論 文 の 内 容 の 要 旨

論文題目

Testing of Earth-based Material Additive Manufacturing to create Temporary Low- cost Housing; Sudan as an Example

（ローコストな仮設住宅の製造に向けた土試料を用いた積層造形技術に関する研究　スーダンを事例として）

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In this study, an earth- based mix consisting of soil, fly-ash, and an alkaline activator was developed for an extrusion- based additive manufacturing process (3D Potterbot 7 SUPER) to build low-cost, temporary housing for the urban poor in Khartoum the capital of Sudan. The architectural design was inspired by elements from local African vernacular architecture, more specifically the circular hut.

Artificial soil components were mixed to create a target soil found in Sudan resulting in an artificial soil with a Liquid limit (LL) of 55.7 %, a Plastic limit (PL) of 29.64%, and Plasticity index (PI) of 25.73% and is classified as inorganic clay of high plasticity, or fat clay(CH). The soil was then mixed with fly-ash class JIS-I and a mixture of Calcium Hydroxide $Ca(OH)_2$ and water. The fly- ash content was maintained at 20%, while the liquid content (water + $Ca(OH)_2$) was tested using the AM system at 30% and 40% of dry content weight. The $Ca(OH)_2$ was tested initially at 1.5 g/l and increased later to 5 g/l to improve structural behavior.

Workability and extrudability tests reviled that the optimum liquid content was at 37%, the optimum nozzle height was @ 5 mm for the 6 mm diameter nozzle, buildability is estimated @ 35 layers, and the average height of layer @ 3 mm. The Unconfined Compression Strength test showed that the increase in strength was not consistent with maximum strength gain of 0.70 kN/ m2 after curing for 28 days. The specimens also showed linear cracking during testing and a brittle breakage behavior and generally displayed poor structural strength.

Evaluation of 3D printed units of same scale and layer number demonstrated that the cost of the printed unit cannot be based solely on the design complexity. Additionally, calculating the cost of an AM construction is very different as there are multiple factors that need to be considered such as the minimized need for formwork and labor, reductions in time and material usage, and the high degree of accuracy of the constructed part. Printing speed is directly related to nozzle size; a larger diameter or size results in a faster printing time and when a low- cost process is the target, speed has more precedent over the detail resolution.

Using 3D printing to construct buildings requires redefining words such as ‘shape’ and ‘decoration’. The building blocks in 3D printing are the material ‘voxels’ and as such, there is no incentive to make any generated voxel volume identical to the other due to the fact that no cast, model, die, or stamp is used regardless of the size or scale (Carpo, 2017). As a result, 3D printing processes are capable of producing any degree of complexity with marginal differences in cost.

`Shape` as it pertains to 3D printing is the culmination of the mathematical locations of the voxels in space; their arrangements, volumes, and densities can be easily controlled using software code. Consequently, it is no longer adequate to think of decoration or ornaments as waste and additional cost, moreover, the used terms don’t apply any more because they reflect the traditional western understanding that ornaments are an addition or supplement (Carpo, 2017).

In the age of Big Data opportunities for building improvement are plentiful; simulation, optimization, and retrieval using the power of Big Data renders the formulaic approach used in modern structural engineering obsolete (Carpo, 2017). As such more complex forms are easier to realize. Working in the digital environment also facilitates combining 3D printing processes with 3D scanning, typography and design optimization software as well as environmental simulations which could result in architectural designs that are capable of responding accurately to any desired criteria such as cost, while maintaining a great deal of complexity.

Since the earth additive manufacturing process is a location- sensitive one and relies heavily in its design on the local soil/ additive types, the local geographical and climate conditions need to be carefully analyzed. The design process also needs to take into consideration the local culture and the common design features, then uses that information to generate forms that are familiar but also appealing to the consumer.