Introduction
The objective of the research was to assess the feasibility of a new method of construction with LEGO-like blocks made of Engineered Cementitious Composite (ECC). This method takes upon the essence of LEGO on which structures can be constructed, deconstructed, and reconfigurated in a whole new configuration. The purpose is to reduce landfill waste, energy usage and CO₂ emissions.

Engineered Cementitious Composite
ECC is a super ductile fiber reinforced material with tensile strain capacity up to 300-500 times more than that of normal concrete or fiber reinforced concrete [1]. The strain-hardening behavior of ECC, much like the behavior of metals, leads the material to its ductility and toughness. ECC exhibit self-controlled crack width under increasing load with failure cracks having width under 100μm [2].

Method Considerations
- Joint Integrity
- Safety
- Durability

Figure 1: Factors to be considered for the proper function of LEGO-like construction method.

Experimental Program
- Phase 1: Design
  - Unitary block
  - Rapid construction and deconstruction
- Phase 2: Testing
  - Joint behavior when subject to tensile stress
  - Two types of specimen: Green-ECC, Green-ECC with steel mesh reinforcement in the joint region

Figure 2: Research experimental procedure and objectives of each phase.

Results
Table 1: Mixture Properties (7 days water curing @ 60°C)

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive stress</td>
<td>47.5 MPa</td>
</tr>
<tr>
<td>Tensile stress (first crack)</td>
<td>4.7 (3.9) MPa</td>
</tr>
<tr>
<td>Tensile strain</td>
<td>1.0 ~ 1.8%</td>
</tr>
</tbody>
</table>

Figure 3: Load as a function of displacement obtained from tensile test. (a) G-ECC specimens (b) G-ECC specimens with steel mesh in the joint region.

- Average maximum load was 388 and 505 N for specimens without and with steel mesh respectively. A 30% increase in load carrying capacity was achieved from specimens without steel mesh to those incorporating a mesh.
- Displacement in specimens without steel mesh ranged from 4.2 to 5.4 mm while specimens with steel mesh in the joint region had a strain in the range of 4.2 to 6.4 mm.

Figure 4: Joint region of specimens after tensile test; failure mode can be seen. (a) Specimen with G-ECC through (b) G-ECC with steel mesh in the joint region.

- Failure mode was the same for both types of specimens. Tensile cracks developed in the inner corner of the female element dovetail while crushing occurred in the bottom corners of the dovetail in the male element (Fig. 2).
- Specimens cast with steel mesh developed more cracks and exhibited more crushing than specimens without the steel mesh (Fig. 2b).

Conclusions
- The dovetail geometry tested showed promise as a fast jointing and disassembly method in LEGO-like construction using ECC material. Brittle fracture at the neck of the male joint was totally suppressed. However, cracking at the reentrant corner of the female joint appear to show tension-softening rather than strain-hardening behavior with multiple micro cracks. The tension-softening failure mode limits the load capacity of the joint and also makes the joint difficult to be reused during structure reconfiguration.
- While the steel mesh reinforcement raised the load capacity of the joint, true tensile strain hardening of the ECC material appear critical to resist opening of the two arms of the female joint. In this test, the tensile ductility of the ECC was short-cut likely due to the accelerated curing by heat adopted to meet time constraint of this research project. This research demonstrated the importance of proper ECC material processing and curing.

Future Work
Improvements in the design phase of the project may lead to better results. Geometry modifications such as the elimination (or reduction) of stress concentration zones or the reduction of sectional area in the neck of the male element (in order to induce multiple cracking) could improve load carrying capacity. The usage of bolts to join the female and male elements could also improve the load carrying capacity. Finite element analysis would improve decision making before moving on to the next test phase.

Figure 5: A lap joint could also be included to provide stability.

References

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