Controlling the structural behaviour of 3D printed concrete designs

3D concrete printing is rapidly expanding, with an increasing number of initiatives, printers, research programs and showcase projects. The advantages are manifold, but there also is a major challenge: how to control the quality of concrete that is deposited in a totally different way than conventional poured concrete? Rob Wolfs has developed a numerical model and experimental procedures to remove this complexity, which will help facilitate widespread adoption of this promising technique.

3D Concrete printing holds a great promise. It provides a significant reduction in use of concrete, steel and formwork, and thus, decrease of both costs and environmental impact. Moreover, concrete printing gives designers enhanced geometrical freedom and increased functionality at almost no extra cost. Also heavy labour is strongly decreased by this automated manufacturing technique.

However, new knowledge is required to realize these advantages. Conventional concrete is poured in a supporting formwork, but printed concrete has no formwork. The freshly printed concrete should be sufficiently strong and stable by itself, throughout the printing process to avoid collapse. Moreover, as a consequence of the layerwise nature of 3D printing, the final, hardened product is composed of numerous printed layers which should adhere sufficiently. Otherwise, the structural performance of the final product may not suffice.

This PhD research was performed to control the structural behaviour in both the fresh and hardened material state, to realize a robust printing process and guarantee structurally safe final products. A unique 3D concrete printing facility was designed and realized in the Structures Laboratory Eindhoven of the TU/e, to study the printing process on both small and large scale.

To assess if and how designed structures may collapse during printing, a numerical model has been developed. This model simulates the printing process of designs, before actual printing starts. The model includes the growing geometry and the time-dependent material properties. Such properties were derived from various experimental procedures, which were custom developed for this research. Validation studies showed that the numerical model is a suitable tool to predict, and thus, prevent collapse, by optimizing the printing strategy or the design.

The bond strength between printed layers was studied by means of an extensive experimental program. Here, the influence of numerous process parameters was defined, e.g. the orientation of the layers in relation to the loading, the interval time between printing successive layers, and the environmental conditions during such interval times. The results of this study indicate a clear impact of such process parameters on the strength between the layers, which should be incorporated into structural analyses, or prevented by optimizing the printing strategy.
The numerical and experimental methods have been applied in various large scale valorization projects that were realized over the course of the PhD research: new bridges in Gemert and Nijmegen, and the printed houses project in Eindhoven, Project Milestone. They were used to facilitate the design process, provide input for structural analyses, and successfully optimize the printing strategy.