# IDENTIFICATION OF SINGLE PARTS IN ASSEMBLIES BY 3D SCAN AND GEOMETRICAL SIMILARITY SEARCH

14. INDUSTRY-FORUM
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Dipl.-Ing. Hendrik Grosser
B. Sc. Friedrich Politz

Prof. Dr. Ing. Rainer Stark
Director of the division Virtual Product Creation
Fraunhofer Institute for Production Systems and Design Technology (IPK)



Fraunhofer IPK

# STRUCTURE

- Introduction Fraunhofer IPK
- Need for 3D models
- Research projects and use cases
- Test series and results
- Future potentials and outlook

# PTZ BERLIN – PRODUCTION TECHNOLOGY CENTER

## Two Institutes – One Roof


Corporate Management


Virtual Product Creation


Production Systems

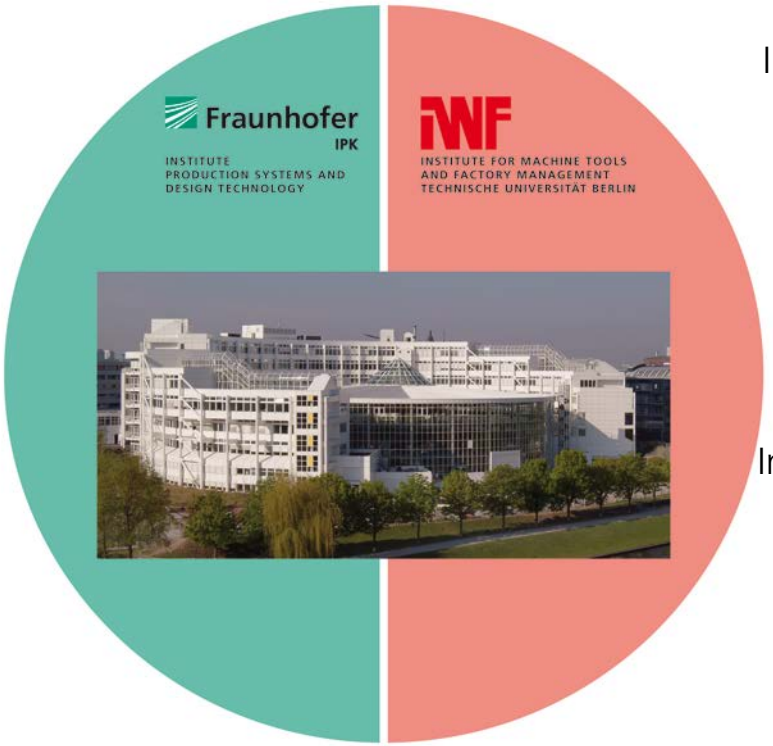

Joining and Coating Technology


Automation Technology


Quality Managemer


Medical Technology

**PTZ Berlin**

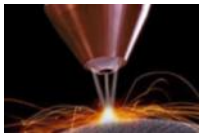




Assembly Technology and Factory Management


Industrial Information Technology


Machine Tools and facturing Technology

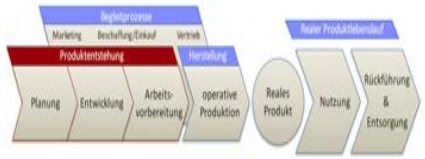

Joining and Coating Technology

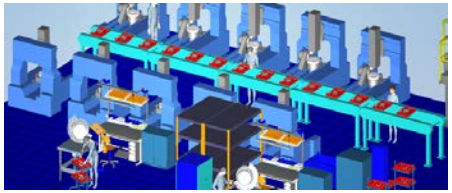

Industrial Automation Technology

Quality Science

# RESEARCH DOMAINS

## Division Virtual Product Creation



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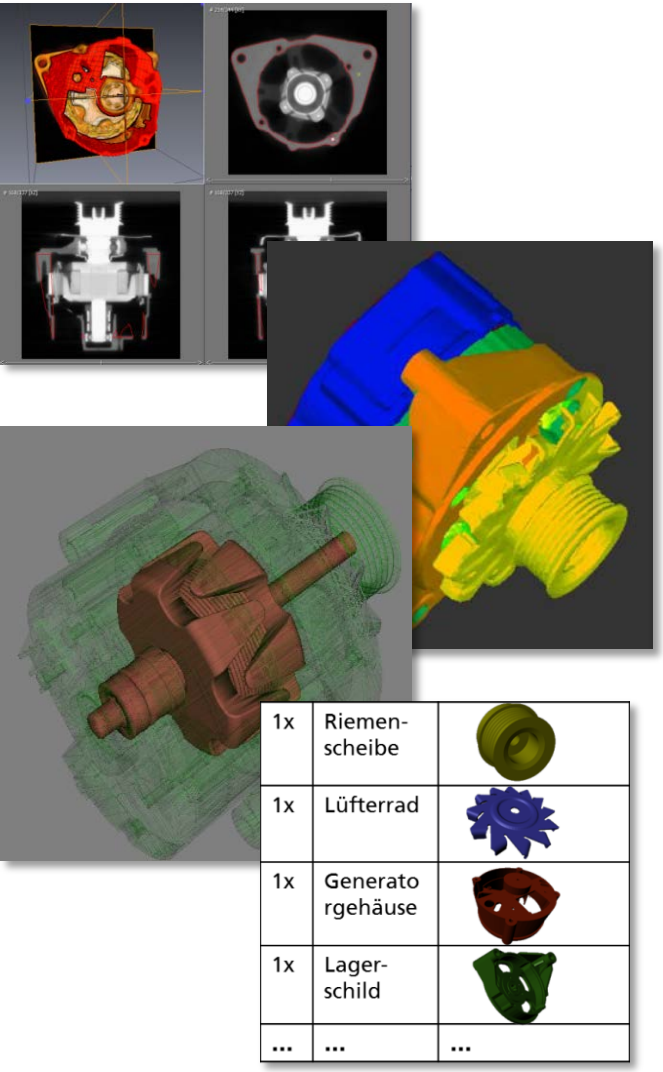
1. **Product development methods and processes**
   Analysis and composition of both product creation processes and sub-processes with regard to methodical and organizational aspects
2. **Product modeling and functional validation**
   Modeling of product properties and characteristics (requirements, structures, functions, geometry generation incl. processing and reparation, quality of digital data, …)
3. **Intuitive interaction with virtual prototypes**
   Context sensitive provision of information for various scenarios and players in product creation (developer, designer, manager, analyst etc.)
4. **Information management for product creation**
   Collection, administration, processing and provision of information, which are generated in product life cycle and to be used for product creation
5. **Digital manufacturing operations and factory processes**
   Modeling of manufacturing process features and characteristics (product, manufacturing/assembly process, equipment, factory layout, ...) in the context of product creation and reviewing of each production process with respect to the specific objectives

# Focus Reverse Engineering

3D scan data processing




## Fields of application

- Inspection (3D measurement, deviation analysis)
- Spare part production (e.g. rapid manufacturing)
- Reengineering or redesign
- Quality control (deviation analysis)

## Challenges

- 3D models are not available or do not represent actual product condition
- Lacking product documentation (BOM, product structure, electric plan, maintenance history)
- Lacking standards for Reverse Engineering processes

## Activities and solutions

- Development of processes and software for Reverse Engineering of mechanical and electronic products
- Automated analysis and processing of geometry
- Studies for Use of 3D scanning technologies

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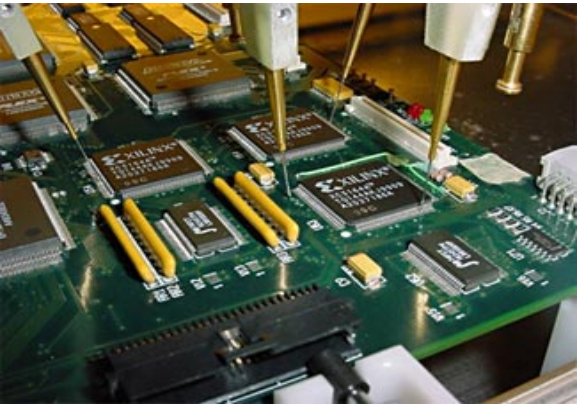
# Initial situation
## Need for 3D models

*Steam turbine (image source: Siemens)*



*Flying Probe Test (image source:* SQC)

**Rising maintenance requirements**

- Increasing product complexity and design variety
- High design variety and unpredictable failures

**Missing data and information**

- OEMs keep back information to protect their design knowledge
- Service provider act without access to 3D models, BOMs, electric plans and other technical descriptions…
- Actual state of a product is often unknown

**Little standardization and high manual effort**

- Long term practical knowledge is needed
- Small degree of process automation

Knowledge of actual and desired product condition is fundamental for a robust planning, operation, and automation of MRO processes

# Solution: 3D scanning and Reverse Engineering

## Need for 3D models

*Image source: Power-technology.com, Hommel, MAN*

**Inspection**

- Deviation analysis
- MRO planning

**Quality control**

- Check of bought-in parts

**Reengineering/remanufacturing/retrofit**

- Modification of geometry models
- Additional design into existing structures

**Production**

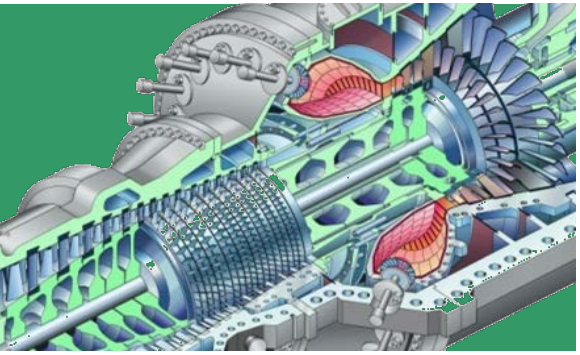
- Own production of spare parts
- Obsolescence management

**Industries**

- Turbo machinery (gas- and steam turbines,  jet engines)
- Transport (e.g. air and rail)
- Plant manufacturing
- Machine tools
- Engines

# Challenges of Reverse Engineering

## Need for 3D models



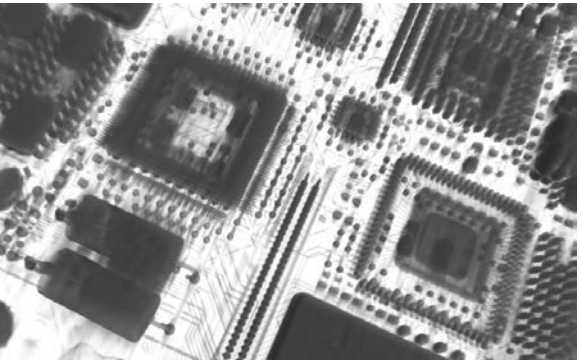


*Image source: GOM, Siemens, Fraunhofer IPK*

**Selection of adequate technology**

- Fast development processes of 3D scanners
- Complex post processing software

**Reduction of disassembly effort**

- In situ 3D scans of single parts
- Identification of single parts

**Identification of product structure**

- Configuration und change management in PDM-systems

**Standardized process from scan to manufacturing (CAD/CAM)**

- Automated parameterization
- Conclusion of target geometry

**Reconstruction of electric plans**

- Low degree of automization
- Error prone results of actual RE principles

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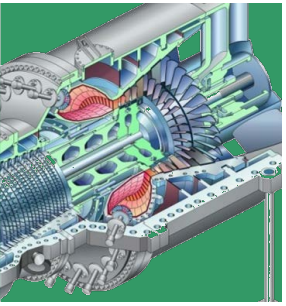
# Condition based digitalization for MRO processes

## Project COSDIMRO



All departments,
Development project

Client: Berlin Senatsverwaltung für Bildung, Wissenschaft und Forschung

Runtime: 12/2009 – 05/2012

Image source: Siemens, MAN

### Content

- Development of an reverse engineering process for automated generation of three-dimensional assembly models of complex machines and facilities
- Facilitating the subsequent use of the 3D-models by means of information technology for MRO-planning- and -assistance systems

### Challenge

- MRO-planning requires – especially in case of an unknown product state – a time-consuming diagnose process
- Restricted automation potential due to nonexistent or not updated product models

### Solution Approach

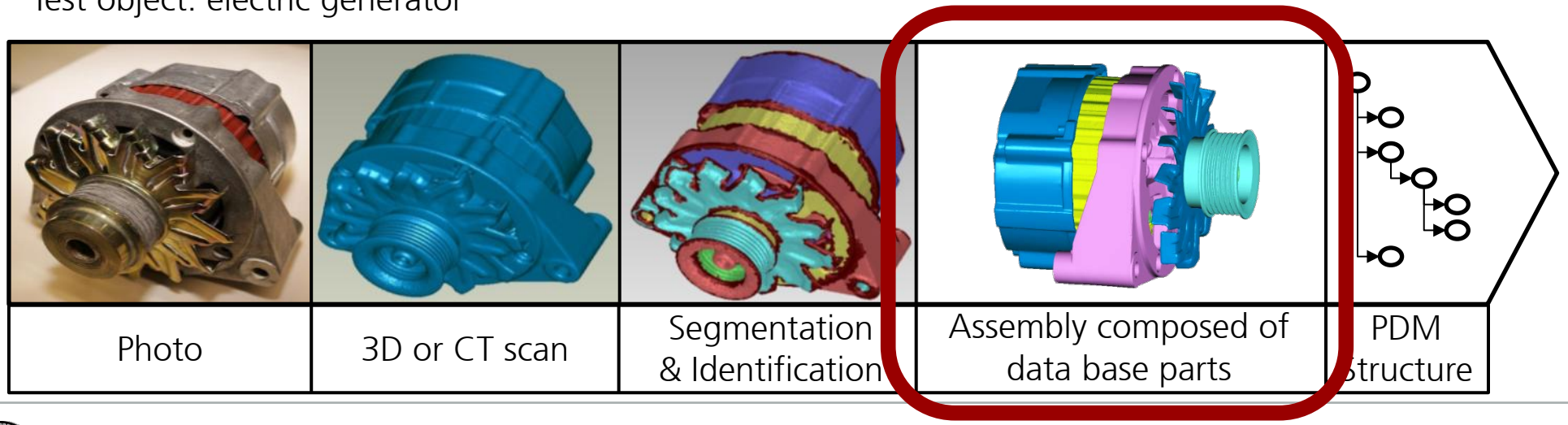
- 3D scanning of products
- Separating the parts of the digital model
- Deducing the product structure
- Enabling data compatibility for IT-systems

# Process for digitization of assemblies

Project COSDIMRO

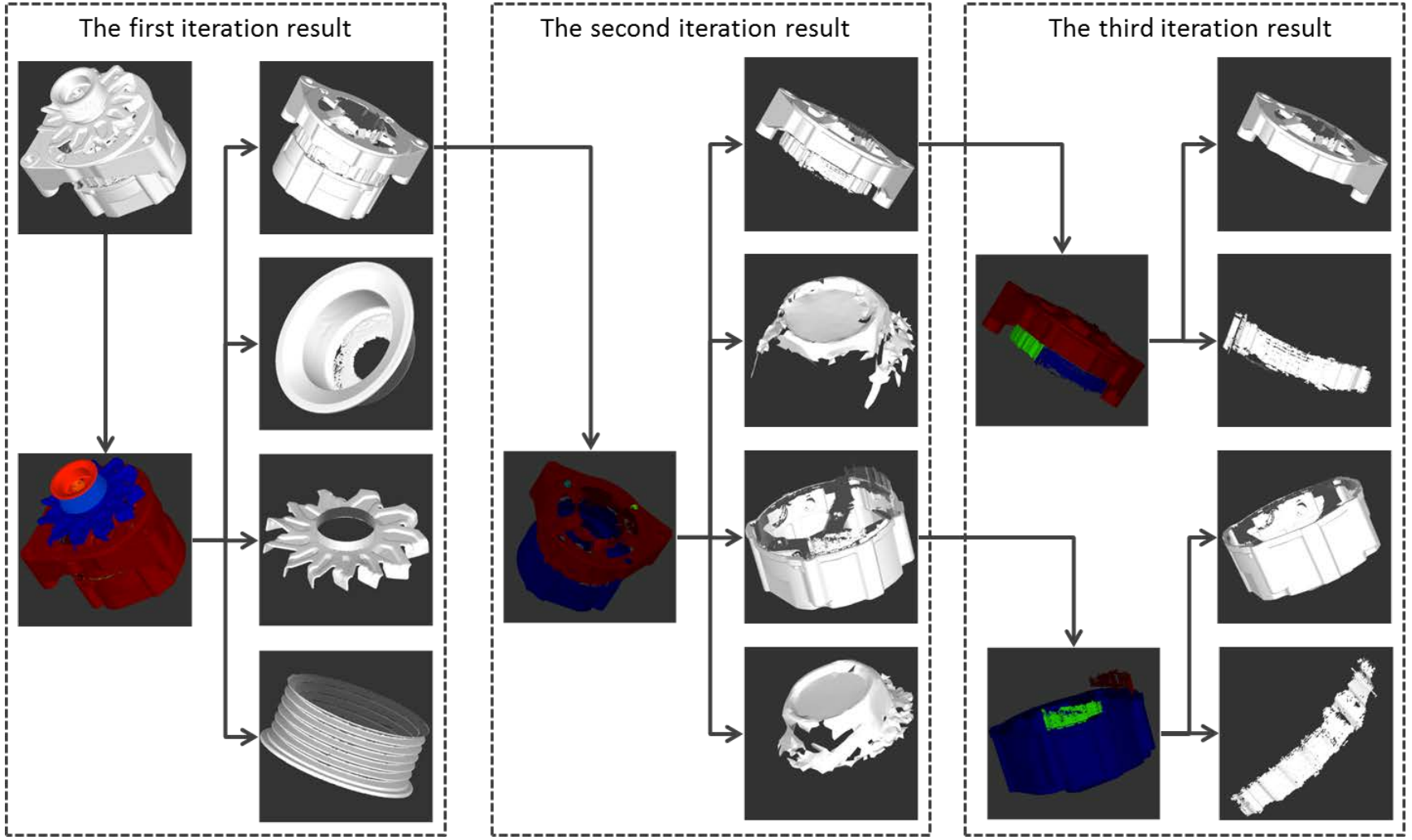
- Development and prototypical implementation of a RE method for effective and efficient support of MRO processes
- Semi-automatic generation of digital models of complex products and facilities
- Identification of parts and assemblies as well as their relationships
- Subsequent processing for PLM and MRO planning and assistant systems

Test object: electric generator



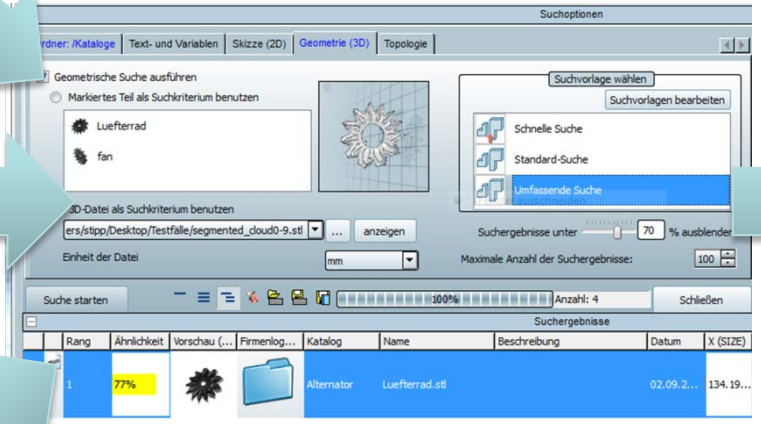
# Segmentation result

## Project COSDIMRO

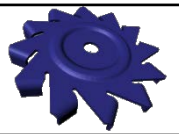
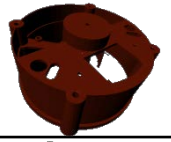


# Part identification
## Project COSDIMRO

*Segmented parts*




*Geometrical similarity search with CADENAS PARTsolutions*

| | | |
|---|---|---|
| 1x | Belt Pulley |  |
| 1x | Fan Impeller |  |
| 1x | Generator Housing |  |
| 1x | Bearing Shield |  |
| ... | ... | ... |

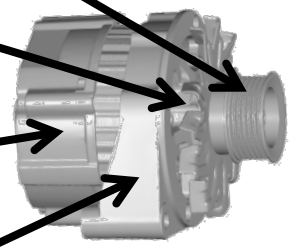
*Identified parts from data base*

# Assembly building

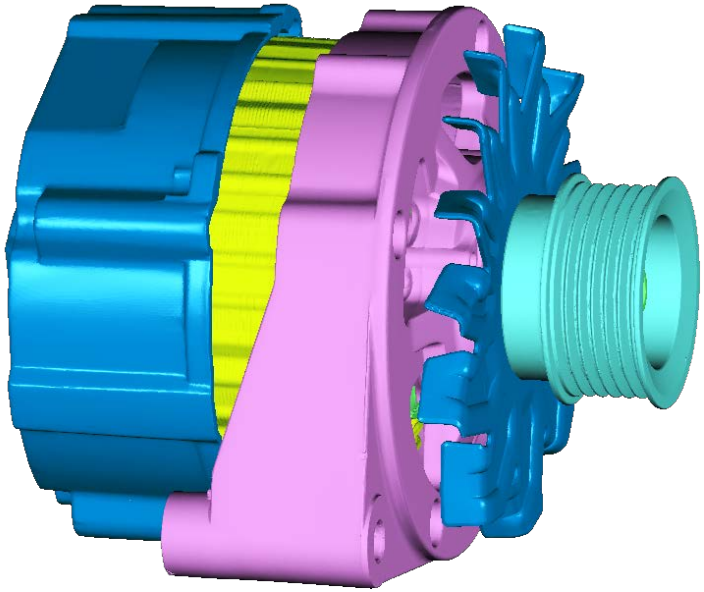
## Project COSDIMRO

| | | |
|---|---|---|
| 1x | Belt Pulley | |
| 1x | Fan Impeller | |
| 1x | Generator Housing | |
| 1x | Bearing Shield | |
| ... | ... | ... |

*Identified parts from data base*

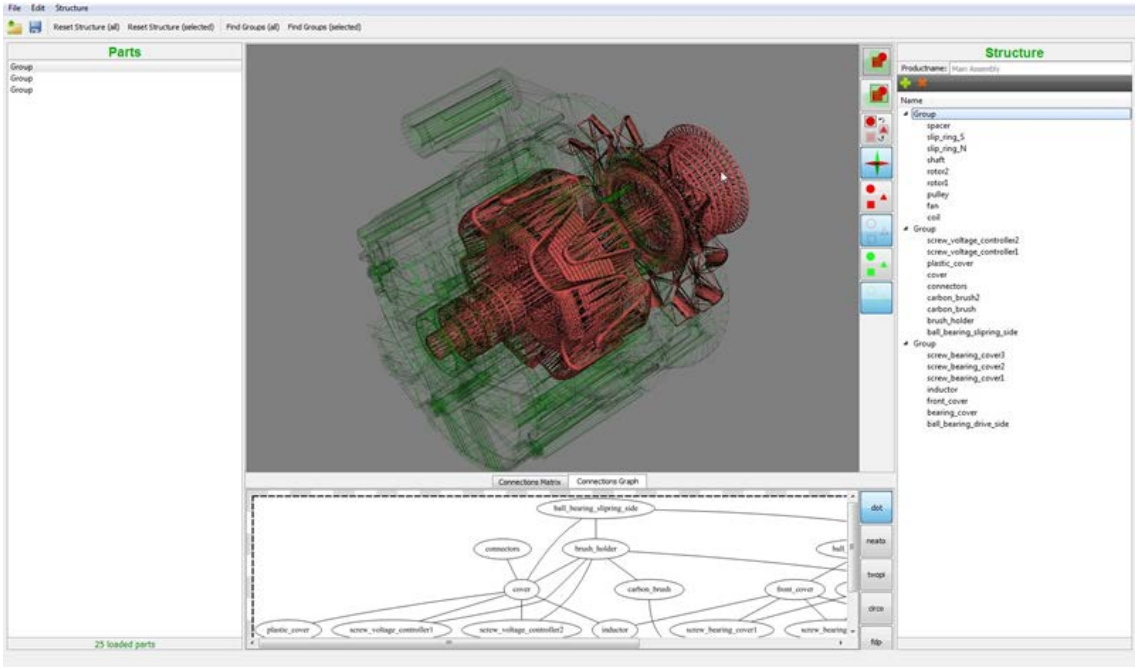


*Fitting of single parts into point cloud*



*Reconstructed assembly*

# Derivation of product structure
Project COSDIMRO



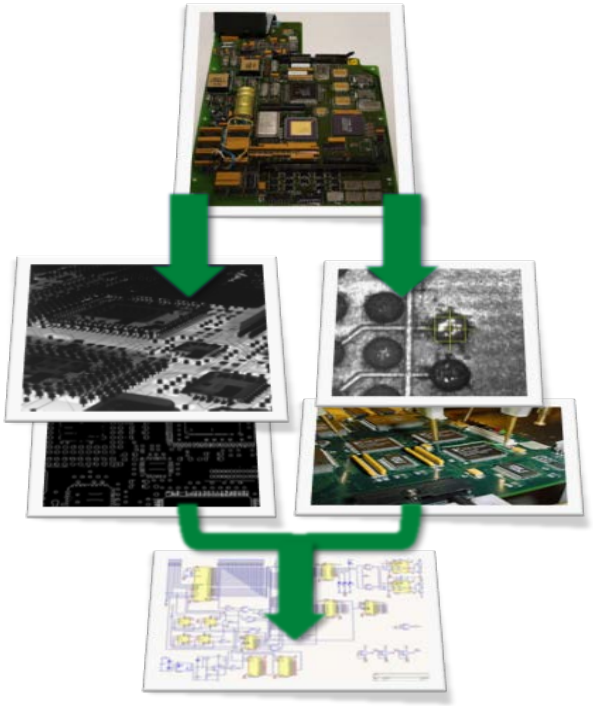

*GUI of structure generator*

## Implementation of a Structure Generator

- Import of assemblies (single parts in STL format)
- Contact analysis of single parts by graph theory approaches
  → contact graph
- Proposal of product structure
- Possibility of manual rework
- Visual user support through inegrated GUI

# Maintenance information recovery for electronics

Project LangzEl



Client:

Investitionsbank Berlin
Leistung für Berlin.

Research in Germany
Land of Ideas
Official Partner

Run time: 01/2010 – 05/2011

## Content

- Automatic generation of circuit diagrams for electric devices to support maintenance operations
- Analysis of Reverse Engineering (RE) methods to create a process chain

## Challenge

- Missing information: Missing electric circuit plan and bill of material, no digital plan of board layout available
- Lack of product data/information hinders diagnose and repair of PCBs* (even of those with reduced complexity)

## Solution Approach

- Digitalization of products with Reverse Engineering technologies
- Definition of a new Reverse Engineering process for PCBs*
- Application of optical and electrical technologies
- Automated generation of circuit plan, bill of material and board layout plan
- Interface implementation to ECAD system

*PCB: Printed Circuit Board



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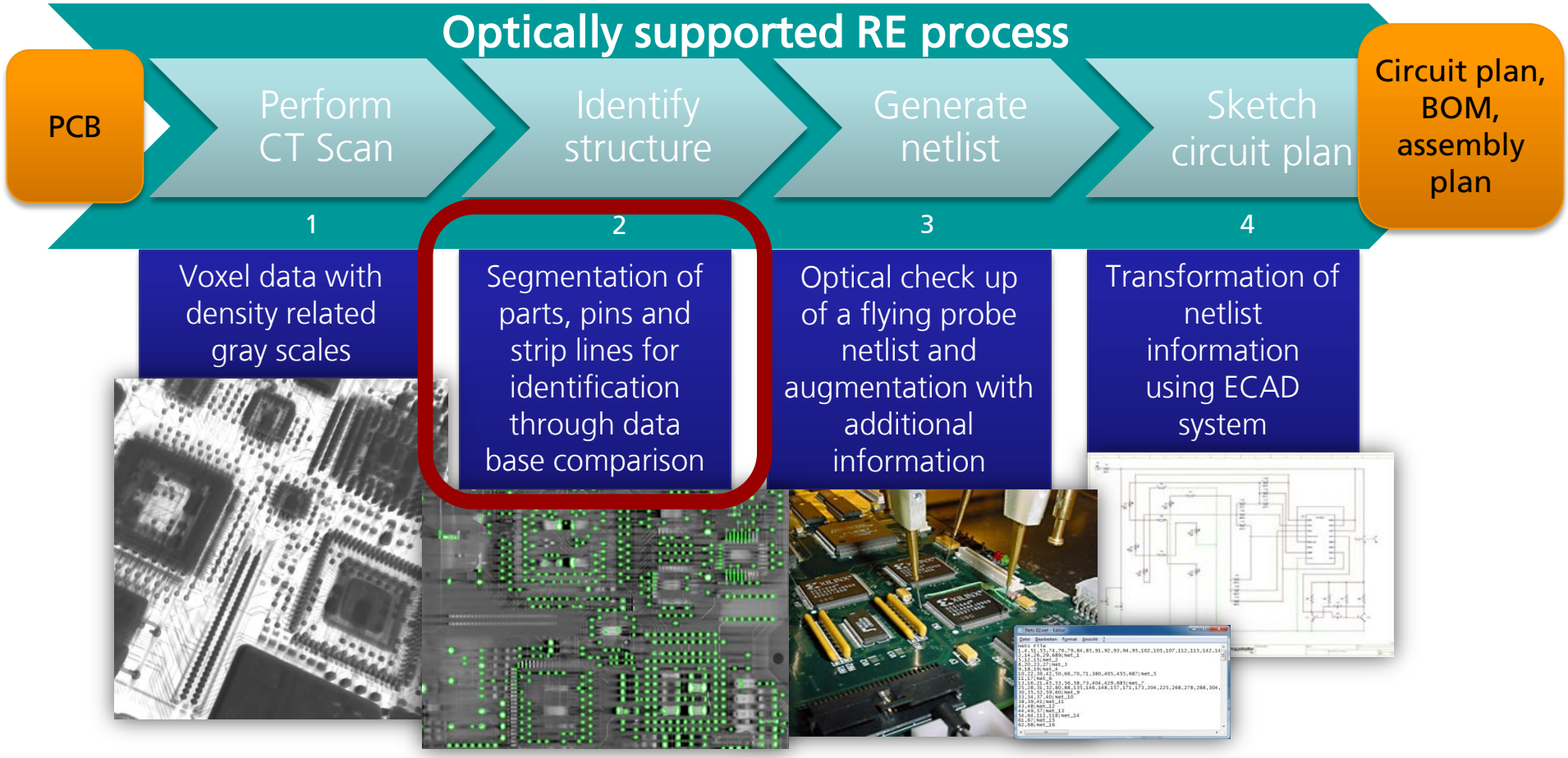
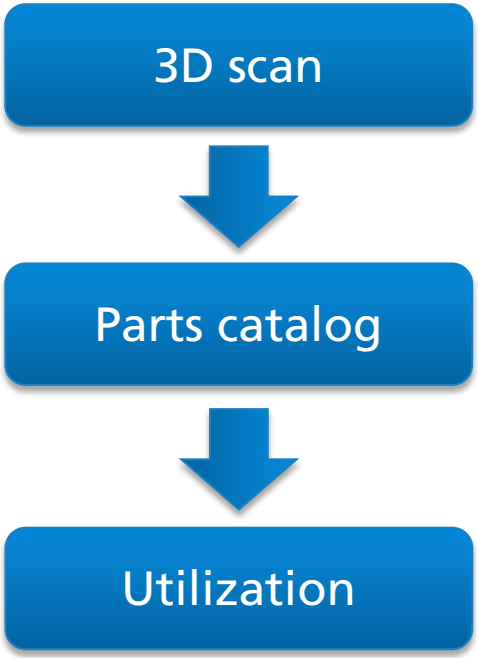
# Hauptphasen des Prozesses

Project LangzEl



# Use cases for geometrical similarity search

Precondition: 3D scan data and parts catalog




## Inspection

- Execution of deviation analysis

## Renovation

- Surface treatment and recovery of original product state

## Usage of spare parts

- 3D measurement for choice of appropriate spare parts

## Reengineering

- Automated building of original assemblies
- Accurate fitting of reworked components

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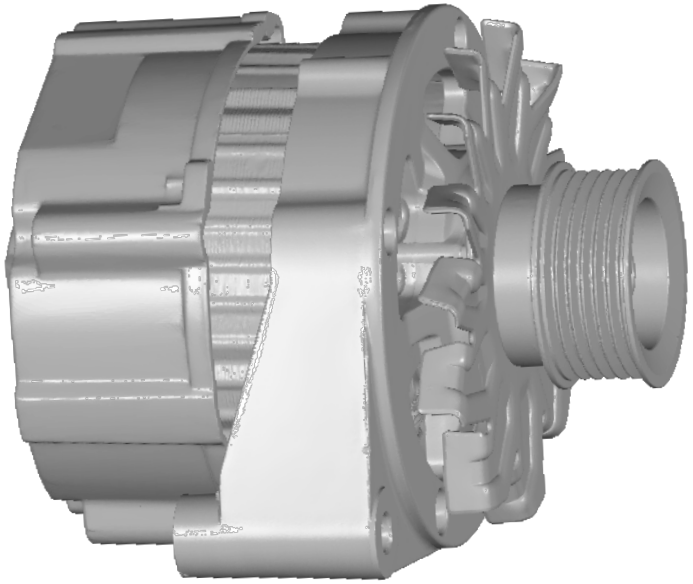
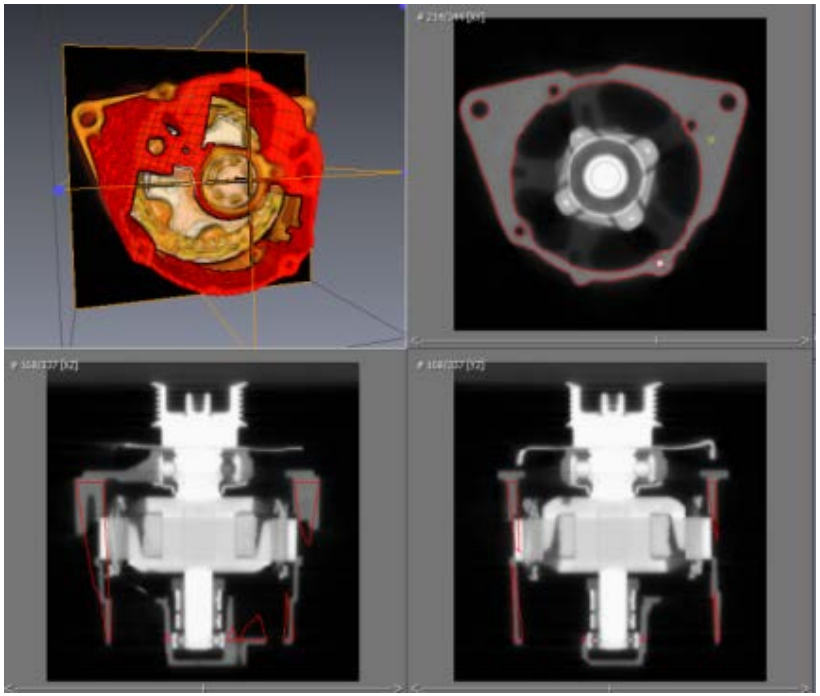
# Test data

Structured light 3D scan and computer tomography





- Scan of a GOM ATOS III structured light 3D scanner
- STL file (triangulated data)

- Scan of a X-ray system
- Complete capture of the entire model

# Preparations

## Development of the test case

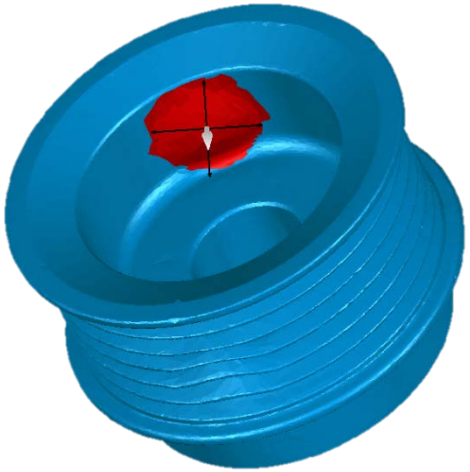
- Creation of a parts catalog with CADENAS PARTsolutions
- Structured light scan of 8 alternator parts


- New „quick search“ profile that works better with corrupted surfaces

# Test series 1

## Preparations

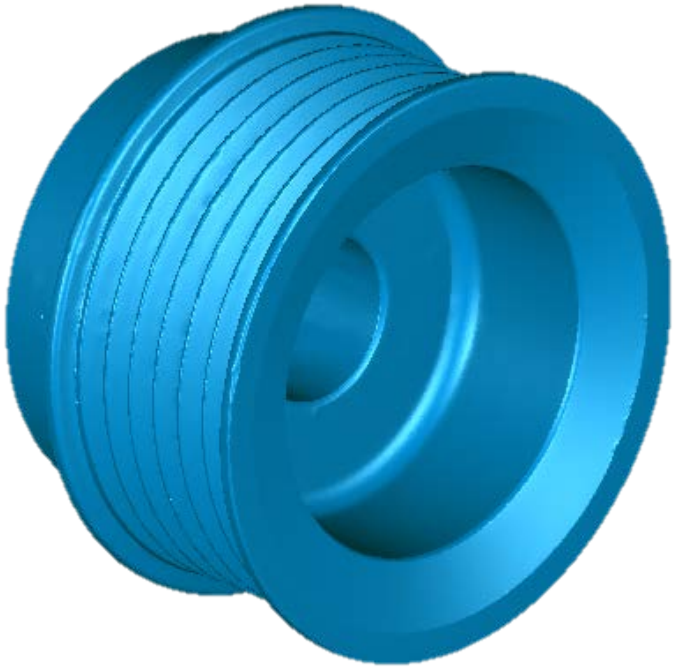
- Structured light scan with a GOM ATOS III
- Parts were completely disassembled and scanned
- Digital deformation of parts to simulate signs of use
- Downsampling to 100k faces
- Search threshold set to 70%, search went over all cataloges (PN – EN – ISO & standard parts)



Disassembly to single parts → Stuctured light scan → Post processing → Downsampling

# Parts from test series 1

Detailed View



# Test series 1

## Results

### Make or Buy Report

Übersicht | Ergebnisse

Suchteile: D:/PartSolutions-Katalog/Test für CIF/search

2 von 2 Teilen (100%) haben Treffer geliefert

Vergleichsteile: cat

**1 .**

| | |
|---|---|
| **Katalog:** | Alternator |
| **Bezeichnung:** | Riemenscheibe_AyM |
| **Norm-Nummer:** | Riemenscheibe_AyM.stl |
| **Norm-Titel:** | |
| **Übereinstimmung:** | [redacted] |

| | |
|---|---|
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| **Bezeichnung:** | p2_deformed |
| **Norm-Nummer:** | |
| **Norm-Titel:** | p2_deformed |

**2 .**

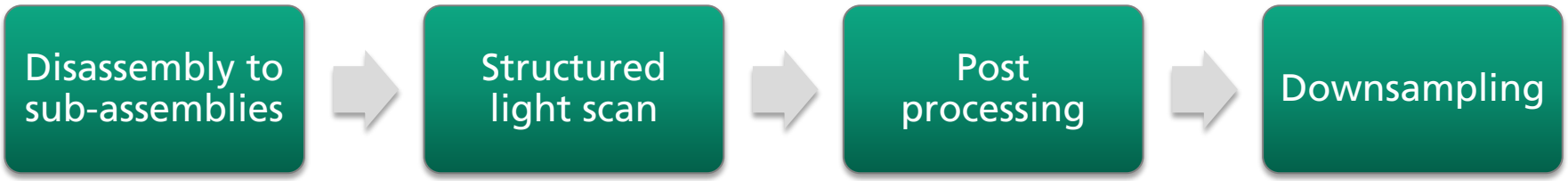
| | |
|---|---|
| **Katalog:** | Alternator |
| **Bezeichnung:** | Luefterrad_1.5_lochfrei |
| **Norm-Nummer:** | Luefterrad_1.5_lochfrei.stl |
| **Norm-Titel:** | |
| **Übereinstimmung:** | [redacted] |

| | |
|---|---|
| **Katalog:** | |
| **Bezeichnung:** | p1_deformed |
| **Norm-Nummer:** | |
| **Norm-Titel:** | p1_deformed |

# Test series 2

## Preparation

- Structured light scan with a GOM ATOS III
- Alternator was disassembled in 2 sub-assemblies
- Parts were not entirely visible
- Test series 2a
  - Manual segmentation of single parts in sub-assemblies
- Test series 2b
  - Automatic segmentation through algorithm
- Downsampling to 100k faces
- Search threshold set to 70%, search went over all catalogues



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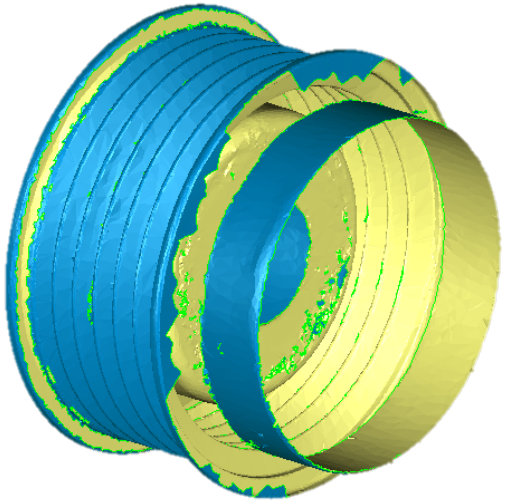
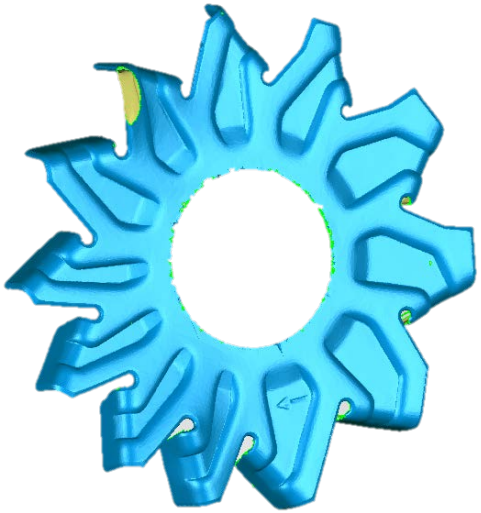
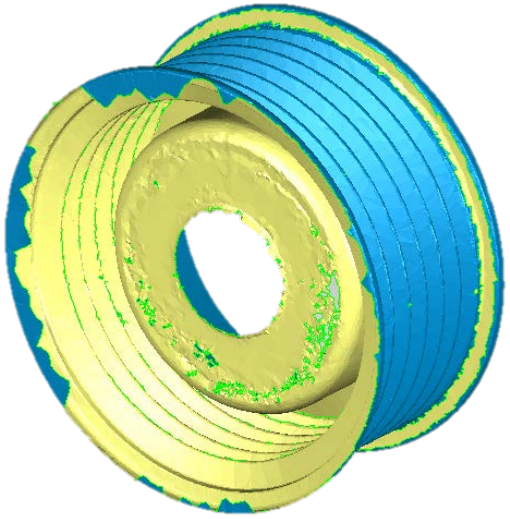
# Parts from test series 2a und 2b

Detailed view







# Test series 2a

## Results

### Make or Buy Report

Übersicht | Ergebnisse

Suchteile: D:/PartSolutions-Katalog/Test für CIF/search_t2

2 von 2 Teilen (100%) haben Treffer geliefert

Vergleichsteile: cat

**1 .**

| | |
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| **Norm-Nummer:** | |
| **Norm-Titel:** | t2_segment |

| | |
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| **Bezeichnung:** | Luefterrad_1.5_lochfrei |
| **Norm-Nummer:** | Luefterrad_1.5_lochfrei.stl |
| **Norm-Titel:** | |
| **Übereinstimmung:** | [redacted] |

**2 .**

| | |
|---|---|
| **Katalog:** | |
| **Bezeichnung:** | t1_segment |
| **Norm-Nummer:** | |
| **Norm-Titel:** | t1_segment |

| | |
|---|---|
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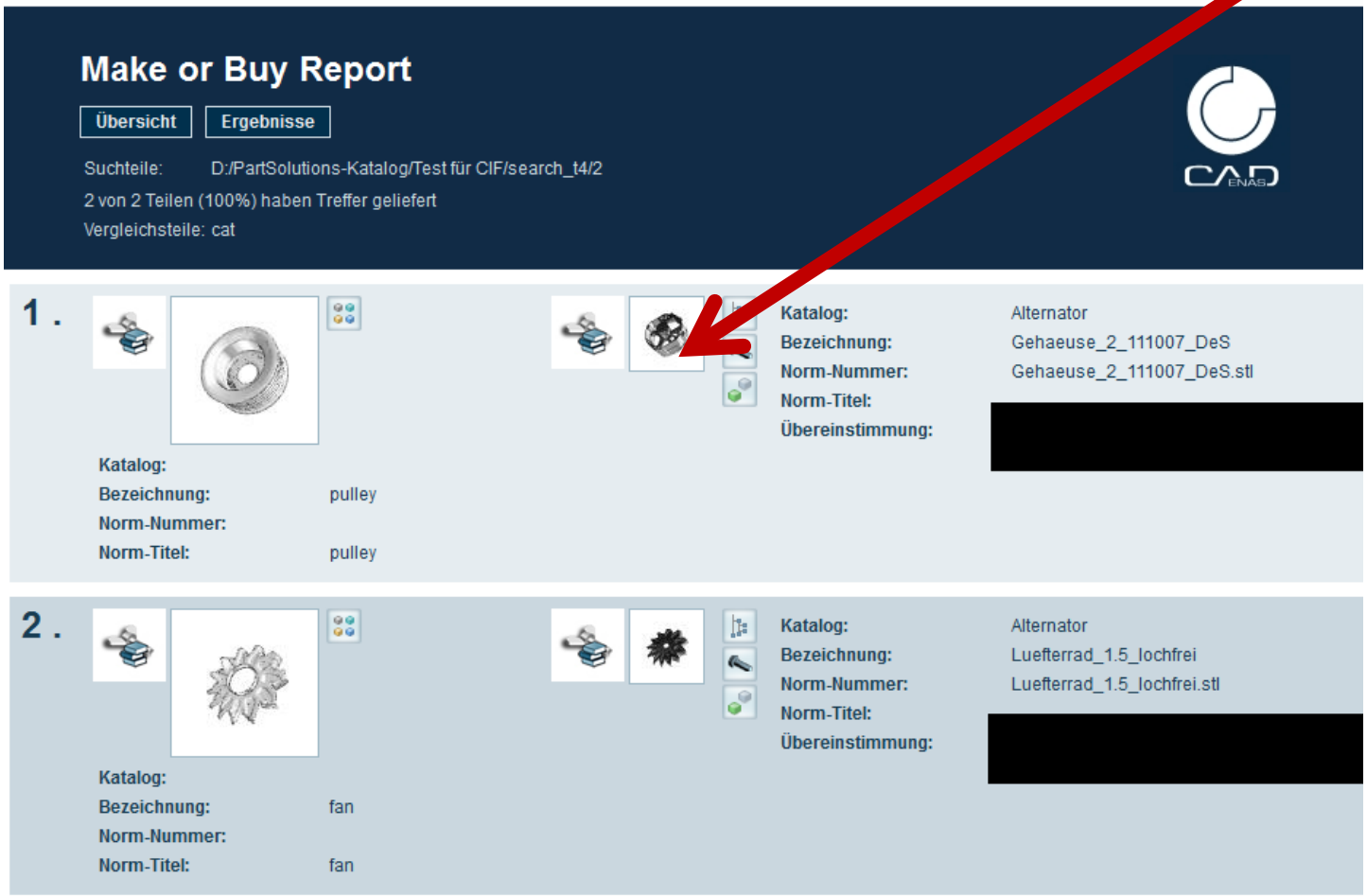
| **Norm-Nummer:** | Riemenscheibe_AyM.stl |
| **Norm-Titel:** | |
| **Übereinstimmung:** | [redacted] |

# Test series 2b

## Results

Incorrect identification



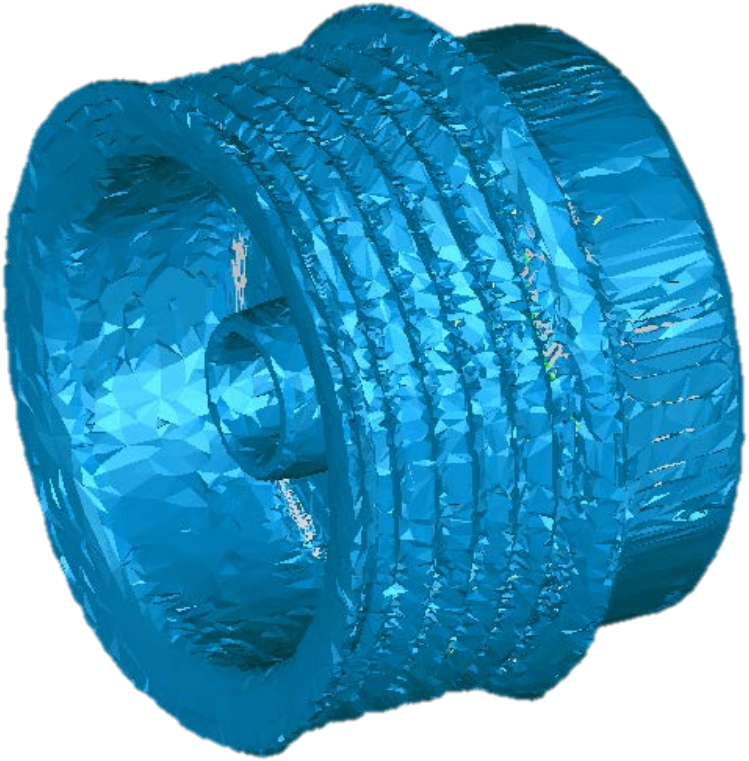
# Test Series 3

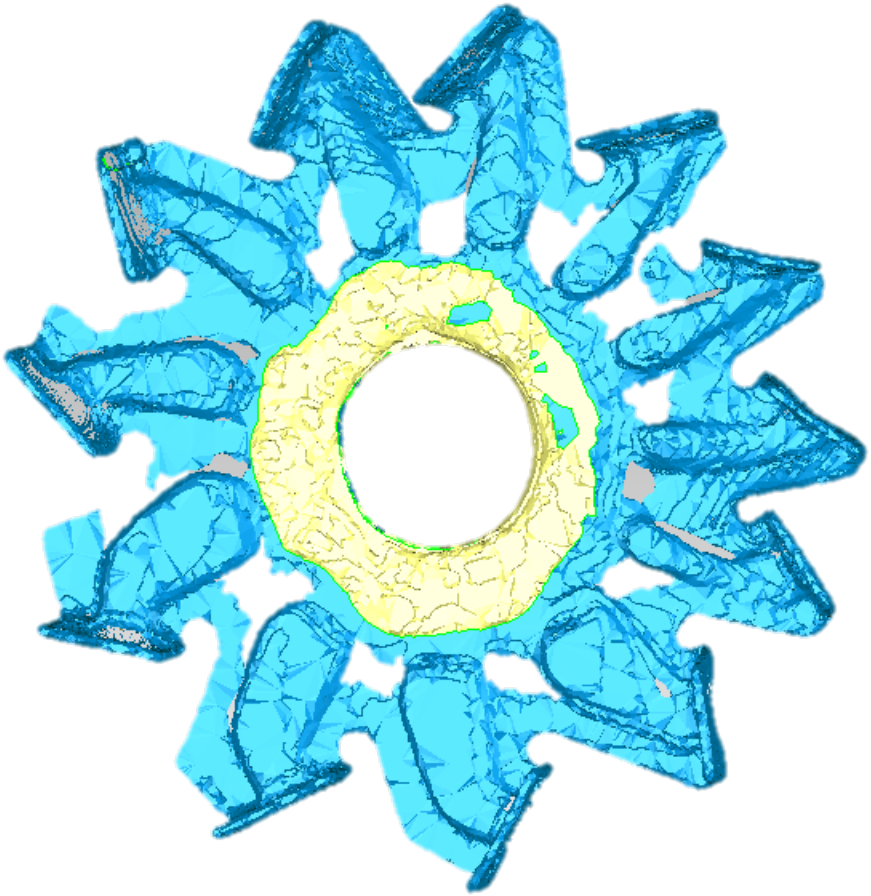
## Preparation

- computer tomography
- Alternator was captured completely without disassembly
- Single parts were segmented using an algorithm according to material density (gray scale segmentation)
- Post processing (Removal of unnecessary faces, separation of connected parts)
- Results have an edged surface as they were generated from voxels
- Downsampling to 100k faces
- Search threshold set to 70%
- Search went over all cataloges

# Parts from test series 3

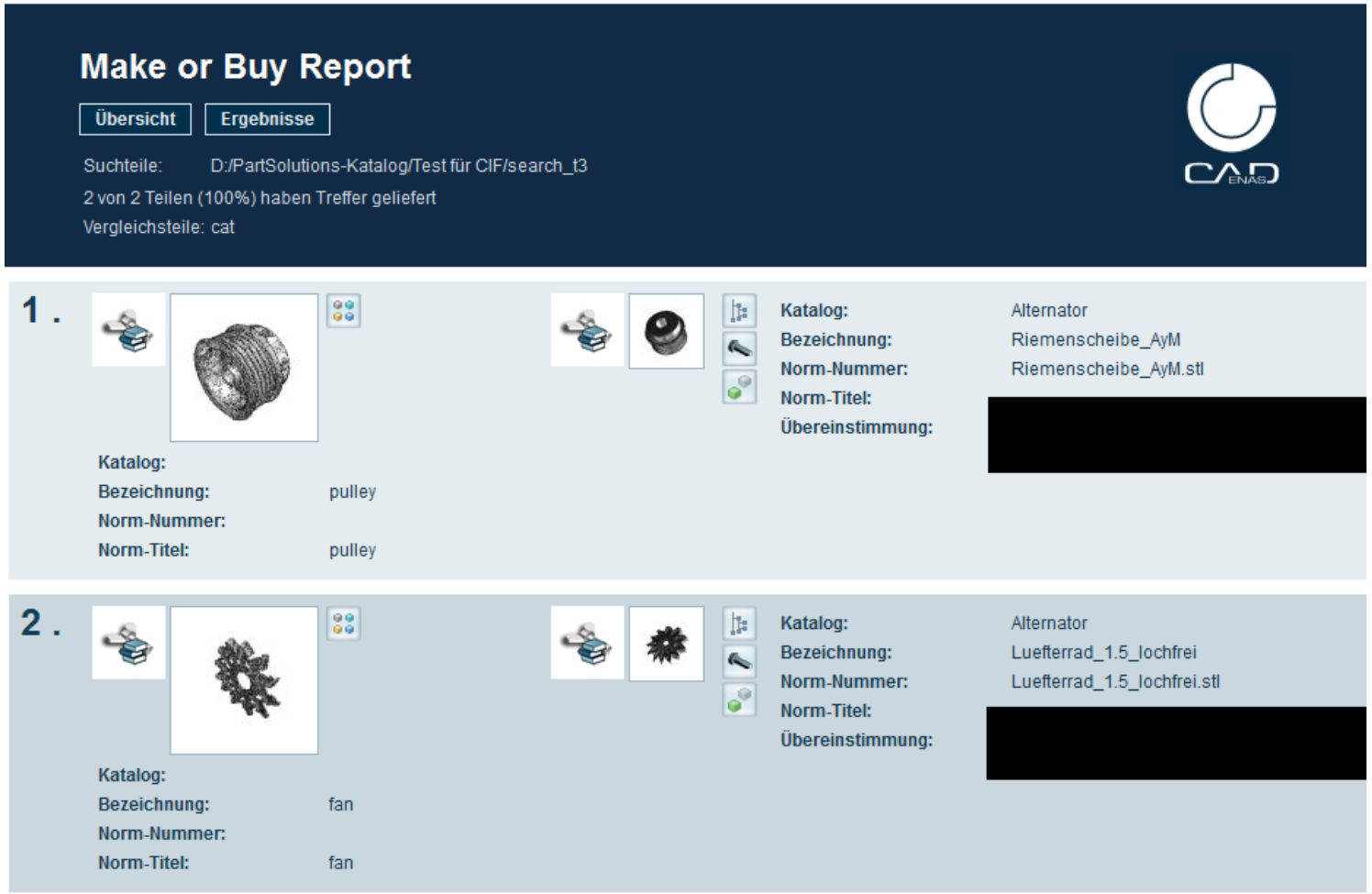
Detailed view





# Test series 3

## Results



**Make or Buy Report**

Übersicht | Ergebnisse

Suchteile: D:/PartSolutions-Katalog/Test für CIF/search_t3

2 von 2 Teilen (100%) haben Treffer geliefert

Vergleichsteile: cat

**1 .**

| | |
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| Katalog: | |
| Bezeichnung: | pulley |
| Norm-Nummer: | |
| Norm-Titel: | pulley |

| | |
|---|---|
| Katalog: | Alternator |
| Bezeichnung: | Riemenscheibe_AyM |
| Norm-Nummer: | Riemenscheibe_AyM.stl |
| Norm-Titel: | |
| Übereinstimmung: | [redacted] |

**2 .**

| | |
|---|---|
| Katalog: | |
| Bezeichnung: | fan |
| Norm-Nummer: | |
| Norm-Titel: | fan |

| | |
|---|---|
| Katalog: | Alternator |
| Bezeichnung: | Luefterrad_1.5_lochfrei |
| Norm-Nummer: | Luefterrad_1.5_lochfrei.stl |
| Norm-Titel: | |
| Übereinstimmung: | [redacted] |

# Summary

Results of test series

| | Test series 1 | Test series 2 | Test series 3 |
|---|---|---|---|
| **Scenario** | 3D scan of single parts | 3D scan of assembly + segmentation | CT of product + segmentation |
| **Measurement method** | Structured light | Structured light | X-ray |
| **Data acquisition** | Ca. 30 min | Ca. 40 min | Ca. 1 day |
| **Preprocessing** | 10 min | 15 min | Several days |
| **Postprocessing** | Ca. 60 min | Ca. 60 min | Ca. 1 day |

- High matching rates across all test series
- Matching rates at complete three-dimensional captured parts nearly perfect
- Very good matching rates for segmented parts
- Indicated correlation between geometrical completeness and matching rate

# STRUCTURE

- Introduction Fraunhofer IPK
- Need for 3D models
- Research projects and use cases
- Test series and results
- **Future potentials and outlook**

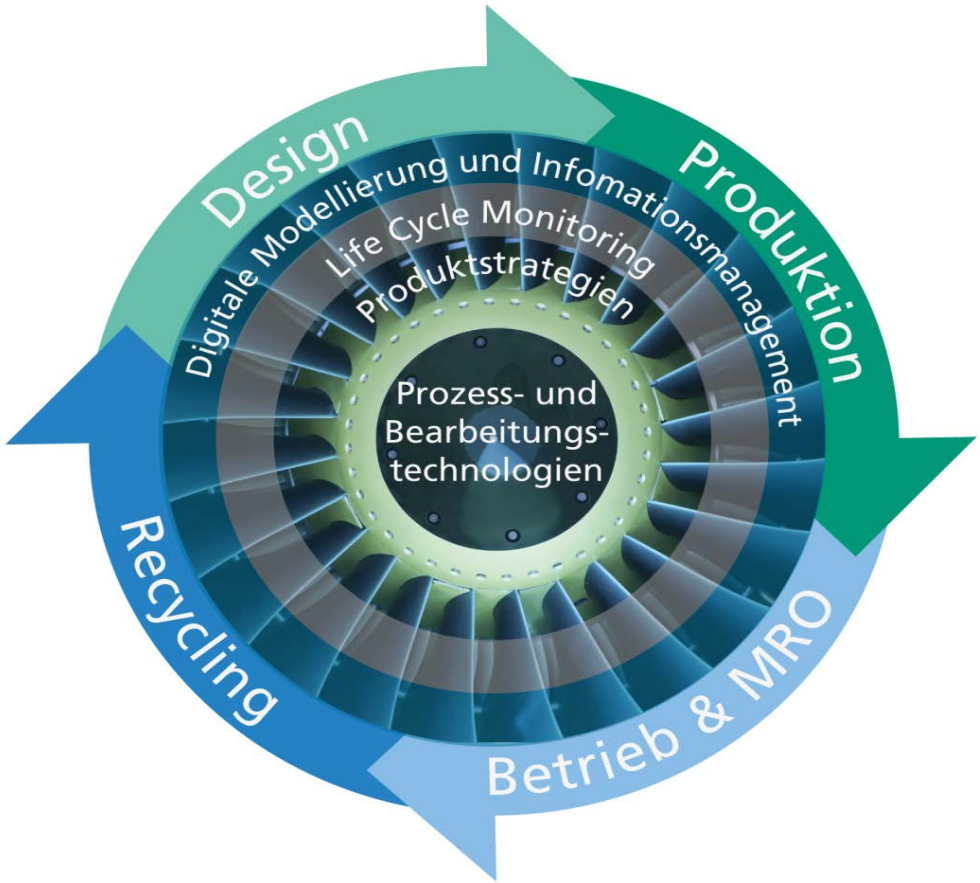
# Future development potentials

From 3D scan to CAD model

- Improvement of robustness of geosearch
  - Strength/weakness analysis of geosearch for specific geometry properties and quality levels of 3D scan data
  - Specific improvement of search algorithms (possibly search directly in point cloud)
- Automated geosearch of 3D scanned parts
  - Interface to software for surface reconstruction of point clouds
  - Use of search results for automated deviation analysis
- Integration of geosearch into a reverse engineering process for automated generation of CAD assembly models
  - API-access onto search results
  - Connection to a segmentation principle for part separation in 3D assembly scans or “pattern matching” in any point clouds
  - Matching of found parts with existing product structures

# Innovation cluster Life Cycle Engineering (LCE)

Outlook of new topics




Development of life cycle oriented engineering processes, methods, tools, and technologies for all life cycle phases *(design, production, operation, MRO, recycling)*

- Innovation fields
  - Product strategies
  - **Digital modelling and information management**
  - Process and manufacturing technologies
  - Life cycle monitoring

# Innovation cluster Life Cycle Engineering (LCE)

Innovation field Digital Modeling and Information Management

- Information management
- Reverse engineering
- Customization, configuration management and tracing of product composition
- Process and project management for a life cycle-oriented system
- Product visualization by VR and AR