# Topology-Optimization-Based Additive Construction for Sustainability

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## Abstract

For decades, concrete structures have been constructed using cementitious materials using conventional methods through formworks (either cast-in-place or precast). Concrete with sufficient slump is needed to fill up the formwork. This approach results in significant material wastage (placing materials in locations where stresses are low or very low) and increases carbon footprint. Additive construction provides unique opportunities to build form-free structural elements with complex geometry, enabling topology and structural optimization. This paper presents (1) an introduction to topologically optimized compression-only (C-only) structures; (2) the development of concrete mixes for additive construction; (3) an explanation of the additive construction process and equipment used to develop 3D-printed C-only structures; and (4) preliminary results of the 3D-printed C-only structures.

**Keywords:** Additive Construction; Topology Optimization; Lower Embodied Carbon; Cementitious Materials

## 1 Introduction

Topology optimization is a method of optimizing geometries using algorithmic models to optimize material usage and layout within a user-defined space for a given set of loads, conditions, and constraints [1]. Topology Optimization maximizes design performance and efficiency by removing redundant material from areas that do not carry significant loads. Topology optimization is used for weight reduction and design challenge solutions for problems like reducing resonance and thermal stresses. The use of topology optimization magnifies the performance of structures and minimizes the amount of material used. Topology-optimized beams are known to perform better than traditional low-weight beam designs. Common topology optimization methods include homogenization [2], evolutionary structural optimizations (ESO) [3], sequential element rejections and admissions (SERA) [4], and solid isotropic materials with penalization (SIMP) [5]. Structural elements designed using these topology optimization methods are commonly constructed using conventional construction techniques (cast-in-place as opposed to additive construction) which limit their use in construction due to complex forming. Additive construction used as a form-free method of application, provides unique opportunities for topologically optimized structures and forms.

Unlike conventional construction, equipment for additive construction is technologically advanced to allow for accurate and precise deposition of 3D-printed concrete in continuous filaments and layers with the desired dimensions and rheology. Automated systems for additive construction include precise concrete mixers capable of proportionally mixing concrete ingredients promptly. The developed 3D-printed mixtures are

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