This proposal focuses on innovative methods of construction of refugee shelters using innovative 3D printing technology that utilizes a combination of waste materials relevant to the Poland, US, and Ukraine. The project will also adopt environmental sustainability framework to guide materials selection for 3D printing approaches. Concrete is the largest material by weight and volume that humanity produces, it has a colossal carbon footprint, accounting for more than 8% of global CO_2 emissions. Rebuilding the country will pose unprecedented engineering and financial challenges that can be mitigated by utilization of waste derived from damaged structures and various other sources. In addition to traditional methods, rapid construction of temporary shelters requires new techniques in construction, where 3D printing of concrete can offer simplified manufacturing processes that can deliver material savings and energy conservation.

There are several scientific and engineering challenges to utilization of construction and other waste materials in new construction. For example, utilizing recycled concrete aggregates (RCA), instead of traditional natural coarse aggregates, can reduce the compressive strength of the resulting concrete: the higher the RCA content, the lower the compressive strength. The inhomogeneous nature of construction waste can also reduce durability of new RCA containing structures. All these factors lead to lower RCA utilization rates in both structural and non-structural applications in the US and Europe. In addition, crushing concrete to prepare homogeneously sized RCA requires significant energy that increases cost and decreases environmental benefits of recycling. Similar challenges are relevant to other waste materials that can be used in concrete (fly ash, bricks, glass, pozzolans and others). These gaps in knowledge are especially profound in the field of developing scalable methods for waste incorporation into 3D printed concrete structures. In addition to challenges mentioned above, achieving printability of waste containing concrete requires fundamental understanding of rheological properties and shape retention of the composites. Moreover, this proposal will focus on a largely unexplored topic of processed food/agricultural waste addition into 3D printed mixtures. This project will address a multitude of challenges to waste incorporation into 3D printing by developing new correlations between waste composition/structure (chemical, physical, and others), and resulting mechanical/durability properties of concrete containing recycled materials. Designing novel hierarchical structures derived from different types of waste with variable (nano, micro, macro) particles that are simultaneously mixed into the same concrete samples will potentially deliver unprecedented mechanical, thermal, durability and even self-healing properties. An especially novel angle of the proposed program is in conducting Life Cycle Analysis (LCA) for the waste-based aggregates' preparation as a function of their size and chemical composition.

Hypothesis 1: Existing issues related to performance and sustainability of 3D printed and tradition concrete structures can be resolved by hierarchical design of waste additives of different size and composition. More specifically, using a combination of highly (micro- and nano-cellulose) and moderately (natural fibers, ground glass, recycled concrete aggregate -RCA, processed waste materials it will be possible to address the existing challenges in waste based traditional and 3D printed concrete.

Approach 1: We will design mixtures containing different proportions of RCA, Ground Glass Pozzolan (GGP), and natural fibers, where the composition will be selected based on specific improvements needed to design shelters. In our experiments, variable compositions of GGP, cement, quartz sand, water and nanocellulose mixtures will be prepared. In addition to 3D printing inks, we will also produce a range of samples that can be used for traditional construction.

Hypothesis 2: Pretreating RCA using physical or chemical methods, with subsequent utilization of Ground Glass Pozzolan (GGP) not only can improve the pore structure of RCA, but also produce additional secondary CSH products to strengthen the ITZ layer through a reaction with the existing $Ca(OH)_2$.

Approach 2: In order to produce traditional and 3D printed concrete with RCA as a replacement for natural fine aggregate (FA), the RCA will be pre-processed in three steps. First, RCA will be reduced to a desired particle size by crushing it, and gradation will be controlled by sieve analysis necessary to mimic natural FA. The second step will include a chemical treatment and pre-soaking RCA particles in an acid and finally particles will be coated in Ground Glass Pozzolan (GGP).

Hypothesis 3: Addition of waste materials into the ink will require adjustment of rheological properties through tuning of concentrations and types of viscosity modifiers and superplasticizers.

Approach 3: Ink design will include testing of different proportions of polycarboxylate based chemical admixtures (PCE) and viscosity modifying agents (VMA). Based on the literature review, PCEs are the most promising superplasticizers used as polymeric dispersants. The VMA will include polyacrylamide as the most promising agent for increasing elastic module.