Anja Lauer, Institute for System Dynamics (ISYS)

Automated on-site assembly of form-fit timber building elements using two large-scale manipulators

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Cyber-Physical On-Site Construction Using a Spider Crane Robotic Platform

RP16-2

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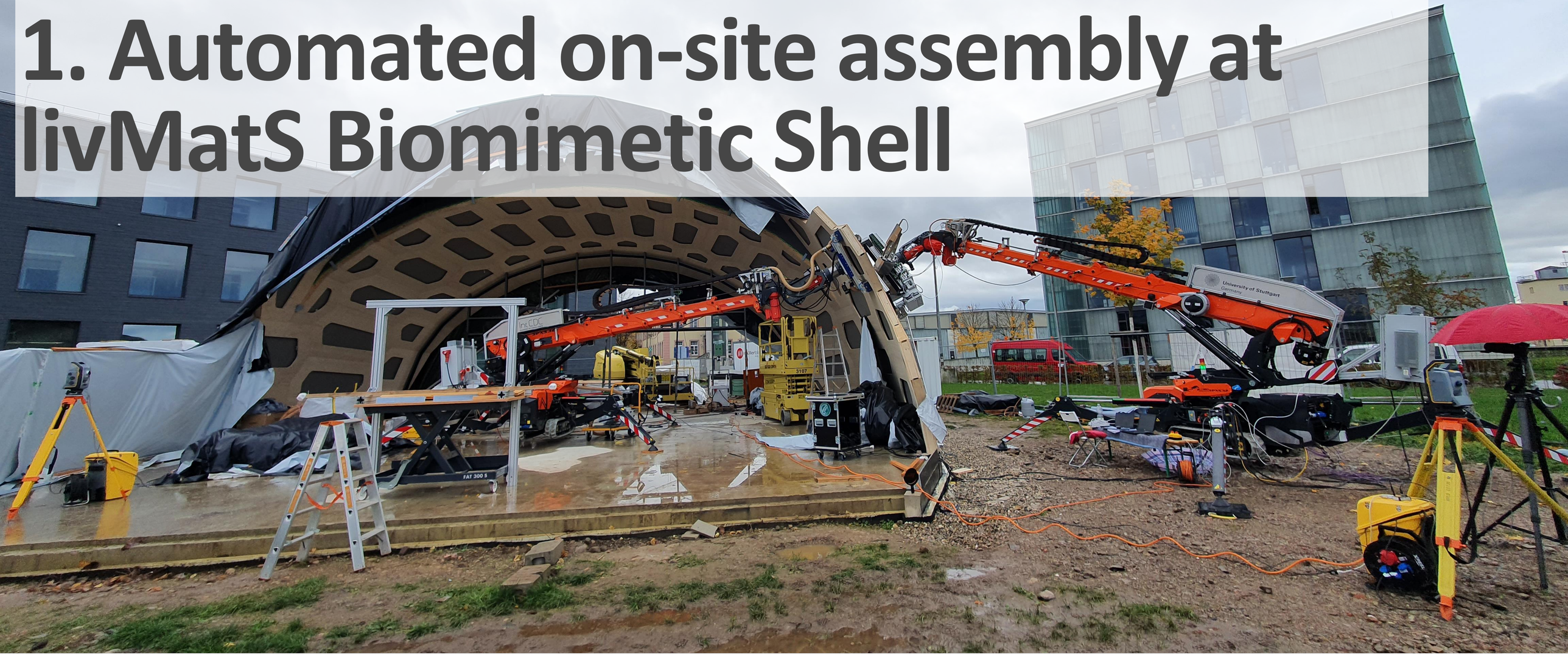
1. Automated on-site assembly at livMatS Biomimetic Shell



Development of Large-Scale On-Site Assembly Manipulators

- **Hydraulic part**
  - Jekko SPX 532
- **Electric part**
  - 3 additional rotational axes to reach all poses
- **End effectors**
  - Vacuum gripper
  - Screwing effector

- **Sensor concept: Integration of additional sensors**
  - IMUs, encoders for all axes
  - Force-Torque sensor (6 DoF, nominal force 50kN, 100kNm)
  - Laser sensor
- **Control unit**
  - Replace control unit from Jekko with dSpace MicroAutobox III
  - Processes all input and output signals
  - CAN bus, wireless CAN bridges

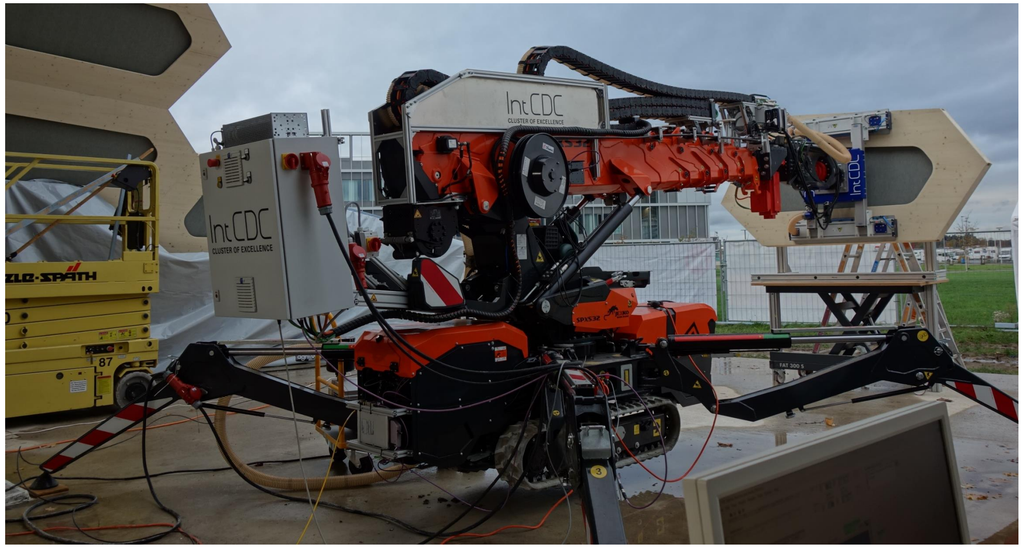
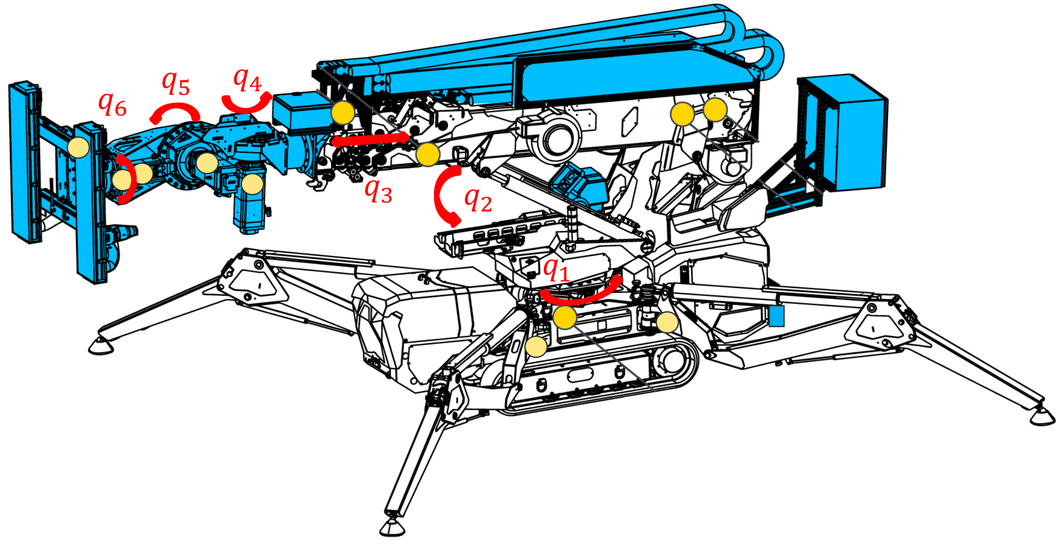


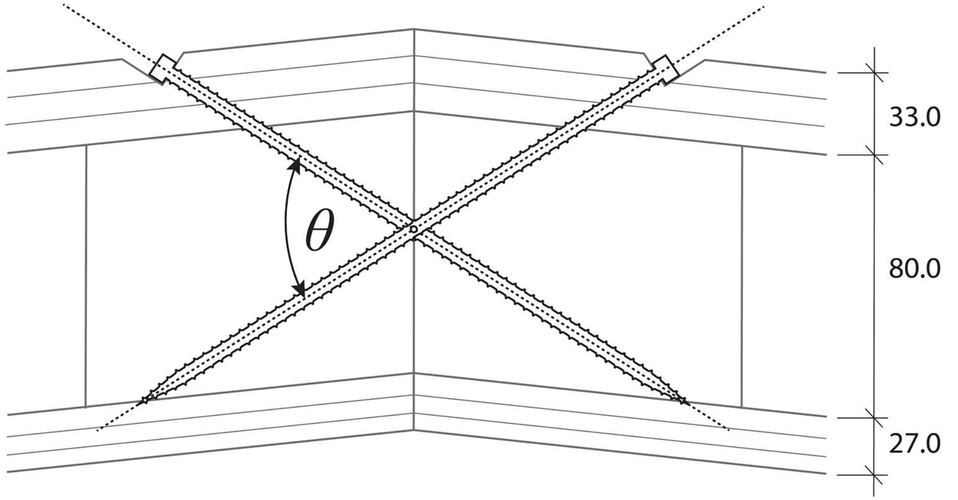
Foto: Anja Lauer

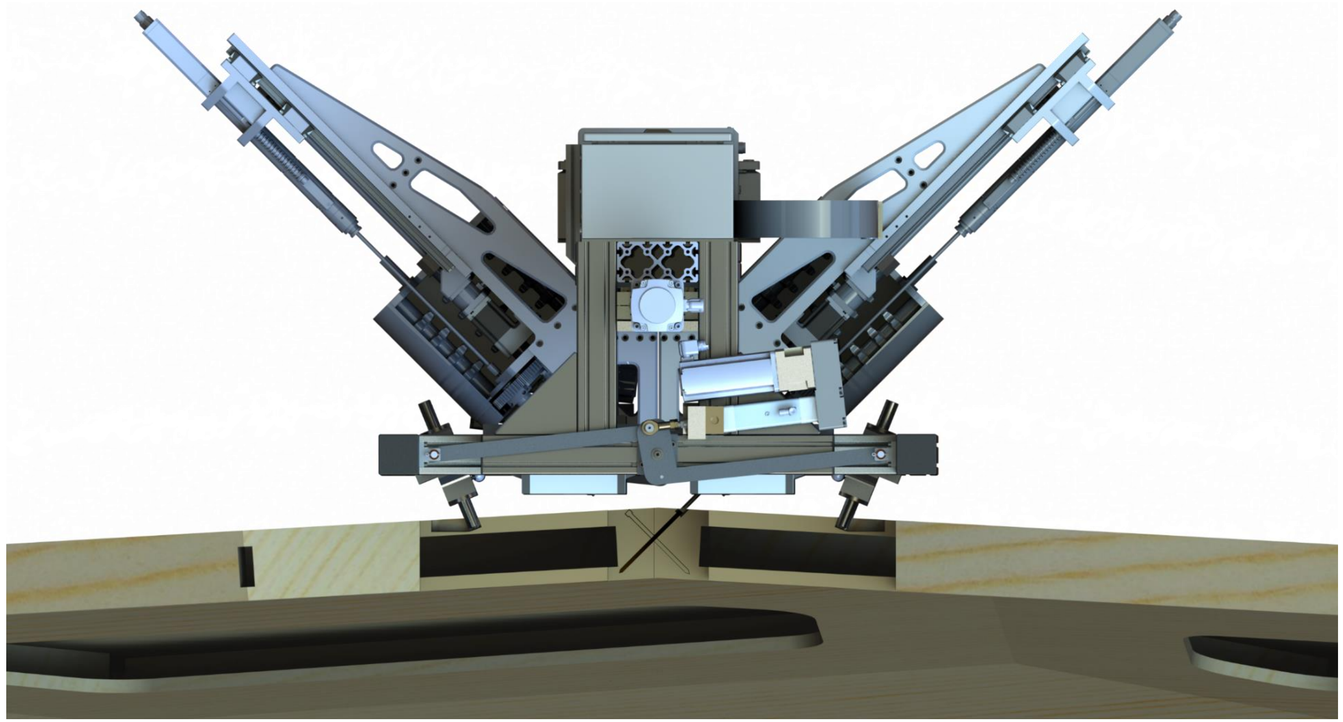


T. Schürmann: „Steifigkeitsbasierte Kraftregelung für Handhabungs- und Montageaufgaben," Master thesis, Institute for System Dynamics, University of Stuttgart, 20.02.2023.

Screwing Effector

- **Connection**
  - Pre-drilled holes
  - Cross screwing
  - Screw dimensions: 6 mm x 180 mm
- **Automated screwing**
  - Main linear axis moves screwing units to predrilled holes
  - Screwing units move to wooden surface
  - Screwing stop based on position





Picture: Sergej Klassen

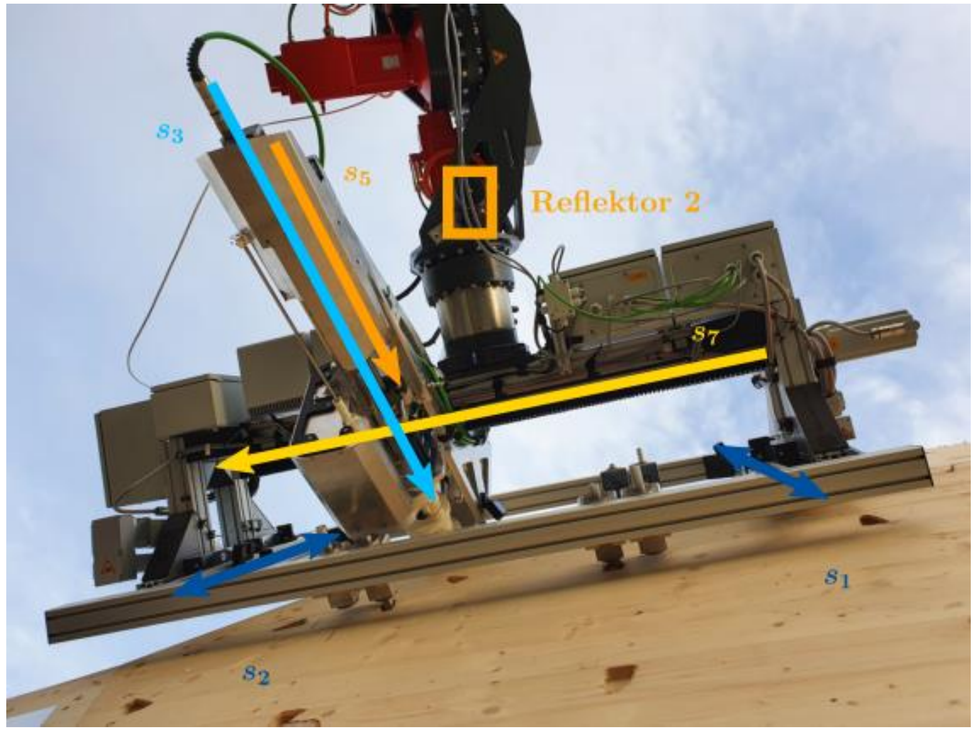
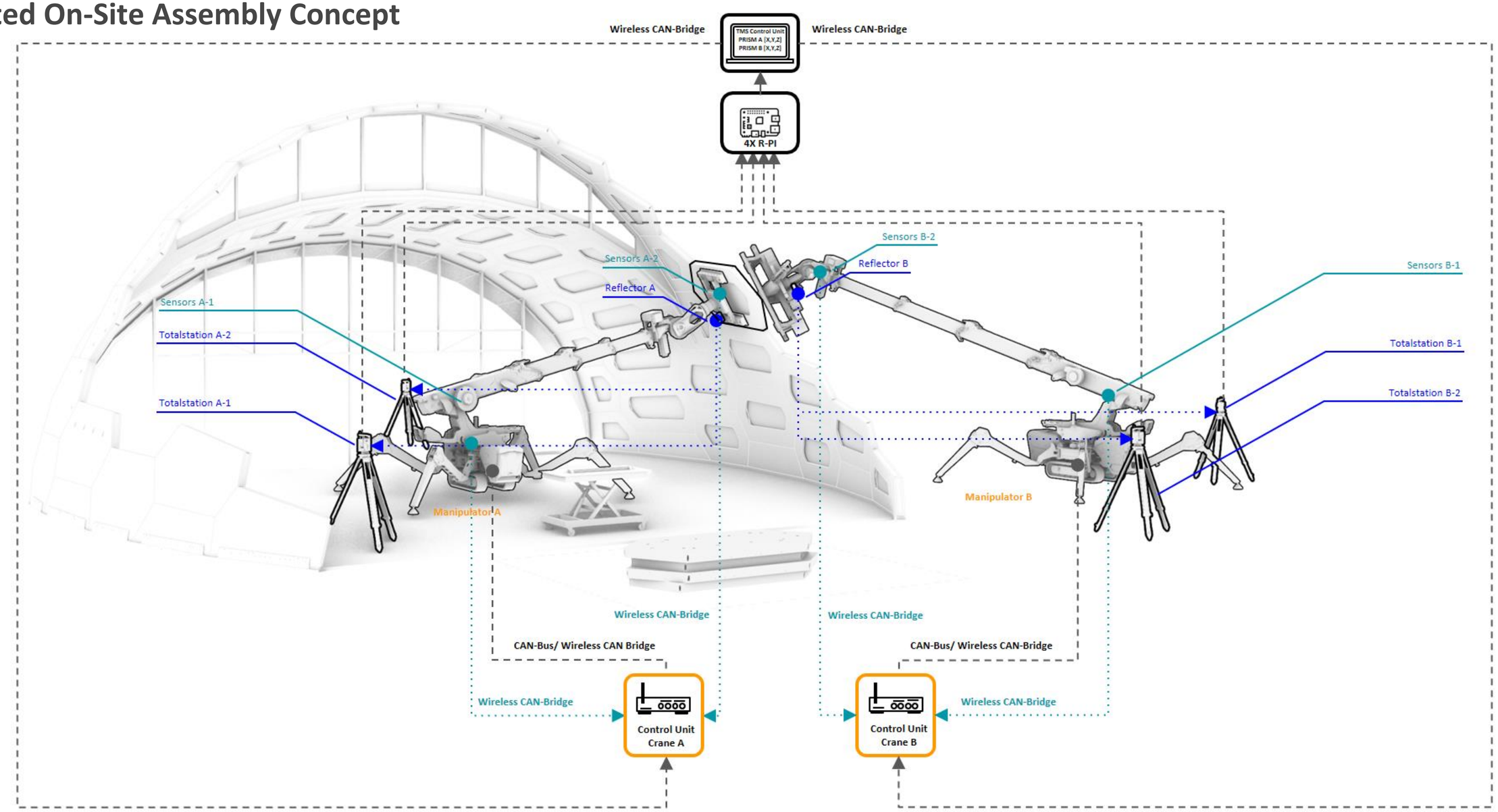


Foto: Anja Lauer

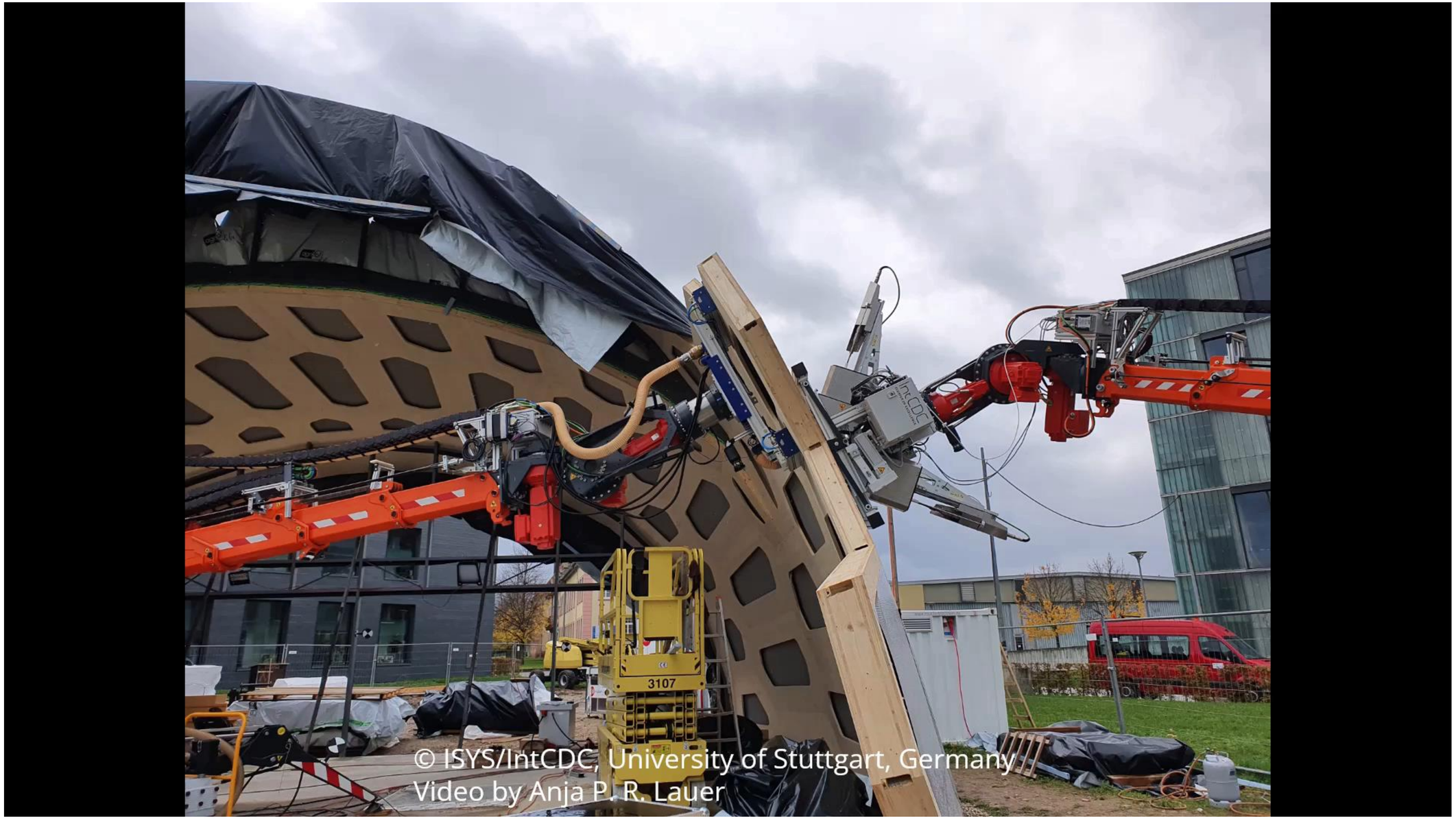
Automated On-Site Assembly Concept



[1] A. P. R. Lauer, O. Lerke, B. Blagojevic, V. Schwieger, and O. Sawodny, „Tool center point control of a large-scale manipulator using absolute position feedback“, Control Engineering Practice, vol. 131, pp. 105388, 2023.

[2] A. P. R. Lauer, E. Benner, T. Stark, S. Klassen, S. Abolhasani, L. Schroth, A. Gienger, H. J. Wagner, V. Schwieger, A. Menges, and O. Sawodny, *“Automated on-site assembly of timber buildings on the example of a biomimetic shell,” Automation in Construction, vol. 156, pp. 105118, 2023.*

Video of Automated On-Site Assembly at livMatS Biomimetic Shell in Freiburg



Video: Anja Lauer

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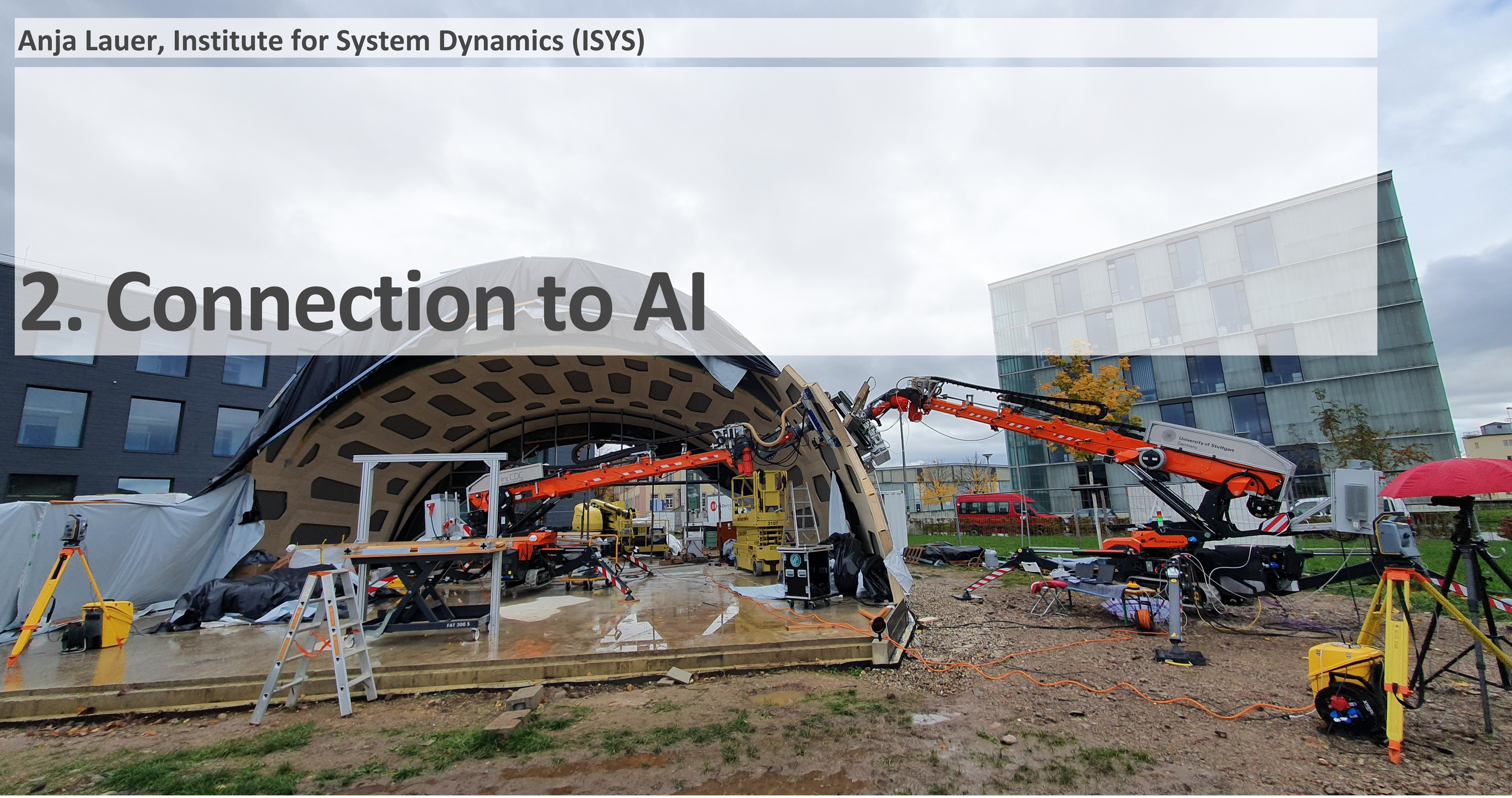
2. Connection to AI

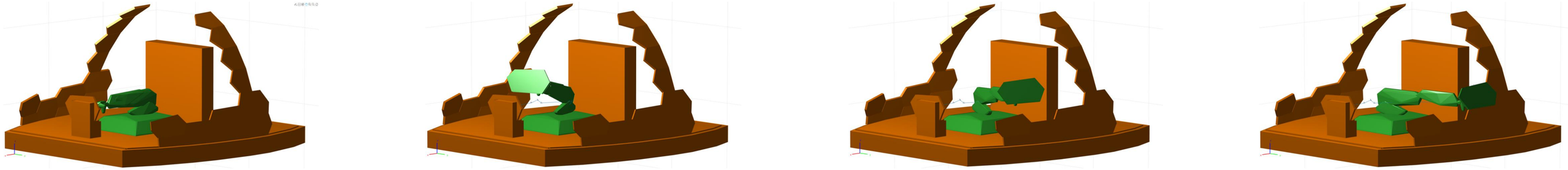


Data-based Reachability Analysis and Robot Placement Optimization [4]

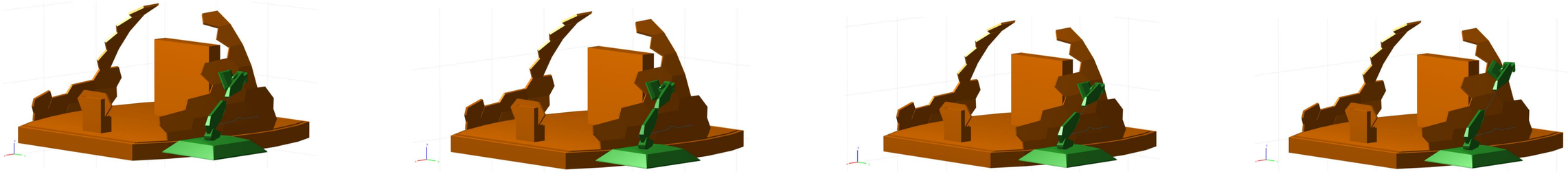
Ensure feasibility of the construction process to avoid problems during the construction phase

- Reachability analysis of building elements and the positioning of construction robots: determine best manipulator position
  - Computing reachability of target poses using inverse kinematics (IK) is time-consuming, no immediate feedback
  - Random Forest classifier trained to replace IK
    - Computation time is decreased by a factor of more than 10^4, immediate feedback on reachability
    - Accuracy of reachability: around 97%
- Optimize robot base positions using the classifier
  - Number of different base positions is minimized such that each target pose is reachable from at least one position
  - Accuracy of optimization: more than 99.99%

- **Manipulator A (Vacuum Gripper)**



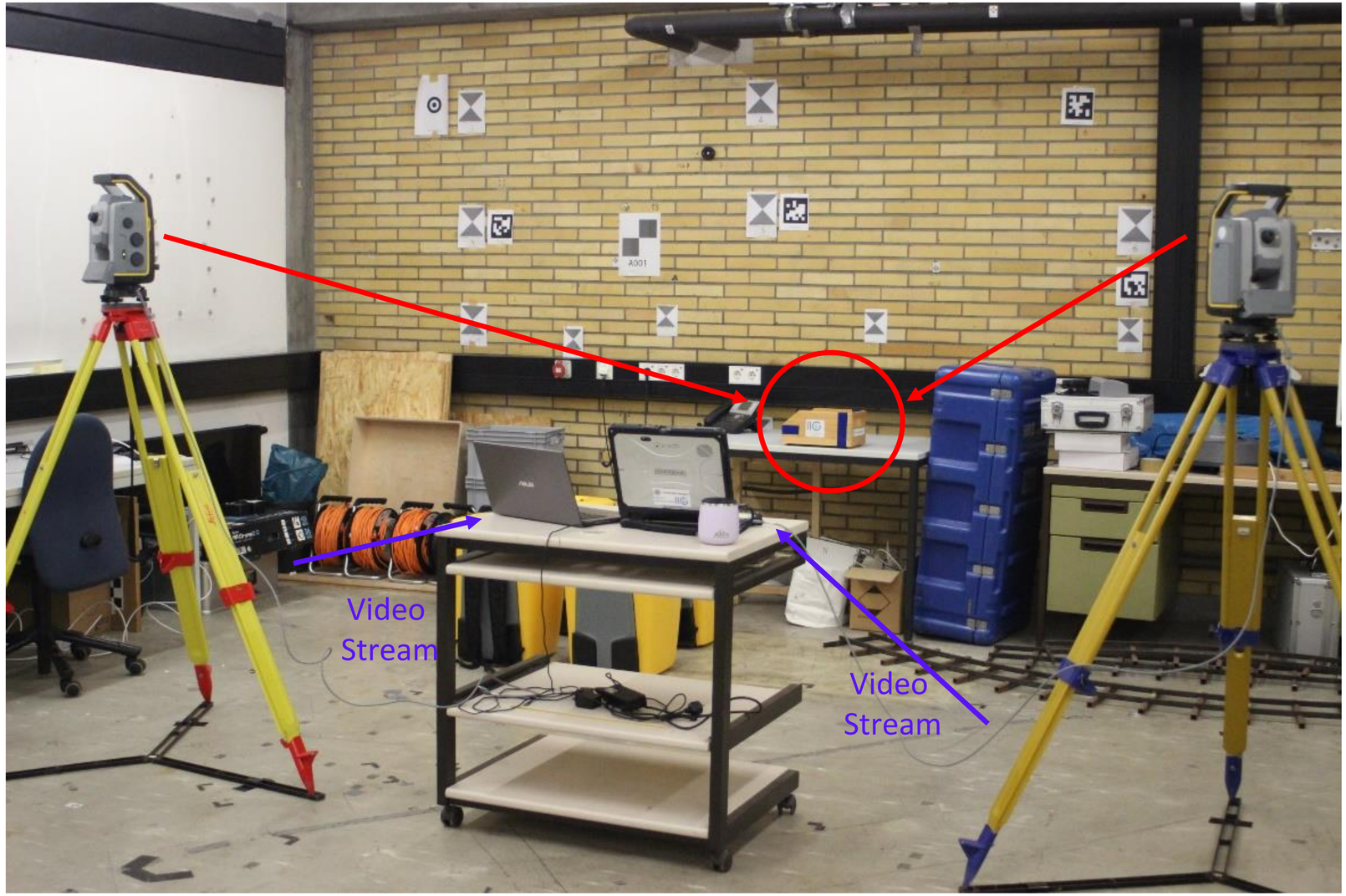
- **Manipulator B (Screwing Effector)**



[4] Gienger, A., Stein, C., Lauer, A. P. R., Sawodny, O., Tarin, C.: "Data-based Reachability Analysis and Robot Placement Optimization for Co-Design of Construction Processes," Accepted to SII2024, 2024.

Calibration
→ Component Detection/ Recognition
→ Positioning and Tracking (Pattern matching)
→ Position analysis/ Trajectory generation

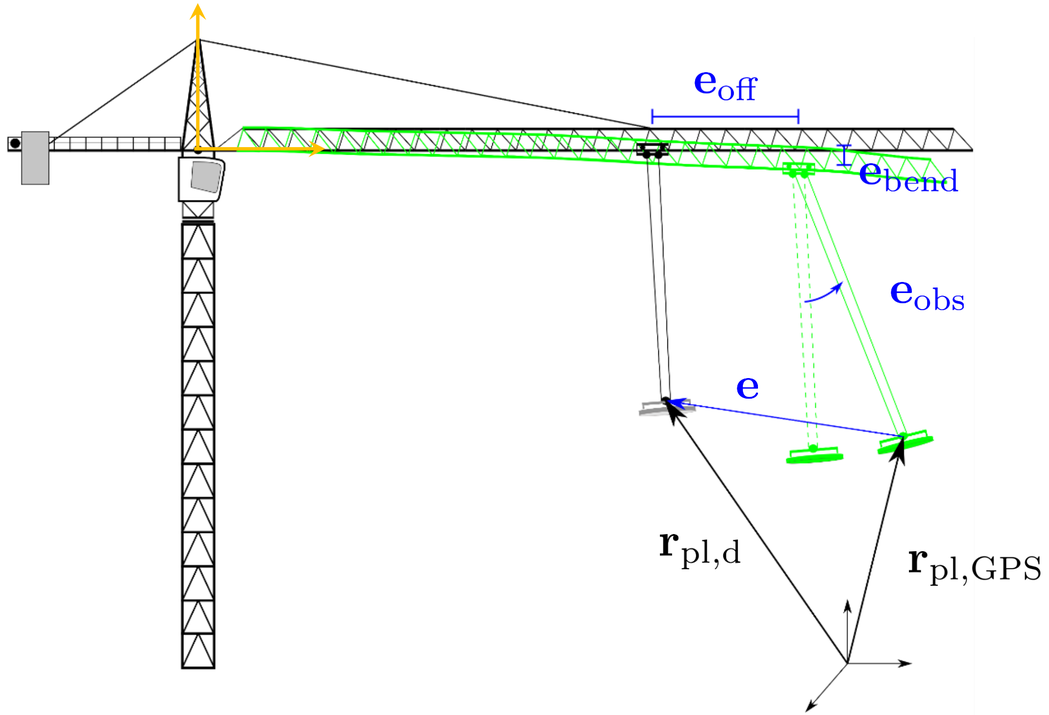
- Image-Assisted Total Station Network (IATS-N) allows for smooth monitoring procedure, provides continued sight of object and its feature extraction
- Object detection algorithms in a frame of the teaching network, based on data sets of images for intelligent object classification and tracking



Data-based Error Compensation for Georeferenced Payload Path Tracking of Automated Tower Cranes [5]

Automation of payload transport by tower cranes

- Tower crane must precisely track planned paths and position payload at specified target location
- Path errors due to bending displacements of mechanical structure, observer errors, or sensor offsets (payload oscillation compensated by anti-sway damping)
- **Approach**
  - **Regression model for predicting path error**
    - Estimation of the position error: by regression model
    - Fitting the error estimation model: Select most important features by Least absolute shrinkage and selection operator (LASSO)
  - **Adjustment of target position**
    - Use predicted error at each position to compute compensating hook path such that measured hook path matches desired hook path
- Experiments show reduction of path error of more than 50% and position accuracy of less than 16 cm



- Accumulated error

$$\mathbf{e} = \mathbf{r}_{\text{pl,d}} - \mathbf{r}_{\text{pl,GPS}} = \mathbf{e}_{\text{off}} + \mathbf{e}_{\text{bend}} + \mathbf{e}_{\text{obs}} + \dots$$

- Output of regression model in polar coordinates w.r.t. georeferenced fixed crane coordinate system

$$\mathbf{y} = \mathbf{e} = \begin{bmatrix} \Delta\gamma_{\text{e}} & \Delta x_{\text{tr,e}} & \Delta Z_{\text{e}} \end{bmatrix}^{\text{T}}$$

Turret rotation difference — Radial difference — Height difference

- Regression model for error estimation

$$\mathbf{y} = \begin{bmatrix} \Delta\gamma_{e} & \Delta x_{\text{tr},e} & \Delta Z_{e} \end{bmatrix}^{\text{T}} = \begin{bmatrix} \mathbf{f}_{\gamma}^{\text{T}}\Theta_{\gamma} & \mathbf{f}_{\text{tr}}^{\text{T}}\Theta_{\text{tr}} & \mathbf{f}_{Z}^{\text{T}}\Theta_{Z} \end{bmatrix}^{\text{T}}$$

$\mathbf{f}_{(\cdot)}$ - Feature vector

$\Theta_{(\cdot)}$ - Coefficients from fit of training data

Estimation of current positioning error in absolute cooridnates using a data-based regression model → Adjustment of target position → Approaching of corrected target position

[5] M. Burkhardt, A. Gienger, L. Joachim, N. Haala, U. Sörgel, and O. Sawodny, “Data-based error compensation for georeferenced payload path tracking of automated tower cranes”, Mechatronics, vol. 94, pp. 103028, 2023.