Additive manufacturing
(Rapid Prototyping)

Ing. Petr Keller, Ph.D.

Additive manufacturing – content

Lectures: (approx. the first half of the semester - both blocks)

- Definition of additive technologies, comparison with other manufacturing technologies, advantages and disadvantages
- Principle of parts building using additive technologies, basic procedure of manufacturing preparation
- Input format of 3D data for additive technologies, properties
- Classification of additive technologies according to the standard, basic division according to the form of materials used
- Introduction of additive technologies based on input material in the form of liquid photopolymers
- Introduction of additive technologies based on input material in the form of powders (both metallic and non-metallic)
- Introduction of additive technologies based on input material in the form of solid material (plastics, waxes, metals, etc.)
- Technological design for additive manufacturing
- Technology of vacuum casting into silicone moulds
- The future of additive technologies, hybrid technologies

Additive manufacturing – content

Exercises: (approximately the second half of the semester - both blocks)

- Assignment of individual work - design of own part for subsequent preparation of manufacturing and manufacturing using additive technologies

- Assignment of the preparation of a short paper on the topic of „additive technologies“

- Preparation of manufacturing and manufacturing of designed parts (see above), the influence of parts orientation on its properties

- The so-called post processing - completion of printed parts

- Practical presentation of selected technologies available in the laboratory (laboratory under CxI - seminar tutor Ing. Šafka, Ph.D.)

- Experiments with so-called RepRap printer

- Presentation of short presentations on the topic of additive technologies, credit

Additive manufacturing – literature

The basis are lectures and exercises + materials from e-learning portal (elearning.tul.cz)

Other literature:

[1] GEBHARDT A. *Understanding Additive Manufacturing.* Munich: Verlag, 2011. ISBN 978-3-446-42552-1.

[2] SRIVATSAN, T. S. a T. S. SUDARSHAN. *Additive manufacturing: innovations, advances, and applications.* Boca Raton: Taylor & Francis, 2016. ISBN 9781498714785.

[3] CHEN, Tin-Chih Toly. *3D printing and ubiquitous manufacturing.* Cham, Switzerland: Springer, [2020]. SpringerBriefs in applied sciences and technology. ISBN 978-3-030-49149-9.

[4] DIEGEL, Olaf a Axel Nordin, Damien Motte. *A practical guide to design for additive manufacturing.* Singapore: Springer, [2020]. Springer series in advanced manufacturing. ISBN 978-981-13-8283-3.

Additive manufacturing – the credit and exam

Credit:

- fulfilment of all teaching tasks
  - part for 3D printing
  - short presentation
  - fulfilment of Dr. Šafka tasks
- (3 absences allowed)

Exam:

- written test based on the material covered (lectures and exercises)
- oral – analysis of a written test + additional questions

The dates of the exam will be specified at the end of the semester, after a previous agreement it is possible to take individual terms (if necessary).

Additive technology - possible distance learning

Teaching is currently planned only in person.

If distance (online) teaching will be ordered, it will take place at the time of standard teaching according to the schedule via Google Meet.

You do not need to register anywhere to connect to Google Meet - you have an account for Google services automatically with a university account – so please use your university email to log in to Google services – you will be automatically redirected to the TUL login page where you enter your LIANE username and password. You may have trouble connecting if you will use your private Google Account.

A link to join the lectures via Google Meet will be sent to the e-mail address you have on STAG – usually the *name.surname@tul.cz* e-mail.

Additive technologies (manufacturing) – definition

Additive manufacturing is a term that describes technologies that create 3D objects by adding material layer by layer. The materials used today can be plastics, metals, glass, ceramics, concrete, etc. One day, maybe even human organs.

Other commonly used names for additive technologies (manufacturing):

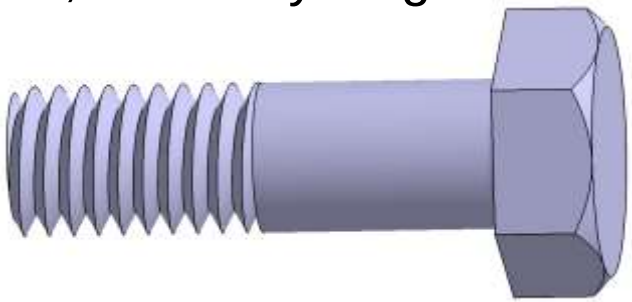
- Rapid Prototyping (RP)
- Additive Manufacturing (AM)
- 3D printing (attention - one of the AM technologies is directly called 3D printing)

Advantages of additive technologies

- **Very complex components can be manufactured.**
- For some technologies, multiple materials can be combined in one print.
- Easy manufacturing preparation.
- Own process of part building is usually a fully automatic process.
- With few exceptions, less wasted material.

Disadvantages of additive technologies

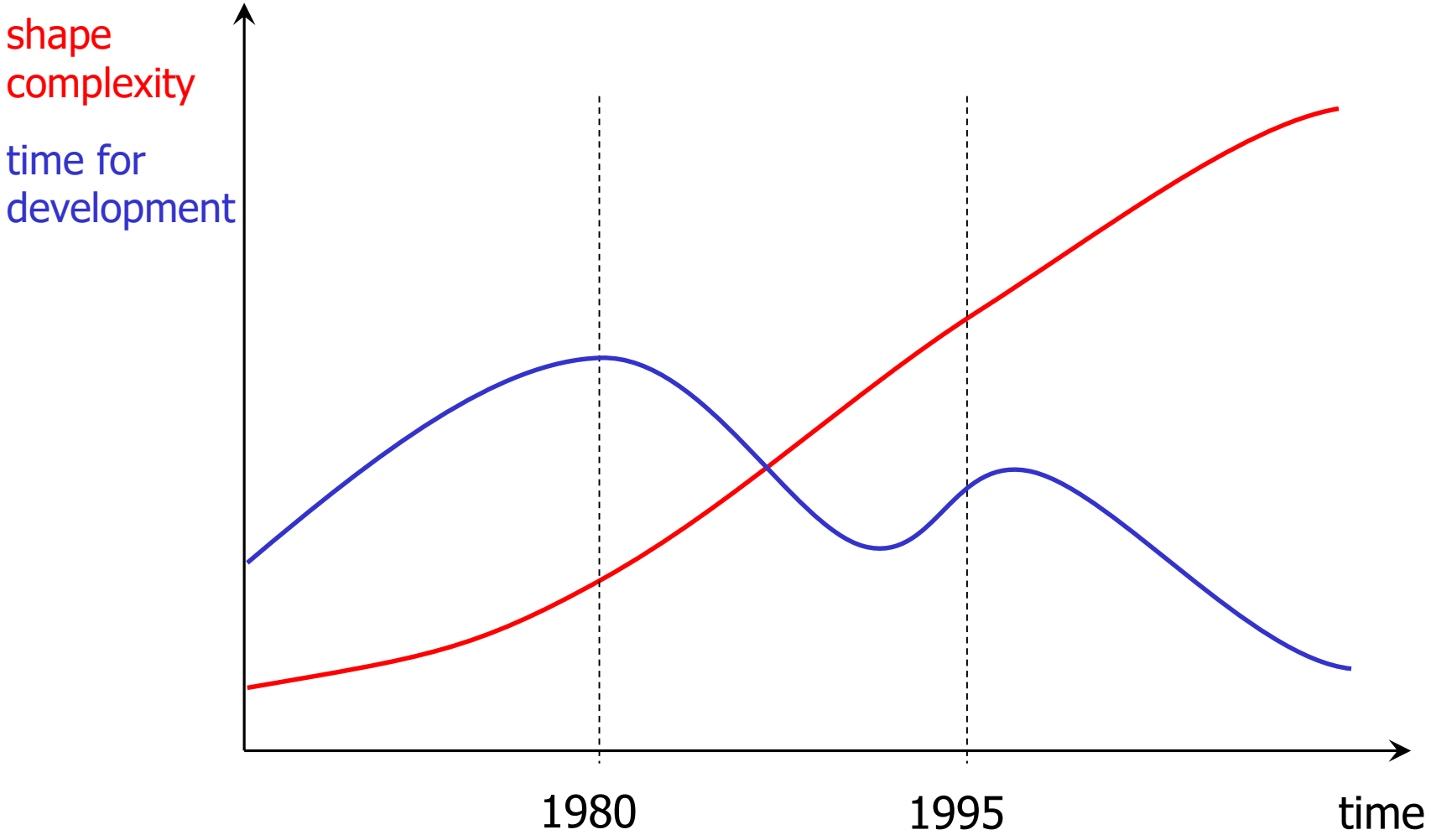
- Worse dimensional and geometric accuracy, often worse surface quality.
- Additive manufacturing components often have worse mechanical properties compared to other manufacturing technologies.
- Machines for AM are not universal - they allow production with only one given method.
- Technologies usually require so-called post-processing (finishing of parts after its building).
- Problem to continue of building when the process was interrupt, for example after a power failure.
- Additive technology changes the demands on the design of parts - other (higher) possibilities of geometric shapes, but everything have to be in a 3D model (cannot be simplified).



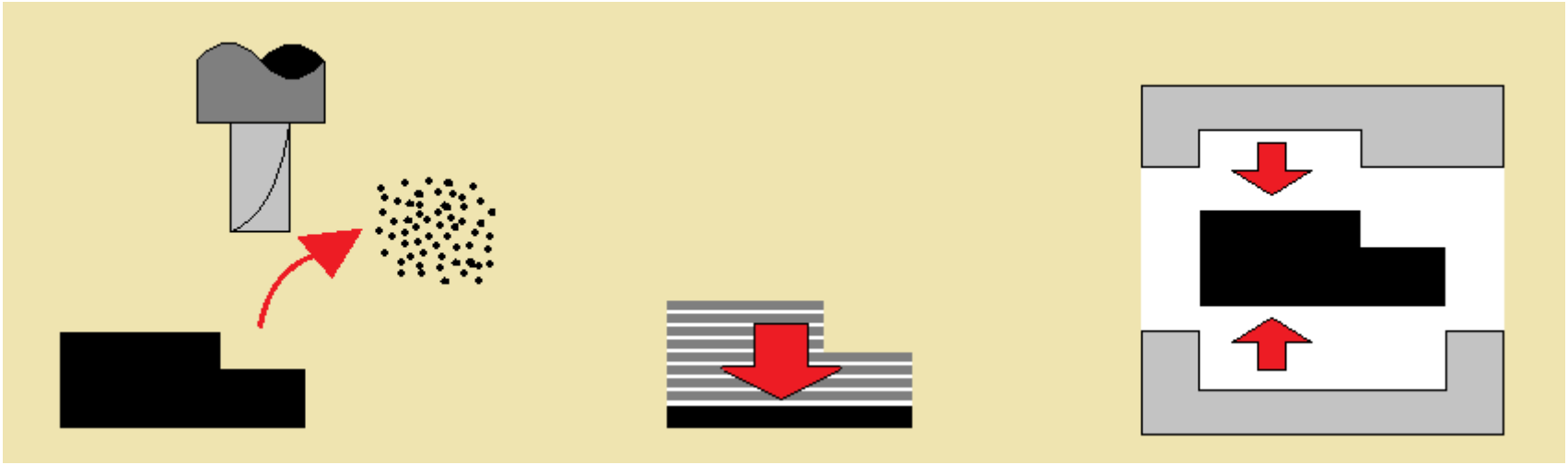
2D drawing,
conventional manufacturing

2D/3D CAD
CNC machines

Rapid Prototyping
Additive technologies



Comparison of basic manufacturing technologies

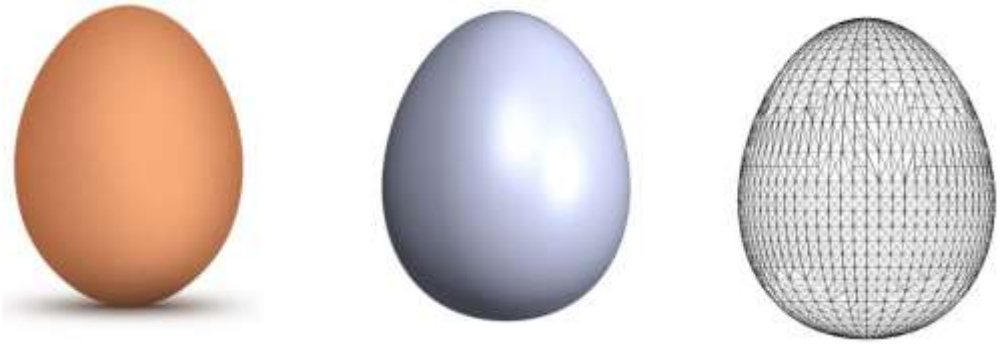


Removing of material
- machining
- tools
- different types
  of machine tools
  for different shapes

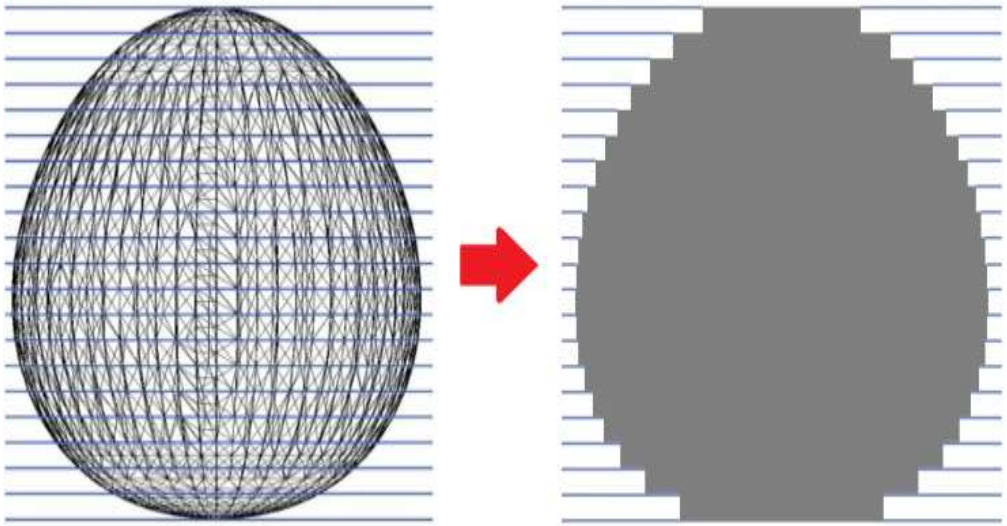
Adding material
- no tools

Forming of material
- forming, bending,
  plastics injection
- complicated tools

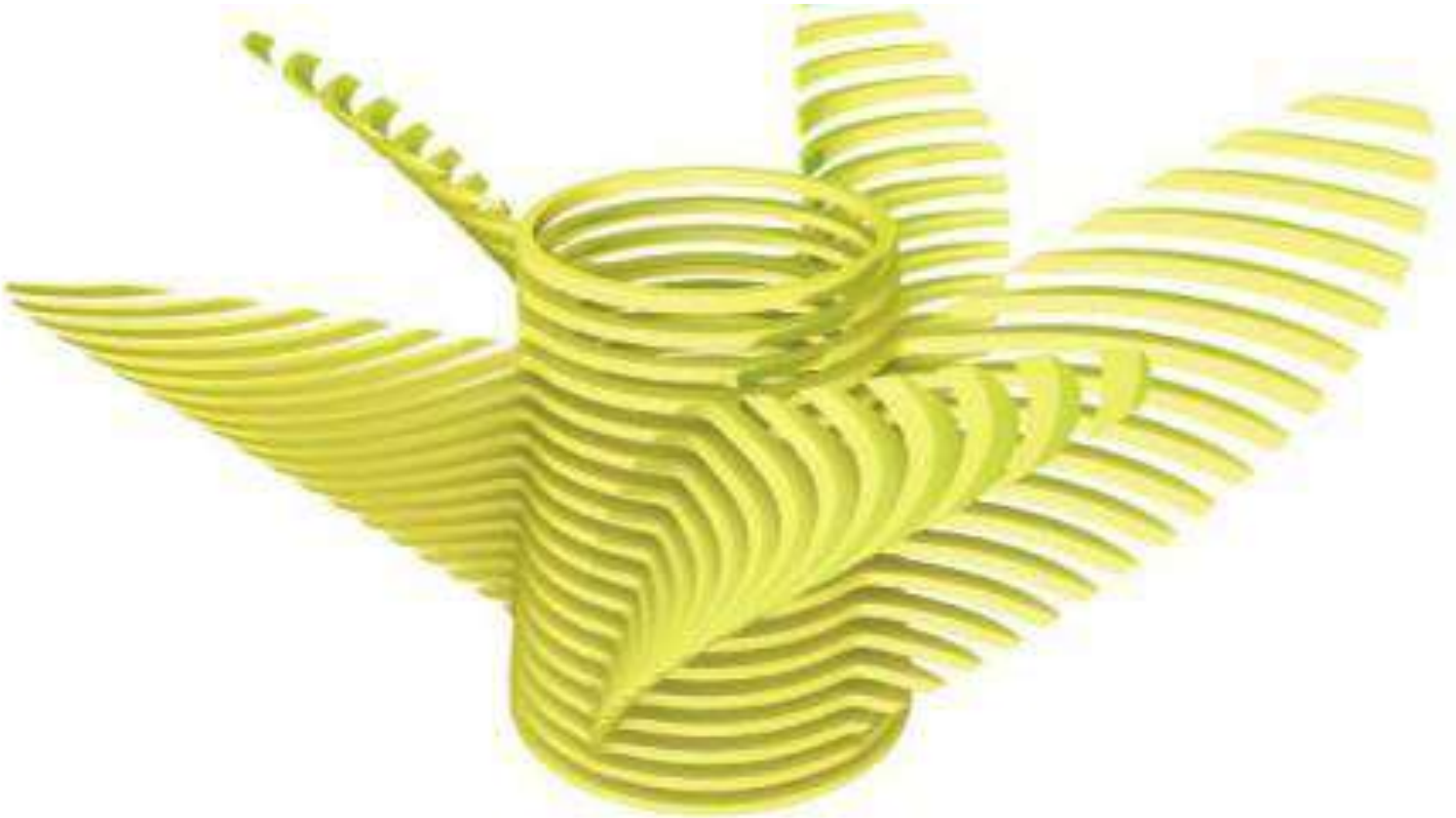
Principle of manufacturing using additive technologies



- 3D object is obtained by layering of 2D shapes (layers) on top of each other
- Simple concept of the manufacturing process – excellent for automation

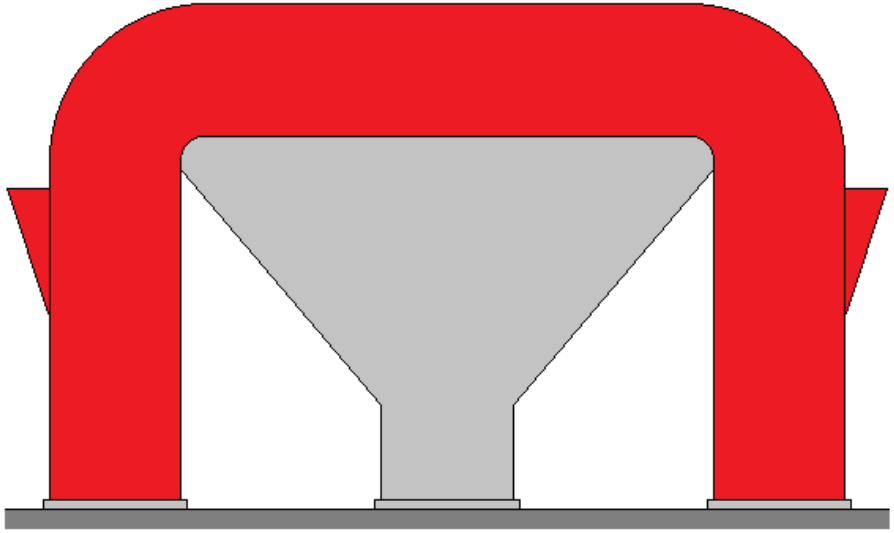


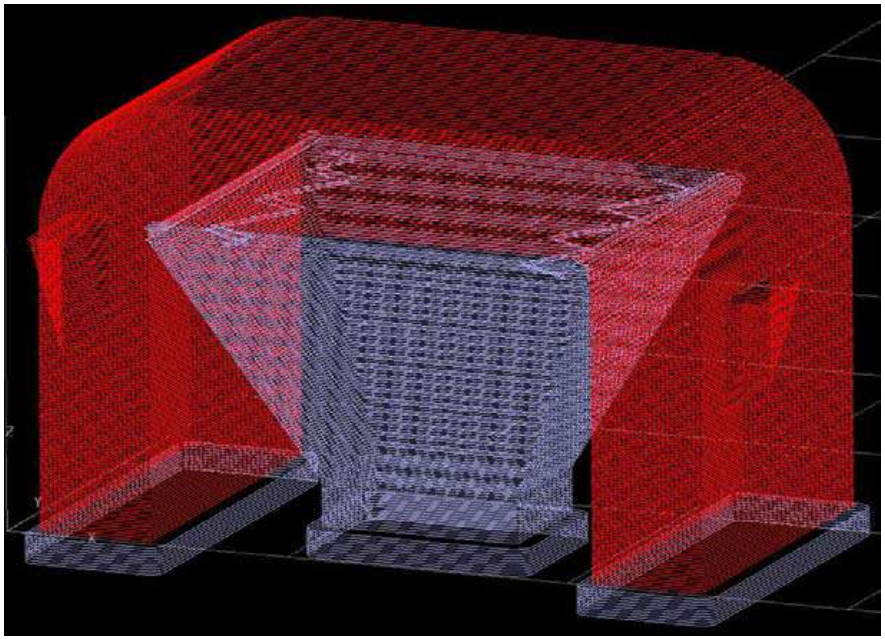
Objects are created from layers



Some additive technologies need to build so-called supports

example of FDM technology

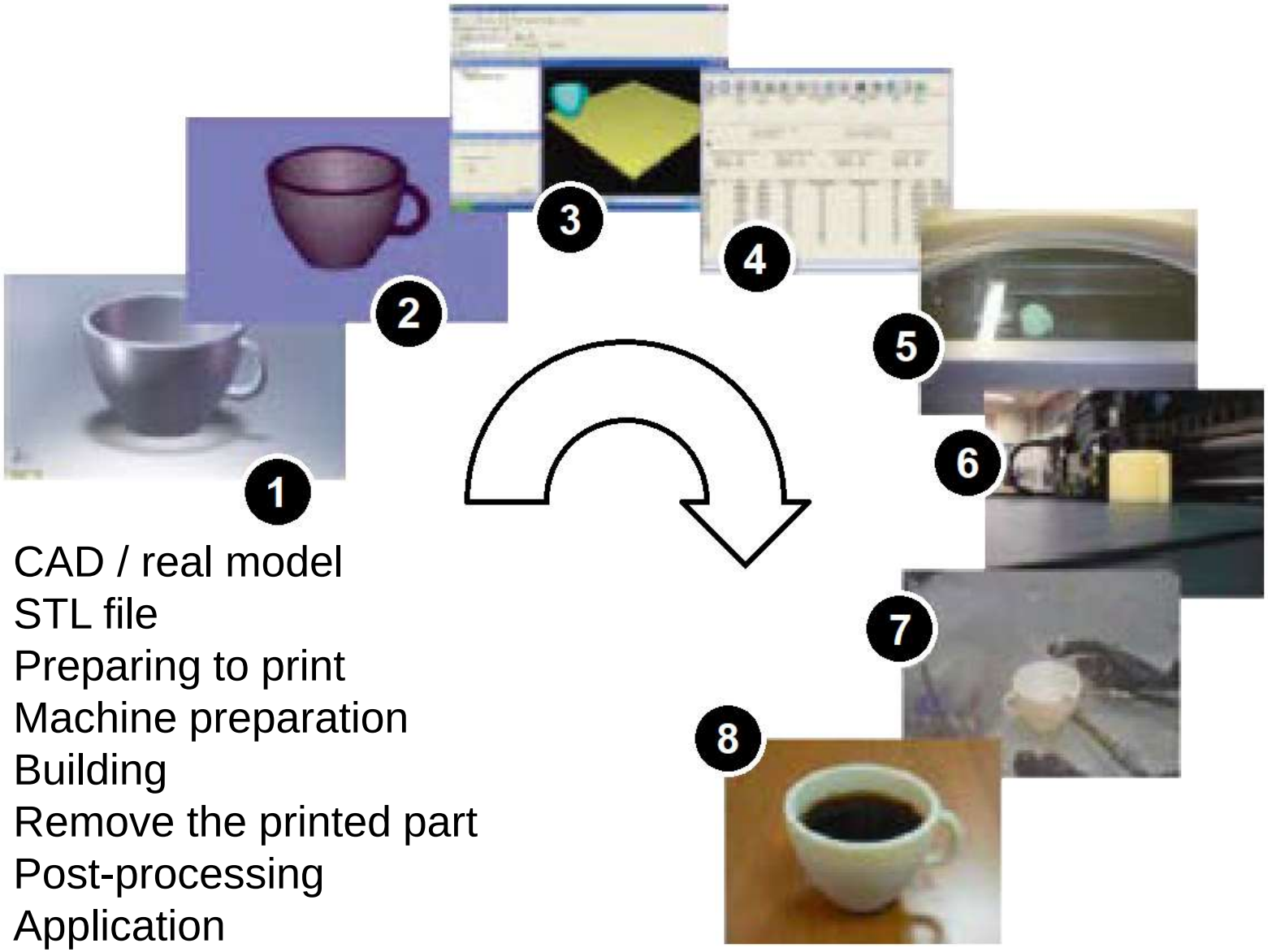




Examples of the use of additive technologies

- **Concept** – sharing of all ideas
- **Suitability** – dimensional and other testing of design
- **Shape** – evaluation of aesthetics and ergonomics of parts
- **Functionality** – testing in the work environment
- **Offer** – valuation of the product in terms of offer
- **Marketing** – communication about design with the customers
- **Production** – especially special parts (aviation, aerospace, medicine, motorsport,…)

Basic common steps of additive technologies



1 CAD / real model
2 STL file
3 Preparing to print
4 Machine preparation
5 Building
6 Remove the printed part
7 Post-processing
8 Application

How to get data in STL format

STL – Standard Triangulation Language

↔ description of the outer surface of the 3D model using a triangular mesh

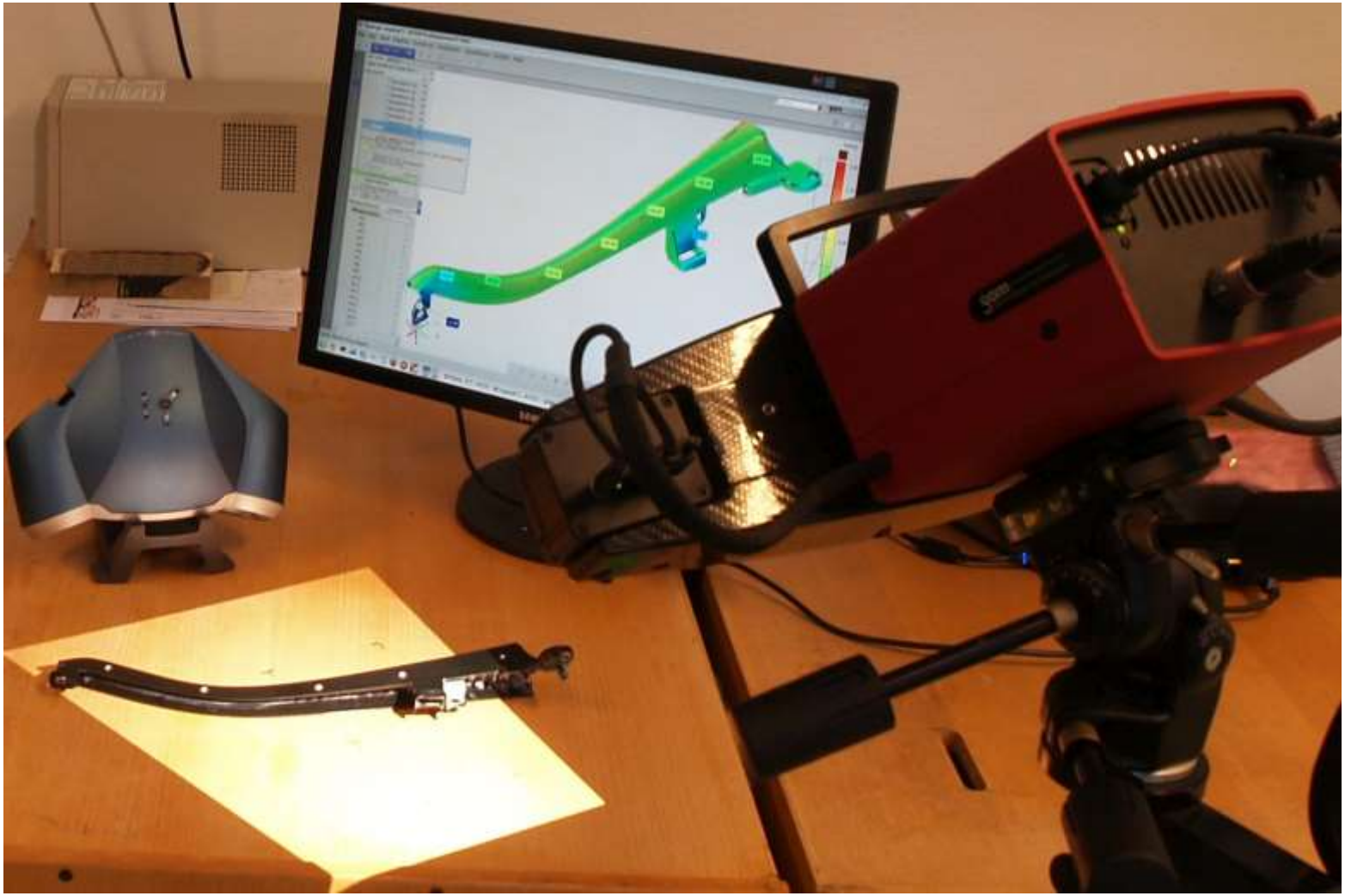
•**3D model in CAD** → File / Save as… / *.STL

- solid body usually without problems
- surface modelling - pay attention to the complete closure of all connected surfaces

•**3D scanning** – from a real part (model) so-called point cloud (points of the part surface in coordinates X, Y, Z) → polygonization → STL data

- it is usually necessary to next work with the resulting data, in particular to fill in the holes, etc.

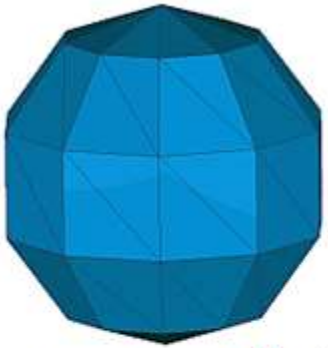
How to get data in STL format



scanning of a real part using the optical scanner Atos

STL format representation

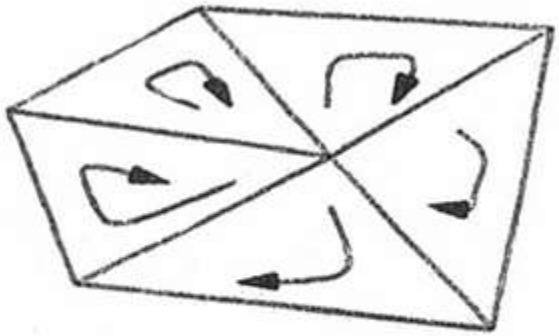
sphere



coarse tessellation

fine tessellation

An example of the representation of triangles in stl data:

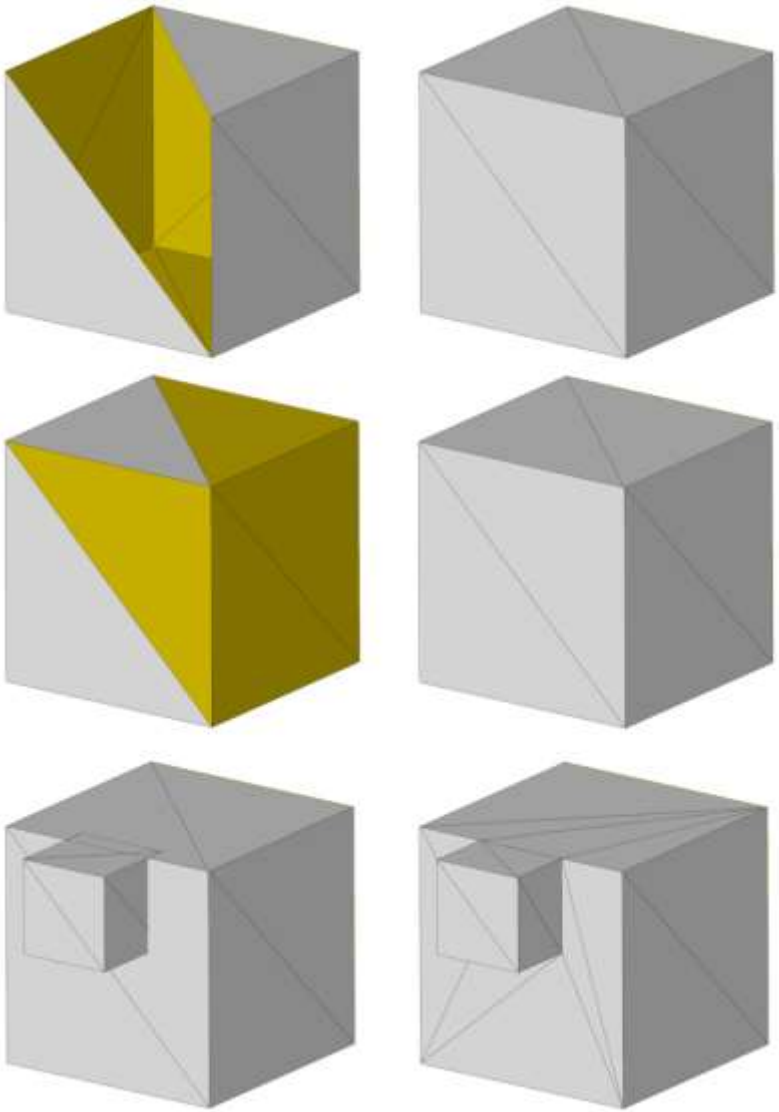


```
facet normal -9.462985e-001  3.177274e-001  5.973599e-002
  outer loop
    vertex -5.000000e+001  2.686733e-015  1.467769e-015
    vertex -4.045085e+001  2.579150e+001  1.408996e+001
    vertex -4.045085e+001  2.914764e+001 -3.760846e+000
  endloop
endfacet
facet normal -9.462985e-001  2.921588e-001 -1.384280e-001
  outer loop
    vertex -5.000000e+001  2.686733e-015  1.467769e-015
    vertex -4.045085e+001  2.914764e+001 -3.760846e+000
    vertex -4.045085e+001  2.137037e+001 -2.017514e+001
  endloop
endfacet
facet normal -9.462985e-001  1.549954e-001 -2.837172e-001
  outer loop
    vertex -5.000000e+001  2.686733e-015  1.467769e-015
    vertex -4.045085e+001  2.137037e+001 -2.017514e+001
```

Possible errors in STL data

with errors

good



Holes - missing triangles

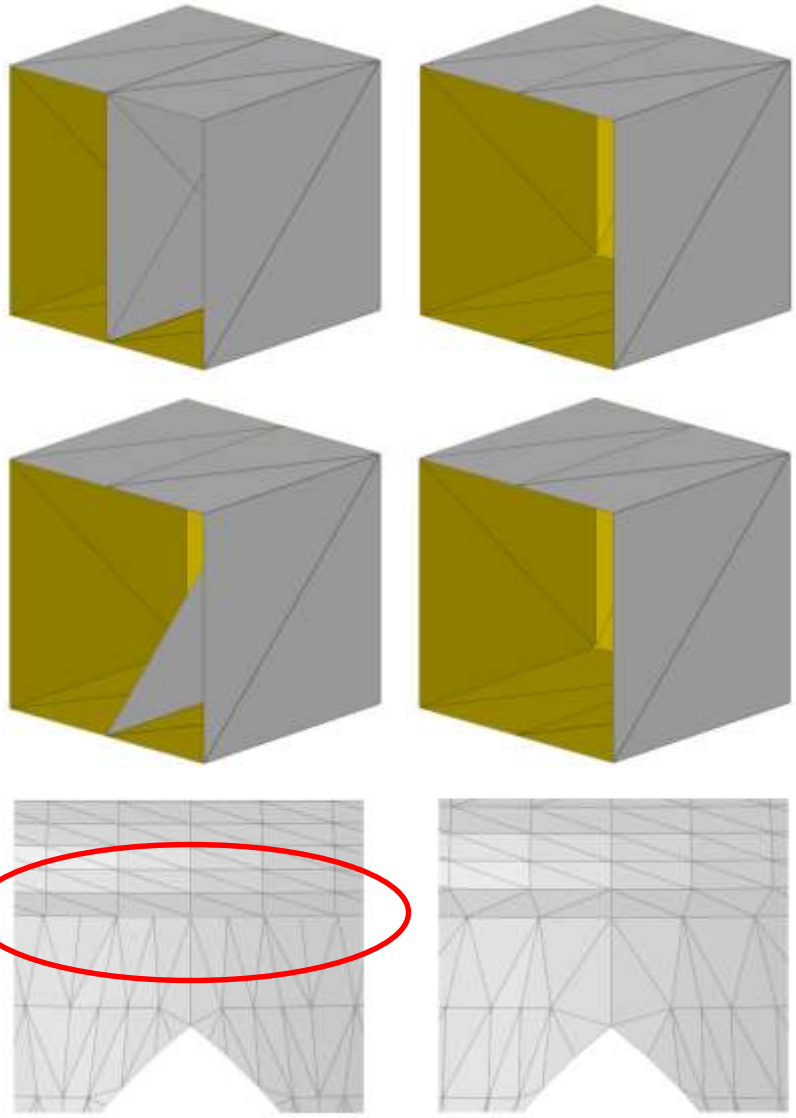
Reverse direction of normal

Intersecting triangles

Possible errors in STL data

with errors

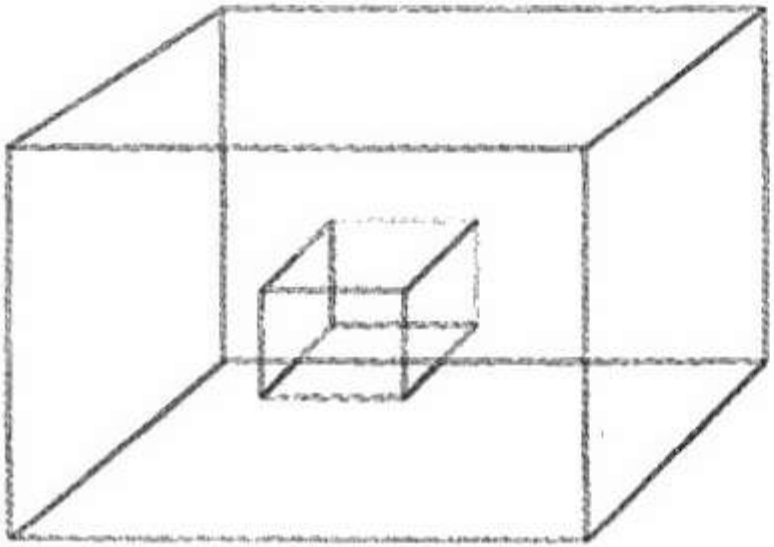
good



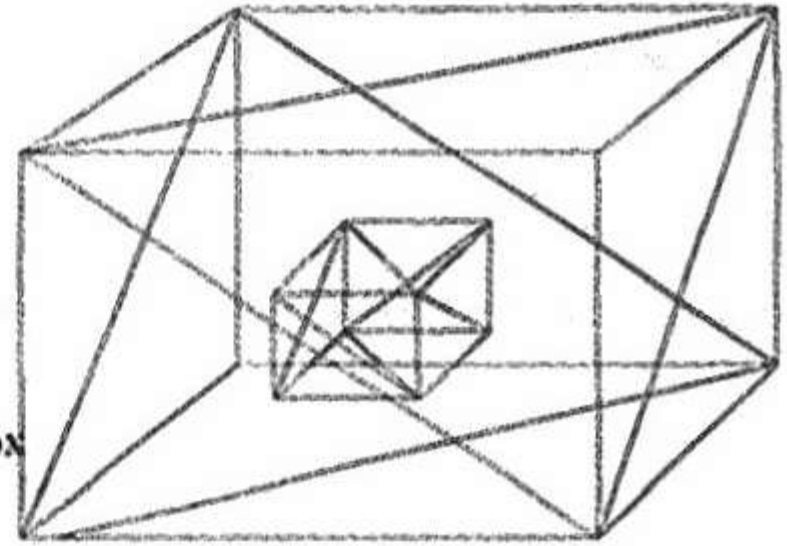
Overlapping triangles
(one side of the model cut off)

Extra triangle(s)
(one side of the model cut off)

Non-contiguous triangles (do not have common vertices)

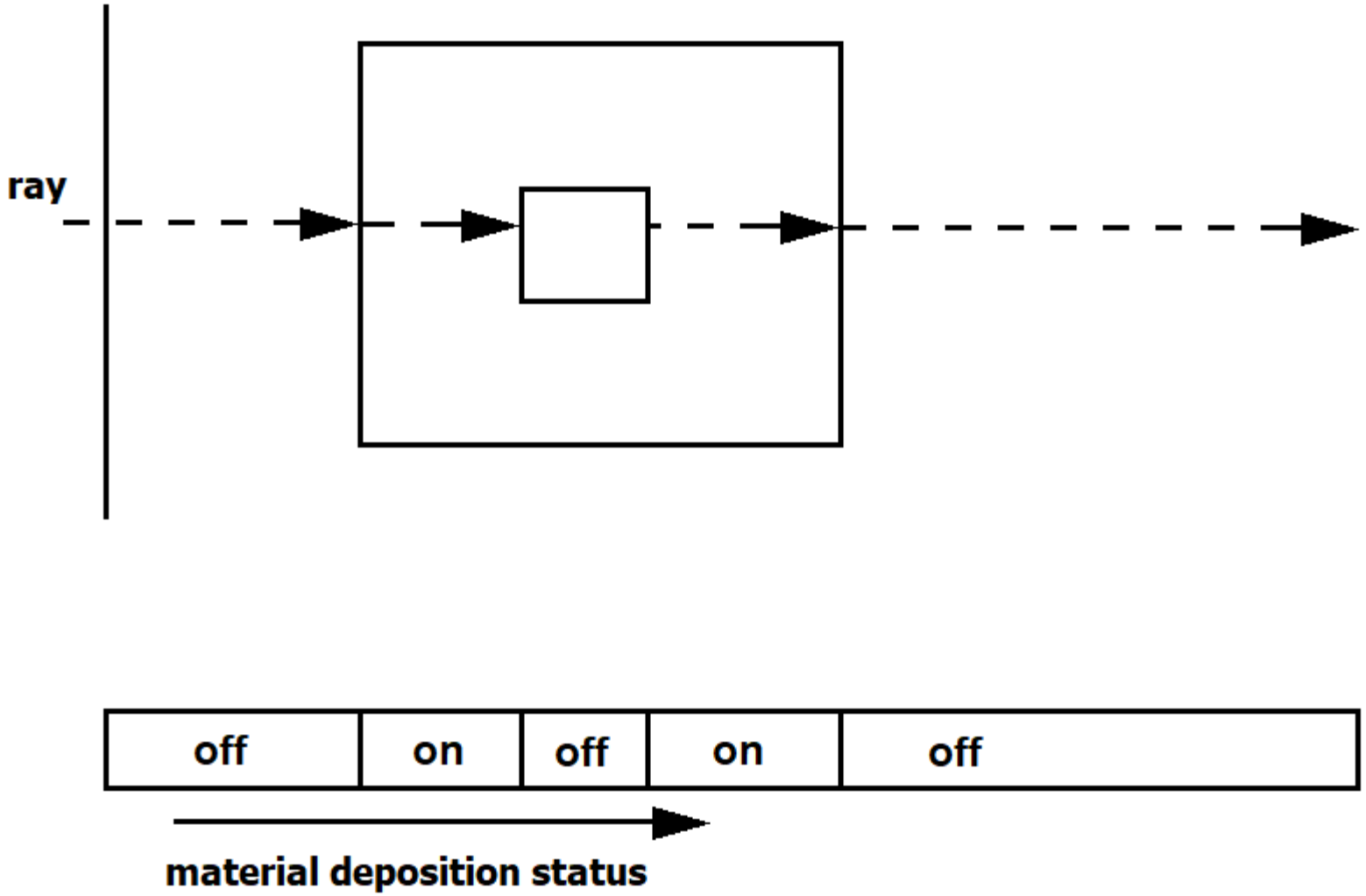


a hollow box

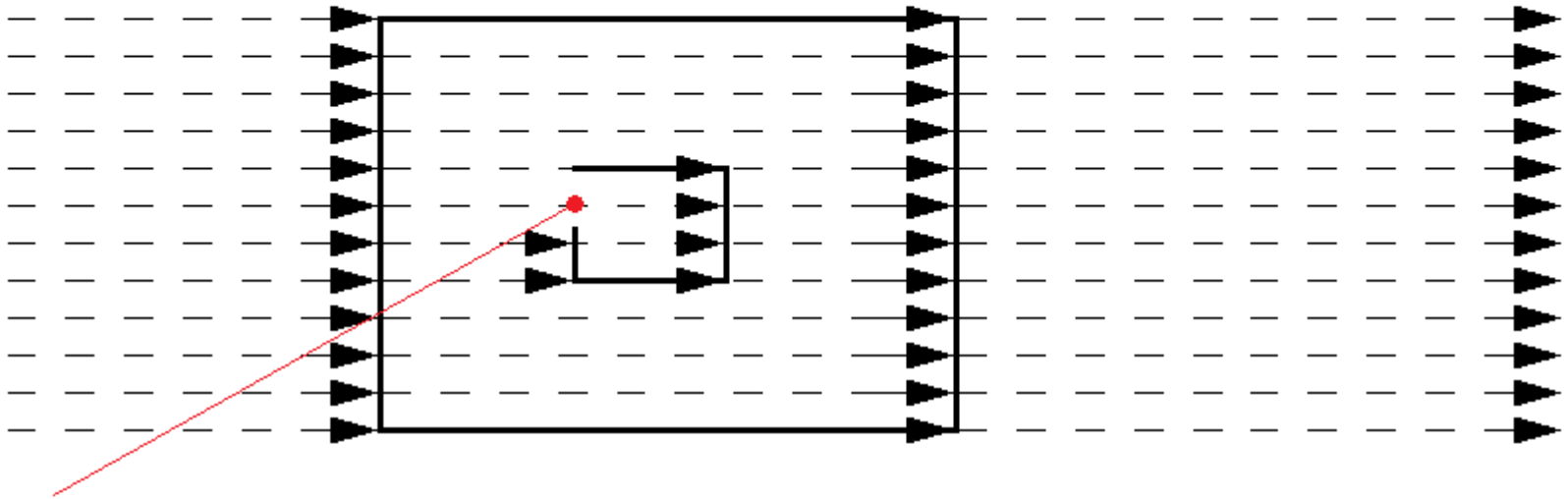


an STL tessellated box

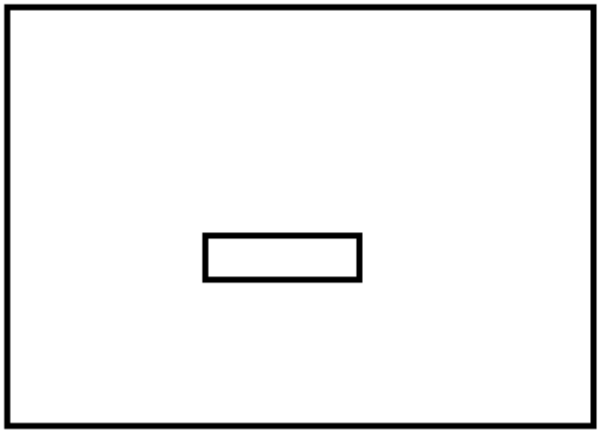
Principle of STL data processing:



Application of the previous principle to stl data with error:

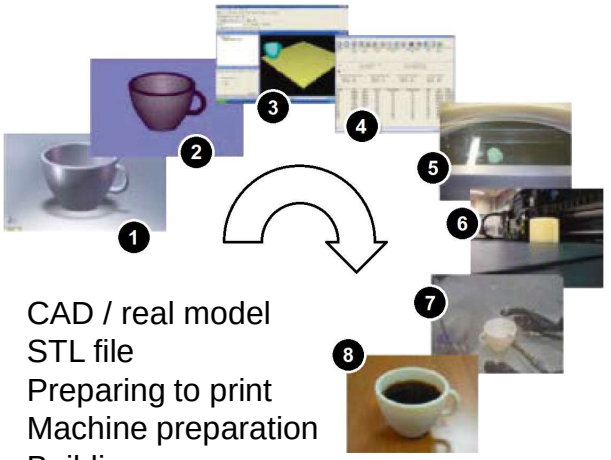


hole in the mesh



the final shape of the manufactured part

Preparing to print



1 CAD / real model
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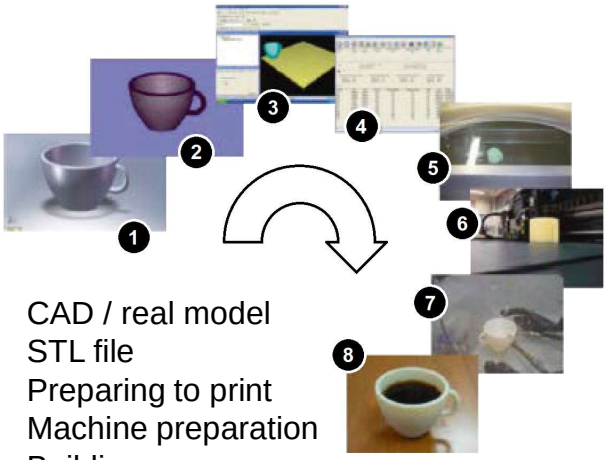
8 Application

- File verification (fix errors)
- Part orientation
- Scaling
- Layer thickness setting
- Generating support
- Setting up multiple copies of a part
- Arranging multiple different parts in the working space of the machine
- Division of large parts
- Simulation of the printing process
- Calculation of time / price estimate

http://nexxttech.com/printers

Machine preparation



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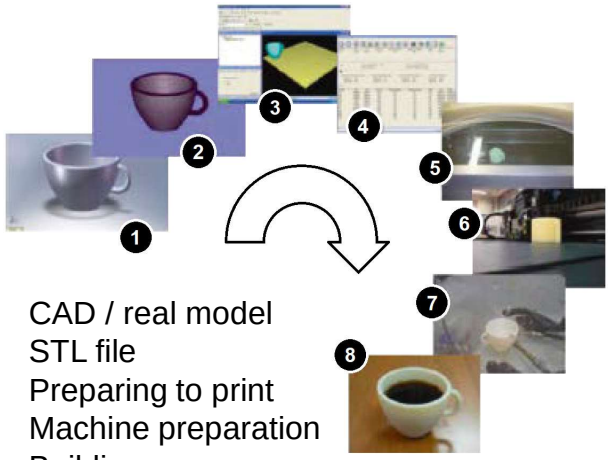
- Setting the print parameters on the machine
- Material preparation
- Warming up
- Modification of the environment in the machine chamber (inert atmosphere, etc.)
- Calibration of print heads
- etc. - depends on the technology used

Building – 3D print



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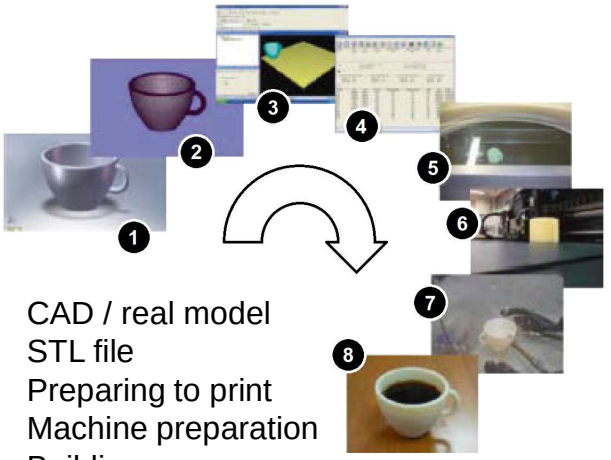
- Usually a fully automatic process
- Typically printing overnight / weekend, etc.

www.ksa.tul.cz

Post-processing



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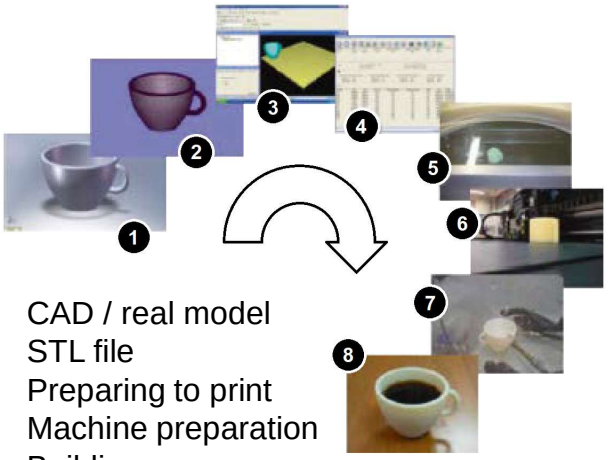
- Part hardening
- Removal of supports
- Annealing to remove internal stress
- Finishing the surface of parts
- etc. - depends on the used technology

http://1prototype.com/freeform_parts.html

Application

Usage of printed parts:

- Functional parts
- Checking of assembly ability
- Prototypes - function checking
- Visualization / presentation of parts
- Models for metal castings
- Development / research
- etc.



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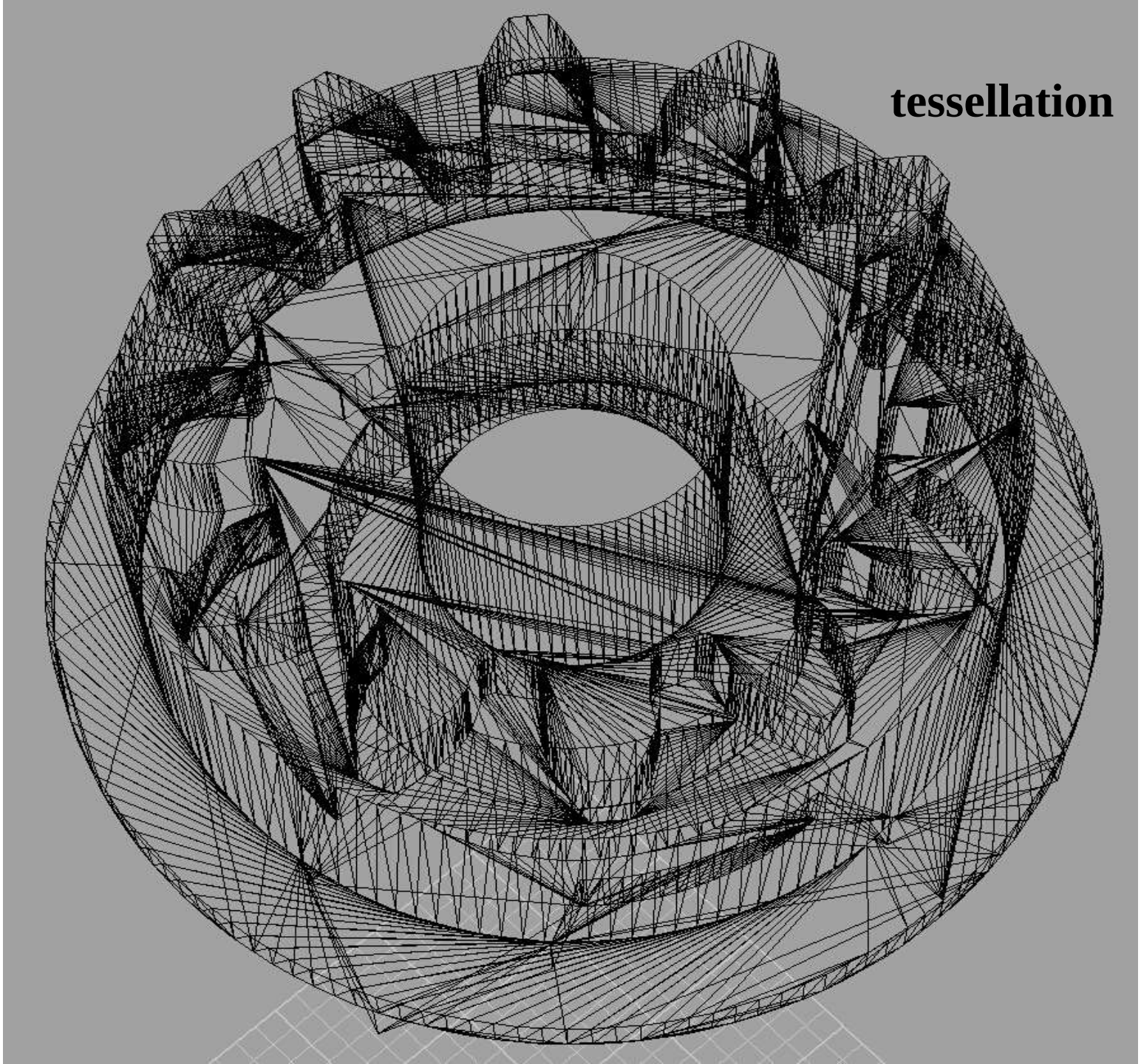
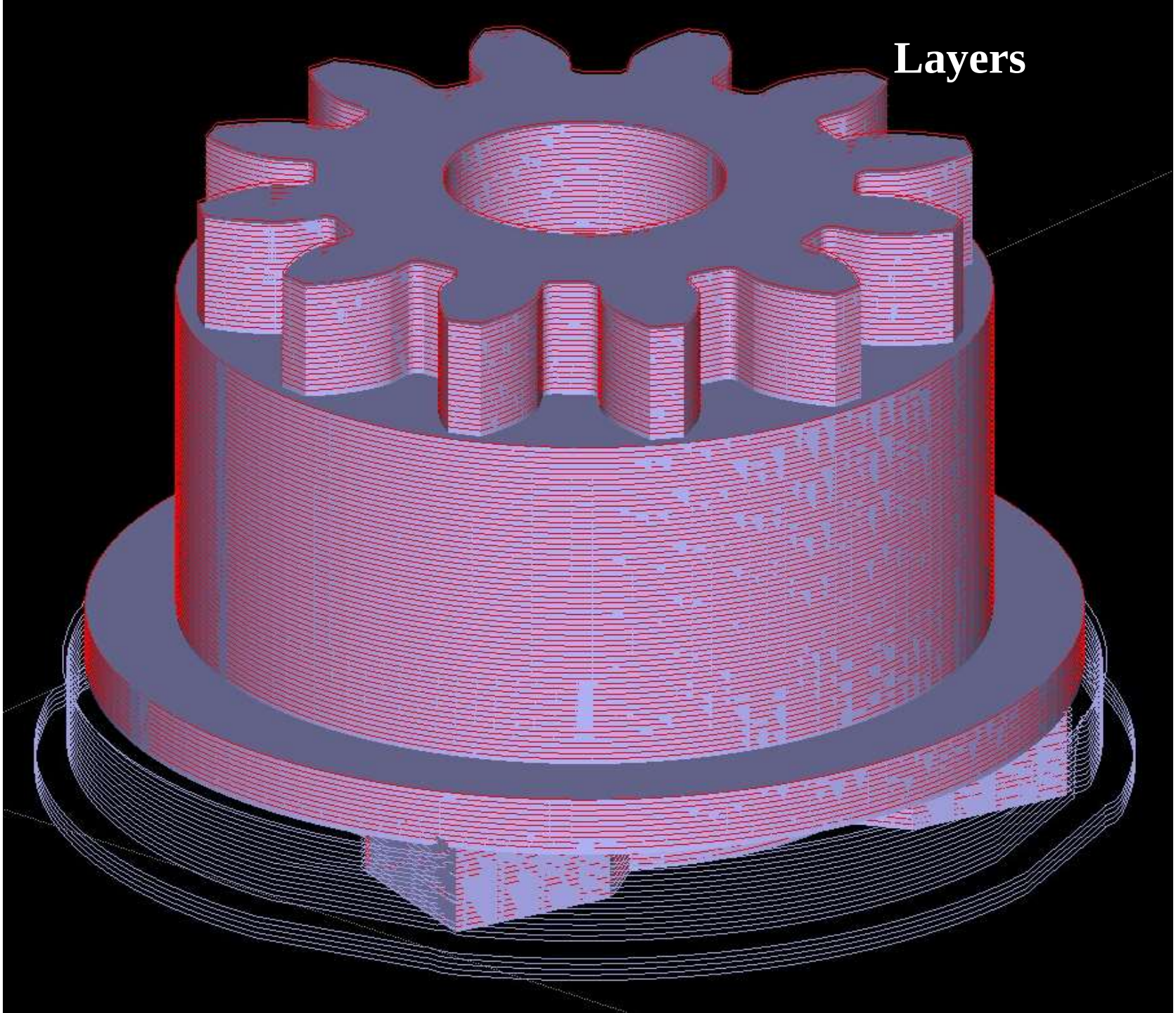
Applications - examples

Example: Lightweight structures

Example: a combination of two or more different materials


tessellation


Layers

PRODIGY
IBM CATIA, MAGIC, CATALYST, INSIDE

PRODIGY

203 x 203 x 305 mm

Layers:

Fine	0.178 mm
Standard	0.245 mm
Draft	0.33 mm

Material ABS:

1. Supporting
2. Building

Structure :

SOLID

SPARSE

DOUBLE WIDE

HYDRAULIC PUMP

Material **cm^3**:
Model: 90
Supports: 34

TIME: 9:50´

Fluid Damper Box

Material **cm³**:
Pattern: 38
Supports: 13,9

TIME: 6:48´

Scan SFING
ATOS
TRITOP

Mesh 3 mil.

SFING SCULPTURE

SFING

Material **cm^3**:
Pattern: 79
Supports: 41

Time: 14:09´

Mirror holder

Material **cm³**:
Pattern: 50
Supports: 64

Time: 7:35′

Blower Cower

SAFETY HELMET

Made of 10 parts

Glued together and assembly mechanically supported

SHELL MOULD
na ABS
100^0 C - max 0,24%
200^0 C - creep
500^0 C - burning
900^0 C - gas & ashes burn