WX303

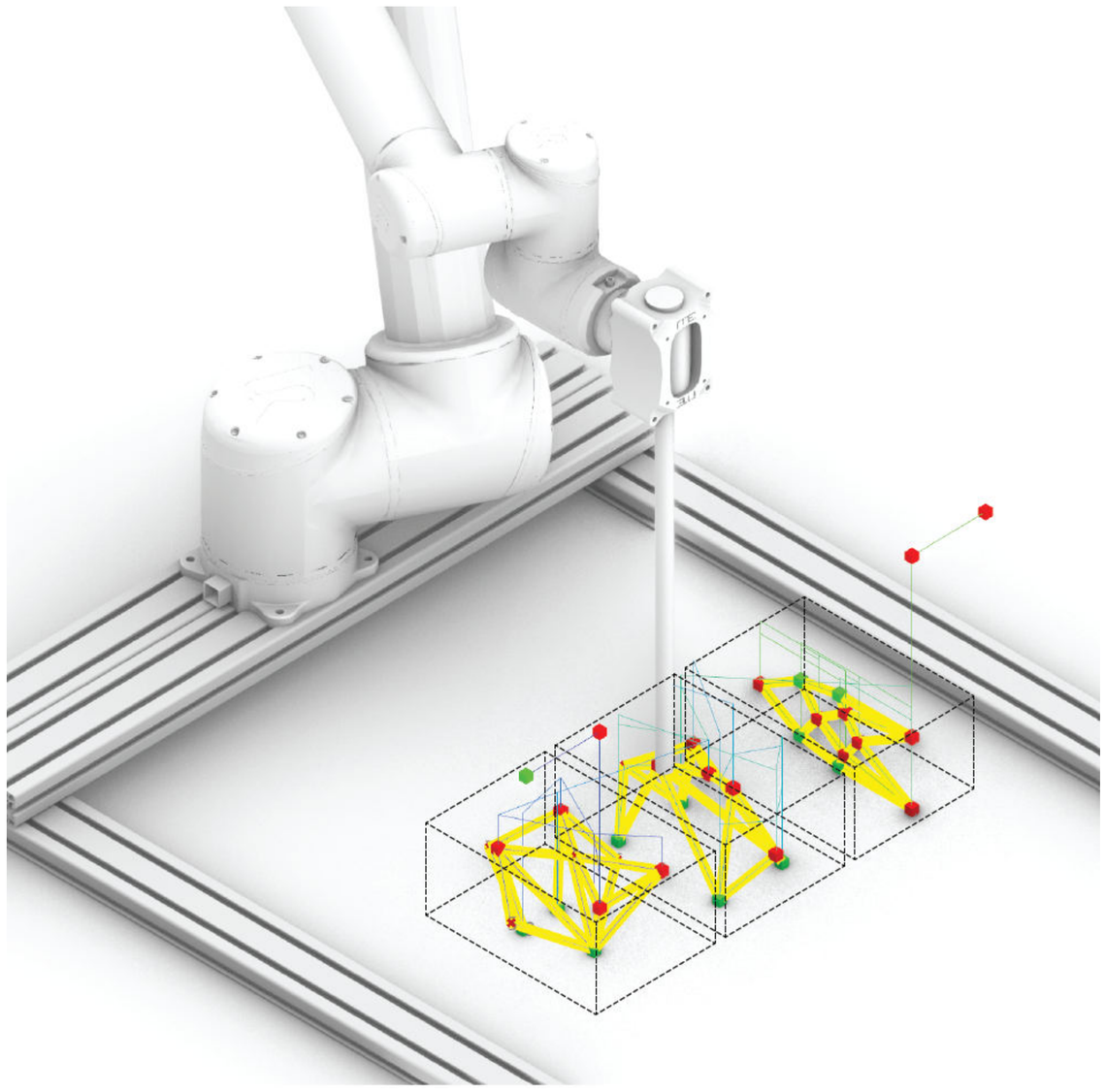
Insulation Block
with
Injection 3D Printing

"Let's get this on the table right away, without mincing words.
With regard to the climate crisis, yes, it's time to panic"
——— Pierrehumbert in 2019

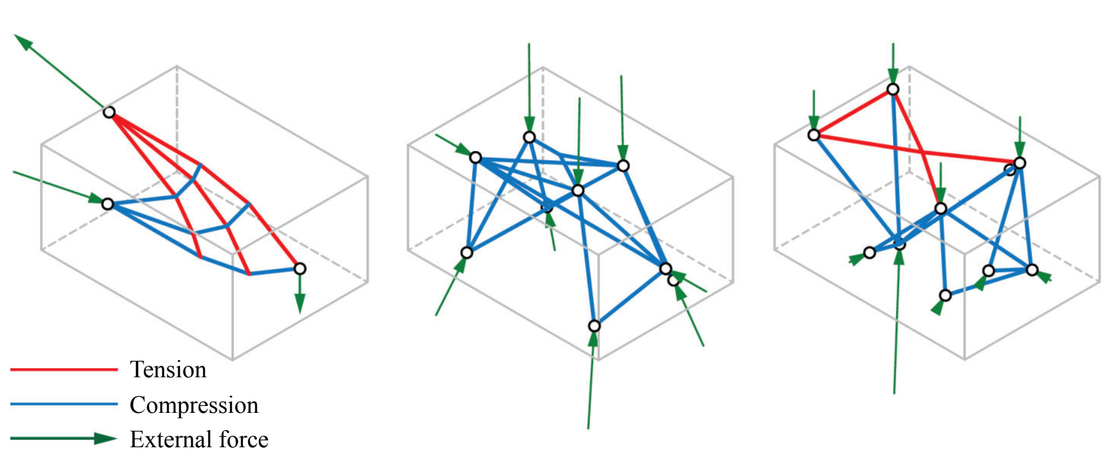
The world is suffering from plenty of environmental issues especially in building and construction section. A large construction and demolition waste (CDW) generation is one of the most critical issues. More than four billion tonnes of CDW have been generated in 2018, most of which were disposed in landfills. Since the majority of CDW is inert materials that can be hardly decomposed, the CDW generation is resulting in the scarcity of landfill spaces. To solve this problem, CDW is considered to be recycled and reused. Nowadays, the products from the recycling of CDW, e.g., recycled concrete aggregate crushed from old concrete, have been used as bases for road constructions as well as in building constructions (e.g., Research and Laboratory Building for Life Science in Humboldt University of Berlin). However, in most application cases, only recycled concrete aggregate with grain size of higher than 2 mm was used. The recycled concrete sand (grain size 0-2 mm) was not considered since it has higher porosity and water absorption than the larger aggregates. Using recycled concrete sand could increase the porosity of the final concrete and reduce the concrete strength.

Another critical environmental issue in construction is the utilization of steel reinforcement in concrete. Although concrete is cost effective with high compressive strength, it has low tensile strength. Therefore, steel reinforcement is usually used in concrete structure. However, the corrosion of steel rebar is one of the major damages to the concrete structure. Additionally, the production of steel is energy intensive and has high CO_2 emission. The energy consumption of steel production was estimated to be up to 11 MJ/kg with an average CO_2 emission of around 1.9kg CO_2e/kg. To overcome the disadvantage of steel reinforcement, compression-only structure was introduced into structure and construction design. The application of compression-only structure dates from the ancient time when stone was used as the major construction material. Example can be found by the Zhaozhou Bridge in China, which was built during the year 581-618. The bridge is durable and still under service. Nowadays, with the support of graphic statics, new compression-only structures can be constructed with wood, brick or concrete. These structures are usually thin shells. The new compression-only structures are light-weighted and can save materials. Therefore they are cost effective and environmentally friendly in comparison with conventional structure using the same materials. The current compression-only structures for example made of blocks are mostly applied as pavilions without closing rooms. It is expected that such compression-only structure can be also used for public buildings for example the roofing of markets, train stations or swimming pools. The limitation lies on the thermal and sound insulation of the thin shell. The installation of insulation layers is complex for such compression-only structure since the insulation should be cut or produced in curved surface to fit the shape of the structure. Additionally, in the construction process of conventional outer wall, insulation layer and the solid wall are separately constructed, which wastes time and increases the thickness of the outer walls.

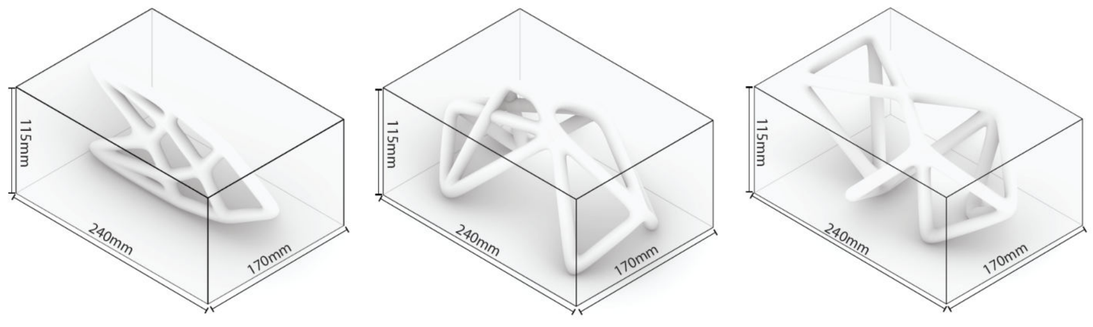
To overcome the aforementioned shortcomings and broaden the application of compression-only structures with block, a novel block has been designed and produced. To ensure the convenience of construction and save the concrete moulds, the block is design as cuboid with a standardized dimension of 240 mm x 170 mm x 115 mm. The block consists of two parts: (a) “skeleton” made of cement mortar, and (b) “muscles” made of coir fibre reinforced recycled aggregate mortar. This structure was achieved by the Injection 3D Concrete Printing (I3DCP) with concrete in concrete technology.



Path for the Injection 3D Printing



Examples of loading condition of skeleton in the insulation blocks



Examples of printed skeleton in the insulation blocks (from left to right: block 1, 2 and 3)

Coir fibre (diameter 0.1-0.5 mm)

Coir fibre in "muscle" of insulation block)

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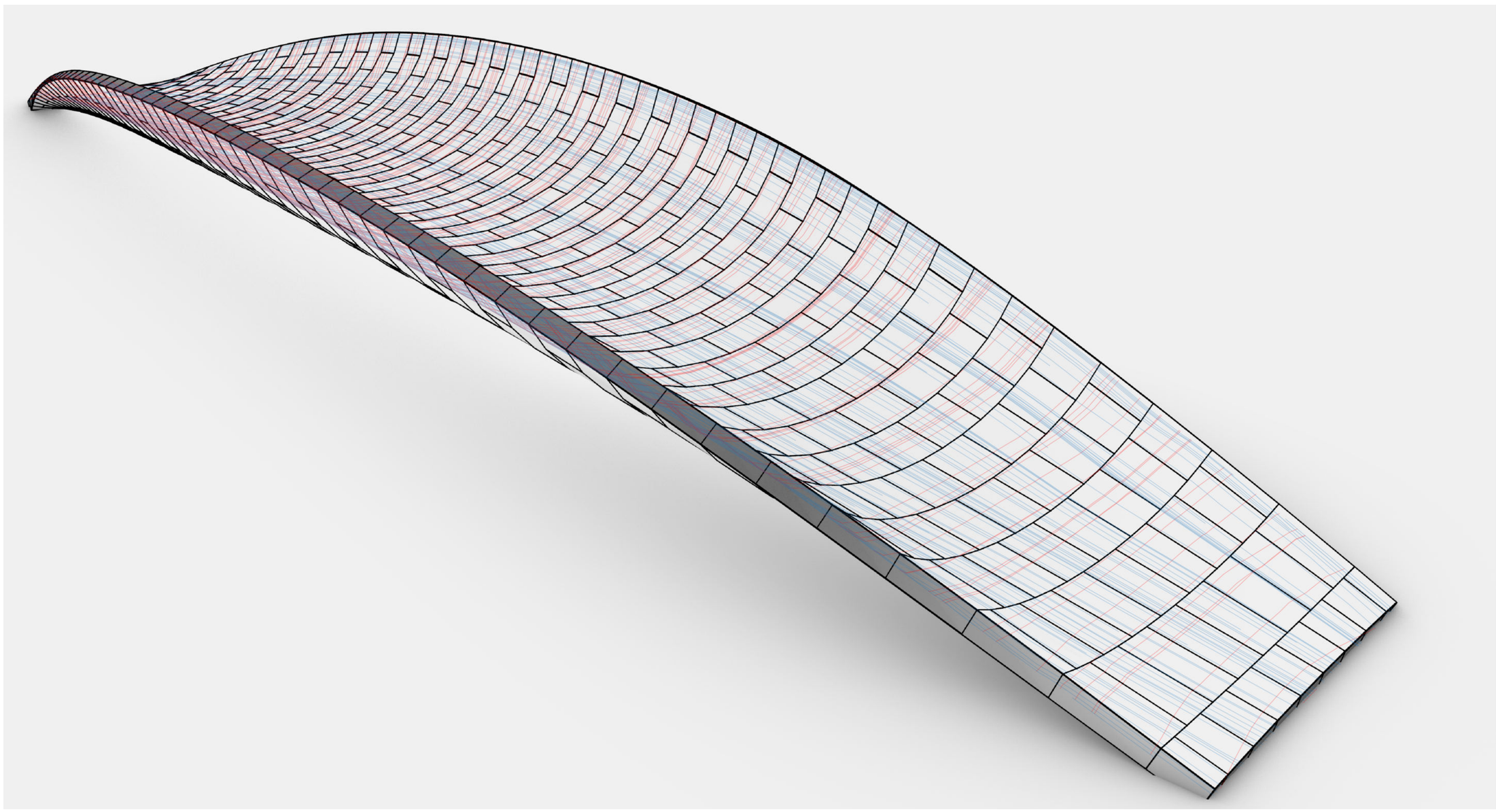


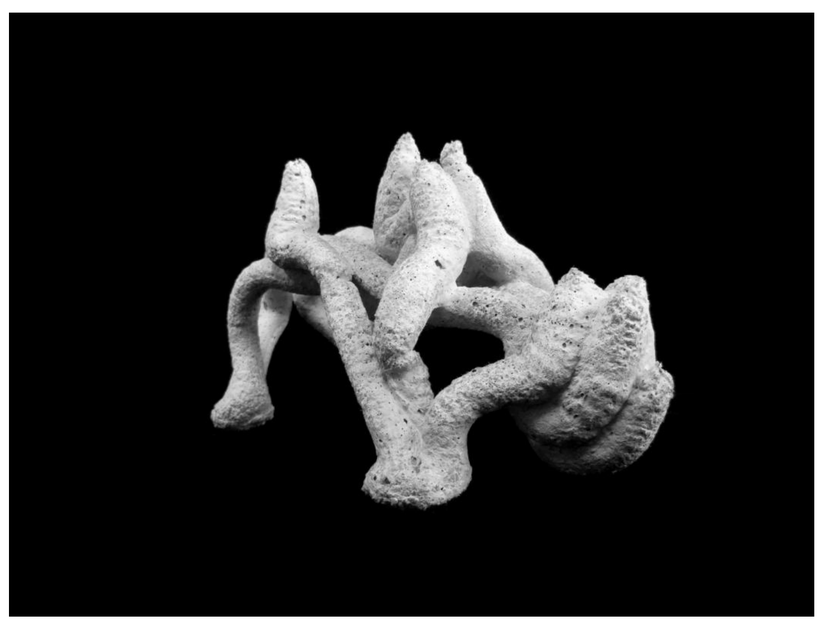
Example of a compression-only structure using the insulation blocks

The cement mortar skeleton acts as compressive load carrying element. It was produced through the I3DCP with the help of graphic statics. Through graphic statics, the skeletons can be designed individually based on the loading condition and position of the blocks in the compression-only structure. Through I3DCP, the production duration of the concrete skeleton (around 2 min per block) can be dramatically reduced in comparison with conventional 3D concrete printing. The muscle, coir fibre reinforced recycled aggregate mortar, was produced by mixing coir fibres, fine recycled concrete aggregate (grain size 0-2 mm), and cement with water and superplasticizer. Coir fibres are the by-products from copra industry, the majority of which is usually disposed as agricultural wastes. Coir fibres are ductile and have porous structure, which make them ideal for insulation. With coir fibre reinforcement, the density of the “muscle” of the block is strongly reduced, making the block light-weight. By using the recycled concrete aggregate derived from CDW the circularity and sustainability of the society can be promoted. The fine recycled concrete aggregate contributes to the stability of the “muscle” of the block and provides the “muscle” with load carrying capacity for the uncommon loading conditions, e.g., crashing from cars, or extreme strong side wind. In such cases, the undesirable loading cannot be fully carried by the skeletons since such conditions have not been considered during the design. These loads are expected to be partially carried by the block “muscle”. Even though the “muscle” made of recycled concrete aggregate is mechanically weaker than that with natural aggregate, recycled aggregate mortar with coir fibre is expected to be sufficient for the uncommon loading condition with small probability of occurrence. Additionally, the fine recycled concrete aggregate has higher porosity than natural sand, resulting the high porosity of recycled aggregate mortar. This leads to a better thermal and sound insulation property of the block than that made of normal cement mortar.

Therefore, the coir fibre reinforced recycled aggregate mortar block with cement mortar skeleton produced from injection 3D concrete printing is expected to be a light-weight thin block with sufficient thermal and sound insulation property, which has the same load carrying capacity as normal plain concrete block. The benefits of this block are summarized in the following bullet points:

- **Design flexibility**. Different designs of skeleton can be achieved by changing the paths of the mechanical arm movement with certain boundary conditions
- **Time saving**. The printing process of one block needs around 2 minutes only
- **Assembling convenience**. The blocks can be easily assembled by numbering them with their positions. They are cuboid and no additional layer of insulation is needed.
- **Less framework**. With the same dimension of cuboid shape, no special frameworks are needed for the block. The frameworks can be reused for concrete block in other construction projects.
- **Light weight**. The majority of blocks is the “muscle” with high amount of coir fibres.
- **Energy saving and waste reduction**. No steel reinforcements are needed in the structure. The use of fine recycled concrete sand and coir fibre reduce the wastes that should be disposed in landfills.
- **Recyclability**. After the service life of the blocks, they could be again crushed to be aggregate for further recycled concrete production.

Overview of an insulation block



Internal skeleton by I3DCP (cast in lime suspension), block 2

Internal skeleton by I3DCP (cast in lime suspension), block 3