Presented at the FIG Working Week 2023,
28 May - 1 June 2023 in Orlando, Florida, USA

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Protecting Our World, Conquering New Frontiers

Geometric Quality Assurance within the Research Cluster IntCDC

Scientific Workshop on Uncertainty and Quality of Multi-Sensor Systems

Session 2: Quality Models and Uncertainty of Monitoring Sensors

27.-28.05.2023 Orlando USA

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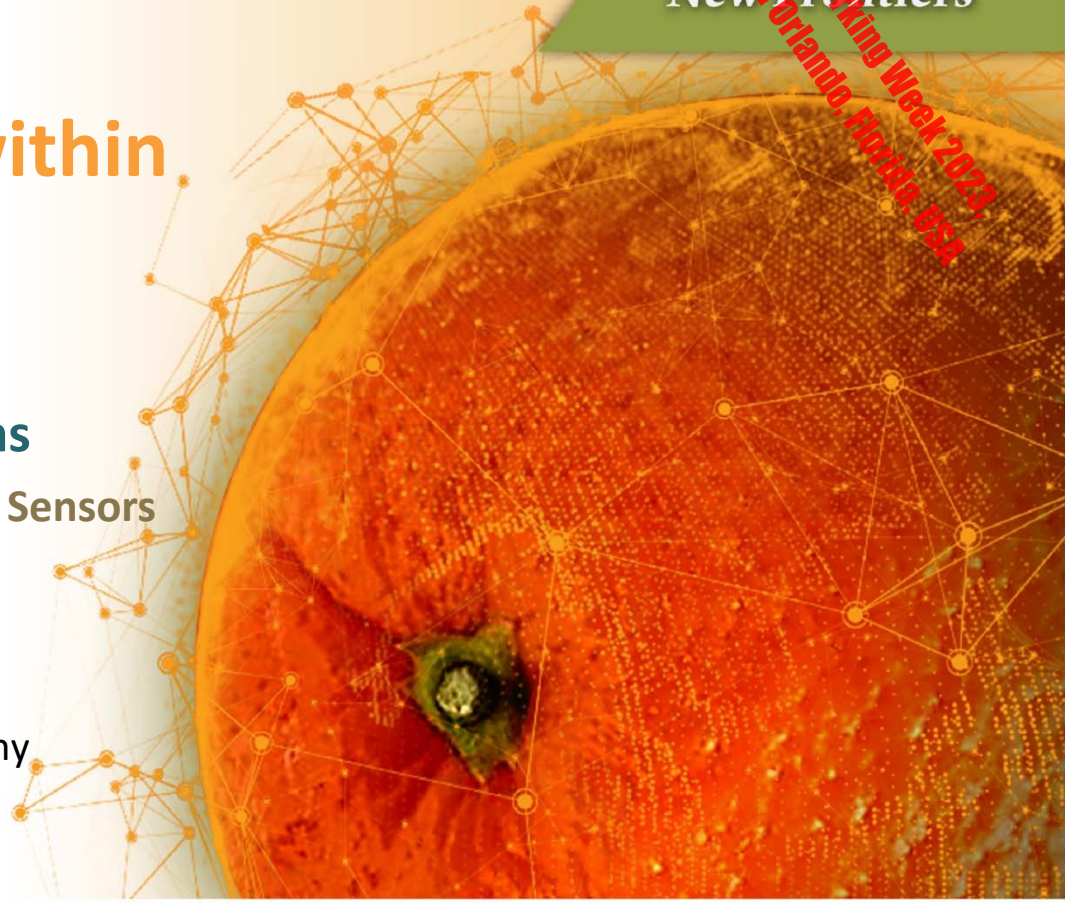

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Outline

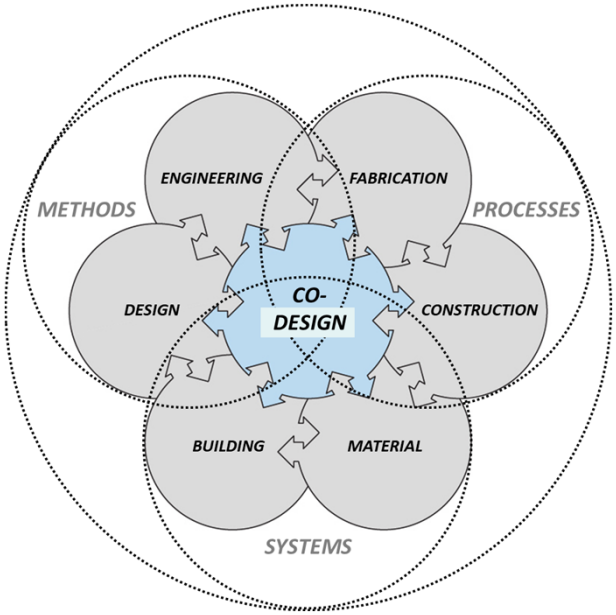
- Introduction
- Quality Assurance Concept and Holistic Quality Models for IntCDC
- Case Studies (Geometric Quality Assurance)
- Conclusion and Outlook

Introduction

Research Cluster

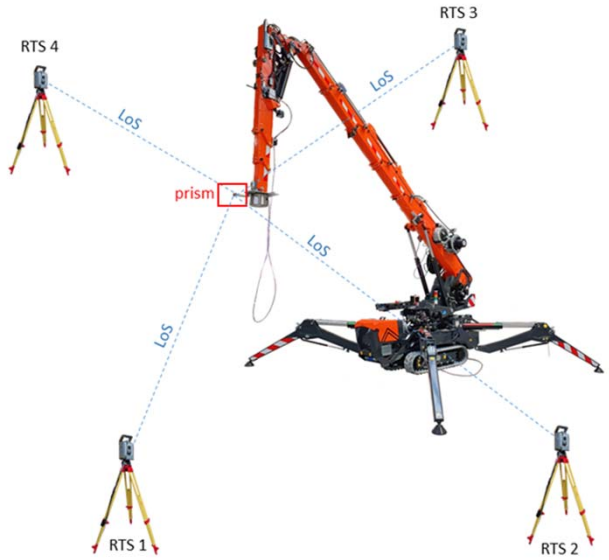
IntCDC -Integrative Computational Design and Construction

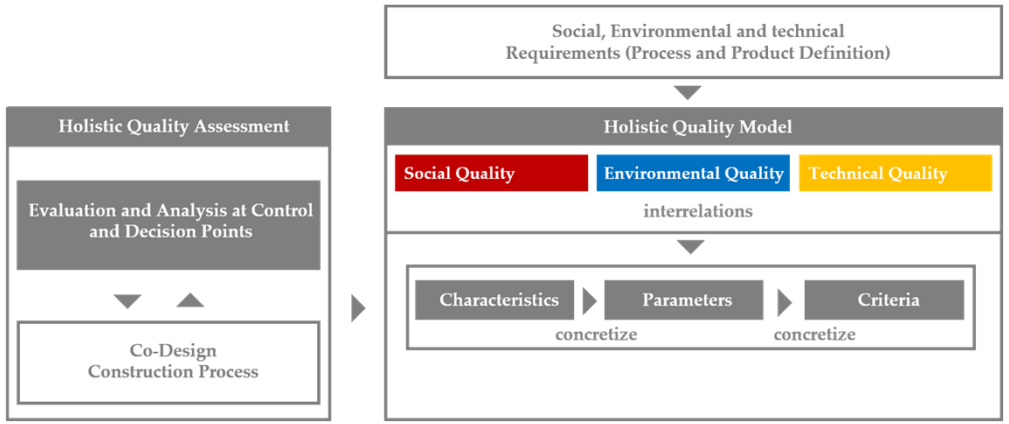
- **Funding**: 2019-2026 by German Research Foundation(DFG)
- **Objective**: Developing fundamental methods for truly integrative design and construction based on computational feedback➔ Co-Design
- ***Interdisciplinary Research:***
  - Architecture
  - Structural Engineering, Building Physics and ***Engineering Geodesy***
  - Manufacturing and System Engineering
  - Computer Science and Robotics
  - Humanities and Social Sciences



Contributions of Engineering Geodesy

- Precise positioning of a spider crane within cyber-physical assembly process using the Robotic Total Station Network
- Quality modelling and geometric quality assurance for the construction process

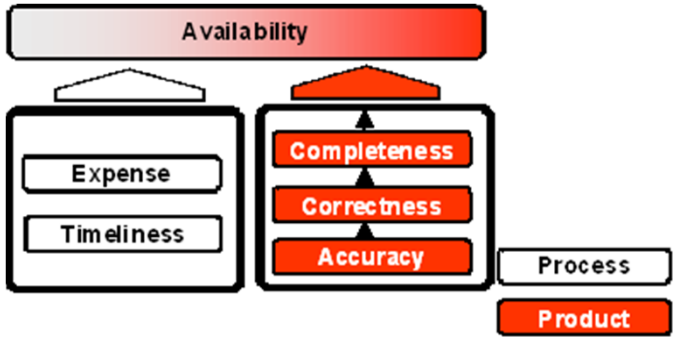


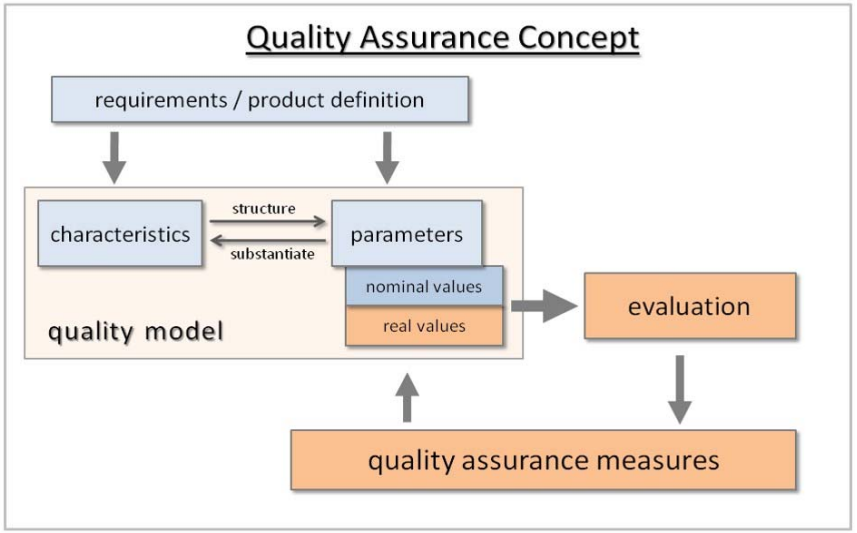


Quality Assurance Concept and Holistic Quality Models (HQM) for IntCDC

Quality Model and Quality Assurance Concept:

- **description and modelling** of the quality structurally
- **product**-related and **process**-related **quality characteristics** based on the **requirements**
- **parameters** concretize the characteristics
- **quality criteria** define targets of quality assessment
- **quality assurance** by **quality evaluation**





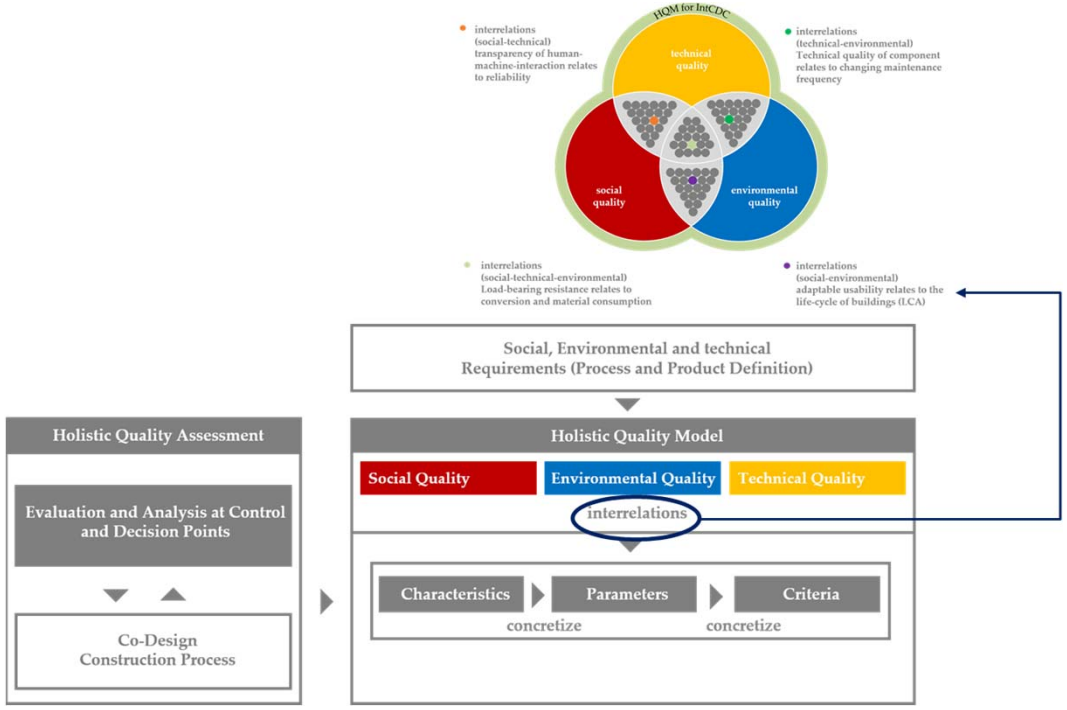
Quality Assurance Concept and Holistic Quality Models (HQM) for IntCDC

Partners:

- Institute for Social Science (SOWI)
- Institute for Acoustics and Building Physics (IABP)
- Institute of Engineering Geodesy (IIGS)

Innovations:

- **Holistic Quality Model (HQM):**
  integration of the **social, environmental and technical** quality aspects with **interrelations**
- **Holistic Quality Assessment:**
  –**control points** for quality assessment
  –**decision points** for decision-making support (predictive assessment)



Quality Assurance Concept and Holistic Quality Models (HQM) for IntCDC

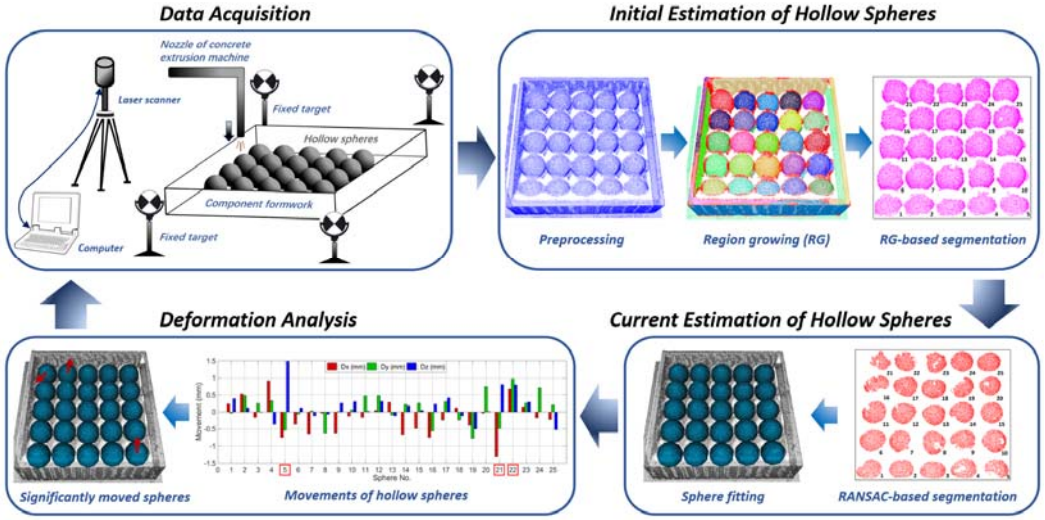
Examples of quality characteristics, parameters and criteria of HQM

	Quality Characteristic	Quality Parameter	Quality Criteria
technical	accuracy	standard deviation	should be minimized
	correctness	tolerance	should be met
	load-bearing capacity	load application time, pressure, tension	should be met
environmental	global warming potential	kg CO2 eq. emitted	should be minimized
	total material	mass	should be minimized
social	control capacity	access to all relevant information, transparency of algorithmic decision making,	should be maximized
	adaptability	conversion potential of buildings: percentage of support-free floor plants	should be maximized

Study Case 1: Geometric Quality Control for Graded Concrete during the Production Process

Monitoring the positions of the hollow spheres (stabile) and concrete level and flatness <u>after each casting step</u> by TLS (load-bearing capacity)

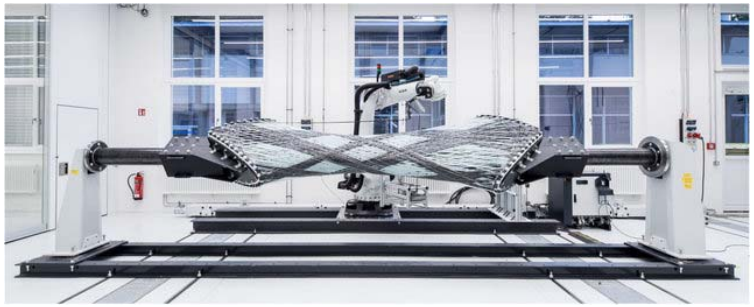
➔ Quality control during the production process and real time feedback necessary



Study Case 2: Geometric Quality Assurance for Fiber Composite Component during the Production Process

- Carbon-fiber (features: low thermal expansion, low weight) widely used in industry fields: automative, aeronautics and shipbuildings
- Nowadays: Carbon-fiber composites are used for constructions (long-span building systems and for densification of existing building stock)
- Construction is realized by the robotic fabrication processes such as coreless filament winding (CFW)

https://www.itke.uni-stuttgart.de/research/built-projects/maison-fibre-2021/

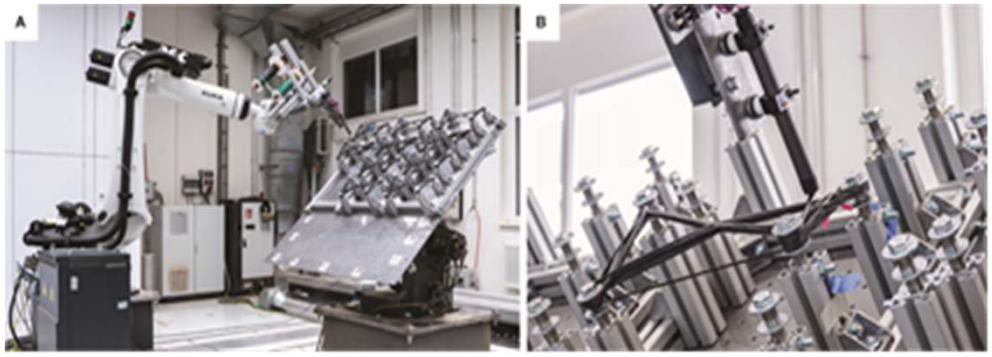


(ICD/ITKE)

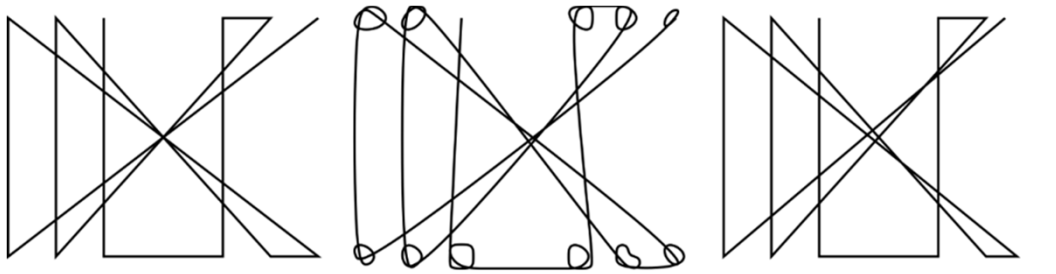
https://www.itke.uni-stuttgart.de/research/built-projects/buga-fibre-pavilion-2019/

Study Case 2: Geometric Quality Assurance for Fiber Composite Component during the Production Process

Motivation:
Structral performance directly dependt on fiber-fiber interaction
However, real fiber geometry is unknown ➔ real load-bearing capacity is unknown



a) b)
a) Fabrication set-up with KUKA robot b) exemplary element (Gil Pérez et al. 2022)



Study Case 2: Geometric Quality Assurance for Fiber Composite Component during the Production Process

Motivation:
Real load-bearing capacity is unknown and currently no standard available for fiber composite component

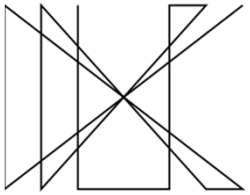
➔ prototype buildings are permitted on a case-by-case base, for high safety factors more material need to be used than necessary

Goal: Understanding what really happened (geometry of the fiber composites) during the production process! Every new fiber will deform the previous ones!

➔ Orientation of the lines and positions of intersection points will change!

➔ Understanding how different parameters can affect the deformations and final geometry is helpful for fine-tuning the simulation

➔ Determination of the fiber geometry in each epoch!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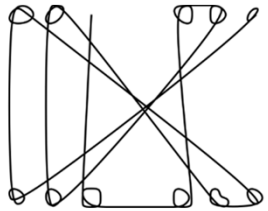
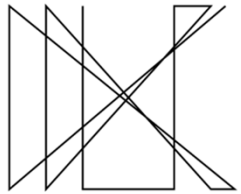

Path Planning


Processed Measurements

Study Case 2: Geometric Quality Assurance for Fiber Composite Component during the Production Process

Geodetic challenges:

- Elements are very thin (diameter is 5 mm -1 cm)
- TLS measurements are very noisy
- Object is obscured (for example by the robot)

➔ data are incomplete➔ unreliable estimation

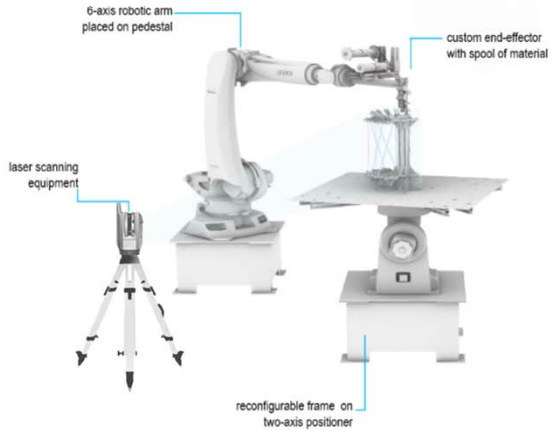
5 mm -1cm

Material:

- Carbon-fiber bundles are pre-impregnated with resin
- Fiber/resin ratio: 50:50

Measurement:

Trimble X7 laser scanner, resolution of 5 mm, 3D point accuracy is 2.4 mm at 10 m

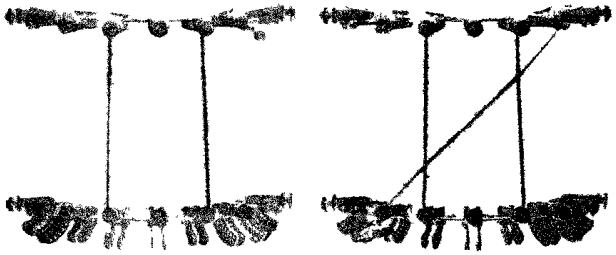


Production and measurement setup

Study Case 2: Geometric Quality Assurance for Fiber Composite Component during the Production Process

Process Quality

- Line segmentation (incl. orientation, start and end point)
- Determination of the intersection points
- Positions intersection points change
  ➔Assignment of intersection points from epoch to epoch and determination of small deformations (e.g. about 1 cm)
- Quality characteristics:
  - Correctness (line parameters)
  - Accuracy (standard deviations of the line and the intersection points estimation)



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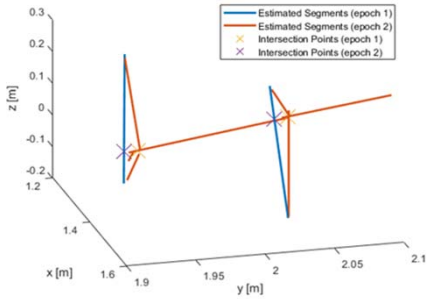
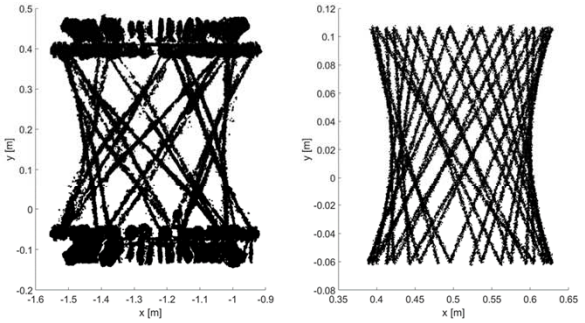


c)

a): first epoch with two separated fibers. b): second epoch with one additionally crossed fiber Line
c) Estimation and calculation of line intersection points of two epochs (Balangé et al. 2022)



Exemplary data sets (Balangé et al. 2023)

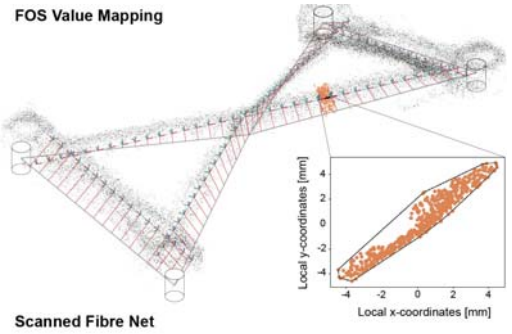
Study Case 2: Geometric Quality Assurance for Fiber Composite Component during the Production Process

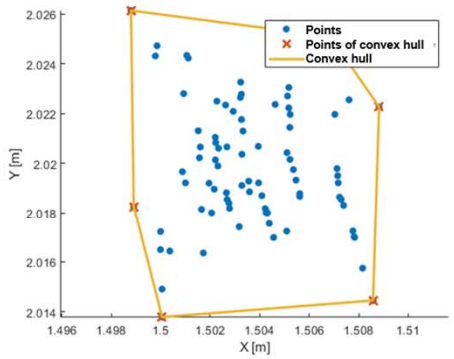
Product Quality

- Geometry of final product
- **Cross-sections** of the fibers varies within the fiber segments, caused by unequal distribution of resin
- The cross-section of fibers along the line segment (besides the position and orientation) ➔ base for calculation of load-bearing capacity
- Finding: calculated areas tend to smaller than they are

➔ Laser beam penetrates the material

- Quality characteristics:
  - Correctness (line parameters)
  - Accuracy (standard deviations of the cross-sectional areas estimation)
  - Completeness (completeness of the measured intersection points and lines)





Conclusion and Outlook

- Holistic quality model (technical, social and environmental aspects) for sustainable quality assurance
- Quality control is especially important for the development of new construction processes, not only for the final product but also during the process at defined control points, understanding the construction process through interdisciplinary cooperation
- Still many challenges for geodetic measurement: e.g. automatic data processing and investigation of influence of the material on the TLS measurements

Thank you very much for your attention !

Acknowledgement

The research published in this article is supported by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy – EXC 2120/1 – 390831618. The authors cordially thank the DFG.

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