



Short report for the research project:

Additive manufacturing of freeform building elements by numerically controlled extrusion of wood chip concrete

Duration:

15.10.2014 - 30.4.2016

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Funded by:

Forschungsinitiative Zukunft Bau
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im Bundesamt für Bauwesen und Raumordnung (BBR)
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This research project was funded by
Forschungsinitiative Zukunft Bau des Bundesministeriums für Umwelt, Naturschutz, Bau und
Reaktorsicherheit

(Reference number: F20-13-1-143 - 10.08.18.7-14.10)

The responsibility for the content of this report lies with the authors.

Munich, 15 June 2016

1 Summary

The focus of the research project was the development of a manufacturing process to create large scale building elements by extruding wood chip concrete. The elements are formed without the use of formwork by depositing fine strands of fresh concrete (Figure 1). This is achieved by moving an extruder with an industrial robot along a path in space which matches the desired geometry.

2 Introduction

Additive manufacturing, or “3D printing”, describes the process of generating solids automatically on the basis of a digital 3D model by adding numerous small (compared to the size of the solid) units of material. Therefore, there are no specialised tools necessary to fabricate differently shaped objects, which makes additive manufacturing particularly economical where single parts and small batches are to be produced. Additive manufacturing methods are already state of the art in numerous fields of industry.

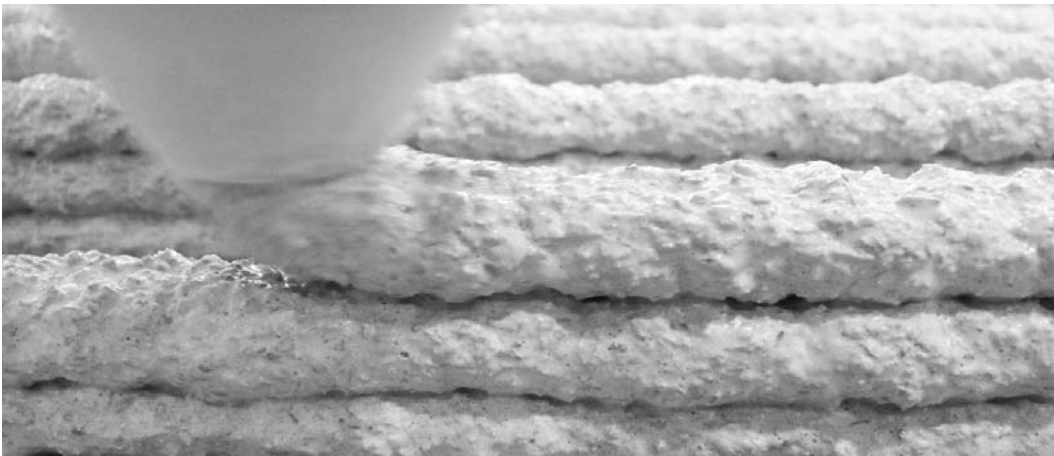


Figure 1: Extrusion of wood chip concrete

Similarly, the field of construction also shows large potential for the use of additive manufacturing methods. Because of its specifications such as geometric freedom in combination with the cost effectiveness of small batch production, additive manufacturing is well suited for the optimisation of element geometry regarding usage, building physics, and structural requirements. Hollow structures for installations can easily be integrated and additions or replacement parts can be manufactured precisely to fit existing buildings. However, additive manufacturing for construction purposes is still in its development stage. Most of the related research and development projects focus on mineral based materials, especially concrete.

3 Objective

The focus of the research presented here was the study of additive manufacturing through the extrusion of wood chip concrete and its suitability for the construction industry.

Replacing the typically used heavy sand and stone aggregates of concrete with the renewable resource wood not only reduces the environmental impact but also leads to a light weight, insulating and easily workable material. This project aims to show that, compared to similar manufacturing methods with regular concrete, the boundaries of production technology can be extended and new areas of application developed.

4 Realisation of the research project

The experiments conducted throughout this project required a fast setting but extrudable wood chip concrete. Preliminary tests with a specialised cement for wood concrete as well as off-the-shelf mineralised wood chips did not yield the desired result. Consequently, a wood chip concrete mixture was developed with Portland limestone cement and untreated softwood chips in a volume ratio of 1:1 and other additives. The resulting concrete has a compressive strength of ca. 10 N/mm² and a bending strength of ca. 4 N/mm². The density of the material is ca. 1,000 kg/m³ with a thermal conductivity of ca. 0.25 W/(m*K). Based on relevant literature it can be assumed that the material can achieve the fire classification A2.

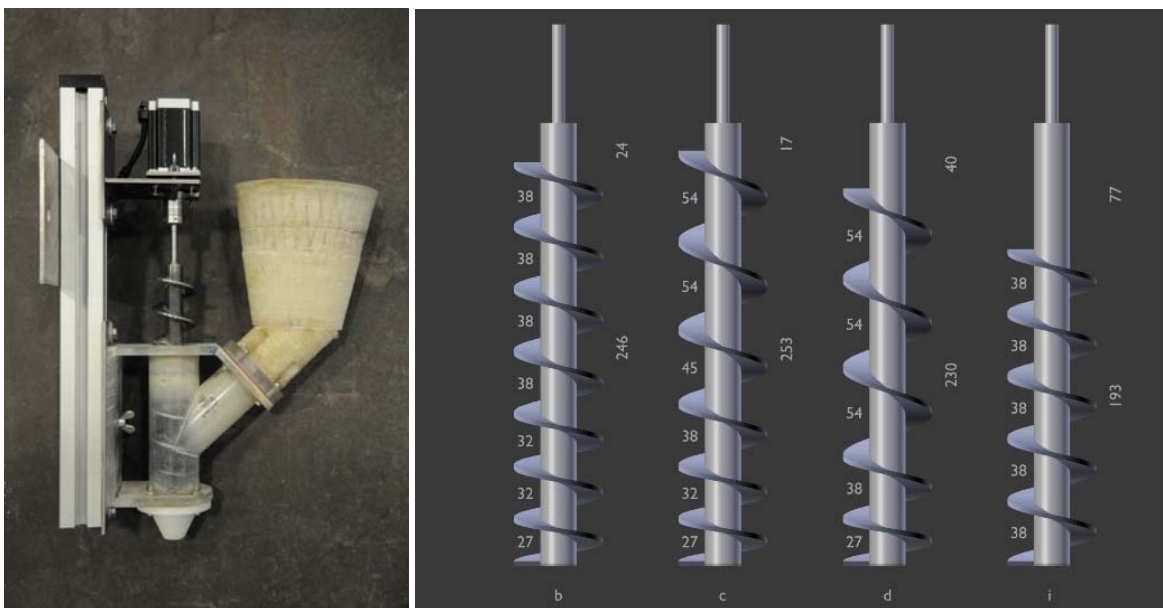


Figure 2: Experimental extruder (left) and different conveyor screws (right). Screws b, c and d with a pitch of 27 mm at the end and varying progression; screw i with a constant pitch of 38 mm.

The extruder consists of a conveyor screw which is powered by a stepper motor. The concrete is transported downward through a nozzle with a round opening. The pre-mixed concrete is fed into the screw through a hopper which is filled by hand in small batches. With this simple method, the time between mixing and dispensing the material can be kept short. The extruder has a screw diameter of 54 mm and is constructed as a modular system which allows for testing different screws, nozzles and hoppers (Figure 2). The best results could be achieved with a hopper connected at the lower end of the extruder using screws with low pitch and little to no progression. Using a round nozzle with an opening diameter of 20 mm and a convergence of 20°,

strands of concrete with a consistent cross section of (W x H) 25 mm x 10 mm could be dispensed.



Figure 3: Gantry system with mounted extruder

The extruder is manipulated by a 6-axis industrial robot with a reach of 3,500 mm and a rated payload of 110 kg (Figure 6). Additionally, a small 3-axis gantry with a processing way of approximately 670 mm x 890 mm x 110 mm (X, Y, Z) was available for small scale tests (Figure 3).

The low thermal conductivity of wood chip concrete and the geometric freedom of the implemented manufacturing method enable the production of building elements optimised in regard to structure and building-physics. One promising area of application of this material-method-combination lies in the construction of optimised façade elements for a simple, monolithic building. Therefore, multiple large scale wall segments with an internal honeycomb structure were 3D printed as test objects. The dimensions of the largest of these wall segments are (L x W x H) 50 cm x 150 cm x 93 cm (Figure 6).

Different overhang tests were conducted in order to study the increase in geometric freedom the lightweight wood chip concrete entails. Among others, an object consisting of ten layers, each with the dimensions (L x W x H) 230 mm x 400 mm x 10 mm, and an offset of 3 mm per layer could be printed (Figure 4). Considering the height of the object, which measures 100 mm, the overhang amounts to 26 %.



Figure 4: Extruded wood concrete test object with overhang



Figure 5: Subtractive finishing of additive manufactured test objects from wood concrete
(sample fabricated by S. Stanglmayr)

Compared to regular concrete, lightweight concrete has advantages in regard to subtractive post processing. Where necessary, the near net shape 3D printed parts can easily be brought to net shape in a subtractive finishing process (Figure 5). Tests with various subtractive treatments showed, that wood chip concrete is easily workable with conventional tools for metal working.

5 Results

Additive manufacturing in construction can be realised through the extrusion of wood chip concrete.

An extruder with a conveyor screw located near the nozzle and an industrial robot as a manipulator is a suitable system.

The use of renewable resources as aggregates for concrete can help reduce the environmental impact.

The strength properties of the used wood chip concrete are comparable to those of purely mineral based light weight concrete.

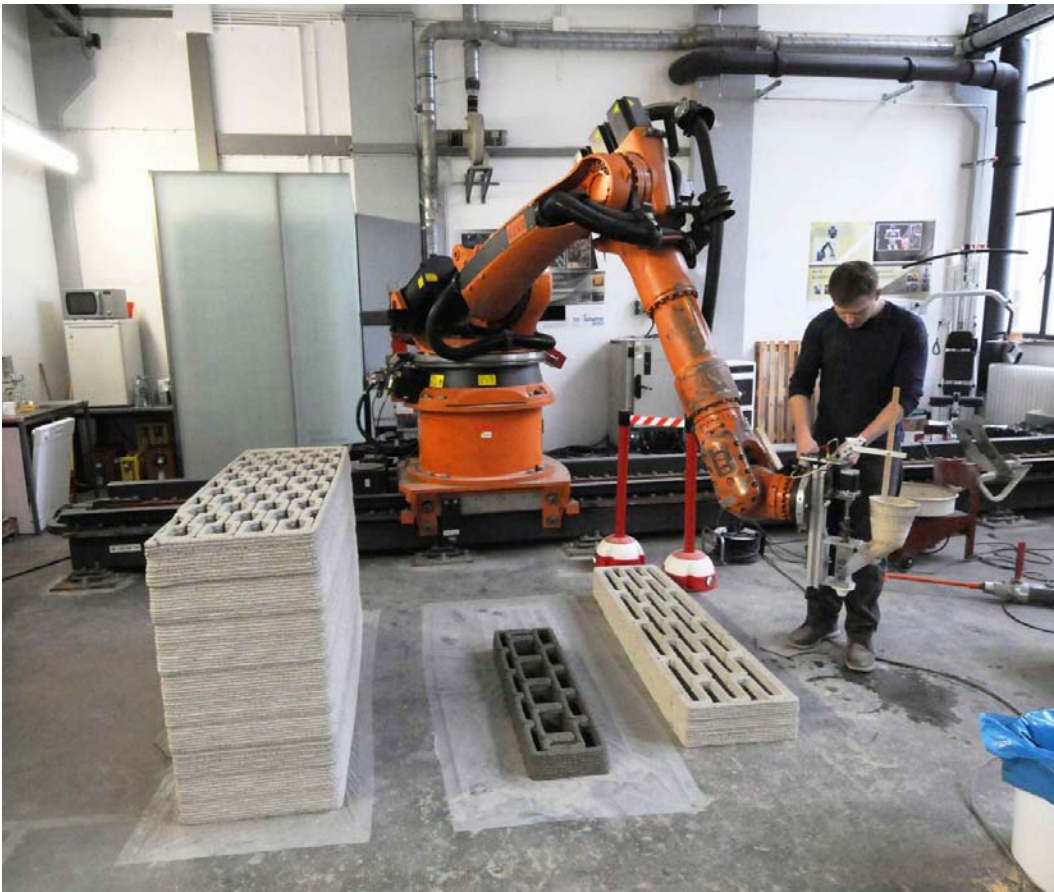


Figure 6: Industrial robot with mounted extruder and various large scale wood concrete test objects

Its low weight and good inner strength help to realise overhangs to a greater extent. This also allows the build-up of special temporary support structures for cantilevering or bridging parts with a minimum of material. Together, this means a significant improvement of geometric freedom for processes of concrete extrusion.

Its good workability enables subtractive finishing in areas, where a high degree of precision is required (e.g. for the joining of parts) or increased surface quality is demanded. The combination of additive and subtractive manufacturing steps represents a promising approach to make high resolution compatible with building speed.

For this special material-process-combination applications can be depicted in new buildings as well as in the existing building stock.

With the possibility of fabricating tailor made elements, this technology, especially in combination with digital building surveying, opens up new ways of retrofitting.

The low thermal conductivity of the material combined with the optimization-possibilities of the additive manufacturing process will enable simple, robust and easy to recycle, monolithic buildings or building parts without the necessity of further insulation.

In summation, additive manufacturing in construction through extrusion of wood chip concrete proved to be a technology with great potential.

For an industrial application of the process, further material development and optimisation is required in order to improve the properties of the fresh as well as the hardened concrete. Apart from different types of cement and additives, investigating alternative aggregates, such as mineralised wood chips and granulated glass seems promising.

Furthermore, the extruder has to be perfected to a continuously working, combined mixer-extruder-unit. The cross section of the concrete strands requires optimisation and the necessary nozzles must be developed. Also, in order to improve the printing time as well as the resolution and surface quality, the possibility of combining additive, shaping and subtractive processing steps should be studied further.