Housing Block Design for 3D Binder Jetting

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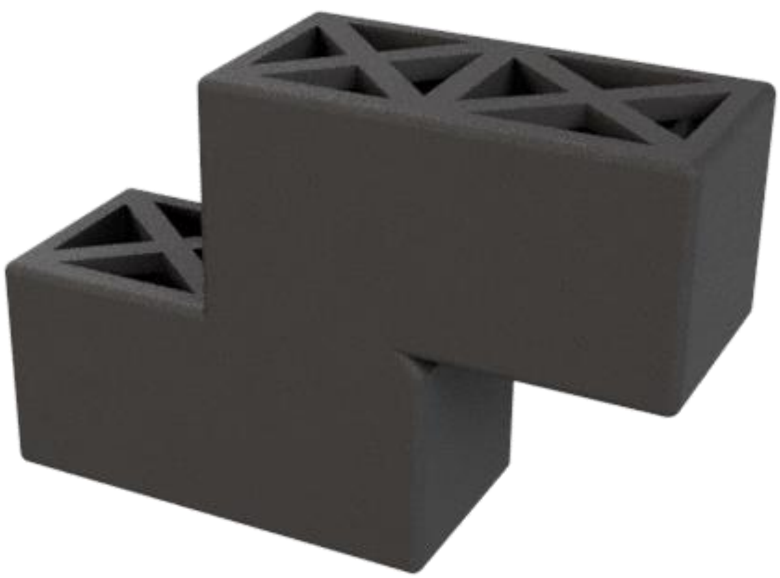
TABLE OF CONTENTS



Project Mission

Natural disasters can have a devastating effect on communities and nations. They have the potential to displace millions of people and disrupt and end the inviolable unity of families globally.

To create a quick response disaster mitigation system was the driving goal of this project. The 3D printed housing block design allows for substantial flexibility in assembly, design, and implementation in domestic and international markets. The design, with its use of recycled material, allows for a new avenue in low energy recycling and empowers the exhibition of additive manufacturing. Yet, primarily, for those in need of shelter in wake of the effects of natural disasters and climate change, this housing block design was designed to meet their needs as people.

Functionality and Durability

The functionality of the housing brick is connected to the geometry of its design. The bricks are stackable and have the ability to make 90° corners. This allows for the quick planning and assembly of exterior and interior structure walls. The blocks will be assembled using an interlocking stack pattern shown in Figure 1 with vertical stakes running through the internal structure to provide support and a stable connection to the earth. Since the brick material is made from a blend of silicone binder and recycled tire rubber, the weather resistance is a strong factor of this product's durability. The rubber/silicone mix exhibits excellent abrasion, UV radiation, crack, and aging resistance [1]. There is also a small notch in each brick making them easier to cut in half at the build site essentially making two rubber cinder blocks that are used in the base and top layer of the housing construction. The strength of the rubber was also of concern. Using FEA, we applied a 2000 lb-force simulation load to the housing block to test deformation and axial stress as shown in figure 2. From this conservative load case, we found a minimal deformation of 8.407 mm and a max stress of 29.72 psi. These values show that structurally, this material is feasible for this application.

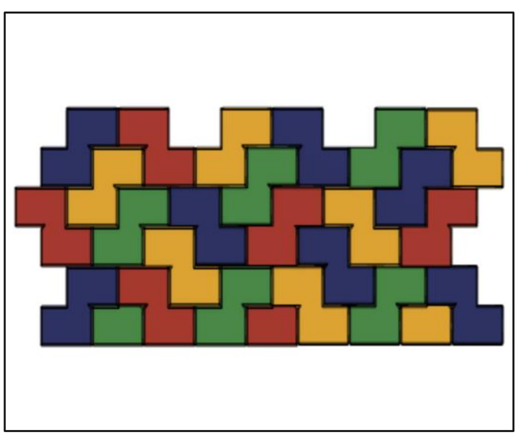


Figure 1. Housing Block Stack Pattern

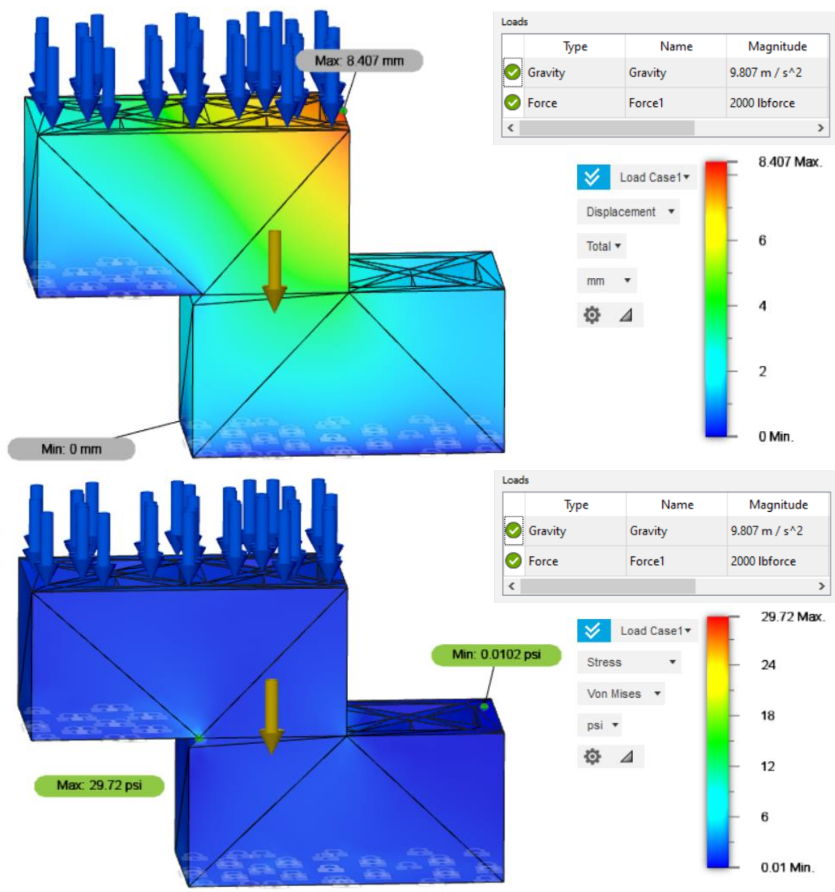


Figure 2. Load Case & Stress Analysis

While this technology can be easily applied to a roof component in the future, this design mainly addresses the structural walls. The flammability of the rubber was a large concern for our team. Therefore, our decision to use silicone as the binding agent significantly decreases the risk of material ignition. Silicone is often added to composite to meet UL standards for flammability [2]. The interlocking design of these bricks was inspired by ancient Incan buildings and walls which used interlocking stones to promote seismic resistance. This block design is similarly sturdy yet allows for structural flexibility in the event of an earthquake.

Cost-Benefit / Value Analysis

The modular capabilities of the block design allow for different batch sizes which increases the need for short lead time and manufacturing flexibility. By using 3D binder jetting, both of these requirements are accounted for. Due to the nature of the printing operation, more easily increase the scale of the manufacturing process for simultaneous brick production. The average bulk density of the crumb rubber is 22 lb/ft^3 [3]. Crumb rubber sells for $0.07-$0.20 per lb [4]. The benefit of being able to use crumb rubber is that even in its most processed forms it costs less than half the price of virgin rubber [5]. This means that the binder jetting process brings cost savings by utilizing cost-effective material. The volume of the block component is 0.608 ft^3. This puts our recycled rubber material cost per block at $1.81 using the average price and density of rubber crumb. The silicone binder will account for a marginal increase in this cost; however, our cost estimates are solely associated with the crumb rubber material. Therefore, by taking advantage of the additive manufacturing process we can cut down on material cost.

Utilization of DDM Materials

Using rubber crumb as a base substrate for our block appeals to a utilitarian case in the larger scope of this design. To begin, the rubber crumb supplies the necessary qualities of structural performance and flexibility to protect against seismic activity. Additionally, rubber crumb provides high weather resistance for a large array of temperatures and climates. Using rubber crumb also provides cost-saving benefits to the recycling industry. Because tires are vulcanized, thermoset rubber such as recycled tires is generally used in limited applications such as mulch flooring deadweight. Using the rubber crumb in a binder jetting process elevates the recycling product from mulch into a house and provides another branch of reclamation for the used tire market. Because of the layer by layer manufacturing used in binder jetting, recycled rubber can be formed into blocks that are light enough to not be compromised under their own weight. Silicone is used as the binder making the block a rubber silicone composite. When the crumb rubber is infused with the silicone, the silicone will act as a barrier to rubber odor and fire retardant.

Utilization of DDM Processes

Recycled rubber, specifically rubber crumb, has been used to create rubber flooring, running tracks, and caution cone bases. However, because of the size of the rubber crumb, it hasn't been used to make building materials. Binder jetting allows rubber crumb to be transformed into building material. The rubber crumb will be loaded into a feedstock bin and the layers will be spread onto the build platform via the doctor blade method. A counter rolling roller will then be used to ensure the smooth application of each layer. The build platform won’t move in the z-axis so the doctor blade and roller, and print will raise for each layer. The build platform is 10 ft x 20 ft x 1.5 ft which means about 180 blocks can be created per print. After the printing process is completed, the build platform will be moved into an oven to cure. Curing is necessary, because of the inherent problem with binder jetting which is porosity. The size of rubber crumb means there will be problems with pores. The silicone will have additives in it that will make it expand during the curing process closing these pores. When the blocks are done curing, they can be taken out of the build platform. The loose rubber will be collected and the unused crumb rubber will be returned to the feedstock bin.

Design Integration and Innovation

The capabilities of additive manufacturing were fully considered in each step of our design process. To maintain structural strength while reducing material usage and weight per component, binder jetting is the most feasible manufacturing process for this product. As shown in Figure 3, the internal structure of our housing block has been optimized for strength and material saving. The rubber/silicone composite is newly achievable using the binder jetting process. Therefore, additive manufacturing justifies material selection by maintaining our production identity and ensuring high material efficiency. By being able to maintain our short lead time and avoidance of high tooling costs, the additive manufacturing process proves essential to the economic and design success of our product's implementation.

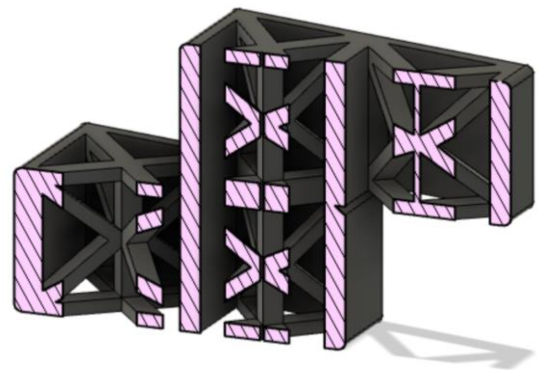


Figure 3. Section View

Marketing

The initial goal is to get this product in the hands of those in disaster-stricken areas. It will allow this product to have an immediate impact on the communities affected by natural disasters. The plan for the product is for it to be used in relief efforts constructing houses and rebuilding communities quickly. Once it has been established as an effective building material, the plan is to bring it to commercial markets. It can, for instance, be marketed as a weekend project. Since the blocks don't require cement it will be marketed as an easy to assemble, sturdy building component. This product also showcases engineering purpose. The rubber block can be used in conjunction with cinder blocks as a dampening tool allowing rigid, masonry walls to absorb vibration. The multifunctional qualities of this new building material mean it will play a role in solving the economic, environmental, and engineering challenges of the future.

Social and Environmental Impact

Rapid response is needed after a natural disaster and most of the time the infrastructure needed to rebuild is weakened or destroyed. Using this product, a hand saw is the only tool required to build a house therefore bypassing the need for heavy machinery and advanced knowledge of construction. Employing the modular 3D printed building block for home construction in such cases can be the difference between homelessness and having a livable, safe dwelling. This product has the potential to assist families in need of a quick response shelter to ease the complications in their disrupted lives. Looking beyond this, this product is not limited to one purpose. Domestically and internationally, this block can form the basis of inspiration for many structural applications in our everyday lives. Speaking of recycling, our product opens a whole new lane for recycling old tires by allowing them to be used more effectively. These blocks also possess recyclability and continue the premise of sustainability thus further minimizing its environmental impact. Also, by showing that recycled rubber can be used in place of virgin rubber, the carbon footprint of rubber will be reduced as recycled rubber becomes a more prominent material solution.

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