Summary and Further research

The presented research provided a novel method of constructing complex geometries using a print-drive-print approach using a mobile robot to 3D print a building component from multiple locations. This approach holds potential for scalability by employing multiple robotic systems to enhance both size and efficiency. Furthermore, the aspiration to utilise fully load-bearing materials for direct 3D printing of structural components opens avenues for further exploration and research in the field.

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Mobile Additive Manufacturing: Clay formworks

The use of mobile robots for 3D printing in construction enables the production of building components directly on building sites. Their mobility proposes methods of fabrication that surpass the limitations of a static workspace to create larger objects. This research focuses on developing methods that exploit the mobile robot's capabilities. In this case study, applied by sequentially 3D printing a clay formwork for the in-situ casting of a reinforced concrete column at full building scale.

The column's geometry is systematically divided into 51 printable formwork segments, accommodating the placement of a prefabricated reinforcement at its core. Strategically, each part falls within the static reach of the mobile robot. With a print-drive-print strategy, the formwork parts are printed while stationary from successive robot positions.

At each new position, the robot is localised in reference to the object printed previously before starting the fabrication of the next formwork segment.

With every third formwork part completed, concrete is poured into the structure, creating a gradual casting process. This approach effectively mitigates hydrostatic pressure on the formwork and provides crucial support to the formwork with the curing of the concrete. The concrete mixture used incorporates lightweight aggregates and a thixotropic enhancement agent, ensuring a liquid state during pouring and a rapid increase in viscosity for enhanced strength. After completion of the printing and casting processes a few hours of curing time, the formwork is manually removed, exposing the reinforced concrete column, and revealing its intricate texture of the 3D-printed formwork.

Figure 1: Succession of six mobile base locations for the manufacture of six respective segments around a reinforcement cage, followed by a cycle of filling the formwork with concrete after every three segments.

The mobile robot is equipped for two-stage localisation, where the first stage maps the environment and provides a rough estimation of the robot‘s global position using a 3D LiDAR, with an estimated accuracy of ±5 cm and ±3°. To refine localisation further, a comparison is made between point clouds obtained from a 2D laser scanner mounted on the robot‘s end effector. Prior to relocating, the robot scans a segment of the formwork, navigates to a new position, and re-scans the same segment. The alignment of these two scans facilitates an accurate estimation of the robot‘s new pose relative to the formwork.

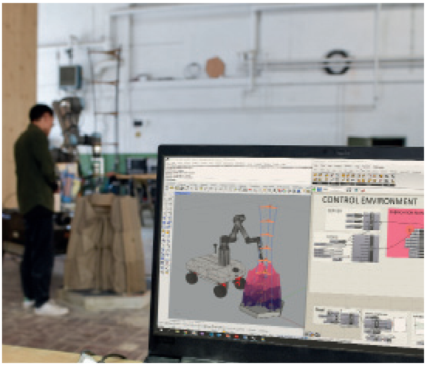

Fig 2. Design-to-fabrication environment

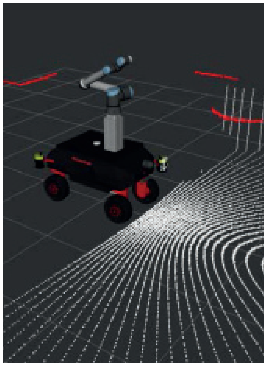

Fig 3. Left: 3D LiDAR output, Top: 2D laser scan of a printed segment, Bottom: Aligning of two segment scans

Design-to-Fabrication Environment

The established design-to-fabrication environment facilitates the entire process, including the design and segmentation of the formwork, robot localisation, and printing process control. This environment is integrated into Rhino/Grasshopper, with Python serving as the backend. A custom-developed fabrication manager empowers the operator to oversee and manage the state of the printing processes running on the mobile robot.

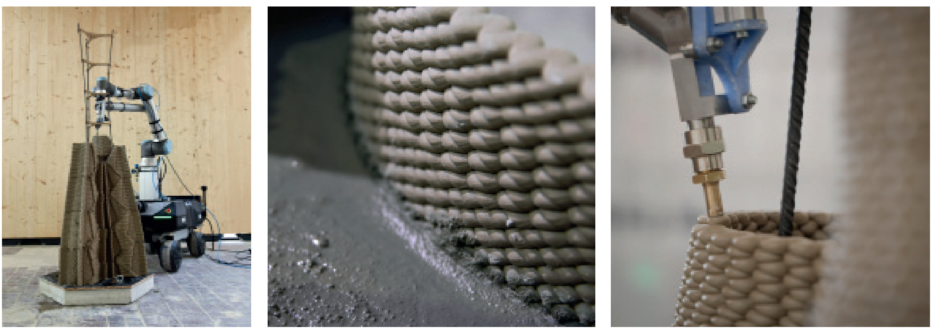

Fig 4-6. Left: Mobile robot fabricating the formwork around the reinforcement cage, Middle: Cast concrete and clay formwork, Right: Formwork printing impression