Additive Manufacturing in Construction
1st funding period: The Challenge of Large Scale

AMC TRR277

B05

Principles of Mobile Robotics for Additive Manufacturing in Construction

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Project summary

This project aims to expand the application of in situ AM by using Autonomous Mobile Robots (AMRs), investigating the opportunities for these systems in architecture and construction. This, by exploiting the potential of AMRs to manufacture structures larger than the static workspace of the system with mobility, and providing scalability through collaborative, parallel actions with extendable AMR teams.

Main outcome of 1st funding period

- Two identical mobile systems capable of omnidirectional ground-based movement, with a vertical linear axis and a 6DOF arm-based robotic manipulator (Figure 1).
- Two-tier sensing for accurate AM actions with mobile systems.
- Integrated design-to-fabrication workflow into the design environment, incorporating computational design, Fabrication Information Models (FIMs), and feedback-based control of the mobile robot.
- A print-drive-print approach was validated through experimental construction of a clay column formwork consisting of 51 elements from 51 respective locations, creating a 2 meter high, lightweight concrete column (with A03, and B04) (see Figure 3).

Key collaborations in 1st funding period

A03 — Implementation of extrusion-based clay and concrete AM processes into mobile robots, with conception and development of customized lightweight extruder systems.

B04 — Mobile robot localisation for part-based AM, realized by a two-tier on-board sensing setup, comprising rough localisation via 2D-SLAM and refined localisation via ICP point cloud registration.

C04 — Development of suitable Fabrication Information Models (FIM) for mobile AM and their integration into a design-to-fabrication workflow.
Investigation of modelling and path-planning strategies for part-based AM (print-drive-print-approach).

C06 — Mobile robot control strategies with sequential manipulator and base motions
Experimental validation that a mobile robot can additively manufacture a 1:1 building element with sufficient accuracy over numerous relocation maneuvers for part-based AM.

AMC-MERCATOR-FELLOW — AMC-MERCATOR-FELLOW Prof. Dr. sc. ETH Ena Lloret Fritschi
Collaboration for the in-place printing of earthen formworks with cooperative mobile robots.

Project status

WP1. Assessment of fundamentals for mobile robotics in AM using material deposition methods.
Evaluation of mobile system requirements for applicability for construction and the establishment of two identical research mobile platforms, see Figure 1.

Figure 1: Two mobile robotic systems, left system is equipped with clay extrusion setup.

WP2. Conception and integration of extrusion AM technology
Integration of an extrusion-based clay printing system for process evaluations and the conceptualisation of a lightweight concrete extrusion end-effector with limited flow restrictions (Figure 2).

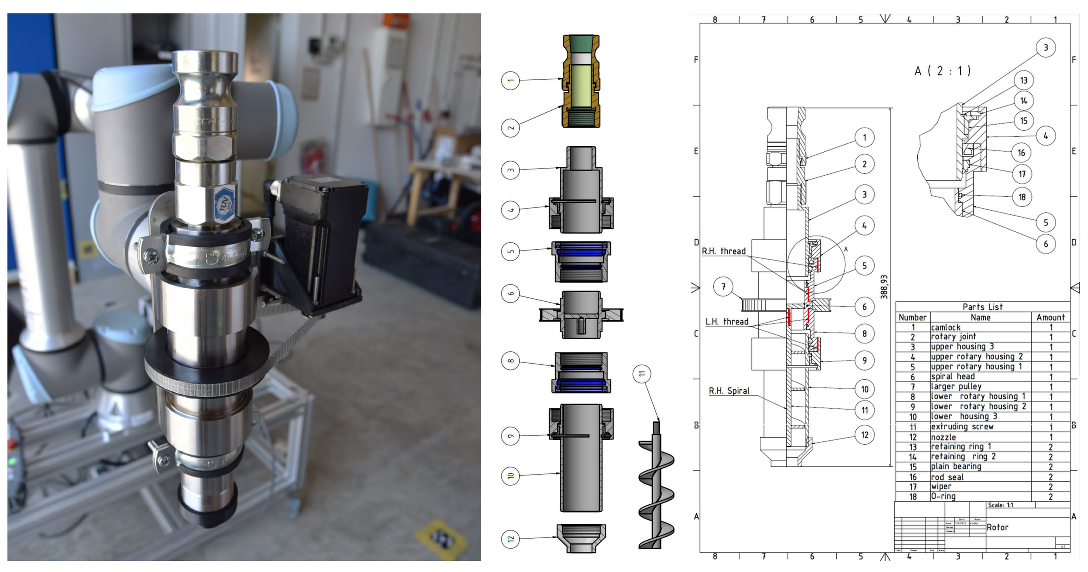

Figure 2: Prototype concrete extruder with straight flow direction and external belt-driven screw for material conveying.

WP 3. Fabrication Information Models for mobile fabrication
- Establishment of a design-to-fabrication environment (Figure 3).
- Discretisation methods for part-based fabrication of building components, for sequential actions with a mobile system (Figure 4) or collaborative actions with two mobile systems.
- FIMs for storage of geometric data and planning of robot trajectories, organised in tasks.

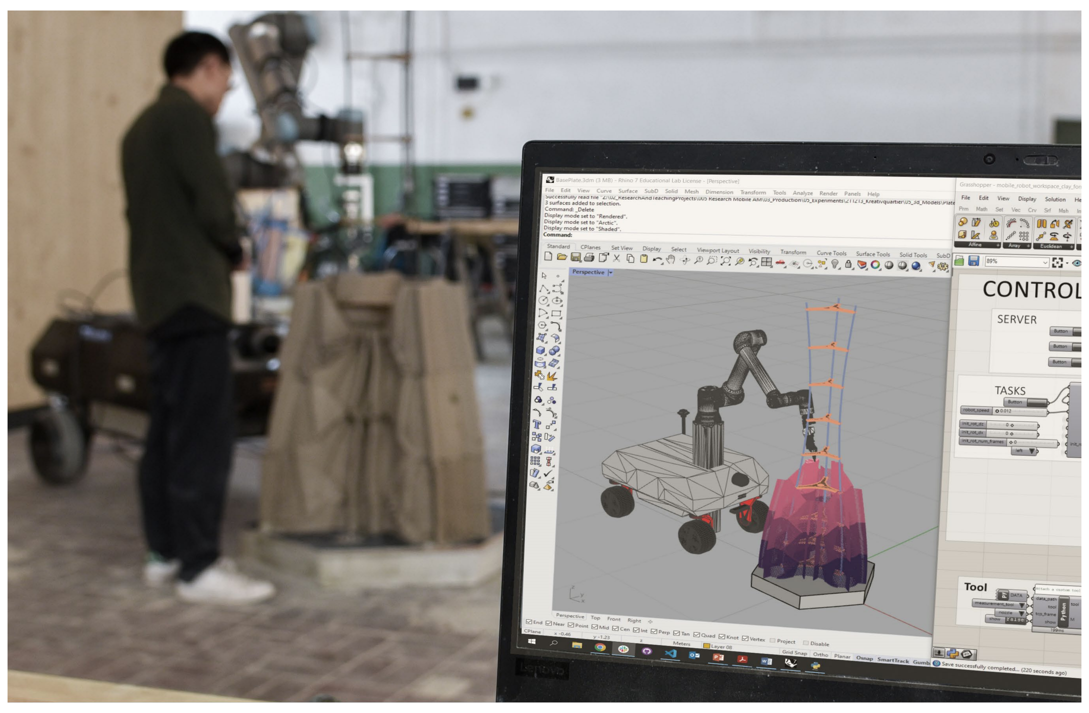

Figure 3: Architectural planning environment with integrated features for mobile robot path planning, localisation, and online control for the base, manipulator, and AM end-effector.

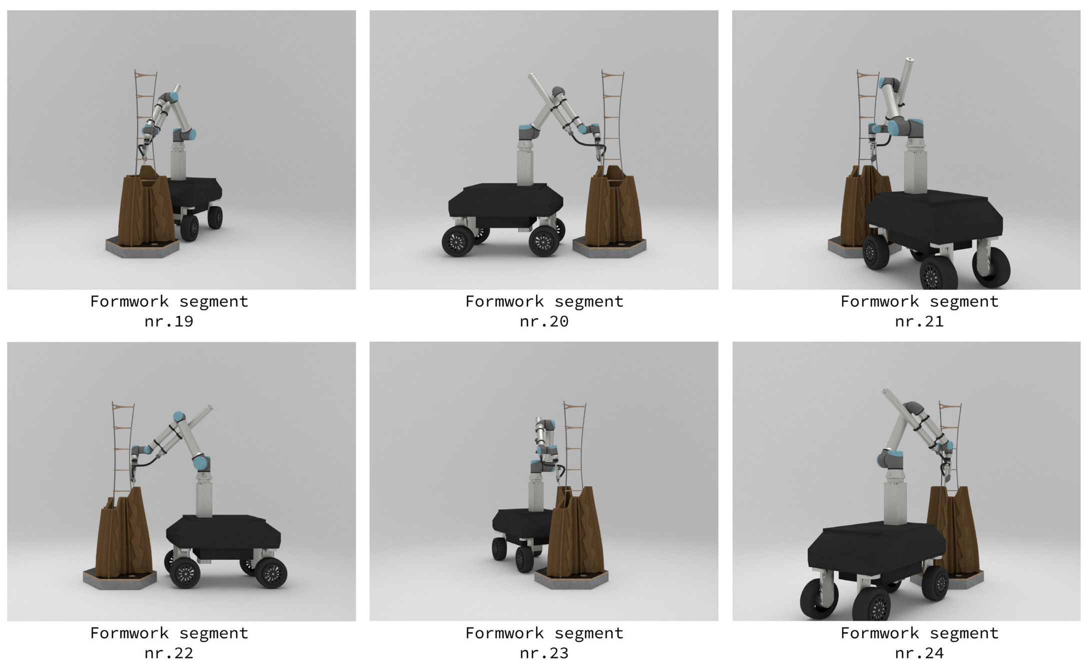

Figure 4: Succession of six location for the manufacture of six segments around the reinforcement cage, followed by another cycle of filling the formwork

WP 4. Sensing strategy and system set-up
- Estimated base localisation using Simultaneous Localisation And Mapping (SLAM), see Figure 5.
- Fine end-effector positioning and object capture with a laser profile sensor, see Figure 6.

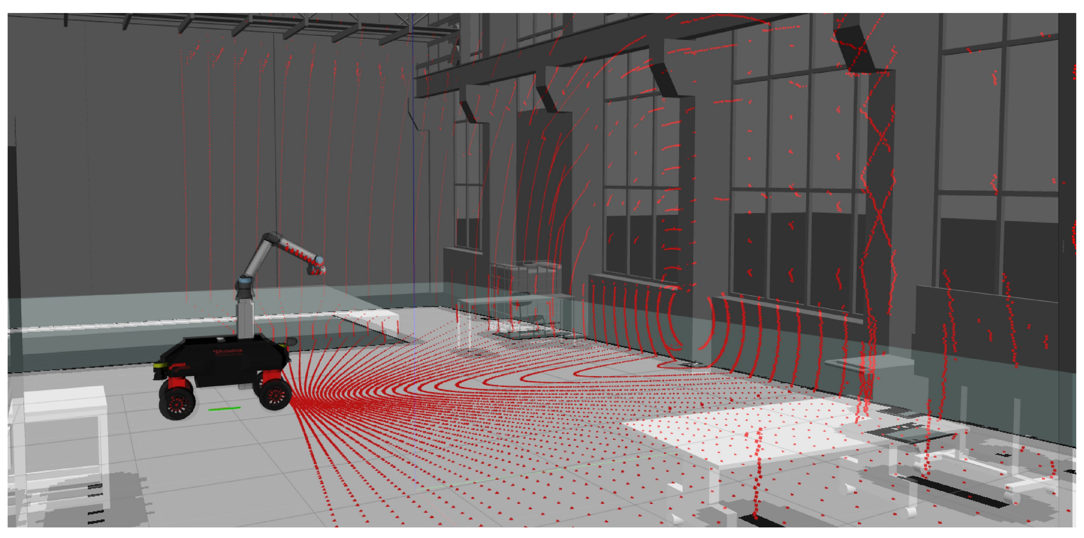

Figure 5: Mobile base localisation, by comparing sensor output with the mapped environment.

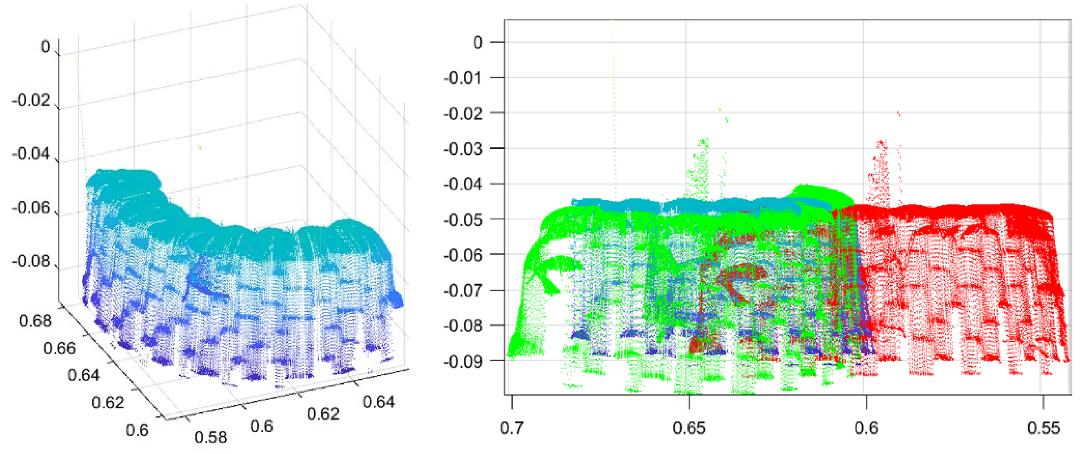

Figure 6: Point cloud scans taken from the robot's laser scanner mounted at the end effector which are used to determine the robot's location relative to the printed object.

WP 5. Design to Fabrication workflow and adaptive control
Creation of a fabrication manager interface for task-based control of the mobile systems, integrating sensor and system feedback, see Figure 7.

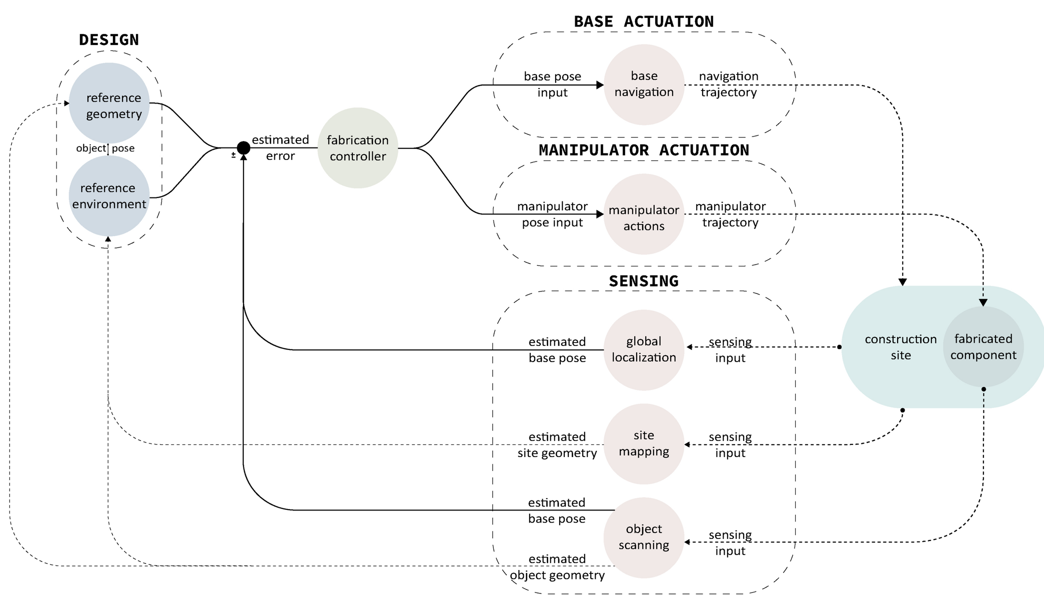

Figure 7: Diagram of sensor-integrated print-drive-print control for mobile robots in on-site scenarios

WP 6. Final demonstrators
In Figure 8, mobile part-based fabrication of a clay formwork for reinforced concrete column construction through repositioning.

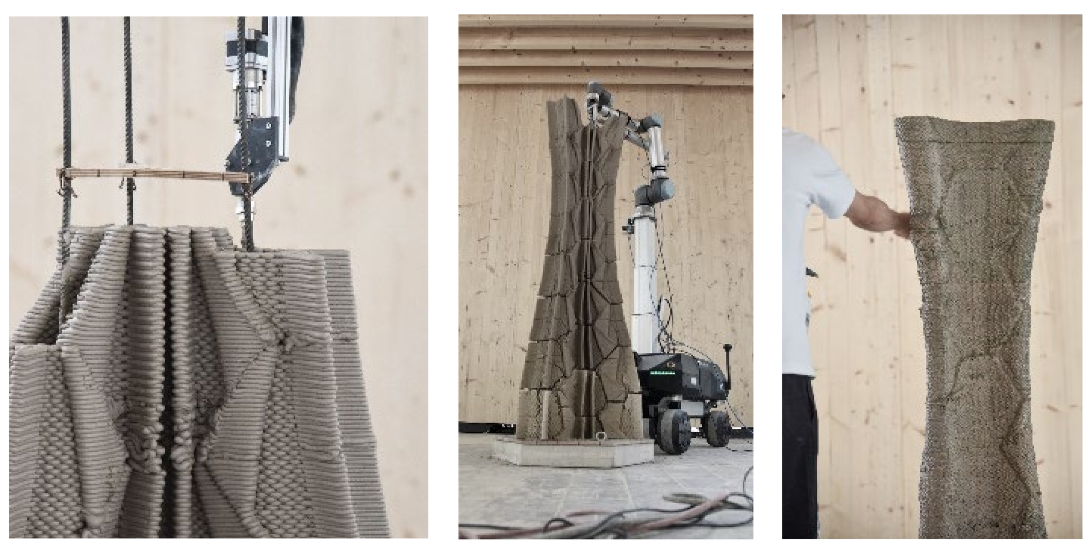

Figure 8: Part-based mobile AM for the creation of an earthen formwork for a reinforced lightweight concrete column.

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