Development of eco-friendly curing methods for constant shrinkage control of 3D printed concrete

Three-dimensional (3D) printing, also referred to as Additive Manufacturing (AM), is a technology to build a 3D object in a layer-by-layer manner without using any formwork support and vibration process. In recent years, there has been substantial interest in 3D printing with cement-based composites, however, large 3D printed concrete elements can suffer from significant shrinkage deformations which can result in the cracking of elements, and thus, in decreasing durability and aesthetic aspects. While many actions have been aimed at solving this obstacle, most of them are at laboratory scale. Traditional curing techniques such as water sprinkling or foil insulation are not suitable and can adversely affect the buildability of the mixture or cause plastic deformations of the material during curing. Therefore, it is essential to develop new curing methods dedicated to 3D concrete printing (3DCP) and understand their fundamental effects on shrinkage development. That will help to prevent printed elements from cracking, and thus suffering a deterioration in durability.

With this in mind, the aim of this project is to develop eco-friendly curing methods for 3D printed concrete, for constant shrinkage control that will be neutral to rheological properties of cement-based mixtures. To achieve this goal through a bottom-up approach, a fine recycled aggregate (fRA) and biochar will be utilized. Recycled aggregates are deemed environmentally friendly and essential for the progression and growth of the construction industry in its pursuit to lower its CO2 emissions. They can be obtain from demolishing old buildings and structures so not only it prevent natural resources but also helps to utilizes waste materials. Biochar is the lightweight black residue, made of carbon and ashes, remaining after the pyrolysis of biomass. During production of biochar CO2 gases are transform in stable form which reduce greenhouse gas emission. It can also be used as cementitious supplementary material in concrete thus reduce cement consumption. By applying the author's measurement technique, it will be possible to investigate crucial deformation of material in its plastic state as well as calibrate and extend numerical models for shrinkage estimation such as the B4 model or the *fib* Model Code 2010.

Controlling and measuring shrinkage development pose complex challenges, as traditional measurements techniques are not applicable for 3D printed concrete. Standard testing for shrinkage requires a hardened state of the material to determine its length change, whereas in 3D printed elements the most important changes occur during the first 12 h when the material is still in the plastic state. Therefore, new methods toward shrinkage determination are required.

To date, there exists no comprehensive knowledge regarding curing methods suitable for 3D printable concrete. This project is therefore the first of its kind in the field. The proposal presented here is interdisciplinary, as it combines three different fields of science: concrete technology, waste materials recycling and numerical simulations. Through the proposed author's method of contactless measurement of deformation it will be possible to monitor length change with accuracy up to 2 μm every 60 seconds. As an outcome the fundamental knowledge on the effect of internal curing in printable concrete on shrinkage development will be obtained. Result will be confirmed by image-based methods as suggested in literature. The test will be carried out on both cast and 3D printed specimens. Obtained results will be used to optimize the shrinkage estimate models used in European Standard and designing guidelines proposed by *fib* or RILEM, with new coefficient for the basic and drying shrinkage of the evaluated mixes. The existing models will also be expanded so as to include the plastic shrinkage component that is critical in 3D printed concrete.

As preliminary studies in proposed project, testing of the physicochemical properties of the fRA, biochar and nanomaterials will be performed using transmission and scanning electron microscopy and X-ray diffraction. The specific surface area adsorption will be measured by BET isotherm. Initial composition consists of a mixture of Ordinary Portland Cement, silica fume, fly ash, fine silica sand and water. Biochar and fRA will be introduced into the mixture as a fine sand and cement replacement, respectively in order to produce low-carbon footprint mixtures with controllable shrinkage behavior. Nanomaterials will be introduced to the mixture as admixtures and buildability controlling agents.

To determine the effects of different internal curing methods on the cement hydration process, quantitative and qualitative methods will be applied. For this purpose, isothermal calorimetry, thermogravimetric analysis and X-ray diffraction will be used. Scanning electron microscopy, mercury intrusion porosimetry and X-ray micro-computed tomography will be incorporated. It will thus be possible to analyze the phenomenon related to the effect of internal curing on the buildability and pores anisotropy. The proposed project will be implemented by an interdisciplinary and international research group composed of experts in the fields of rheology (United Kingdom) and theoretical and numerical analysis of concrete shrinkage (Spain).