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Volunteering for the future – Geospatial excellence for a better living



# The Research Cluster Integrative Computational Design and Construction (IntCDC) Current Engineering Geodetic Contributions

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# Outline

- IntCDC
  - Motivation
  - Research Vision
- Robotic Platform for Cyber-Physical Assembly Process
  - Spider Crane
  - Real time total station network
- Holistic Quality Model
  - Structure and Definition
  - Quality Control for Graded Concrete
  - Quality Control for Fibre Composites
- Conclusion and Outlook

# *RESEARCH RELEVANCE*

***GRAND CHALLENGE***

***Urban population growth:***

***2.6 billion people until 2050***

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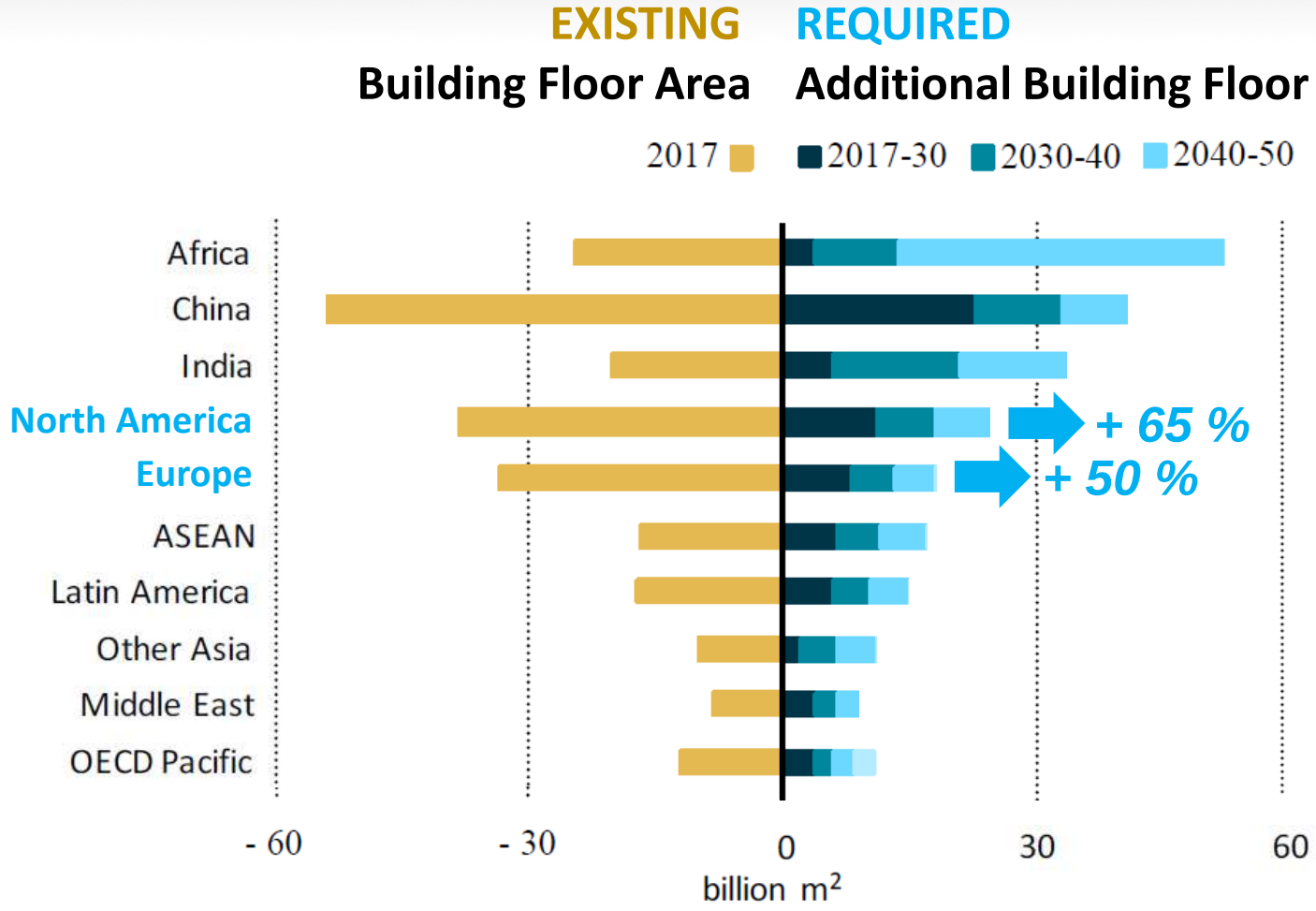
- ***Urban population growth:***
  ***2.6 billion people until 2050***
- ***Building floor area:***
  ***needs to be almost doubled***
- ***Required construction:***
  ***65.000 m² / h for 3 decades***
- ***Substantial increase:***
  ***in Europe and North America***




(SOURCE: UNITED NATIONS ENVIRONMENT – GLOBAL STATUS REPORT 2017)

## ECOLOGICAL CHALLENGE:

- *Greatest impact: Building sector causes*
  - *40% of global resource consumption*
  - *40% of energy use*
  - *50% of global waste*

## ECONOMIC RELEVANCE:

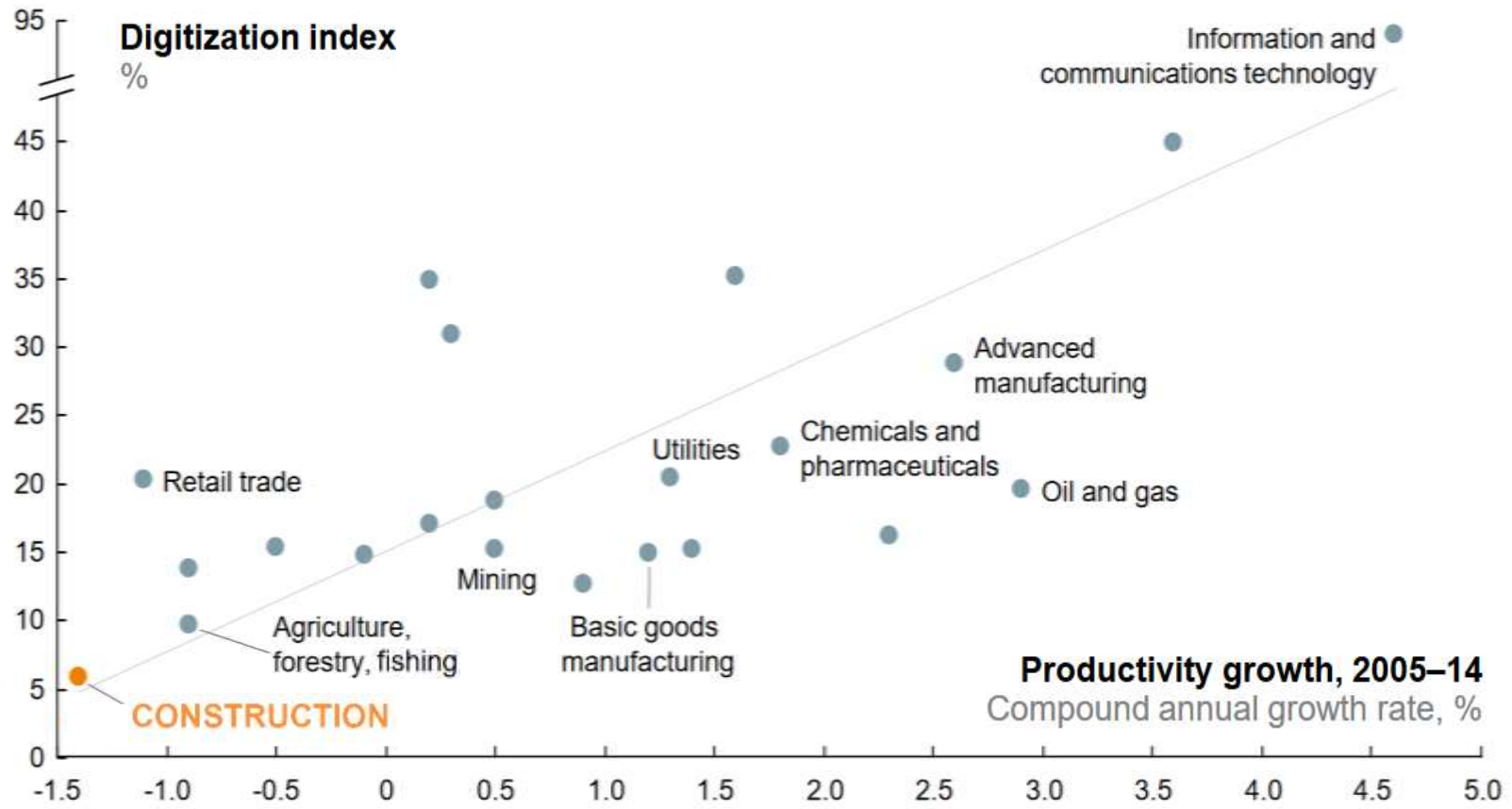
- *Biggest industry: world-wide and in Germany*
- *Prospect of enormous future growth*

## SOCIO-CULTURAL IMPORTANCE:

- *Humans spend 87% of their lifetime in buildings*
- *Direct and long-lasting impact on quality of life*
- *Important cultural contribution*

## *DIGITAL TECHNOLOGIES:*

- ***Adoption is slow and incremental***
- ***Construction least digital of all industries***

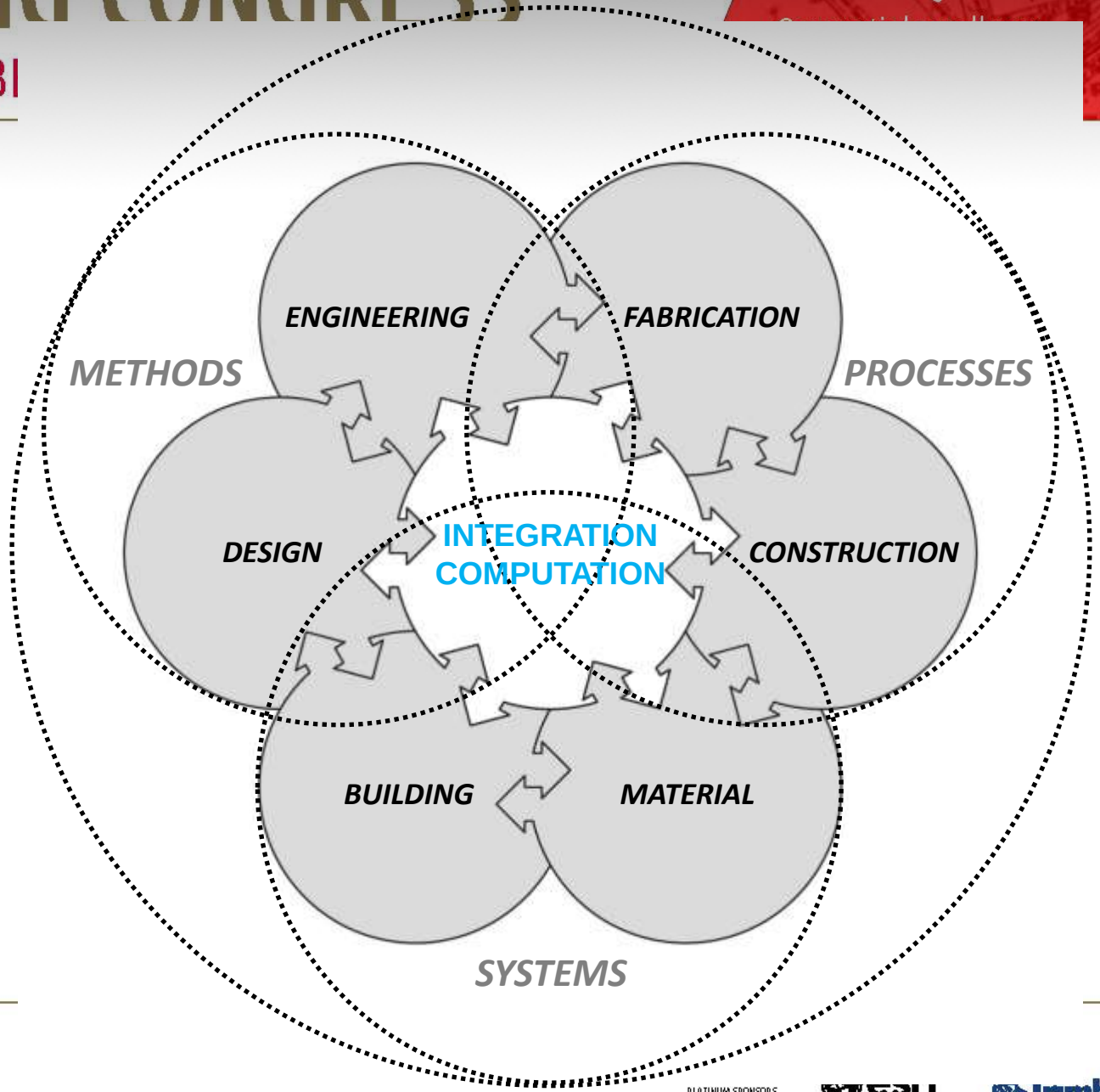



*(SOURCE: BEA; BLS; US CENSUS; IDC; GARTNER; MCKINSEY)*

# RESEARCH VISION AND OBJECTIVES

➡ ***Harness full potential of digital technologies for game-changing innovation***

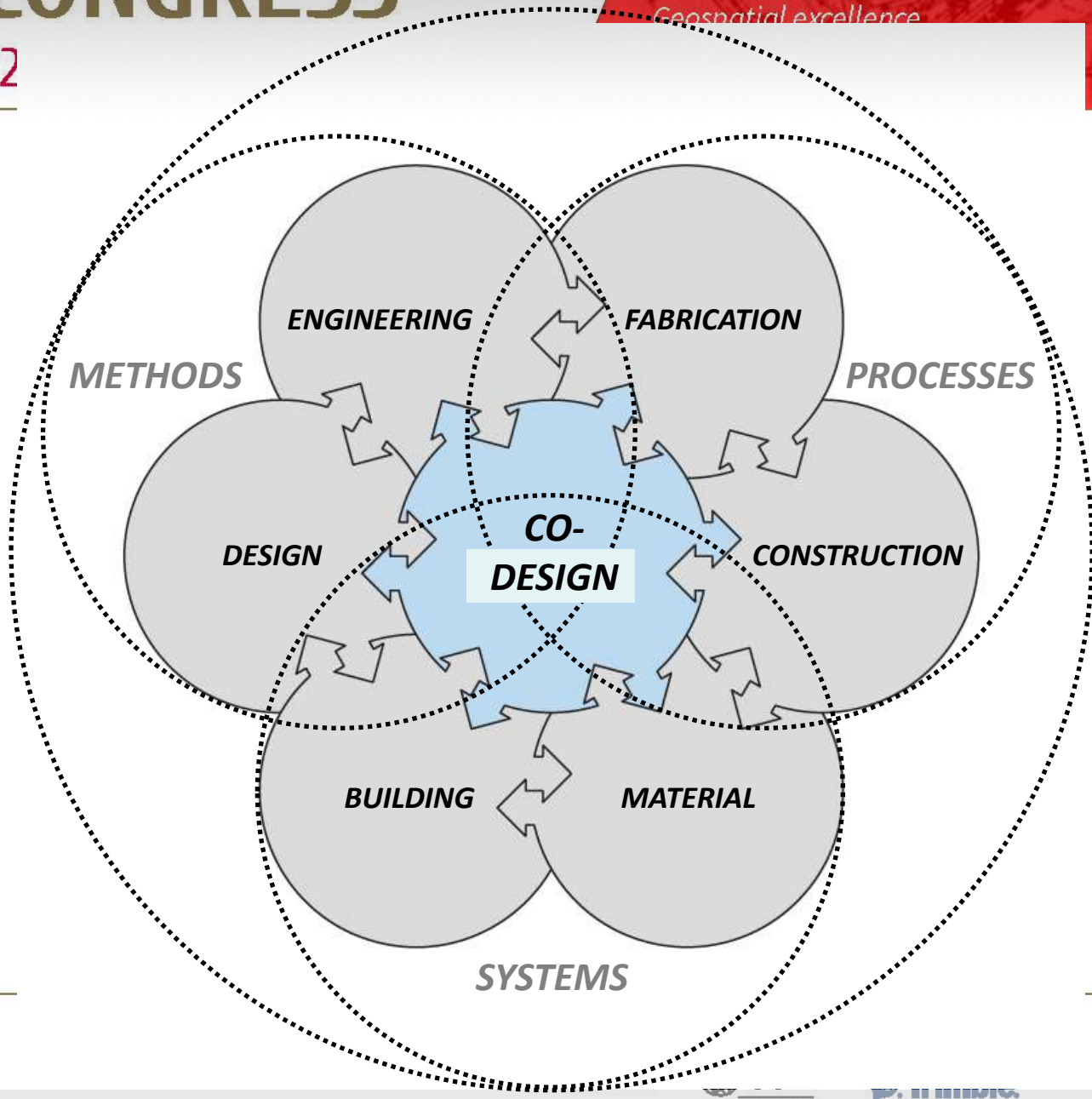
- ***Computational design and engineering METHODS:***
  ***>> ENABLE INTEGRATION***
- ***Cyber-physical robotic fabrication and construction PROCESSES:***
  ***>> IMPROVE PRODUCTIVITY***
- ***Effective, truly digital material and building SYSTEMS:***
  ***>> ENHANCE SUSTAINABILITY***
- ***ENVIRONMENTAL, SOCIO-CULTURAL AND ETHICAL REFLECTION***



# RESEARCH APPROACH

- ***CO-DESIGN** as a powerful fundamental methodology*

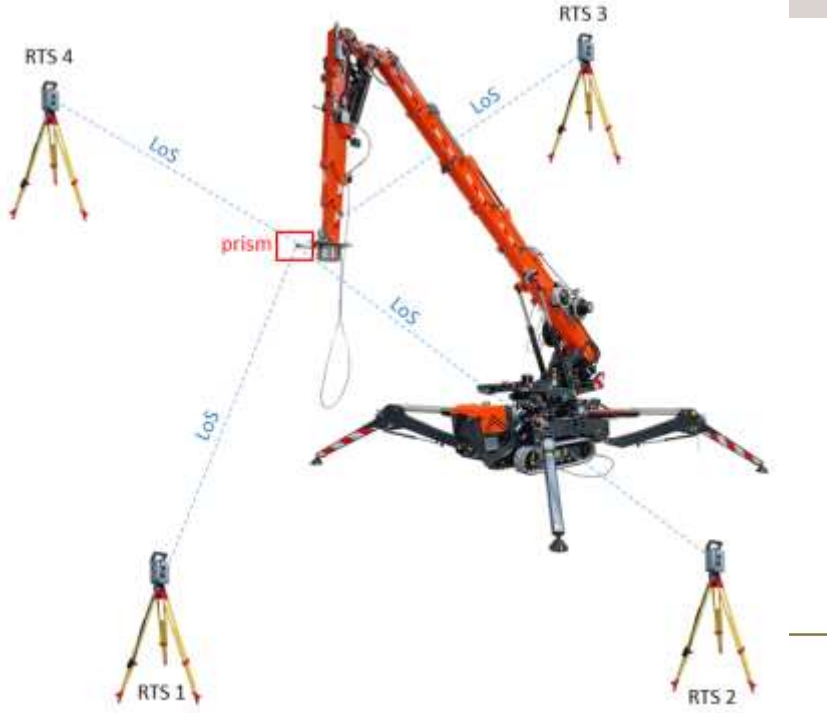
- ***INTERDISCIPLINARY RESEARCH:***
  - ***Architecture***
  - ***Structural Engineering, Building Physics and Engineering Geodesy***
  - ***Manufacturing and System Engineering***
  - ***Computer Science and Robotics***
  - ***Humanities and Social Sciences***



# RP 16 - ROBOTIC PLATFORM FOR CYBER-PHYSICAL ASSEMBLY PROCESS


- Institute of Engineering Geodesy
- Institute for System Dynamics
- Haptic Intelligence Department (HI),
  Max Planck Institute for Intelligent Systems

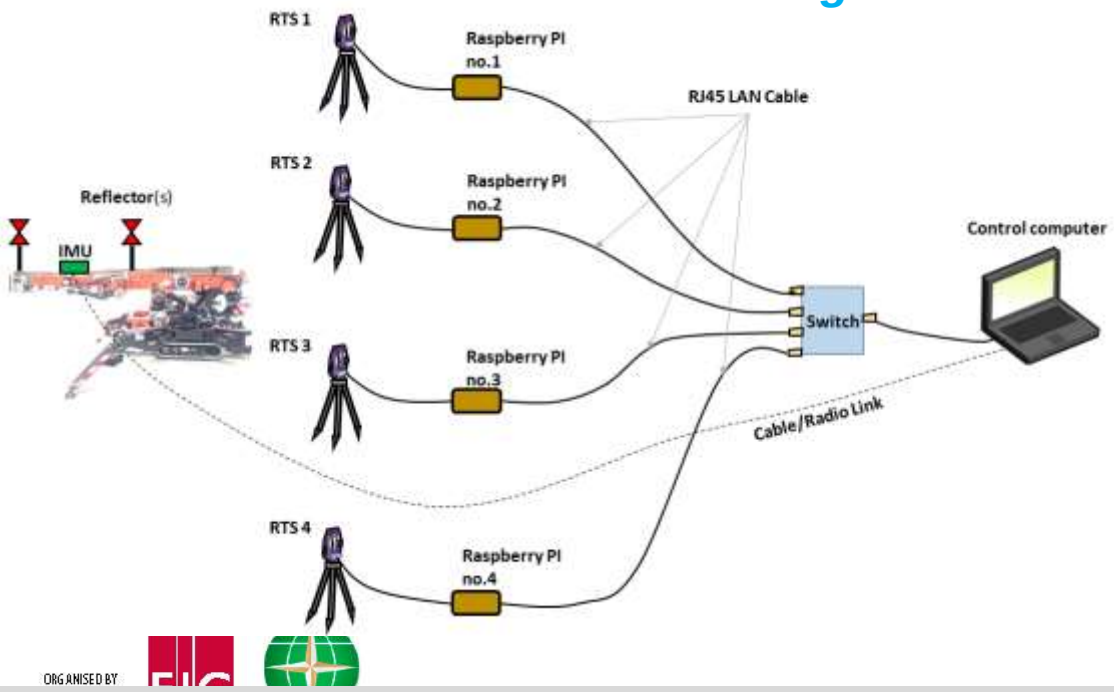

- **Project Description**
  - Robotic Platform (Spider crane) contributes to automatic assembly process of buildings
- **System Items**
  - Automatically controlled robotic platform for on-site construction processes (spider crane)
  - Kinematic and dynamic models
  - Cartesian pose trajectory following control algorithm
  - Retargeting algorithm to map human motion to robot motion with wireless vibrotactile feedback system
  - Robotic total station network (RTS-N) for pose determination in real-time with appropriate data fusion models and algorithms
  - Feedback of RTS-N data to control loop of spider crane's boom & jib



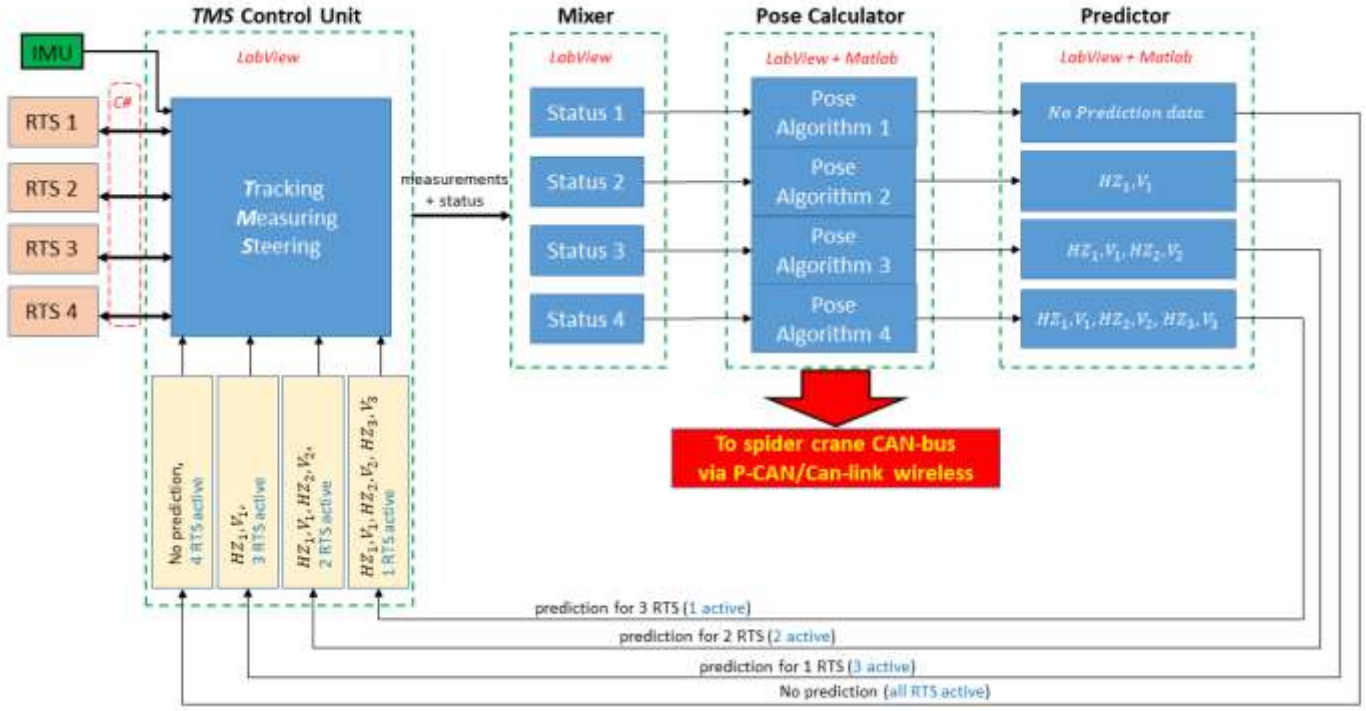
# ROBOTIC TOTAL STATION NETWORK

- **Goals**
  - 6-DoF pose determination (position and attitude) of the robotic assembly platform by the use of robotic total station (RTS) network and subsequent feedback to control loop → 2 configuations
    *A: 4 RTSs – 1 prism, for position + IMU for orientation; B: 4 RTSs – 2 prisms, for position and 2 orientation angles*
  - Investigation on network quality: accuracy and reliability aspects
- **Realization**

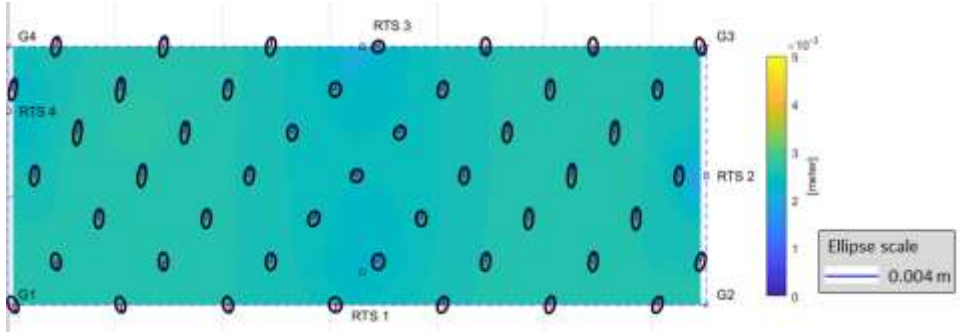
## Hardware configuration

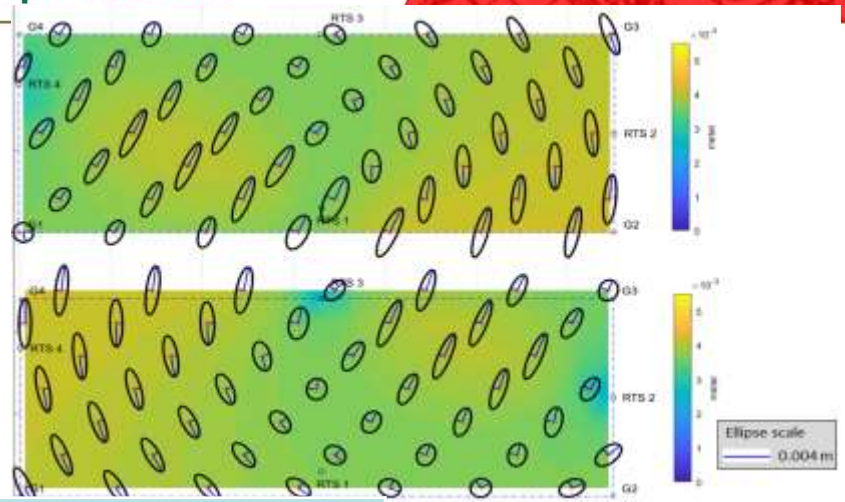



## Software: RTS-network steering algorithm



- **Pose accuracies**
  - ***Simulated results***




  - ***Real-world test results***

| Unit [m] | Configuration A | | | Configuration B | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | RTS combination 1/(4) | | | RTS combination 2/3 | | |
| | $\sigma_{yxz}^{min}$ | $\sigma_{yxz}^{max}$ | $\sigma_{yxz}^{avg}$ | $\sigma_{yxz}^{min}$ | $\sigma_{yxz}^{max}$ | $\sigma_{yxz}^{avg}$ | $\sigma_{yxz}^{min}$ | $\sigma_{yxz}^{max}$ | $\sigma_{yxz}^{avg}$ |
| Regular case | 0.0018 | 0.0027 | **0.0025** | 0.0029 | 0.0041 | **0.0038** | 0.0023 | 0.0041 | **0.0038** |

*Configuration A: 4 RTSs – 1 prism, for position + IMU for orientation*

- ***~ 2.1 mm 4 RTS***
- *~ 2.6 mm 3 RTS*
- *~ 3.0 mm 2 RTS*
- *~ 3.1 mm 1 RTS*
- ***IMU: 0.05° Pitch/Roll, 0.8° Yaw** (from manufacturer's data sheet)*

*Configuration B: 4 RTSs – 2 prisms, for position and 2 orientation angles*

- ***~ 2.2 mm 2 RTS per prism***
- *~ 3.3 mm 1 RTS per prism*
- *~ **0.03° - 0.1° Pitch/Yaw** (depending on measurement configuration)*

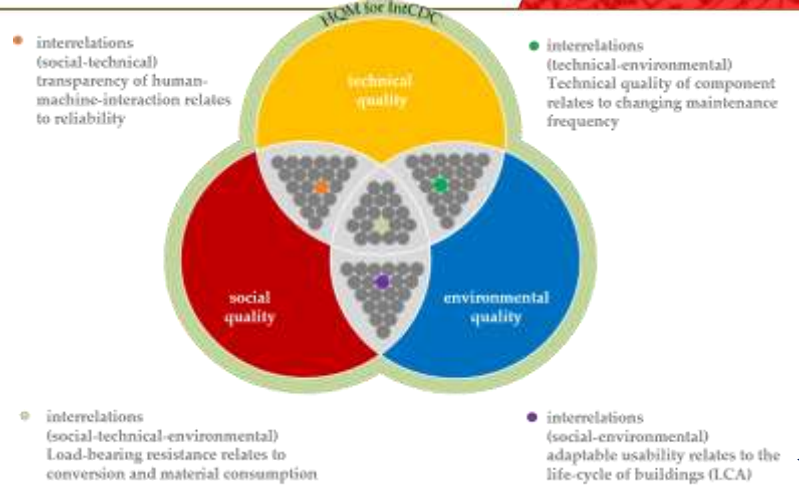
# RP 18 HOLISTIC QUALITY MODEL (HQM)

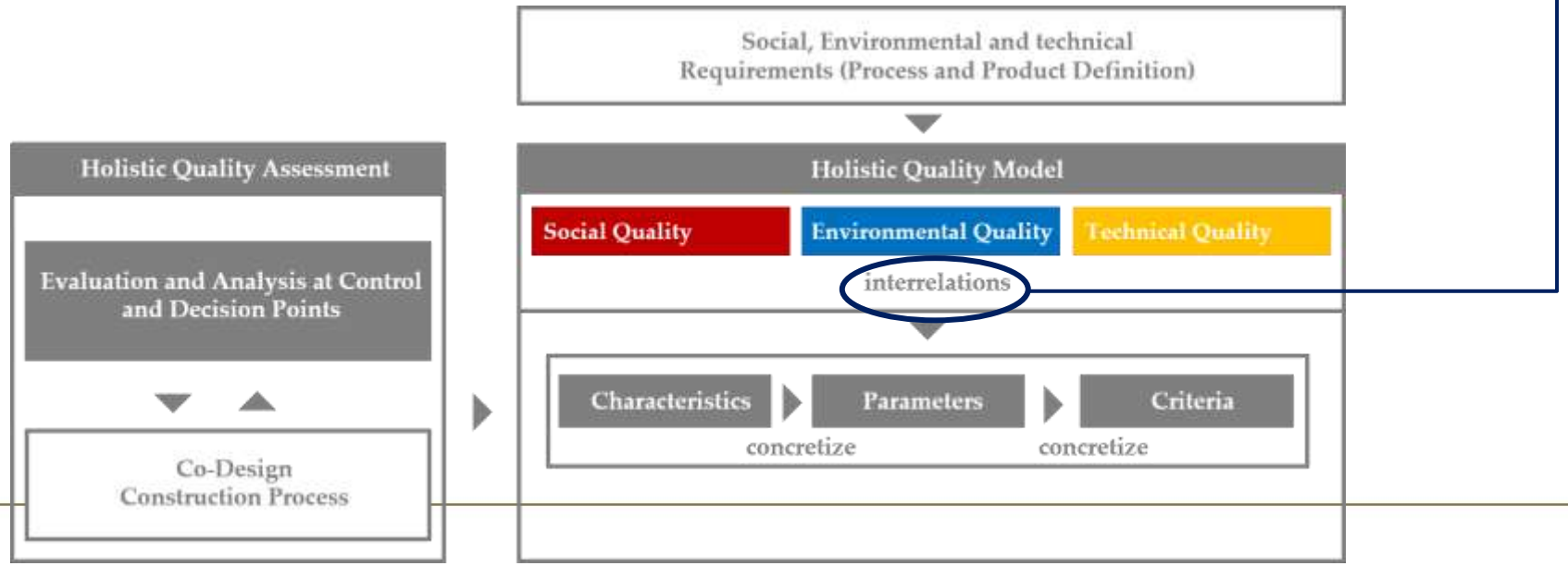
- Institute of Engineering Geodesy
- Institute for Acoustics and Building Physics
- Institute for Social Science

- **Project Description**

  HQM defines the base for IntCDC (requirements and their assurance)

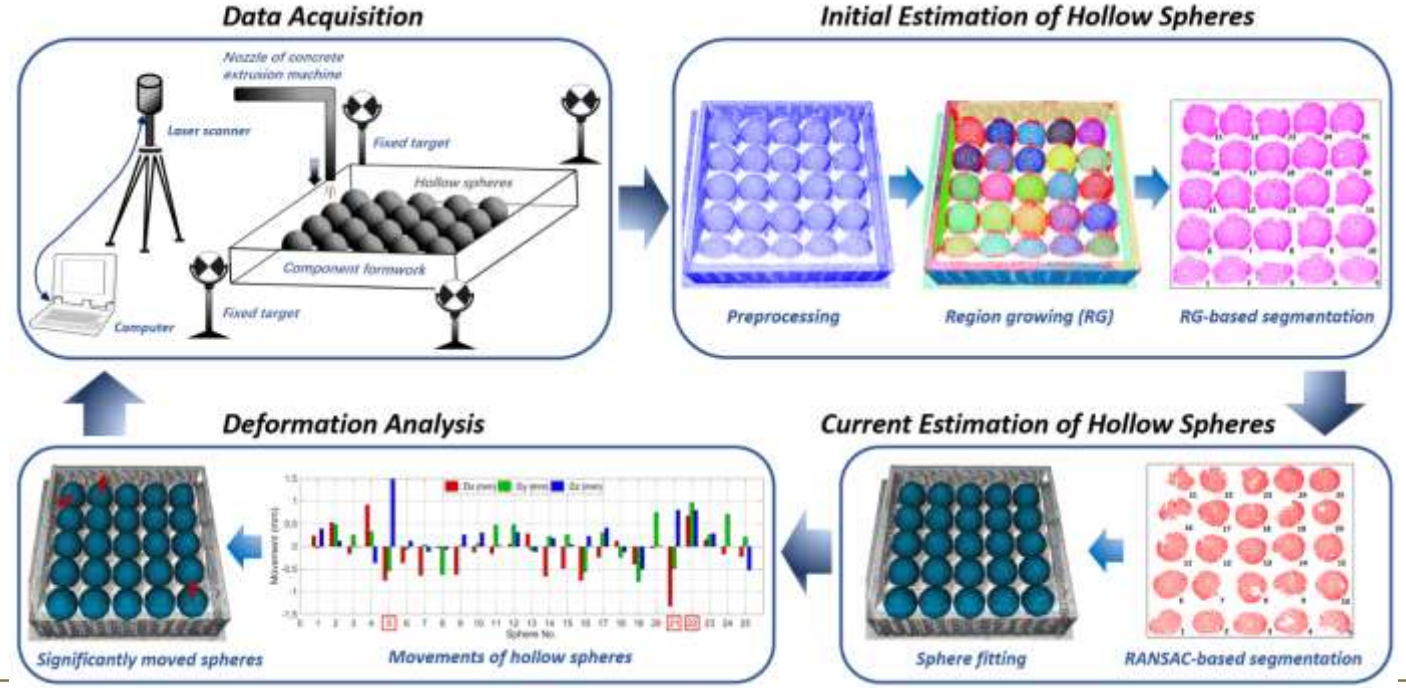
- **Concept**
  - Framework HQM published in Sustainability
    - Requirements;
    - Characteristics;
    - Parameters;
    - Criterions.
- **Quality assessment**
  - Control points
  - Decision points



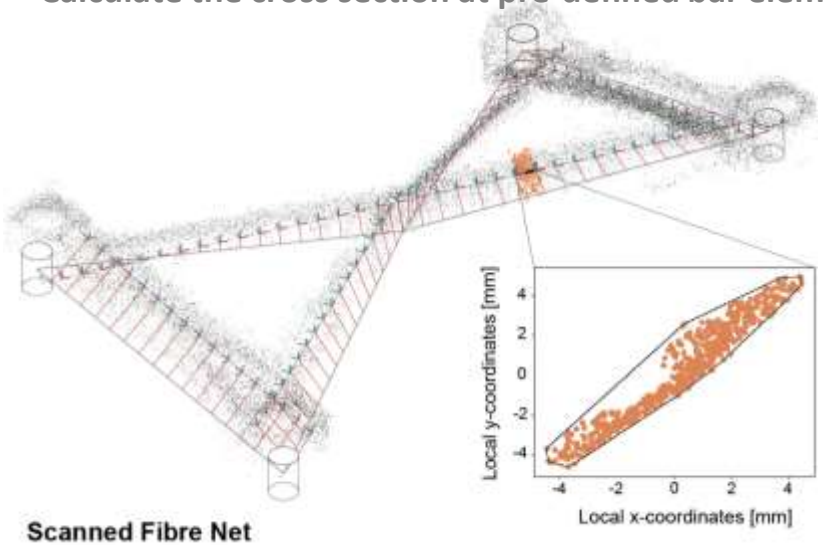
# QUALITY CONTROL FOR GRADED CONCRETE

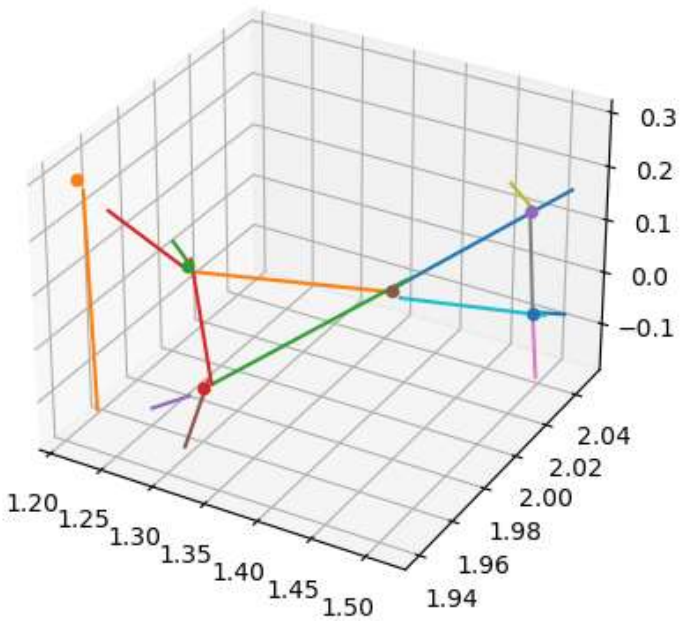
- Are the positions of the hollow spheres stable?
- What is the height of the concrete level after each casting step?
- Monitoring of the sphere position by TLS
- Investigation of concrete level and flatness by TLS

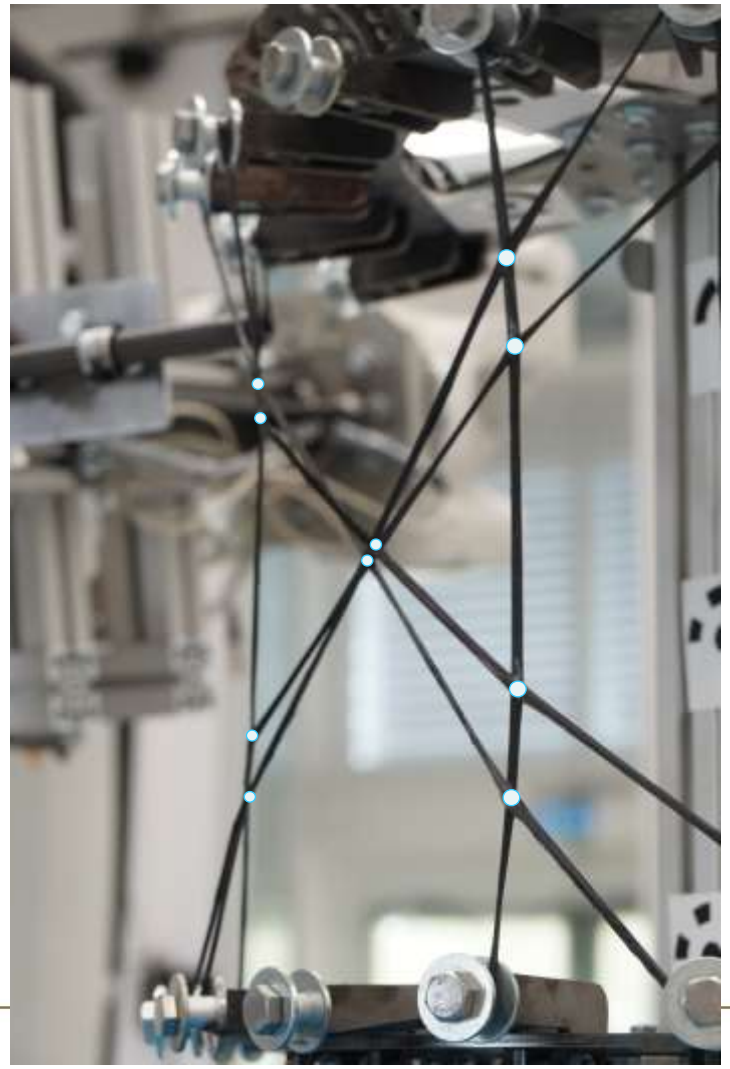



# QUALITY CONTROL FOR FILAMENT FIBRE WINDING

- Data Acquisition by TLS
- Line segmentation from the point cloud
- Estimation of intersection points
- Find corresponding points of the previous epoch
- Calculate the cross section at pre-defined bar elements



# Conclusion and Outlook

- Unique research cluster in domain of construction and architecture
- High relevance for mankind: ecological and economical

- Essential role of Engineering Geodesy for all geometric contributions
- Exemplary contributions:
  - interdisciplinary quality model
  - quality control for graded concrete (sub-mm sphere positions)
    and fibre composites (cross-sections and intersection points of fibres, both by TLS)
  - mm accurate and reliable real time RTS network to deliver 6 DoF for spider crane control

# INTCDC - CLUSTER OF EXCELLENCE

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More information on the cluster:

https://www.intcdc.uni-stuttgart.de/