Visions and Strategies for Reinforcing Additively Manufactured Constructions 2023
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In-Process Integration of Reinforcement for Construction Elements During Shotcrete 3D Printing

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Abstract. The current state of the art for additive manufacturing often utilises horizontal layer printing approaches for a variety of materials and applications. However, it imposes restrictions on the integration of utilities, mounting fixtures, installations, and reinforcement. Particularly the integration of reinforcement into 3D concrete printing still faces many challenges. It is currently restricted by the nozzle to strand distance, the lack of bond quality, automation, and geometric limitations of the respective 3D concrete printing techniques. The following research presents a case study on additively manufactured concrete construction elements utilising the Shotcrete 3D Printing (SC3DP) technique, focusing on interlayer- and short rebar reinforcement. To demonstrate the potential benefits for an automated reinforcement integration and to uncover further challenges and research questions, a wall segment was produced using a unique combination of Interlayer Reinforcement (ILR) and Short Rebar Insertion (SRI). By incorporating these methods, it was possible to generate three-dimensional continuous reinforcement structures within the wall. The innovative approach showcased takes full advantage of the SC3DP technique, enabling the integration of reinforcement during the printing process itself, thus utilising the geometric freedom, the fast build up rate and the kinetic energy during application. This eliminates the need for premanufactured reinforcement structures, enabling a more efficient and flexible manufacturing process. Furthermore, the discussion includes the potential for surface finishing and attainment of geometrical accuracy through the direct integration of reinforcement. An outlook is given as future construction elements can be produced structurally reinforced without formwork and with a high degree of geometric freedom.

Keywords: Digital Robotic Fabrication, Shotcrete 3D Printing, Automation, Additive Manufacturing in Construction, Reinforcement

1. Introduction and motivation

In the construction industry, the lack of labour, the use of non-recyclable materials, and the high CO_2 consumption are currently widely discussed [1,2]. These challenges call for rapid action in order to increase the sustainability and productivity of the utilised construction processes in the construction sector. Especially with the urgent need to address the environmental impact of construction practices, a wide range of innovative solutions are being introduced to revolutionise the industry [2]. These solutions include both low- and high-tech materials, each offering unique benefits for the reduction of the carbon footprint resulting from the construction industry. In addition to new materials, innovative processes are gaining popularity to reduce labour cost and decrease the material usage. Automated processes, such as the implementation of advanced robotics in construction offer significant potential for complementing traditional methods, substituting manual labour and creating new opportunities for technically skilled on-site jobs, and reducing the industry's carbon footprint [3]. One notable example is Additive Manufacturing (AM) in the form of concrete 3D printing. This technique provides geometric freedom, precise material application, and automated execution, resulting in reduced waste and energy consumption compared to traditional construction methods [4]. Additionally, the shortage of skilled labour in the construction sector is a major challenge, particularly in Western countries which is addressed by automation.

The following research offers a unique approach to address the specific challenges faced by the construction industry by introducing the novel Shotcrete 3D Printing Process (SC3DP) for manufacturing a prefabricated wall segment with automatically integrated reinforcement and a high surface quality.

2. State of the art for 3D printed reinforced concrete elements

AM is a widely explored research area, demonstrating both the possibilities and difficulties associated with this method. The following paragraphs give an overview on the three main topics addressed in this study.

Concrete 3D printing technologies

DIN EN ISO / ASTM 52900 categorises the variety of AM processes, which are independent of the used material [5]. For the construction industry, especially the processes “material extrusion”, “material jetting” and “selective particle bed binding” are commonly investigated and in some instances already implemented into industrial applications. Each of these processes have their advantages and challenges. A key challenge for extrusion is the interface and the bond strength between layers [6]. Nevertheless, most of the construction elements currently build with these novel techniques are manufactured through the extrusion of concrete itself or utilising it as a “lost” formwork for casting [7].

In contrast, material jetting processes such as SC3DP also called Robotic Shotcrete Printing (RSP) show a high interlayer-strength [8], the possibility to easily integrate external elements and overall more possibilities for process control, since certain parameters, e.g. air volume flow, nozzle distance, accelerator dosage, can be adjusted precisely (**Figure 1** b) [9,10]. During the “wet-spraying” process, the concrete is pumped to the nozzle, where pressurised air is introduced into the concrete mixture. This causes the concrete to be accelerated into a jet and applied with high impact energy on the subsequent layer. As presented in Figure 1 a, this allows greater application distances between the nozzle and the printing layer as well as a sufficient coverage of integrated elements, resulting in a versatile process and advantages for the integration of reinforcement.

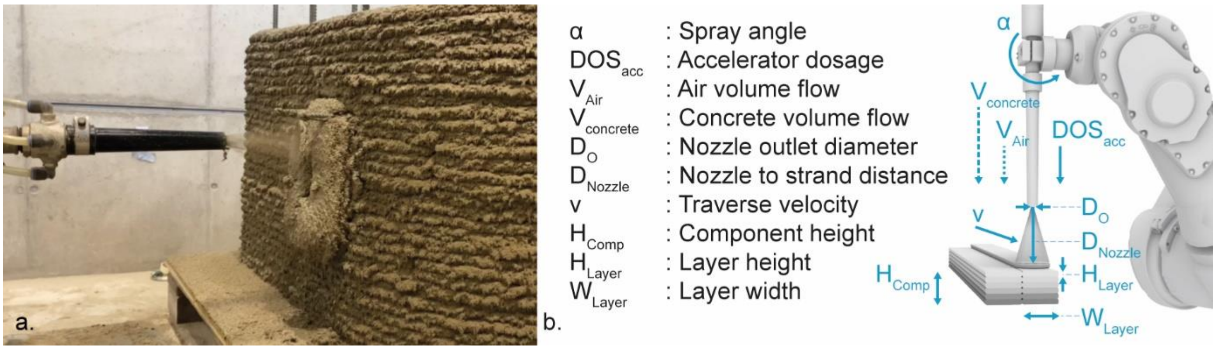

Figure 1. A process overview of SC3DP process; a) advantages of nozzle to strand distance for the integration of rebars [10] and b) parameters relevant for SC3DP process

Integration of reinforcement

As reinforcement is a crucial part of the design of structural concrete elements, there are already many approaches for the integration of reinforcement structures. As presented by Kloft et al. [11] three different strategies are feasible for additive manufacturing processes in construction. In the first concept „Concrete Supports Reinforcement“ (CSR), concrete is applied before the reinforcement. The initial strength of the concrete provides the necessary support and holds the reinforcement elements in place. This technique is feasible for flexible reinforcement materials, such as fibres and steel cords [12], horizontally placed fibre mats [13], horizontal interlayer rebars [14,15] or vertically placed threaded rod reinforcement [16]. The integration is usually performed shortly after the concrete deposition. For the insertion of rebars perpendicular to the layer structure, experimental results showed that a rotational insertion provides a higher bond quality compared to a direct insertion [17]. The second concept „Reinforcement Supports Concrete“ (RSC) uses premanufactured reinforcement structures such as fibre meshes [18,19] or rebar cages as basis for concrete application. Depending on the reinforcement design and fabrication strategy, complex construction elements can be manufactured incorporating an optimised component design based on force-flow principles [20]. The third strategy suggests incremental integration of reinforcement during the printing process. Currently research is being conducted regarding the integration of Wire-Arc-Welding as reinforcement into concrete printing, however no large scale methods have been tested.

Surface finishing of concrete elements

Different tools and approaches are used in order to finish the surface of 3D printed concrete elements. In addition to the characteristic horizontal layer structure, which provides a unique finish as technological artefact, the surfaces can be finished with a cover layer [21]. Another approach is the implementation of process parallel slipforming using sliding formwork, as seen in various techniques [22], sometimes even developed and patented by specialised companies [23]. In post processing, traditional handheld tools such as trowels and fillers are commonly used. Other processes, such as CNC controlled green-state milling offer further potential for reaching a desirable geometrical surface quality [24].

3. Concept, design and manufacturing

This chapter presents the process from designing to manufacturing a reinforced wall segment using the novel SC3DP technique and automated end effectors to integrate reinforcement and apply a surface finish. Based on the mentioned challenges, the manufactured segment demonstrates new techniques to manufacture prefabricated construction elements quickly and accurately before transporting them to the desired location for final build-up/construction. Section 3.1 presents the overall concept, infrastructure and tools used. In section 3.2 the computational design including path planning for robot trajectories and process orchestration is described. The used materials and prototypical manufacturing process, including process parameters are shown in section 3.3.

3.1 Concept and Infrastructure

Process

AM shows great potential to complement on-site construction or precast factories to increase the productivity and sustainability. The process chain for manufacturing consists of five consecutive steps (see Figure 2). As a basis of the manufacturing process, the desired component must first be designed and adapted to the AM process. Followed by the printing process, the material is applied in parallel with the reinforcement integration in the element. When the application process has reached the desired geometry, a surface finishing is applied to create architectural surfaces. Finally, after hardening, the element can be transported and assembled at a construction site.

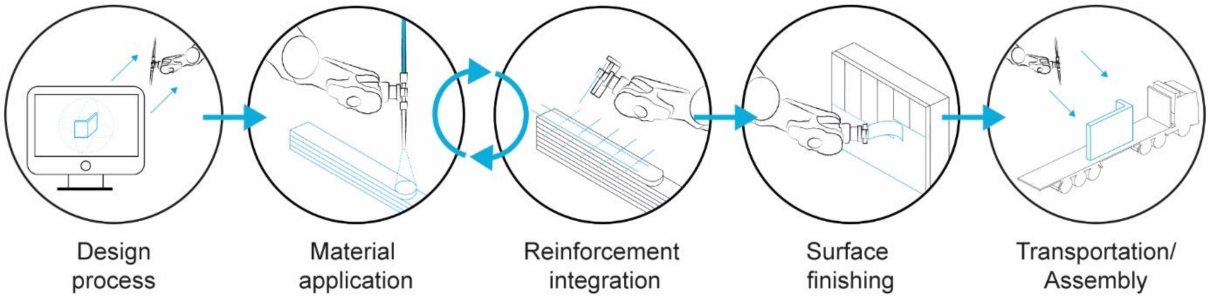

Figure 2. Process chain for manufacturing reinforced components with precise surface quality

Infrastructure

To demonstrate the capabilities of the robotic spraying process and automated reinforcement integration, followed by a precise surface finishing, the Digital Building Fabrication Laboratory (DBFL) at TU Braunschweig is used to manufacture a wall segment using the process chain presented in **Figure 2**. The uniqueness of DBFL stems from its integration of two different manufacturing units: a CNC-controlled 5-axis portal milling machine used for finishing, and a 6-axis heavy-duty robot mounted on a 3-axis portals for printing. Both modules can move on an independent y-axis, offering increased flexibility for manufacturing. By combining the robot control with the CNC control environment, the DBFL allows for independent operation of the CNC portal and the robot portal, as well as collaborative working processes. The facility has a work area of approximately 16 m x 9 m x 3 m, enabling the production of large-scale architectural components. Additionally, the DBFL includes an automated concrete mixing system provided by Kniele. This system consists of three Bigbag silos connected to the cone mixer KKM 375/550. Water, additives, and binders are added using digital weighing and dosing devices. The integration of digital control facilitates enables the preparation of customised material mixtures tailored to the requirements of AM.

As part of the infrastructure used in this experiment, the developed end effector used for the SRI process is shown in Figure 3. It was developed based on VDI 2221 [25] in an iterative process and composes of three modules with specific tasks. The first module is the gripper module. In contrast to the end effector for inserting helical geometries, such as screws or sheet metals [16], a pneumatic centric gripper is used for handling and aligning the rebars. With this approach rebars of various diameters (4 – 12 mm Ø) can be inserted. A stepper motor (ST6018-D4508-B) is used to rotate the gripper with a rebar attached. The maximum torque of 3.44 Nm can be achieved at 100 rpm. For faster rotations, the torque is reduced to 1.25 Nm at 800 rpm. To operate the pneumatic gripper, a hollow shaft is used to supply the gripper with compressed air via two air inlets and a rotation union. The second module is a magazine for up to 25 rebars. It is mounted on top of the end effector and can be exchanged easily with two clamps on the side of the end effector. To supply the gripper module with another rebar after insertion, a pneumatic stepping gear is used. The next module is the insertion module. Its basis is a linear axis consisting of a guide rail (FDA-20) and a threaded stainless steel spindle (IGUS

Ds12x15) to convert the rotational movement of a stepper motor (ST5918L2008-A) into a linear motion with up to 2.1 m/min for the vertical insertion process.

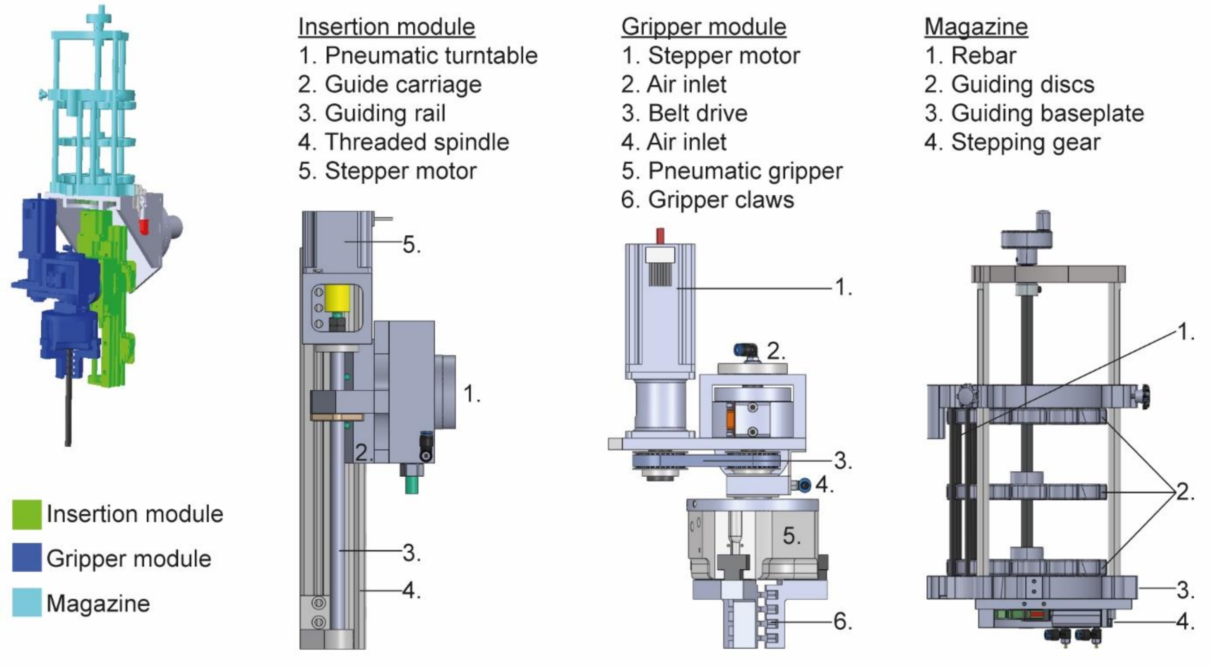

Figure 3. Robot guided end effector for SRI; a) overview with different modules; b) detailed view of insertion module (left), gripper module (middle) and magazine (right)

On the guide carriage, a pneumatic actuated turntable (SMC MSQ 20) is mounted to rotate the gripper into a loading position for a rebar. After the gripper is loaded, the module rotates back facing a downwards in the insertion position. Both positions are visible in Figure 4. For controlling the stepper motors, pneumatic valves and the pneumatic turntable a "Controllino Mini" is used. The process is described as follows: Before the SRI process starts, the linear module is initialised by moving upwards until a reference position is reached. The next initiation is being carried out by an external digital signal.

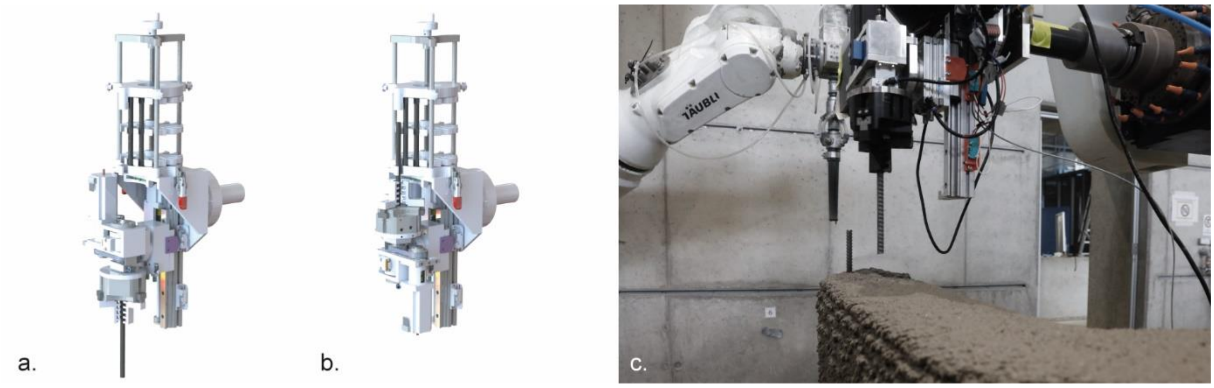

Figure 4. SRI end effector; a) insertion position and b) in loading position c) loaded end effector before inserting a rebar into the concrete next to an SC3DP robot in waiting position

The gripper module engages in the loading position (Figure 4 b) by rotating 180° and opening its gripper claws facing upwards. Following, the pneumatic stepping gear rotates one step, releasing a rebar into the open gripper claws. After closing the gripper, the pneumatic turn-table rotates the gripping module downwards into the insertion position (Figure 4 a).

When the insertion position is reached, both steppers rotate synchronously at a defined insertion and rotation speed to match the set inclination of the rebar. At a defined insertion depth, the insertion process stops and the gripper opens, releasing the rebar. The gripper returns to its starting position and awaits another signal to start the loading and insertion process anew. By tilting the end effector, an angled insertion of rebars is also possible. The process parameters used for the insertion are summarised in section 3.3.

Design

The selected element design for the technology demonstration resembles a segment of a load-bearing concrete wall (see Figure 5). Due to the structural requirements the wall element needs to be reinforced. To integrate a continuous three-dimensional reinforcement structure, two different methods were chosen. In the horizontal direction interlayer reinforcement (ILR) are integrated between the applied concrete layers. In the vertical direction short rebars (SRI) were integrated. The reinforcement structure is based on a traditional rebar cage spanning in x, y and z direction. To provide a continuity of the reinforcement inserts, the concept of overlapping joints is utilised by placing the rebars adjacent to each other with a minimal distance.

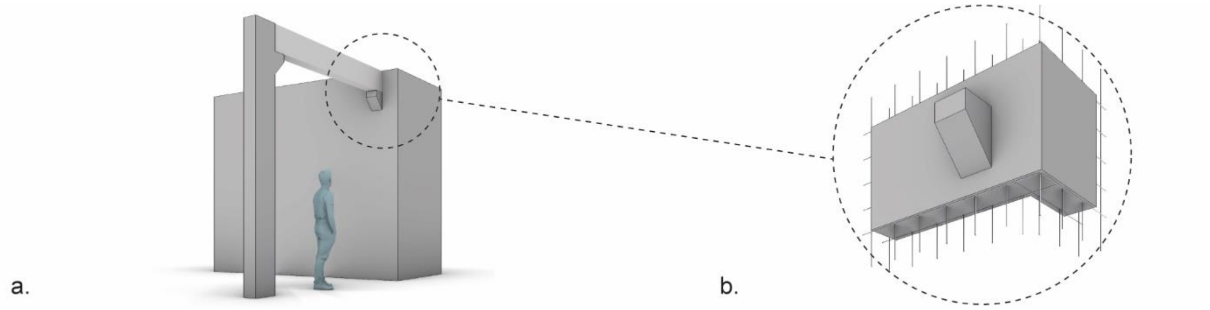

Figure 5. Conceptual design of the construction element used for technology demonstration

Lastly, the surface of the element is finished to approach the precision of precast elements and architectural surfaces. This post-processing should be performed within an automated process for optimal efficiency in the green state of the concrete. A net near shaped component geometry close to the digitally designed object should be achieved.

3.2 Computational design and path planning

As design framework, the software Rhino 3D and its plug-in Grasshopper is used to model the element. Rhino provides an intuitive workspace and an easy integration of robotic manufacturing software into the workflow. The printing paths are programmed using the grasshopper interface in conjunction with 'robots', a plug-in developed by the Bartlett School of Architecture. As a result, the design and the robotic fabrication planning are visualised within a single interface, enabling a feedback loop and quick adaptions based on manufacturing limitations.

The element consists of a vertical wall extending in both the x and y directions, serving as a building corner, with an attached console to support a beam. As measurements for the wall segment 1.00 m length x 0.60 m width and a height of 0.60 m were chosen. Furthermore, the process limitations have to be regarded and the design has to be adapted for the manufacturing process. The process limitations are the geometric restrictions, possible strand width, the printable overhangs, and the integration of reinforcement. As geometric restrictions of the process only allow for rounded edges, the corner of the element is filleted (R = 300 mm) to accommodate the spray cone radius. Smaller radii are possible as well: however, they would result in material agglomerations in the inner side of the path. The strand width was set to approx. 130 mm and the strand height to 15 mm. Considering the attached console in the wall element, an adjustment in the overhang has to be made. The bottom angle of the console was increased from 30° in the initial design to a 45° angle to decrease the volume (weight) of the console and to stabilise the structure during the printing process. Lastly the element was divided into 150 mm high segments to integrate 250 mm long rebars into each segment and to create a 100 mm overlap to the next section. **Figure 6** shows the element adjusted to the process limitations as well as the selected surface area to be post processed with a trowel.

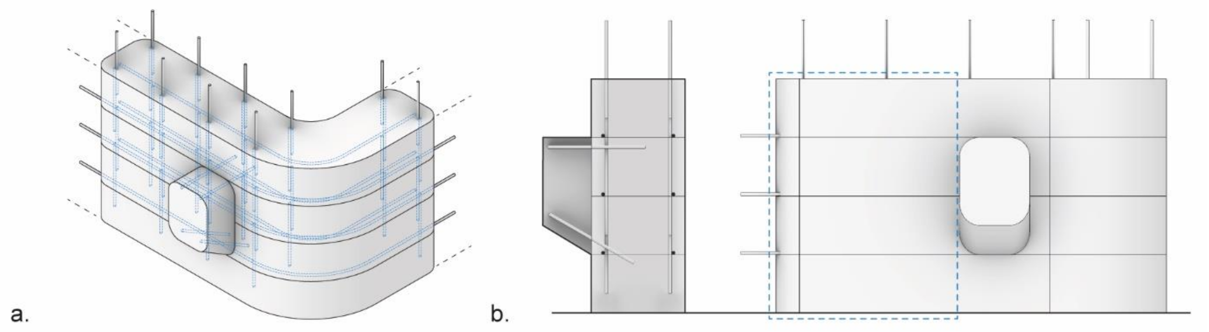

Figure 6. Design adjusted to process limitations; a) isometric view with reinforcement structure inside the element b) section and elevation of element, dotted line: section to be post processed

Although the design of the wall element is rather simple and based on traditional building forms, the production process is challenging due to the complex interplay of various automated processes and the need for precise orchestration of these processes. The first step is the programming of the robot path for the spraying process. The element has been sliced into horizontal layers with a height of 15 mm each. To achieve the width of 24.00 cm, the layers are printed in succession next to each other with an overlap of 10 mm to compensate the sloping layer geometry at the edge of a strand. After printing a segment of 150 mm height, the robot has to reach a waiting position outside the collision zone of the second portal. Two processes are carried out during this interruption. First, the SRI process is started. Therefore, the second portal waits for its start command, which is given by a human input. Next, the portal moves to its first position to insert a short rebar. The exact subroutine for inserting a rebar is described in section 3.1. Each rebar is 250 mm long and was screwed 100 mm into the concrete. Afterwards, the next short rebar is placed in the same layer at the next position, in this case 200 mm apart from the previous rebar.

To prevent collisions between the end effector and already inserted rebars, an insertion strategy is necessary when inserting multiple rebars in two dimensions. The main challenge is the 180° rotation after feeding a new rebar to the gripper module while switching from the loading position to the insertion position. There are several possible strategies to avoid collision. The first strategy is to move the end effector into a position where the rotation of the gripping module cannot collide with an already inserted rebar, e.g. 1 cm above the remaining height of an already inserted rebar. This has the disadvantage of a longer process time necessary for the SRI process. In addition, a longer guide rail must be used or the robot guiding the tool must alternate between a “loading position” and an “insertion position”. Another approach is the implementation of a different insertion orientation to avoid collisions. If the end effector is rotated 30° from the prior position, an insertion can be achieved without collision. However, this strategy is only feasible above a minimum distance between the rebars. By inserting many rebars close to another, a collision might still happen. The selected approach for insertion order planning involves working in equidistant half circles from the far right position of a component. This ensures, that the right side of the SRI end effector, the rotation path of the distributed rebar, is always free of collisions. Strategy 3 is therefore used in Section 3.3 to produce the reinforced component.

Lastly, the path planning for the surface finishing was programmed. To process the surface a rotating disc trowel is used. For this purpose, two surfaces were selected to showcase the final state of the prefabricated element. The two opposite sides were divided into horizontal layers, and the path continued from top to bottom to redistribute excess material. The paths are distanced by the radius of the rotating trowel (100 mm) to overlap and create a smooth surface without defects caused by omitted areas.

3.3 Prototypical production process

The DBFL was used to manufacture the wall segment. The material distribution system, responsible for transferring the material to the end effector, consists of a WM-Variojet FU Pump from Werner Mader GmbH and the automated mixing plant (Section 3.1). The sprayable mortar used for spraying the component is a commercially available mixture procured from MC Bauchemie. The maximum grain size is 2mm. The process parameters used for the manufacturing of the reinforced component are presented in Table 1.

Table 1. Process parameters used during the SC3DP process and reinforcement integration

Parameter SC3DP	**Value**	**Unit**	**Parameter SRI**	**Value**	**Unit**
Concrete flow	0,4	m³/h	SRI insertion speed	2100	mm/min
Air volume flow	40	m³/h	Rotation speed	300	min^{-1}
Traverse speed	4500	mm/min	Rebar inclination	7	mm
Nozzle distance	200 / 150	mm	Insertion depth	100	mm
Spraying angle	0 / 90	°	Distance before insertion	50	mm

Before the printing process starts, the material water content is adjusted and controlled by means of a slump test according to DIN EN 12350-5. When the material has the correct properties, it is conveyed to the nozzle and the printing process begins. Figure 7 a shows the material application during the first 150 mm high segment.

Figure 7. a) SC3DP process during first 150 mm segment b) integrated ILR and SRI after the first printed layer c) covering of integrated reinforcement and build-up of SC3DP layers

The layers are placed next to each other with a 10 mm overlap to avoid gaps between the layers and to ensure full coverage of the reinforcement. The short rebars are placed 40 mm inside the planned geometry on each side to ensure a sufficient concrete cover. Using the precisely integrated short rebars, the horizontal bars can be placed manually adjacent to the rebars and pressed slightly into the fresh concrete. In addition, the ILR placed in front of the vertical rebars will also have a cover of at least 20 mm. The cover can be precisely controlled by the post-treatment process. Figure 7 b shows the distance of the rebar from the external surface and the cover of the rebar during the process.

The robot now awaits another human safety input to assure a safe distance between the portals and a start command to continue the spraying process (Figure 4 c). The second spraying layer covers the integrated reinforcement and fills any voids created in the previous steps. After applying the next segment, the process is repeated (Figure 7 c). Due to a necessary overlap, the particular end effector movement and to compensate inaccuracies from the rebars, the rebars were placed 5 mm apart from each other. They overlap by 100 mm in the vertical direction throughout the layer. DIN EN 1992-1-1:2011-01 was used as guideline to create the overlapping reinforcement structure, however due to technical limitations, an overlap of 100 mm was the maximum for this experiment. As a result of the collaborative automated process, the reinforcement can be placed next to each other with a high accuracy of +/- 2.5 mm.

The printing process and reinforcement integration was repeated in four layers to achieve a total specimen height of 60 cm. After the horizontal layer application, a console was added. Four more rebars were inserted robotically and angled (45° and 90°) on the side of the element. By consecutively decreasing the path length vertically, a 45° angle is printed for the console and to cover the angled rebars.

Finally, a rotating trowel with a diameter of 200 mm was used to finish the surface (**Figure 8** a). The characteristic layer structure is blurred and a clean architectural surface is created step by step (**Figure 8** b). The transformative process of trowelling the surface distributes the material evenly across the surface and creates a smooth finish. Furthermore, the elements final geometry can be adjusted by the finishing process, e.g. by adjusting the trowel distance and subtracting more material for a thinner component cross-section. For this element, a path was programmed directly on the designed geometry edges to achieve the highest near-net-shape geometry.

Figure 8. Details of the surface finishing process; a) finishing process of construction element using a rotational trowel b) finished surface after two steps of post processing with a rotational trowel

Figure 9 shows the planned geometry and the manufactured structure in comparison. The created fabrication model was used to apply the process limitations to the design as well as for the robotic path planning. The manufactured element showcases the potential of automated reinforcement integration and combined processes.

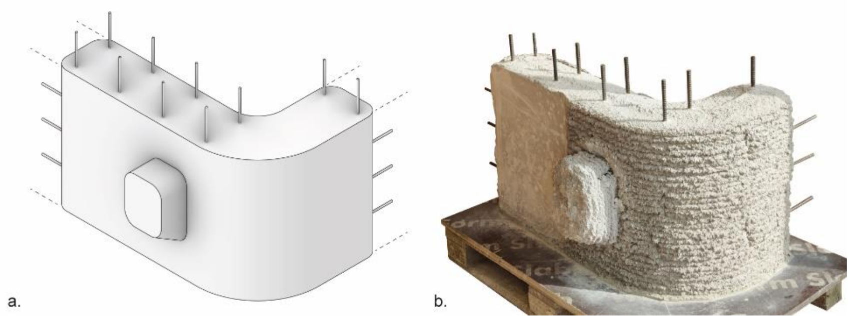

Figure 9. Comparison of planned and manufactured element; a) digital twin / fabrication model with integrated reinforcement used for robotic path planning b) finished manufactured element

4. Discussion

The presented approach demonstrates a first attempt to produce fully reinforced 3D printed concrete elements and provides valuable insights into the benefits and challenges associated with this automated process. The findings underscore the importance of future research efforts to comprehensively address these challenges and will be discussed in the following paragraphs.

First and foremost, the design process plays a central role in the manufacturing of construction elements through SC3DP. The limitations of the process have to be carefully considered in the designing phase of future elements. Although the current experiment primarily involved simple geometries, the realisation of more complex free-form geometries requires precise process control. Besides the mentioned limitations (geometric restrictions, strand width, printable overhangs, integration of reinforcement) more complex elements have to be adapted regarding the strand height, the strand orientation, the machine limitations and different reinforcement integration methods. To control these process influences, sensors have to be used to precisely control the printing [26,27]. However, the large amount of control parameters require a highly advanced sensorics system and various studies to create reliable data. Moreover, a preceding simulation of the process can enhance the outcome printing. These simulations are critical for collision avoidance and accurate control of material application, thereby ensuring the required level of process precision. The printed component, despite not utilising sensor based process geometrical control or simulations, shows a satisfying precision and a stable build-up of material. The as-printed geometry deviates +/- 10 mm from the CAD geometry, which can later be compensated through post processing. Simple geometries can thus be printed using simple setups and single parameter settings. The post processing process using a rotating trowel shows sufficient results in terms of surface quality. It can also be used to finish angled and convex surfaces like the rounded edge or console. Through this process, a near net shape is reached with a deviation of +/- 2.5 mm. The undulating surface is transformed in a smooth surface and the material is distributed throughout the layers. Furthermore, encouraging results were observed when applying horizontal elements (console) to vertical structures (wall), with the inserted reinforcement effectively supporting the horizontal console. However, a slight sagging phenomenon was observed, indicating the need for longer waiting times before applying stress to the additionally integrated rebars in both horizontal and diagonal directions. Consequently, further developments regarding the printing strategy are required for further optimisations.

Secondly, the combination of various reinforcement methods, including SRI and ILR, in the field of 3D printed concrete elements has immense potential for the creation of complex freeform construction components. However, further research is required to fully exploit this potential. The current approach relies on the use of overlapping joints to establish continuous vertical reinforcement. Notably, this method is associated with higher material consumption. It is therefore essential to research alternative joining techniques for rebars as well as conducting thorough research to integrate these techniques into the manufacturing process. In addition, it is necessary to investigate different orientations of rebars to align the reinforcement with force-flow patterns.

Thirdly, a notable challenge encountered during the experimental phase relates to compensation of handmade elements used in automated processes. The rebars exhibited eccentricities or slight bending, which adversely affected the screwing process and resulting in the formation of voids and unreliable bond quality between the concrete and the rebar. The precise placement of overlapping joints requires the insertion of rebars in immediate proximity to one another. Consequently, the development of an end effector capable of accommodating these irregularities becomes imperative. This end effector should be technologically improved to enable a safely embedding process of rebars deeper into the concrete, ensuring enhanced overlapping joints that conform to regulatory standards.

Lastly, to validate the efficacy of the approach, it is essential to carry out experiments on large structural elements. The pursuit of more complex geometries requires complex path planning and adjustments in the manufacturing process. Consequently, future research efforts will focus on scaling up of the approach, allowing for the incorporation of force-flow oriented reinforcement structures throughout the elements. This broadening of the scope of the approach promises to reveal additional challenges, foster a deeper understanding of the process and provide valuable insights for further refinement and improvement.

5. Conclusion and outlook

The manufactured wall element demonstrates the potential of additive manufacturing in construction using automated tools and processes. The combination of SRI and ILR as reinforcement integration methods, enables the incorporation of three-dimensional reinforcement structures into 3D printed load-bearing concrete elements. These elements have the potential to serve as building or infrastructure components, all while preserving the geometric freedom offered by AM, specifically the SC3DP process. In comparison to traditionally on-site casted and precast elements, the printed object indicates accuracies close to precast standards. Moreover, the elimination of formwork in the process led to cost and time savings, especially for expansive and elaborate geometries.

Future research will focus on optimising the workflow and integrating more complex three-dimensional reinforcement structures oriented along the force-flow in the construction element. Moreover, larger construction elements and the challenges of large scale will be addressed. To improve the automated SRI process, a force sensor will be added to the end effector to observe and control the insertion motion and to detect collisions with previously inserted rebars. Additionally, such a sensor could be used to determine and monitor the curing process of the concrete by tracking increasing forces during reinforcement insertion between the layers.

Data availability statement

There is no relevant additional data to this article beyond the presented content.

Author contributions

Conceptualization, R.D., M.D., K.D. and H.K.; methodology, R.D., M.D., K.D. and H.K.; software, R.D. and M.D.; validation, R.D. and M.D.; formal analysis, R.D. and M.D.; investigation, R.D. and M.D.; Provision of study materials, reagents, materials, patients, laboratory samples, animals, instrumentation, computing resources, or other analysis tools, K.D. and H.K.; data curation, R.D. and M.D.; writing—original draft preparation R.D. and M.D.; writing—review and editing, M.D., N.F., K.D. and D.L.; visualization, M.D. and N.F.; supervision, K.D. and H.K.; project administration, K.D. and H.K.; funding acquisition, K.D. and H.K.. All authors have read and agreed to the published version of the manuscript.

Competing interests

The authors declare no competing interests.

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