## Contents

- **Rapid Prototyping and Rapid Tooling**
- Introduction
- RP and RT in product development
- Economic aspects
- Overview about systems and technologies
- Examples of application
- Future and perspectives
- Conclusions
### Problem and intention

#### Situation
- Reduction of product development time forced by innovation pressure and market competition
- Increase of product complexity
- Despite of Virtual Reality tools need for physical models
- Time-consuming conventional, often also manual, model making

#### Solution
- Development of techniques for generative production of prototypes directly from CAD-data
- Mobilizing of adjacent time and cost advantages

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### Rapid Prototyping and Rapid Tooling – definitions

<table>
<thead>
<tr>
<th>Rapid Prototyping (RP)</th>
<th>Rapid Tooling (RT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>– Generative (layer-by-layer) build up of parts directly from CAD-data</td>
<td>– Same principles and characteristics as for Rapid Prototyping</td>
</tr>
<tr>
<td>– Usually no molds or tools required</td>
<td>– Layer-by-layer build up of molds and dies (direct RT)</td>
</tr>
<tr>
<td>– Accessing of high economic potentials while producing complex geometries in small batches</td>
<td>– Shaping of molds and dies from RP-made master patterns (indirect RT)</td>
</tr>
</tbody>
</table>
### Contents

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---

### Key factor »Time to Market« I/II

**Product development time**

- Boundary conditions during product development process:
  - Non-concrete or quickly changing customer’s demands
  - Growing importance of design and individualization
  - Environmental aspects
  - Decreasing product lifetime
  - Falling prices and cost pressure
  - Law-enforced boundaries and standards

- Often more than 25% of product development time are spent for manufacture of prototypes and models

- Delays in market maturity lead to over-proportional profit reduction compared to other cost factors

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acc. to: Gebhardt et al.
Key factor »Time to Market« II/II

Costs
- Most of the later costs are defined in a very early stage of product development cycle

Conclusion
- Models, prototypes and patterns have to be available in a very short time to guarantee a successful product

Needs for prototypes during product development

<table>
<thead>
<tr>
<th>PD phase</th>
<th>idea</th>
<th>pre-development</th>
<th>functional testing</th>
<th>prototype phase</th>
<th>Pre series phase</th>
<th>Market introduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of prototype</td>
<td>design</td>
<td>functional</td>
<td>technical</td>
<td>pre series</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary demands</td>
<td>optical and haptic</td>
<td>funktional/ geometrical</td>
<td>near series simul. of all properties</td>
<td>identical to series simul. of all prop.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material</td>
<td>usually model making</td>
<td>model mak./ near serial</td>
<td>near series</td>
<td>serial</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production method</td>
<td>manual/ model making</td>
<td>manual/ model making</td>
<td>near series with preser. series tools</td>
<td>series tools</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Numbers needed</td>
<td>1</td>
<td>2-5</td>
<td>3-20</td>
<td>up to 500</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

acc. to Gebhardt et al.
Use of RP models by branches

- Consumer products and automotive are taking more than 50% of RP-models produced
- Increasing trend in medical areas
- »others«: sporting goods, non military marine use, ...

Data based on a survey to 16 system manufacturers and 47 RP-service providers


Use of RP models by application

- Functional models
- Visual aids for engineering
- Fit/assembly
- Patterns for prototype tooling
- Patterns for cast metal
- Proposal/quoting
- Visual aids for toolmakers
- Other
- Direct tooling inserts
- Ergonomic studies

Data based on a survey to 16 system manufacturers and 47 RP-service providers

Contents

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Economic aspects

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Examples of application

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RP-/RT-system installations worldwide

1750 units / year
17500 units cumulative


Data for 2002 and 2003 estimated

Fraunhofer Institut Produktionstechnologie
Worldwide revenues of RP-/RT-branch


Data for 2002 and 2003 estimated

Ranking of the most important RP-/RT-systems

Contents

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---

**Stereolithography (SL) as example for generative model making**

**History**
- Worldwide first RP-technology at all
- Patented 1984
- Commercialized 1988 by 3D-Systems Inc.

**The generative approach**
- Production of parts by addition of material instead of removal (like for example by cutting, ...)
- Layer-by-layer build up »bottom-to-top«
- Easy manufacture of undercuts, complex structures, internal holes, ...

**Realization by Stereolithography**
- Local solidification of a light-sensitive liquid resin (photopolymer) using an UV-Laser
- Scanning of the cross-section areas to be hardened with the laser focus
Schematic layout of a Stereolithography machine

Main components
– Exposure system
– Vat with liquid photopolymer
– Table with z-drive

Process principle of Stereolithography

Process steps
– Lowering of table by the thickness of one layer
– Application/leveling of liquid resin
– Scanning with Laser
– Again lowering of table

Supports
– Needed for manufacture of undercuts
– Build up with part similar to a honey-bee-structure

Simplified animation of SL-process
Process chain of Stereolithography I/II

CAD-Model

Triangulation

Supports

Slicing

- 3D CAD-data must be available
- Conversion into »STL-data«
- Representation of surfaces by small triangles
- Orientation of geometry to the machine’s workspace
- Generation of support data
- Will be built up together with part
- »Honey-bee-structure« for easy removal
- Slicing of part’s geometry and support data into layers

Process chain of Stereolithography II/II

Process set-up

Production

Cleaning/Finishing

Post curing

- Data transfer to machine
- Setting-up of job
- Start of building process
- Layer-by-layer exposure of geometry
- Taking out of part
- Cleaning of excess resin
- Removal of supports
- Surface finish (if required)
- Final curing under UV-light
System's overview: Stereolithography (SL)

Process principle
– Layer-by-layer curing of a liquid photopolymer by a laser
– Control of laser by a scan-mirror system

Characteristics
– High part complexity
– High accuracy
– Support structure required

Materials
– Only photopolymer of different qualities available (temp.-proof, flexible, transparent, ...)

Max. part size & accuracy
– Part size: 250x250x250 mm³ to 1000x800x500 mm³
– Accuracy: 0.05 mm

Facility costs
– 50 000 - 605 000 US$

System's overview: Solid Ground Curing (SGC)

Process principle
– Layer-by-layer curing of a liquid photopolymer through a mask by an UV-lamp
– Exposure of each layer in one step

Characteristics
– High complexity
– Support realized by wax, no extra construction necessary
– Very complex machine layout

Materials
– Only photopolymers

Max. part size & accuracy
– Part size: 500x300x500 mm³
– Accuracy: 0.1 mm

Facility costs
– Approx. 324 000 US$
System's overview: Laminated Object Manufacturing (LOM)

Process principle
– Laminating and cutting of self-adhesive foils

Characteristics
– Limited part complexity (removal of inner parts in hollow areas)
– No support required
– Wood-like properties when working with paper

Materials
– Paper (but also plastics, metal, ceramic)

Max. part size & accuracy
– Part size: 813x559x508 mm³
– Accuracy: +/-0.25 mm

Facility costs
– 55 000 - 278 000 US$

System's overview: Selective Laser Sintering (SLS, DMLS) I/II

Process principle
– Local melting/sintering of a powder by a laser
– Direct: the powder particles melt together
– Indirect: the powder particles are coated with a thermoplastic binder which melts up

Characteristics
– High part complexity
– Many materials available
– Burning out of the binder and infiltration might be required
– Relatively high porosity and surface roughness
– Usually no supports needed

Materials
– Paper (but also plastics, metal, ceramic)

Max. part size & accuracy
– Part size: 813x559x508 mm³
– Accuracy: +/-0.25 mm

Facility costs
– 55 000 - 278 000 US$

Removal of excess material
LOM model of a car

SLS of plastics: computer mouse
SLS of sand: core for sand casting (EOSINT-S machine, EOS GmbH)

SLS of metals: injection molding inserts
System's overview: Selective Laser Sintering (SLS, DMLS) II/II

Materials
- Wax
- Thermoplastics
- Metal
- Casting sand
- Ceramics

Max. part size & accuracy
- Part size: 250x250x150 to 720x500x450 mm³
- Accuracy: +/-0.1 mm

Facility costs
- 275 000 - 850 000 US$

System's overview: Fused Deposition Modeling (FDM)

Process principle
- Melting of a wire-shaped plastic material and deposition with a xy-plotter mechanism

Characteristics
- Limited part complexity
- Two different material for part and support

Materials
- Thermoplastics (ABS, Nylon, Wax, ...)

Max. part size & accuracy
- Part size: 600x500x600 mm³
- Accuracy: +/-0.1 mm

Facility costs
- 66 500 - 290 000 US$


Source: alphacam
**System’s overview: Genisys™**

**Process principle**
- Extrusion of molten plastic through a nozzle system (similar to FDM)

**Characteristics**
- Material supply in tablets
- Support generated from same material as part with perforated connections
- Office-suited concept modeler

**Materials**
- Polyester

**Max. part size & accuracy**
- Part size: 203x203x203 mm³
- Accuracy: ±0.3 mm

**Facility costs**
- Approx. 45 000 US$  


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**System’s overview: ModelMaker™**

**Process principle**
- Application of molten wax using an ink jet
- Cutting of each layer for constant z-level
- Two materials for part and support

**Characteristics**
- High precision
- Geom. Prototypes, Master patterns for Investment casting

**Materials**
- Wax

**Max. part size & accuracy**
- Part size: 305x152x229 mm³
- Accuracy: 0.02 mm

**Facility costs**
- Approx. 67 000$  

Source: BMT

Source: alphassem
**System's overview: Multi-Jet Modeling (MJM)**

**Process principle**
- Layer-by-layer deposition of molten plastic droplets using a line of piezoelectric ink jets

**Characteristics**
- Designed as 3D-network-printer for concept models

**Materials**
- Thermopolymer based on Paraffin

Max. part size & accuracy
- Part size: 250x190x200 mm³
- Resolution 400x300 dpi in x-y-direction

**Facility costs**
- Approx. 50 000 $

**System's overview: Three Dimensional Printing (3DP) I/II**

**Process principle**
- Local bonding of starch powder by a binder using an ink jet (patent of MIT)

**Characteristics**
- Very high building speeds
- Easy handling
- Binder available in differ. colors
- Infiltration necessary
- Ideal for fast visualization

**Materials**
- Starch powder (Z Corp.)
- Other manufactures offer systems for ceramics or metal

Max. part size & accuracy
- Part size: 200x250x200 mm
- Resolution 600 dpi in x-y-direction

**Facility costs**
- 49 000 - 67 500 $

Source: 4D Concepts
System's overview: Three Dimensional Printing (3DP) II/II

Video sequence of 3DP-process

System's overview: Laser generating

Process principle
- Local melting of metal powders or wire using a laser

Characteristics
- Parts have properties close to serial parts
- Surfaces need post processing
- Also suited for repair purposes

Materials
- Stainless steel, Titanium, special alloys

Max. part size & accuracy
- Part size: 460x460x1070 mm
- Accuracy: +/- 0.5 mm

Facility costs
- 440 000 - 640 000 $

Source: Lulea Tekn. University, Optomec, Inc., Fraunhofer IPT
Combination of techniques: plastic vacuum molding

Process principle
- Casting of a (RP)-master pattern in silicon and reproduction

Characteristics
- Very detailed reproduction
- Undercuts are possible
- Silicon mold can be used several times
- Suited for small lots <50

Materials
- Various reaction resins
- Properties comparable to numerous plastics

Max. part size & accuracy
- Max. part size: Approx. 1000x1000x2000 mm³
- Accuracy depend. from master

Facility costs
- 25 000 to 250 000 US$

Process chain of vacuum molding
1. Master pattern
2. Casting with silicon under vacuum
3. Cutting of mold in parting plane
4. Vacuum casting with reaction resin
5. Curing under heat
6. Removal of model

Housing for drilling machine

Fast production of injection molding tools

Motivation
- Requirements to parts (material, production process, amount of shots, ...)
- Production with serial process

Problems
- High efforts in tool making
  • Complexity of geometry
  • Cutting
  • EDM
- Performance and amount of time/money disproportionate to demands of pre-series

Solution
- Making of tools and inserts using RP
- Direct and indirect approaches
- Opening of cost and time potentials
Overview about manufacturing techniques for inj. molding tools

**abrasive techniques**
- cutting techniques
  - milling
    - 3-axis
    - 5-axis
  - turning
  - drilling
  - grinding/polishing
  - SPM (Space Puzzle Molding)

**erosive techniques**
- EDM
  - sinking EDM
  - wire EDM
- ECM

**casting techniques**
- with master
  - investment casting
  - sandforms
  - Keltooling
- direct
- vacuum casting
- MCP tool
- Keltooling
- indirect

**without master**
- PU-GFK
- SLS sand

**Legend:**
- established
- available
- under development

**Rapid Tooling**
- powder
- SLS-metal
- direct (EOS)
- indirect (DTM)

- 3D-printing (metal)
- laser generating
- LENS (Laser Engineered Net Shaping)
- CMIB (Controlled Metall Build Up)
- SDM (Shape Deposition Manufacturing)
- FPM (Freeform Powder Molding)

- foil/sheet metal
- Laminated Tooling
- LOM (metal)
- Conveyed-adherent Autofab

- others
  - Stereolithography tool
  - LOM-paper

Closeness to serial parts and recommended amount of parts for various RP/RT approaches

**Part properties**
- Surface quality
- Form and dimensional accuracy
- Mechanical properties (stiffness, density, ...)
- Physical properties (thermal, ...)

**Legend:**
- non-ident. to series
- identical to series

**Batch number**
- 01 0 102 103 104 105
Rapid Tooling: Keltool™

Process principle
- Duplicate molding of SL-master patterns by longtime-low temp-sintering

Characteristics
- Very high hardness, stiffness and surface quality
- Process chain takes two weeks

Material
- Tool steel/Wolframcarbide mixture infiltrated with copper

Max. part size & accuracy
- Max. size: 150x215x120 mm³
- Tolerance +/-0.2%

Facility costs
- System price approx. 200 000 US$
- License fee 57 500 US$ / year for 5 years, 172 500 US$ for 1st year

Process chain of Keltool™-process
1 Master pattern
2 Silicon casting
3 Casting with a tool steel/Wolframcarbide/epoxy mixture
4 Burn-out of binder, sintering and infiltration with copper in an oven
5 Tool insert ready for production

Rapid Tooling: Indirect Metal Laser Sintering (RapidTool™-process)

Process principle
- Indirect selective laser sintering of metal powders
- Burning out of binder and infiltration with copper

Characteristics
- Production of tool inserts for injection molding and die casting
- Tool life up to 50 000 shots

Materials
- Approx. 60% steel and 40% copper

Max. part size & accuracy
- Max. size: 380x330x447 mm³
- Accuracy: +/- 0.1 mm

Facility costs
- 275 000 US$

Process chain of RapidTool™ technology
1 SLS of a polymer-coated steel powder
2 Burning out of binder and infiltration with copper
3 Polishing and insertion into tool frame
Rapid Tooling: Direct Metal Laser Sintering (DirectTool™-process)

Process principle
– Direct SLS of powder particles (DMLS)

Characteristics
– Production of tool inserts for injection molding and die casting
– No burn-out of binder required, advantages in accuracy and time

Materials
– Steel or bronze nickel, infiltration with epoxy possible

Max. part size & accuracy
– Max. size: 250x250x150 mm³
– Accuracy: +/- 0.1 mm

Facility costs
– Approx. 320 000 US$

Process chain of DirectTool™ technology
1 SLS of metal powder (directly)
2 Bronze nickel powder: infiltration with copper
Steel: not necessarily required
3 Polishing and insertion into tool frame

DMLS-insert in tool frame
Source: Fraunhofer IPT in cooperation with Robert Bosch GmbH

Rapid Tooling: Controlled Metal Build Up (CMB)

Process principle
– Layer-by-layer build up of parts in a combination of laser deposition welding and HSC

Characteristics
– Production and repair of tool inserts for injection molding and die casting
– Intermittent cutting allows small cutter diameters to be used
– Surfaces in cutting quality

Materials
– Steel

Max. part size & accuracy
– Workspace: 600x600x600 mm³
– Accuracy: +/- 0.02 mm

Facility costs
– Estimated approx. 300 000 EUR

Source: Fraunhofer IPT
**Inhalt**

- Rapid Prototyping and Rapid Tooling
  - Introduction
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  - Economic aspects
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  - Examples of application
  - Future and perspectives
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---

**Examples of application: computer mouse**

**Approach**
- Manual design of a 1st model
- 3D-scanning and import of data to CAD-system
- Production of two shells using Stereolithography
- Construction of inner geometry
- Production of a technical prototype using Stereolithography
- Manufacture of a functional prototype using SLS
- Optimization of construction
- Production of a pre series tool using SLS of metal
- Injection molding of mouse housings

- Design and SL-models
- SLS prototype (polyamide)
- Laser sintered injection molding inserts
- Pre series production

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Fraunhofer Institute Productionstechnologie
Examples of application: miniature collector’s car models

Approach
– Import of CAD-data
– Data processing and production of a SL master model
– Reproduction by silicon vacuum casting
– Manual modeling of model-specific details
– Copy-milling of die casting tool/EDM electrodes

Examples of application: medical business

Background
– Preparation of medical operations
– Detailed representation of surrounding areas prior to a medical engagement
– Education, visualization

Approach
– Gaining of data by computertomography (CT)
– Data processing and model production

Stereolithography model of a human brain
Contents

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- Overview about systems and technologies
- Examples of application
- Future and perspectives
- Conclusions

**Trends and perspectives I/II**

Tendencies for Rapid Prototyping technologies
- »Personal Modelers«
- 3D-printers for concept models
- Rapid Prototyping for complex models with high demands regarding materials
- Rapid Tooling
- Rapid Manufacturing

3D-Printing
- Reduction of purchasing and running costs
- Systems improvement
  - Accuracy
  - Handling
  - Materials, mechanical properties
  - Speed
- Decentralized use in the various development departments of a company

Source: 4DConcepts
Trends and perspectives II/II

Rapid Tooling
– Improvement of systems
– Increase of tool lifetime
– Comparability of molding parameters to serial steel tools
– »Conformal cooling«
– Graduated build up of tools with changing properties

Rapid Manufacturing
– Use of RT-technologies for end product production
– Small series production (racing, aerospace, executive/special products, ...)
– »Mass Customization«
– Establish beneath/instead of conventional production methods

Contents

Rapid Prototyping and Rapid Tooling
Introduction
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Overview about systems and technologies
Examples of application
Future and perspectives
Conclusions

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Product development
– Main goal: reduction of »Time to Market«
– Manufacture of models, samples and prototypes using RP/RT opens cost and time savings
– Requirements to models depend on product development phase

Rapid Prototyping/Rapid Tooling
– Layer-by-layer generative build up of parts
– Production of a model or a tool
– Selection of a technology regarding required properties, stiffness, materials, batch number, ...
– Future developments gain to optimization of handling, closeness to serial products, production of final products