Paste matter 3d printing in monolithic shells fabrication methods

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Fabrication methods with 3d printing for monolithic shells remain largely unexplored, in terms of the technologies implemented to ensure the integrity and the essential continuity of the structure during the construction phase. This crucial condition is directly related to the matter implementation during the fabrication process, which is further exacerbated when materials are applied in wet stage (such as concrete and clay mixes), including the proper composition of the material, the support system chosen, the placement protocol, and the deposition techniques, among other factors.

This paper features some case studies of material deposition in concrete and clay for monolithic shells using robotic extrusion and spraying, aiming to identify critical aspects required for its correct execution, with an emphasis on its transformation during the construction process. The use of different digital technologies was explored, including 3d scanning, Rhino 3d, Kuka prc (interface kuka robotic arm to Rhino through a Grasshopper plug in), exposing different ways of creating robotic trajectories for the correct deposition of the material.

The 3d printing process was implemented by depositing concrete and clay through digital interface and real time recalibration. The deployments was performed in 3 main categories (actions tools): 1] Matter extrusion with no formwork; 2] Matter spraying with temporary formwork; 3] Hybrid with material extrusion on structure in progress once the temporary formwork has been removed.

The materiality chosen was paste-like materials that were carefully formulated because their composition includes several elements that were adapted for additive manufacturing: concrete composed by granular, gravel, and sand ingredients; and clay with natural or artificial fibers of different densities, sizes (from short straw pieces to long horse hair), and natural stabilizers (Roedel, Protein Cured Concrete CIFE, Stanford University, 2016).

The results of these experiments unveil that matter characteristics during the digital fabrication process has tremendous implications on the possible geometries that can be achieved. The material implementation process in 3d printing monolithic shells using clay and concrete exhibits significant challenges, such as the fundamental type of support system employed; the control of paste viscosity (water & air ratios); the presence of air bubbles; the weight of the material due to gravity and drying time; the velocity of deposition; the stirring techniques to ensure humidity and plasticity; and the drying ratios needed for each formation.

Both concrete and clay mixes were applied wet, therefore their weight and drying processes were embedded in the 3d printing set up, by using mixes with different air content the weight of the deposition had fluctuations because paste material dried at different rates. In addition, it was confirmed that crucial invisible elements in the mix, such as air ratio and water density, had a key role to achieve suitable fitness criteria of homogeneous matter deposition with no air bubbles while being deposited. For this purpose, the following vibrated methods were implemented: constantly stirred mix to keep the right humidity level while being poured, and shaking matter to avoid bubbles while being applied.

Material deposited by spraying allowed more freedom, as very thin layers could be applied (Chaltiel, Dubor. Smart Geometry 2016 Gothenburg, cluster: “Mud, Fabrics and Robots for Large structures”). In addition, the deposition stage required the implementation of real time feedback loops, where the structure in progress was monitored to help detect areas or points of rupture, so that matter consistency was supervised, and information was immediately translated to digital tools and could be rapidly corrected.

Variable parameters while matter was being deposited were important considerations for the correct implementation, such as the distance to the support, angle, pressure or force, velocity, trajectory (points, irregular, regular continuous, lines, vertically or horizontally, or following the curves of the shells and depositing by contours). Combination of different parameters became fundamental considerations, for example during the first layers of extrusion material was poured at a velocity of 2cm/s, and after layer 5 the pouring velocity was increased to 5 cm/s.

The academic and practical implications of this research are manifold. Firstly, suitable material composition, distribution and deposition techniques for 3d printing were detected. Secondly, important areas of research were identified whether the drying should be continuous or should happen only at certain stage of the material deposition according to the kind of geometry to save energy. Lastly, it was discovered that the deposition of matter through digital interface required real time recalibration of the tools actions, which can become crucial to large scale 3d printing improvements. These findings hope to complement future improvements of academic experiments that already exist, by pushing further real time feedback loops strategies relying on radars and light sensors.

Keywords

Monolithic shells; digital fabrication; adaptation tools; real time control, deposition techniques, additive manufacture, 3d printing, robotic spraying, robotic extrusion.