Areal Monitoring of Digitally Fabricated Structures Early after Construction

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SUMMARY

The construction industry is currently undergoing major changes due to automation and digitization in all phases of a building's lifetime. This affects design, fabrication, assembly, and maintenance. The goal of this innovation is to boost productivity, enhance sustainability and maintain a high level of resilience. Achieving these goals requires the standardisation of automated fabrication processes and an improved understanding of the behaviour of the fabricated (structural) elements. For both aspects we need geometrical information about the fabricated objects and their changes over time with sufficient spatio-temporal coverage, resolution, and accuracy. Point-cloud based methods, augmented with traditional geodetic metrology are well suited to provide the necessary information. Digital fabrication, in particular currently, at the transition from lab and idea to real world application, requires the core-competence of engineering geodesists to design, plan, and realize measurement systems with the appropriate technical characteristics and the required connection to a well-defined reference frame.

Herein we present four digitally fabricated structures along with the specific geodetic challenges for monitoring during the early phase after construction, and the solutions chosen. The structures are parts of a real building designed and built within the highly interdisciplinary National Centre of Competence in Research Digital Fabrication (NCCR dfab) at ETH Zürich. Concretely, they comprise (i) a curved wall realized by robotically spraying concrete onto a wire mesh previously built in-situ, also by a robot; (ii) an ultra-thin curved ceiling created by spraying concrete onto 3d printed formwork, (iii) mullions fabricated using 3d printing of concrete within an adaptive gliding formwork, and (iv) a robotically cut and assembled timber beam construction. For all these elements, the geometry had to be checked after the on-site installation and over the first few months of the normal use of the building, i.e. the as-built state was compared to the designed one, and the deformation history was determined over several months.

We report about the acquisition of point clouds using terrestrial laser scanners and a laser tracker with a hand-guided triangulation scanner. Additionally, selected individual points were measured repeatedly using the laser tracker and corner cube reflectors. The acquired point clouds were used for a cloud-to-mesh (C2M) computation of displacements, whereas the measured discrete point coordinates were used for the calculation of 3D displacement vectors. Virtual monitoring points were established on the structures at parts where mounting a reflector holder was not possible but where the geometric features of the surface and the high point density of the triangulation scanner allowed us to determine displacements of small surface patches between epochs by locally correlating parts of the high-density point clouds.

The analyses show that the structures produced using the 3D printed formwork agree with the plan to within about 1.5 cm (maximum C2M deviations). The mullions deviated by up to 2 cm from their design. Most of this deviation has likely built-up during concrete hardening, and they also deformed significantly when their orientation changed from horizontal (during storage) to upright (after assembly within the building). The concrete and the timber structures showed changes of a few mm over time spans of several months. On the other hand, 3D displacements determined with accuracies better than 50 μm using the tracker showed clear movement patterns, very likely related to temperature variations, concrete creep, and shrinkage. The major technical challenge was the inter- and intra-epoch registration made difficult by the combination of nearly feature less surfaces and surfaces with lots of edges and surface roughness, by the absence of stable areas within the scanned scene, and by the prohibition of markers or bolts installed for a longer time.

The results presented in the paper highlight the importance of geodetic metrology within innovative construction processes in order to assess the readiness of fabrication techniques to be adopted by the general industry, to assure and convey safety to users, and to provide valuable data for the adaptation and improvement of models and processes.