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A new robotic spray technology for generative manufacturing of complex concrete structures without formwork

Stefan Neudecker*[a], Christopher Bruns[b], Roman Gerbers[c], Jakob Heyn[c], Franz Dietrich[c], Klaus Dröder[c], Annika Raatz[b], Harald Kloft[a]

[a]*Institute for Structural Design, Pockelsstrasse 4, Braunschweig 38106, Germany*
[b]*Institute of Assembly Technology, An Universität 2, Garbsen 30823, Germany*
[c]*Institute of Machine Tools and Production Technology, Langer Kamp 19, Braunschweig 38106, Germany*

* Corresponding author. Tel.: +49-531-391-3574 ; fax: +49-531-391-5835. *E-mail address:* s.neudecker@tu-braunschweig.de

Abstract

The robot-assisted manufacturing is introduced for many years in automated production areas, while the production of buildings still follows the traditional manual process. Using new possibilities of digital planning the construction industry demonstrated potential for the implementation of freeform architectures, which are only possible using expensive and only once usable formwork structures. This paper focuses on sprayed concrete technology for automated production processes to build up freeform concrete components. A study case of the production of a concrete wall by an industrial robot, equipped with a concrete spraying tool is presented in order to investigate the possibilities and tolerancing issues of this technique.

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Keywords: generative manufacturing; concrete spraying; free form; formwork; robotic fabrication; digital process chain.

1. Introduction

Sprayed concrete technology exists in Germany since the 1920s. The main fields of application are tunnel construction, rock stabilization and strengthening of old concrete parts. This technology could be used to produce freeform concrete structures for modern buildings.

While the current discussions in industrial production concern future developments of the subjects "industry 4.0", which means networking of production techniques, the so-called "smart factory" and the "human-robot cooperation", the construction industry has not even arrived in industry 3.0.

The digital revolution has indeed taken place in the construction planning offices in the form of powerful design, calculation, construction and simulation software. However, on the worksite high-quality materials and semi-finished products are still set "stone-on-stone" to each other or "seam-for-seam" welded together. These procedures incur large losses in quality and cost-intensive work processes. The practical construction is still dominated by standard system formwork, which means flat formwork elements to produce simple and mostly planar components such as walls. This discrepancy between the possibilities and complexity in the digital planning of sophisticated concrete structures and what can be implemented on site has been increasing steadily the last years.

A basic requirement to implement resource-efficient construction is an enhanced component performance through the interaction of external form and internal material structure. To achieve this component performance, it is necessary to provide a powerful manufacturing technology. In this paper the idea of the automated manufacturing of freeform concrete structures for modern buildings by utilizing spray concrete technology is introduced. This process should be explored in the future in a research facility which is currently under construction at TU Braunschweig. It consists of two portals, one with a concrete spraying industrial robot and another to carry a dynamic formwork.

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To approach the proceeding the state of the art shows the history of sprayed concrete and already realized building components. In this context the new research facility and its application is introduced. Finally, practical experiments validate the use of the robot assisted concrete spraying system.

2. State of the art

Sprayed concrete or “shotcrete” is a concrete which is conveyed in a closed tube line to a nozzle, from where it is pneumatically sprayed onto a surface and compressed by the impact energy. The shotcrete process is often referred to as "Torkretieren". The term has its origin in the German engineer Carl Weber who first registered the shotcrete process patent in Germany and founded the company Torkret in 1919. Aggregates, cement and water are transported with compressed air and sprayed onto a surface (Figure 1). The three steps conveying, compacting and the application procedures are performed in one operation [1].

Figure 1: „Torkretieren“ of a road in 1926 [Torkret GmbH]

Nowadays “shotcrete” is mainly used for the retrofit of concrete structures, facades and rehabilitation of historic concrete structures, as well as for rock consolidation and temporary support in tunneling systems. In addition to these conventional application areas there have been hardly any exploration into new areas of application, despite the advantages and potentials that shotcrete brings with it. The reasons for this lie mainly in the traditional manual process of spraying. To achieve good results, a high level of experience in the movement and usage of the tool as well as the suitable material mixture is required. Often too much or too little material is applied and sometimes the concrete composition of the coating layers is not particularly homogeneous. The attainable qualities in terms of geometric accuracy, as well as the visual and haptic surface qualities are significantly lower than those of poured concrete are.

The great advantage of the spraying process lies in the flexibility of the application, in particular in the production of complex geometries with thin material layers. The construction company of engineer Ulrich Müther has applied the sprayed concrete technology for various shell structures as well as for the construction of bobsleigh runs. For the construction of the bobsleigh run in Oberhof (Figure 2) concrete was sprayed on separate curve sections of wire grating without using a mold. A very fine mesh size was used in order to prevent the concrete mass from slipping down the inclined surface. This technique was so convincing that shortly thereafter all tracks were built in this method.

Figure 2: Shotcrete method used for the construction of the bobsleigh run in Oberhof [Torkret GmbH]

Many domes, like the planetarium in Wolfsburg, were produced with the shotcrete method. On a self-supporting and reinforced rod network, a tightly woven wire mesh was braided. The concrete was applied with the wet spraying technique in layers and in ring formations without the use of additional formwork, Müther [2].

Another recent example in manual concrete spraying for freeform architectures was tested at the TU Vienna [3]. With the help of pneumatically-assisted molding as semi-permanent formwork, sculptural forms were produced. A newly developed concrete recipe made it possible to cover the air cushion with a thin layer of concrete and thus produce viable concrete sculptures.

As formwork is immanent for the process of spraying concrete, it is necessary to take another technology in consideration. With the method of “slip forming” (Figure 3) a dynamic formwork is used instead of static formwork.

Figure 3: Slip forming of rain water drainage [5]

The formwork is moved hydraulically to extrude complex concrete elements in a continuous production process on a building site. The concrete is poured, simultaneously consolidated and finished with a high surface quality and low tolerances. The investment into complex constructions for formwork can be dramatically reduced by this method and significant time savings can be realized. This technology is widely used to generate horizontal or vertical structures such as chimneys, columns, walls, multi-story buildings and street pavements. As the machines for this process are constructed for