surface reconstruction

Surface reconstruction is means of processing data generated through 3D digitalisation. Starting from the computer-generated point cloud, mathematically described curves and surfaces are generated with sufficient topological information to adequately recreate the object surface. This data can then be stored separately or integrated into an existing CAD volume model. Reverse engineering thus creates a bridge between 3D digitalisation at CAD modelling.



Nur für die Normungsarbeit

Figure 16 — Data flow from product idea to actual component

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#### 5.1.2.4 Polygonisation/triangulation

This software-assisted process is used to generate a volume-based facet model either from the point cloud following 3D digitalisation or from the volume model after 3D CAD modelling. The object surface is represented by a multiplicity of tiny, planar facets, or polygons, which are stretched between the points. The number and size of the facets determines how accurately the actual surface geometry is reproduced. This process creates a STL dataset.

#### 5.1.2.5 Slicing process

The slicing process is an essential prefabrication stage in all additive layer manufacturing processes. It involves slicing the facet (volume) model into several successive layers and recording the information contained within each layer. The sliced contour data are no longer connected to one another in the z axis, which means that subsequent scaling is no longer possible. With some technologies, this process is automatically performed by the software, once the necessary parameters (e.g. layer thickness) have been set. Other systems require separate software to prepare and store this layer data.

## 5.2 Data formats

### 5.2.1 General

The most common interface formats used within the dataflow are explained in 5.2.2 till 5.2.6 (see also [6; 7]).

The STL format is the standard data format for data transfer. Some systems can read and process data in VRML format.

If the STL format cannot be exported due to the absence of the interface module (not supplied as standard with all CAD software programs), the data can be transferred to other CAD programs via interface formats (e.g. STEP, IGES or VDA-FS), which should then enable an STL output. However, conversion problems may arise when transferring data via system-neutral interfaces, since interfaces capabilities (despite established standards) vary greatly and programs operate with varying degrees of accuracy (e.g. in the acceptance of the joining of two adjacent surfaces).

### 5.2.2 STL

The STL file format (surface tessellation language, or stereolithography) has established itself as a quasi-industry standard format for transferring data to rapid technologies. It is a system-neutral data format for exchanging pure geometric data. The boundary surfaces of volume models are described by triangles (planar facets) and their normal vectors. STL datasets can be stored using either ASCII or binary representations. The binary format is preferable because the volume of data is greatly reduced. The STL data format tends to be unsuitable for exchanging data between CAD/CAM systems because the geometry is irreversibly faceted.

### 5.2.3 VRML (WRL)

VRML (virtual reality modelling language) (file extension “wrl”(world) or “wrz” for compressed VRML files) is a still a relatively new, platform-independent three-dimensional image format supported by network functionality. VRML is not restricted to the input of point or edge data in the form of lists; it also describes 3D objects or scenarios in an objectorientated way in one type of computer language (plain text ASCII or UTF-8). The basic components of VRML are “node types” and communication channels: shape nodes (basic geometrical shapes such as cuboids, cylinders, cones and spheres), appearance nodes (colour, texture (material properties), geometric transformations), light nodes, camera nodes (parallel perspective projection) and group nodes to implement hierarchical structures, as well as prototypes to extend the existing range of node types.

### 5.2.4 IGES

IGES (initial graphics exchange specification) is a neutral data format and international standard for exchanging CAD data between different CAD systems. IGES was mainly developed for transferring geometric data relating to 2D drawing models and 3D surface models (including Bezier and NURBS surfaces). IGES version 5.3 and above also uses volume elements (cuboids, cylinders, spheres, etc.) and around 40 additional geometric elements (surfaces, curves, arcs, points, coordination systems, etc.) and more than 35 non-geometric elements (text, dimensioning, tolerances, etc.). IGES version 6.0 is the latest and also the last version of the standard; further action will be continued by STEP.

### 5.2.5 VDA-FS

VDA-FS (Verband der Automobilindustrie-Flächenschnittstelle) is a CAD interface standard of the VDA (the Association of German Automotive Manufacturers) primarily designed for exchanging body work data. VDA-FS is particularly suited to exchanging freeform surfaces which have been generated by surface-orientated 3D software. Points, point volumes and vectors can also be transferred. Volume models cannot be exchanged. VDA-FS was standardised in DIN 66301, which primarily describes the exchange of geometric data.

### 5.2.6 STEP

STEP (standard for the exchange of product model data) is a system-neutral interface format to describe and exchange product model data between different CAD systems. STEP can be used to transfer product data (e.g. colours, text or layer support) in addition to geometric data (as with DXF or IGES). All forms of CAD data model can be integrated in the geometric representation (wireframe models, surface models and volume models).

## 5.3 Data preparation

### 5.3.1 The importance of data quality for component quality

A faultless reproduction of the geometry in the STL dataset is a prerequisite for ensuring high-quality, trouble-free fabrication of components using rapid technologies. Attention should be paid to the following:

- all surfaces of surface models must be smoothly blended together and trimmed (a perfectly sealed, watertight model);
- all surfaces must be oriented such that the volume can be clearly identified;
- when performing triangulation, no construction aids (layers, cylinders, axes, elements in the noshow, etc.) should be selected;
- surface models should ideally be converted to solid volumes before performing polygonisation/triangulation.

The generation or supply of poor quality data may call for dataset repairs, which in some cases can be very time-consuming and costly and therefore require individual approval.

For this reason, and due to tolerance problems, it is advisable to supply dimensioned drawings.

### 5.3.2 STL export parameters

The setting of export parameters when inputting the STL dataset and thus the accuracy of polygonisation/triangulation determines how accurately the desired geometry is approximated. A too coarse resolution affects the accuracy and appearance of the finished prototype. However, a very high resolution demands a large storage capacity (excessive file size) and increases preparation time (see Table 8).

Various different export parameters may be set depending on the CAD program:

- chord height, aspect ratio, resolution;

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- surface tolerance, absolute surface smoothing, absolute facet deviation, max deviation distance, conversation tolerance, adjacency tolerance, etc.;
- triangle tolerance, angular tolerance, angle control, surface plane angle, etc.

For a few programs which do not allow the setting of individual parameters during export, the output parameters are adjusted to the display parameters. In this case care should be taken to ensure that a correspondingly high display resolution in the program has been selected by prior adjustment.

Increasing the number of facets retrospectively to increase the image quality cannot be achieved without considerable expense. In contrast, it is generally possible to subsequently reduce the number of facets without causing problems.

**Table 8 — Potential formatting errors in the STL dataset and their impact on the fabrication process and component**

| Formatting error | Process effect | Component affect | Possible measures |
|---|---|---|---|
| Too coarse triangulation | none | Poor approximation of the actual geometry | STL generation with adjusted resolution |
| Too fine triangulation | Excessive computing time, long construction times<br>Process errors due to large volumes of data | Defects caused by process errors | STL generation with adjusted resolution |
| Uneven and/or untrimmed surfaces in the CAD model | Process errors caused by undefined parts definition | Geometric distortion defects | Repair = clean cut "closed volumes" |
| Incorrect orientation of the surfaces in the CAD model | Process errors caused by empty layers or undefined parts definition | Geometric distortion defects<br>Delamination and loss of strength in z-access | Check normal vectors<br>"Closed volumes" |

### 5.3.3 Special considerations in data processing

#### 5.3.3.1 Machining allowances

Depending on the component or the chosen method, fabrication may require post processing. In this case it is essential to allow for appropriate over- or undersizing in the areas concerned when generating the CAD model. The contractor/fabricator must be additionally informed of the machining areas.

#### 5.3.3.2 Volume reduction (mass reduction)

Some rapid prototyping technologies can be very lengthy and expensive when used to fabricate large volumes. However, it is often possible to reduce the volume in the CAD model stage in those areas where no shaping cavities are required, using tools for example. This should be taken into account at the design stage. Volume reduction should be agreed in advance for build-to-order fabrication.

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#### 5.3.3.3 Component alignment and supports

The three coordinates produce variations in accuracy and different component characteristics depending on the process. This is to be taken into account when aligning the component in the build space. In addition, fabrication times often depend on the positioning.

Some fabrication processes require the use of additional supports, to support overhanging geometries from below. These are applied prior to fabrication and generally removed manually on completion of the fabrication process.

The system user creates the supports using either the options in the system software or separate software tools.

It is not always possible to avoid damaging the surface finish entirely when attaching the supports. For this reason it is essential to mark those areas where it is imperative that no supports are attached.

## 6 Performance and selection criteria

### 6.1 General

Each development and fabrication phase has a specific purpose. The performance criteria determine the type of component or prototype (see Clause 3) and the choice of rapid technology.

### 6.2 Performance criteria and quality characteristics

Table 9 illustrates the performance criteria and associated quality characteristics.

**Table 9 — Performance criteria and quality characteristics**

| Performance criteria | Relevant quality characteristics |
|---|---|
| Artistic requirements | Size, scale, weight, density, visible edges and surface structures, colour, transparency, feel, smell |
| Geometric requirements | Component size and complexity, length and angle dimensions, dimensional tolerances, deviations in shape and position, shrinkage behaviour, minimum structures, walls, slits and layer thicknesses |
| Process-related requirements | Machinability, plasticity, can be relieably joined, surface treatment (painting, coating, polishing) |
| Strength requirements | Tensile, compressive, bending and torsional strengths, static and dynamic creep strengths, impact strengths, hardness, frictional coefficient, abrasive wear |
| Thermal requirements | Operating temperature range, dimensional stability in heat, softening temperatures, specific heat, thermal conductivity, coefficient of linear thermal expansion |
| Electrical requirements | Disruptive strength, surface and specific volume, dielectric property values, creep resistance |
| Chemical requirements | Flammability, toxicity, chemical resistance, water absorption, suitability for food applications, biocompatibility, photostability, translucence |
| Financial requirements | Number of units/batch sizes, fabrication times/supply times, fabrication costs, reliability, waste and disposal costs |

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## 6.3 Selection criteria

The three tables below give an overview of the current options for performance criteria, component types and rapid technologies.

Table 10 illustrates options for selecting performance criteria for component types. The different performance criteria (artistic, geometric, process-related, mechanical, thermal, electrical, chemical and financial) are compared and assessed for each component type listed.

**Table 10 — Selection of performance criteria for the component types**

| **Component type** | **Performance criteria** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | artistic | geometric | process-related | mechanical | thermal | electrical | chemical | financial |
| Product | + | + | + | + | + | + | + | + |
| Technical prototype | o | + | + | + | o | o | o | o |
| Functional prototype | o | o | + | o | o | o | o | o |
| Geometric prototype | o | + | o | o | o | o | o | o |
| Concept model | + | o | o | - | - | - | - | o |
| + necessary<br>o partially necessary<br>- unnecessary | | | | | | | | |

Table 11 illustrates options for selecting appropriate rapid technologies for the various component types. All processes listed in Clause 4 are assessed in terms of their typical applications for each component type. Table 12 illustrates options for selecting appropriate performance criteria for rapid technologies. The various performance criteria (artistic, geometric, process-related, mechanical, thermal, electrical and chemical) are compared and assessed for each rapid technology listed.

Financial considerations are determined less by the process than by the application.

**Table 11 — Options for selecting appropriate rapid technologies for the component types**

| **Prototype** | **Rapid technologies** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | direct processes | | | | | | | Indirect processes |
| | SL / SL | LS + laser melting | FLM | MJM + PJM | 3DP | LLM | MS + DLP | Rapid tooling |
| Product | o | o | o | - | - | - | - | + |
| Technical prototype | o | + | o | o | - | - | - | + |
| Functional prototype | o | + | + | o | o | o | o | + |
| Geometric prototype | + | + | o | + | o | o | + | o |
| Concept model | + | o | o | + | + | + | o | - |
| + necessary<br>o partially necessary<br>- unnecessary | | | | | | | | |

**Table 12 — Options for selecting appropriate performance criteria for rapid technologies**

| Rapid technology | Performance criteria | | | | | | |
|---|---|---|---|---|---|---|---|
| | artistic | geometric | process-related | mechanical | thermal | electrical | chemical |
| SL / SL | + | + | o | o | o | o | o |
| LS + laser melting | o | + | + | + | + | + | + |
| FLM | o | o | + | + | + | + | + |
| MJM + PJM | + | + | + | o | o | - | - |
| 3DP | + | o | o | - | - | - | - |
| LLM | o | + | o | o | o | - | - |
| MS + DLP | + | + | o | o | o | - | - |
| Rapid tooling | - | + | + | + | + | + | + |

\+ necessary
o partially necessary
\- unnecessary

## 7 Component and process testing

### 7.1 General

The manufacturing of prototypes as products is subject to numerous variables. The processes described above can be used to manufacture prototypes that meet technological and financial requirements only if these factors are controlled, optimised and, if necessary, customised for each order. When assessing prototype quality, comparison with the specific requirements is one of the most important aspects.

Processes used for prototypes typically require the selective application of thermal and/or chemical mechanisms to generate the component. Thus it is possible to produce components with different characteristics, depending on the method used and the process parameters. However, complete testing of all component characteristics is neither cost-effective nor technologically feasible (destructive testing). Therefore, when formulating prototype specifications, their impact on the nature and scope of testing must also be taken into account.

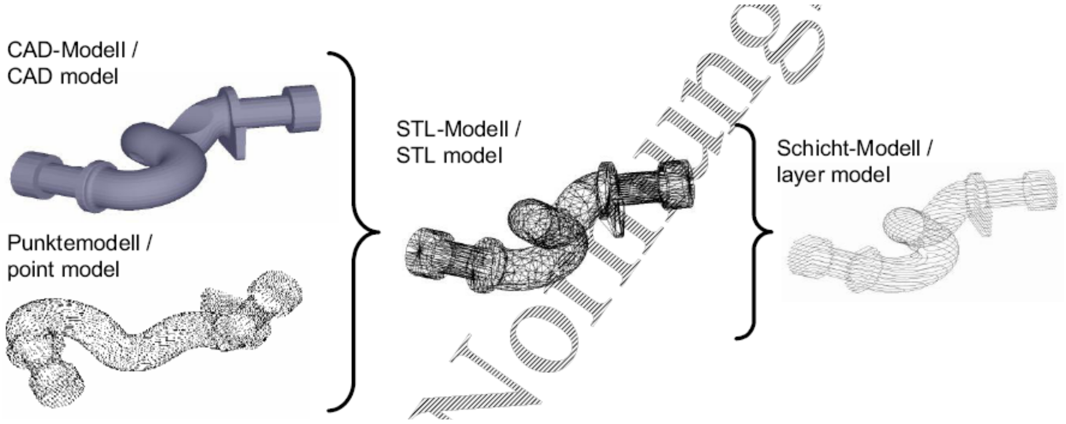

Figure 17 — Data process chain

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## 7.2 Specifications and quality criteria

### 7.2.1 General

The quality of a component, and therefore also that of a prototype, is determined by its suitability for a specific application and therefore by its ability to meet those specific requirements. Since prototypes are generally used to test only a limited number of features, these must be precisely defined during the design and order stage. A definition or discussion that lacks clarity can result in considerable additional costs and delays and/or inferior quality.

The form of specifications depends on the application, the nature of the features being tested and the materials used. Specifications may also vary within one component (e.g. critical mass). Some intrinsic properties depend on the choice of material and the technology used. Relevant test procedures must be stipulated and adhered to.

Table 13 illustrates the typical requirements for each different prototype and specifies whether the component concerned typically requires a high, medium or low specification for each category of performance criteria. This serves to classify the different prototypes in terms of their respective characteristic values. Individual characteristic values must be stipulated in the supply agreement for each application. Quality, productivity and process reliability are controversial specifications which require optimisation. Figure 18 shows that a authoritative process assessment should be performed only on a chosen component.

**Table 13 — Quality criteria for prototypes**

| Criteria category | Concept model | Geometric prototype | Functional prototype | Technical prototype | Product |
|---|---|---|---|---|---|
| **Geometric sizes** (dimensions, geometry, angle, surface, etc.) | + | +++ | ++ | ++ | +++ |
| **Mechanical properties** (strength, hardness, elongation, etc.) |  | + | ++ | +++ | +++ |
| **Material properties** (weight, porosity, conductivity, isotropy, chemical and temperature resistance, etc.) |  |  | ++ | +++ | +++ |
| **Processing properties** (weldability, machinability, coatability, paintability, etc.) |  | + | ++ | +++ | +++ |
| **Appearance** (shape, feel, texture, colour, etc.) | +++ | ++ | + | ++ | +++ |
| **Efficiency and organisation** (costs, delivery times, flow, etc.) | +++ | ++ | + | ++ | +++ |
| + necessary<br>++ partially necessary<br>+++ unnecessary |  |  |  |  |  |

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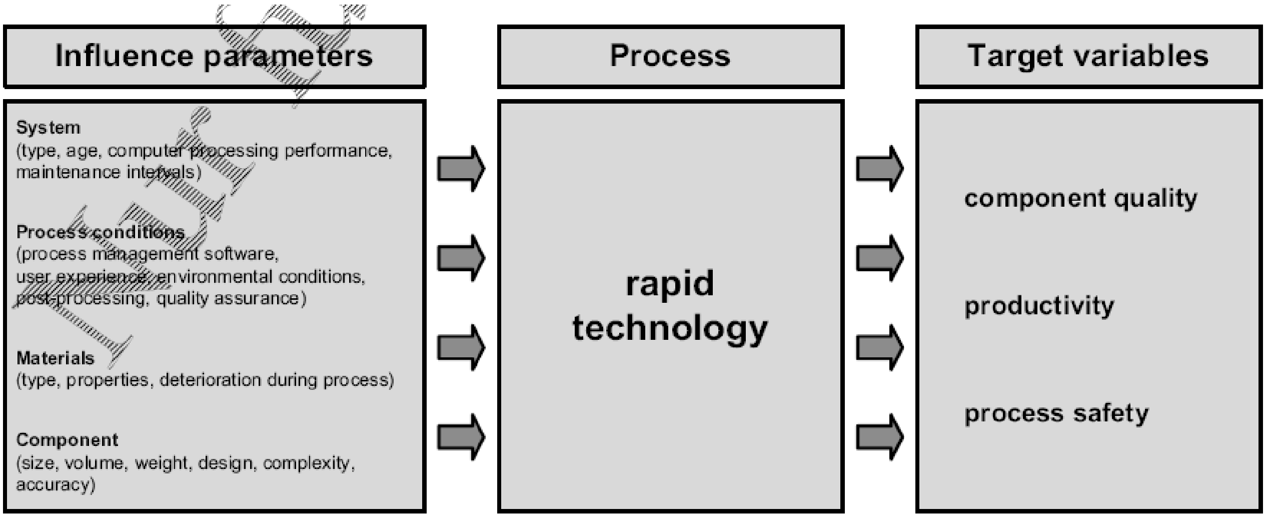

**Figure 18 — Illustration of influence parameters and target variables: rapid technology process**

### 7.2.2 Testing the source material

The condition of the source material can have a significant impact on the properties of the component. Significant variations can arise due to storage and reutilisation of the source material, and batch variations. Essential data relating to the source material must be provided by the material supplier in the form of safety data sheets.

### 7.2.3 Monitoring the process

All rapid prototyping systems are computer-assisted. Therefore it is fundamentally possible to record and statistically analyse important process-related data such as process temperature, process climate, time lapse and process speeds, and other process-related parameters. The need for and scope of process monitoring depends on the required or anticipated reproducibility of the process and component quality for each application.

The routine construction of test specimens is an established method of assessing and documenting the process. This approach reveals the complex correlations between processes, manufacturing conditions, materials and component design.

Artistic specifications can generally be assessed quickly and simply by means of a visual examination. Component testing of the geometric specifications (i.e. strength and load-bearing capacity) is time-consuming and expensive. The construction of test specimens under process conditions has proved valuable in practice as a means of solving this problem. The process stability can also be monitored repeatedly at different intervals at a constant geometry. Test specimens should be as small and flat as possible in an effort to reduce time and keep costs to a minimum. On the other hand, larger test specimens are called for to improve the testing of dimensional accuracy, reproduction accuracy and process stability. The form of test specimen to use and the nature and frequency of testing must be stipulated for each application. The sample test specimen in the Annex (Figure A1) and the density determination of the components are established methods of assessing process accuracy and stability.

## 7.3 Testing the component

Quality is assured by testing and examining the actual component. The inspection effort can form a substantial part of the manufacturing costs, depending on the scope of inspection required. It can be significantly reduced using sampling inspection methods common to serial production. However, prototype manufacturing often does not produce the necessary number of identical parts needed for this approach. Sample testing can be expanded to a certain extent to include geometrically different parts on the basis of the process capability test described above. However, in many cases, only a limited number of prototype

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characteristics is critical and must be fully tested. Geometric tests of dimensional, shape and position tolerance (e. g. tactile measurement) and material tests (hardness, strength, etc.) are normally carried out, depending on the application and type of component. Functional tests and special tests must be specifically arranged, depending on the component and industry.

The inspection effort must be set out in the contract specification or supplier agreement prior to manufacturing to enable the manufacturer to estimate the amount of time required and the customer to estimate the associated costs.

## 8 List of requirements and supply agreements

The special characteristics of additive fabrication processes require special agreements between the customer and the supplier which record in detail the process handling. This may include delivery terms, including packaging arrangements, price delivery date, delivery and place of delivery, for example (see Annex). Information about the application, and consequently the type of component required, should also be included in individual agreements between the customer and the supplier (see clause 3).

Technical supply agreements are no substitute for contractual regulations. They do not regulate liability or warranty issues and do not encroach upon general terms and conditions. Statutory regulations apply if no special supply agreements have been made.

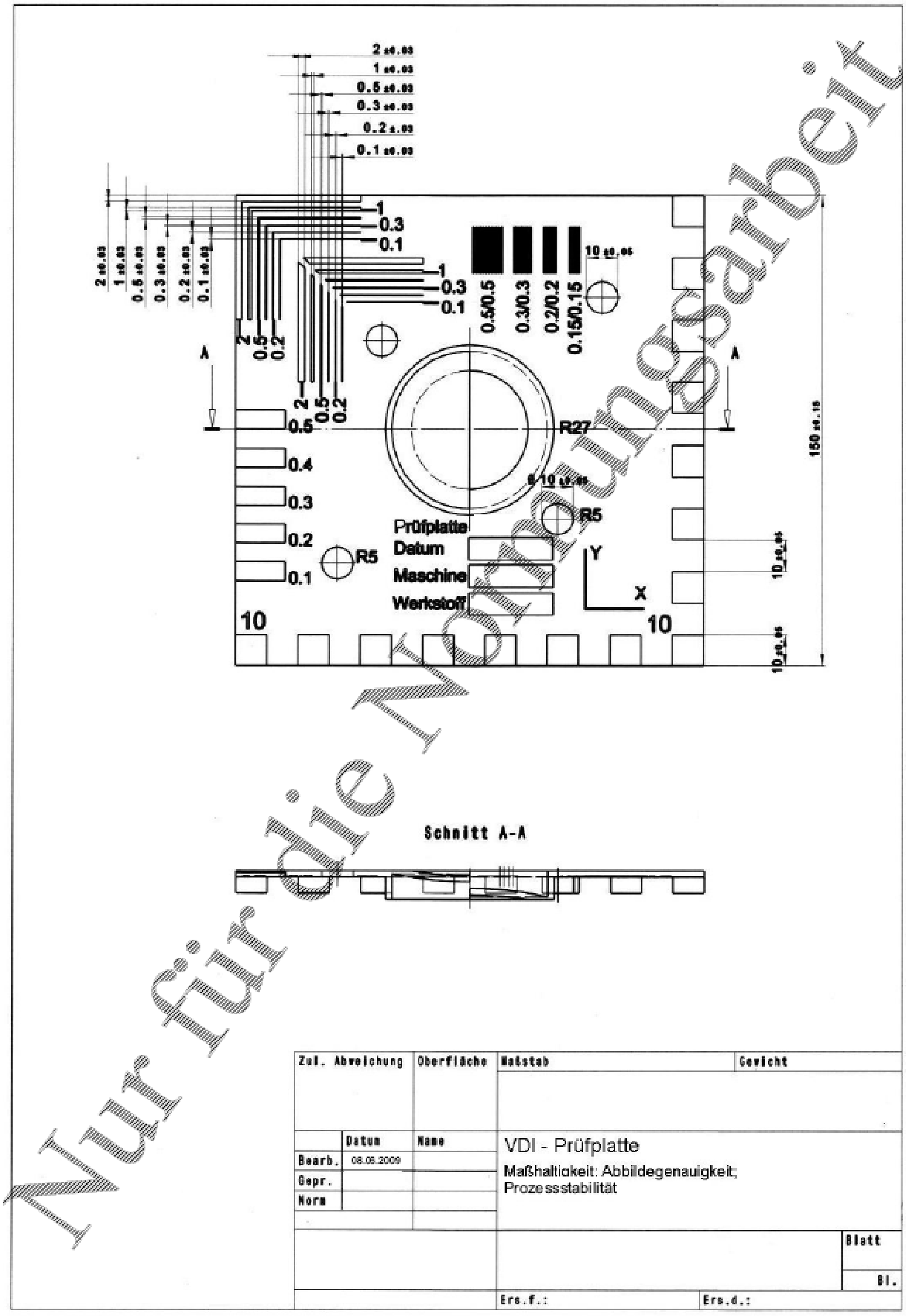
## 9 Safety and environment

The technical, organisational and personal requirements for working with rapid prototyping technologies and materials must be taken into account when considering safety and environmental aspects. In particular, the contractor and those responsible for occupational health and safety (supervisor, foreman, plant manager, scope of health and safety extending up to the management and board of directors) must ensure compliance with these aspects. Statutory national health and safety guidelines, especially local authority guidelines and laws, must be observed. Manufacturers safety data sheets must be consulted if necessary.

# Annex A
(informativ)

# Addendum

## A.1 Addendum to 7.1.2



Nur für die Normungsarbeit

Figure A.1 — Test specimen to assess process accuracy and stability

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## A.2 Addendum to clause 8

### A.2.1 General information

The following general information should be recorded in individual discussions between the customer and supplier:

a) Service provider information:

   1) date, time;

   2) person in charge, department;

   3) tender number, miscellaneous filing criteria.

b) Customer information:

   1) contact, sector, department;

   2) contact for CAD, RP processes, interfaces, etc.;

   3) phone, fax, e-mail;

   4) delivery address (department, gate, building);

   5) invoicing address if different;

   6) confidentiality;

   7) miscellaneous remarks.

c) Services required:

   1) CAD modelling;

   2) concept model, geometric, functional and technical prototypes, product;

   3) secondary operations (production part, casting);

   4) miscellaneous services;

   5) delivery date.

### A.2.2 Model information

Scope of work:

a) image of model (sketch, screenshot);

b) size of model, possible divisibility;

c) number of models;

d) miscellaneous;

Application (choice of process and material):

a) intended use;

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b) period of use;

c) position of sectional planes;

d) recommended technology (LS, FLM, etc.);

e) miscellaneous.

## A.3 Relevant quality characteristics required

### A.3.1 General

Refer to clause 5 and clause 6:

- dimensional accuracy
  - absolute and relative errors in mm or in %, fit, shape tolerance, information about areas of increased accuracy
- surface finish
  - roughness (*Rz* value), polished/ground, etc., surface coating is necessary
- mechanical load
  - permitted strain in N/mm2, orientation, static, dynamic, elongation at break in %, elasticity, E-module in N/mm2
- thermal load
  - special requirements
- chemical load
  - special requirements
- biocompatibility
  - special requirements
- other desired characteristics
  - (density, transparency, conductivity, etc.)
- error tolerance
  - particularly when casting, potential interactions with requirement specifications (DIN, VDI, etc.)
- miscellaneous

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### A.3.2 Geometric information

- check geometry using sketches or drawings
- basic structure, complexity (compact part, hollow part, flat part, pipes, boxes, turbine/propeller, profile, etc.)
- regularity
- functionality, interlocking structures, fits
- wall thickness variations
- free-standing ribs (shape, number, position)
- mould drafts
- undercuts (shape, number, position), solid areas (shape, number, position), minimum wall thickness (shape, number, position)
- inaccessible areas, cavities, channels (shape, number, position)
- division
- miscellaneous problem areas
- Can a similar part be viewed for comparison (even one with different geometry)?
- Miscellaneous

### A.3.3 Information about order process

Data preparation:

- 3D data available, if yes, which CAD system (Pro-E, CATIA, I-DEAS, etc.)? Clarify interface if necessary IGES, STL, etc.);
- quality of STL data (see Section 4);
- data by DVD, e-mail, etc.;
- date transfer of (authoritative dataset);
- data security;
- miscellaneous;

Deadlines:

- delivery date (time and place);
- miscellaneous;
- acceptance.

The wide range of parameters described above is also reflected in consultations with the customer. During the course of these discussions, the number of parameters may be significantly reduced, or even increased.

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