Designing for **Multiple Material Lives**

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INTRODUCTION

The scarcity of virgin resources and the growing issue of waste materials in the construction industry has heightened the need for recovery and upcycling of waste materials into higher value secondary products with lower embodied energy to allow the substitution of virgin resources and reduce the environmental burden of construction.

Construction and Demolition (C&D) waste constitutes one of the most significant waste streams in the United States and all across the world. According to the EPA's waste characterization report, around 600 million tons of C&D debris were generated in the U.S alone in 2018, which is more than twice the amount of generated municipal solid waste. (Construction and Demolition Debris Generation in the United States, 2015, n.d.). Moreover, according to a report by Transparency Market Research, the volume of C&D waste around the world will nearly double to 2.2 billion tons by 2025.

Given the concerns around depletion of raw materials, degradation of the environment, and anthropogenic climate change, an emerging concept of a circular economy emphasizes a closed loop system for sustainable material use. C&D waste streams provide an opportunity to utilize the same as an alternate material stream. As Brennan et al point out, in order to move to a more sustainable building life cycle, we must move from a linear process of extraction, production, and consumption, towards a cyclical approach, where products and components are designed in such a way that they further re-enter into another life cycle in substitution of virgin resources. (Brennan et al., 2014)

Concrete and wood present the most significant material that are salvaged for the C&D waste stream, and will be the focus of the research. Even though there is an existing "next-use" market for C&D waste material, which depending on the material, may include fuel, manufactured products, aggregates, compost, and mulch, a vast majority of these are low-value uses specifically for concrete such as in roadworks and to a very limited extent, construction activities (fillings and bases for foundations). There has been a lot of research and progress in recent years to use C&D waste in other high value products for the architecture and construction industries, e.g., upcycling wood-waste into cement- bonded particleboard among others.

Upcycling of C&D waste materials presents a viable opportunity to convert otherwise low-value materials that are destined for the landfill into higher value secondary construction materials thus reducing the environmental burden of construction. However, existing methods of converting C&D waste into secondary products mostly utilize highly energy intensive processes and addition of other toxic materials, thus perpetuating the vicious cycle of a linear material flow. To curb this vicious cycle and convert this concept into a closed loop system, this research paper proposes combining C&D waste, specifically concrete aggregate and wood, with non-toxic materials such as bio resins to make composite secondary construction materials of higher value for further use in the architecture and construction industries.

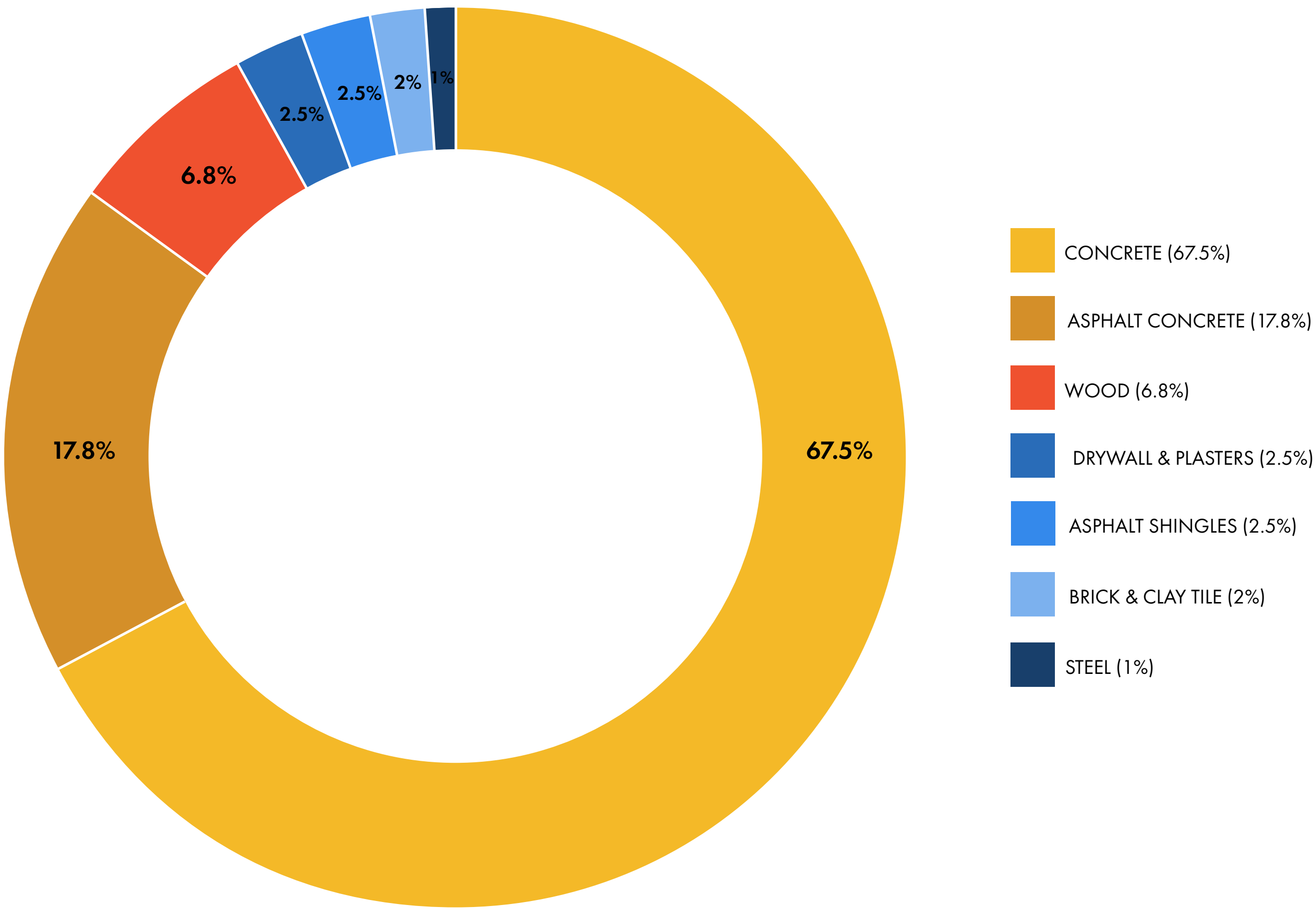

Figure 1: Distribution of construction & demolition (C&D) waste in the United States by material

Such products would not only help reduce the C&D waste that ends up going to landfills, but also create a closed loop system for the further re-use of these materials once they have reached the end of their life.

One of the biggest challenges to upcycling of resin-added salvaged concrete and wood products into higher value secondary products is the issue of scale. Most industries that work on large scales rely on a high degree of standardization which makes the product financially and economically viable. However, when dealing with C&D waste, this high degree of standardization is certainly not possible due to the diversity in available materials from the waste stream. Therefore, there is a certain element of 'ad-hocism' involved when dealing with local waste streams. This does not mean, however, that upcycling of C&D waste cannot be taken up at a large scale, if anything, it encourages a diverse range of products that don't fit within existing industrial norms. Rather than a top-down industrial approach, an ad-hoc bottom-up approach to utilizing C&D waste at a large scale gives impetus to designers and makers to utilize their skills in creating new material systems from post-consumer waste.

This research's main goal is to produce multiple mockups of secondary products such as façade panels and others by acquiring salvaged concrete and wood and combining them with multiple non-toxic materials such as bio resins to create Bio-Resin Induced Concrete (BRIC) and Bio-Resin Embedded Wood (BREW) to show how we as designers can contribute to a closed loop system in the construction industry.

The literature review will discuss plant-based materials and their properties and emerging fabrication techniques for architectural elements such as facade panels and tiles. The study will further advance the knowledge of current trends and research in academia and industry to provide a case for upcycling of concrete and wood waste and combining them with non-toxic plant-based materials to move towards a closed loop material system that replaces petrochemical materials, and reduces the amount of concrete and wood waste that ends up in landfills.

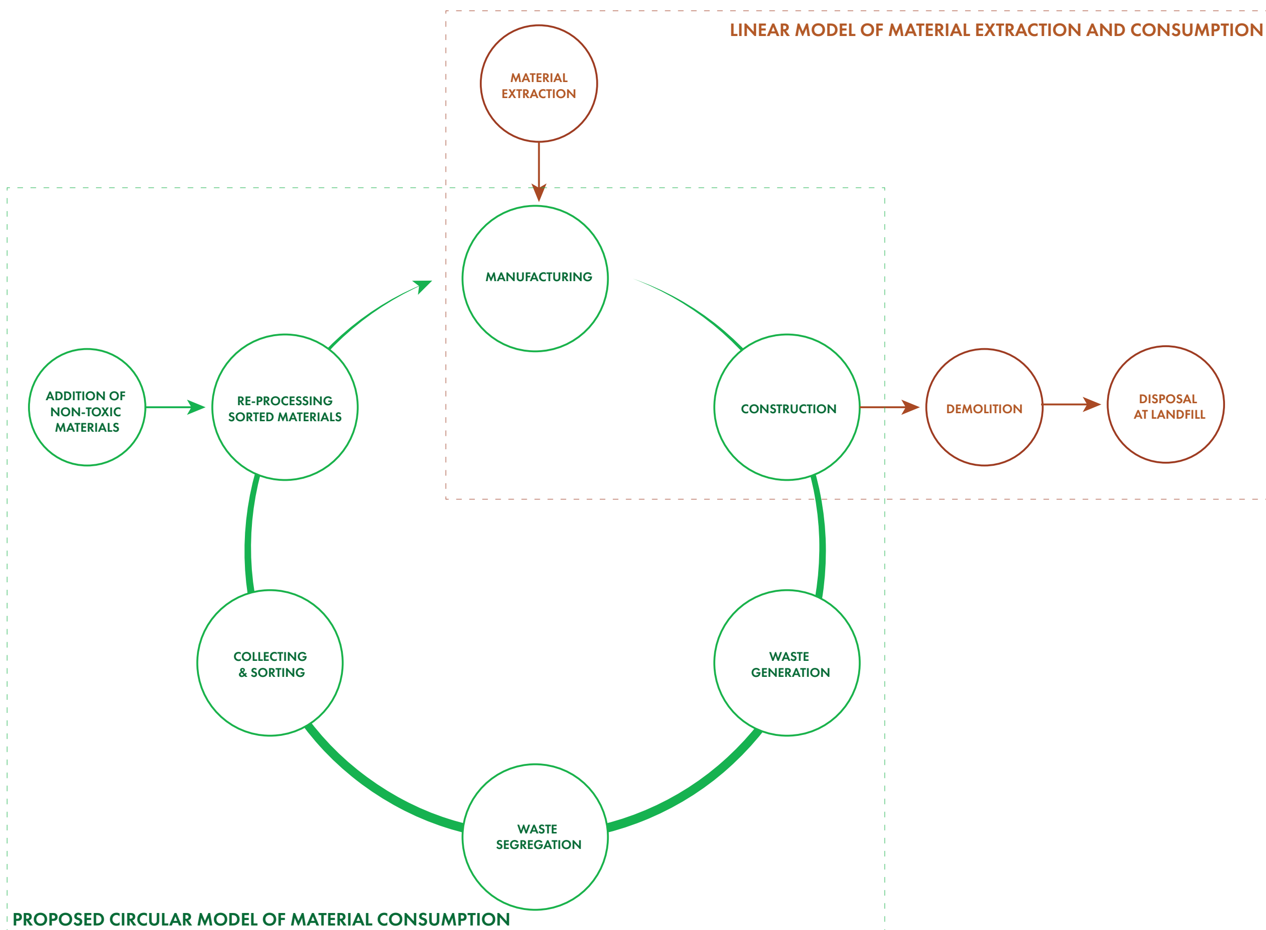

Figure 2: Existing material cycle vs proposed material cycle

BIO-RESINS AND THEIR APPLICATION

Composite building products made from plant-based biomaterials and bio-resins represent an increasing area of research in the architecture and construction industries as the energy consumption and waste generation in the construction sector continues to grow. Building products made from renewable resources have the potential to significantly reduce the CO_2 emissions in the building sector.

A bio-resin can originate from biomass products, microorganisms, biotechnology, and petrochemical products. Research has shown that bio-resins made from plant oils can be widely used as they present a highly available source of renewable resins. Some of these include, but are not limited to, linseed oil, soybean oil, peanut oil, karanja oil, and sunflower oil. In recent years, an Epoxidized Soybean Oil (ESO) has shown great commercial viability as a replacement for traditional petroleum-based polymers. It is used as one of the most popular green materials in commercial applications such as bioplastics, resins for green composites, and adhesives because its yearly renewable, fully biodegradable, and inexpensive. (Lutton et al., 2017)

Recent research on other bio-based binder materials by Bumanis et al (2020) focuses on the binder aspect of bio-composites such as straw, hemp, flax shives, wheat husk, maize, and sunflowers. Through their research, they show the viability of replacing lime and magnesium-based binders, which release CO2 during curing, with alternative binders like gypsum, geopolymers, and starch to form bio-composites for thermal insulation and envelope structure applications. The main advantage of using biomaterials as filler is their low environmental impact due to their renewability and cascade use. (Sandak et al., 2019) In fact, Temmink et al have developed and researched bio composites made from post-consumer denim waste and thermoset bio-resins for structural applications. Their research tests the viability of using ESO in combination with denim waste through four fabrication techniques: compression moulding (COM), vacuum infusion (VAC), resin transfer moulding (RTM), and hand lay-up (HND). Results have shown great promise in combining the two to develop bio composites that reduce the environmental burden of denim waste ending up in landfills and can be used as structural materials thus extending their life cycle. Their methodology revolves around using denim waste as reinforcement for the structural panels that are then bound together with the ESO polymer.

This sort of an application is directly analogous to my research, but instead of using denim waste, I will be proposing to use wood and concrete waste as filler reinforcement materials for the composite materials.

RESEARCH OBJECTIVES

For this study, I propose using post-consumer concrete aggregate and wood waste as reinforcement materials and combining it with bio-resins such as ESO to make bio-composite secondary products. BRIC and BREW are the two composite materials being proposed. The objective of the research is to make several mockups of BRIC and BREW to test the viability of combining concrete and wood aggregates with bio-based resins to create new composite products that can be used for non-structural architectural applications.

The larger objective is to further research on using materials from the C&D waste stream as a virgin material resource to combat problems of an unsustainable linear material cycle and move towards a more cyclical material approach in the Architecture and Construction industries. The composite materials created will also raise questions about reusability and biodegradability of the material once combined with one another. Currently there is no research on how bio-based resins would perform or behave in terms of biodegradability once combined with concrete or wood.

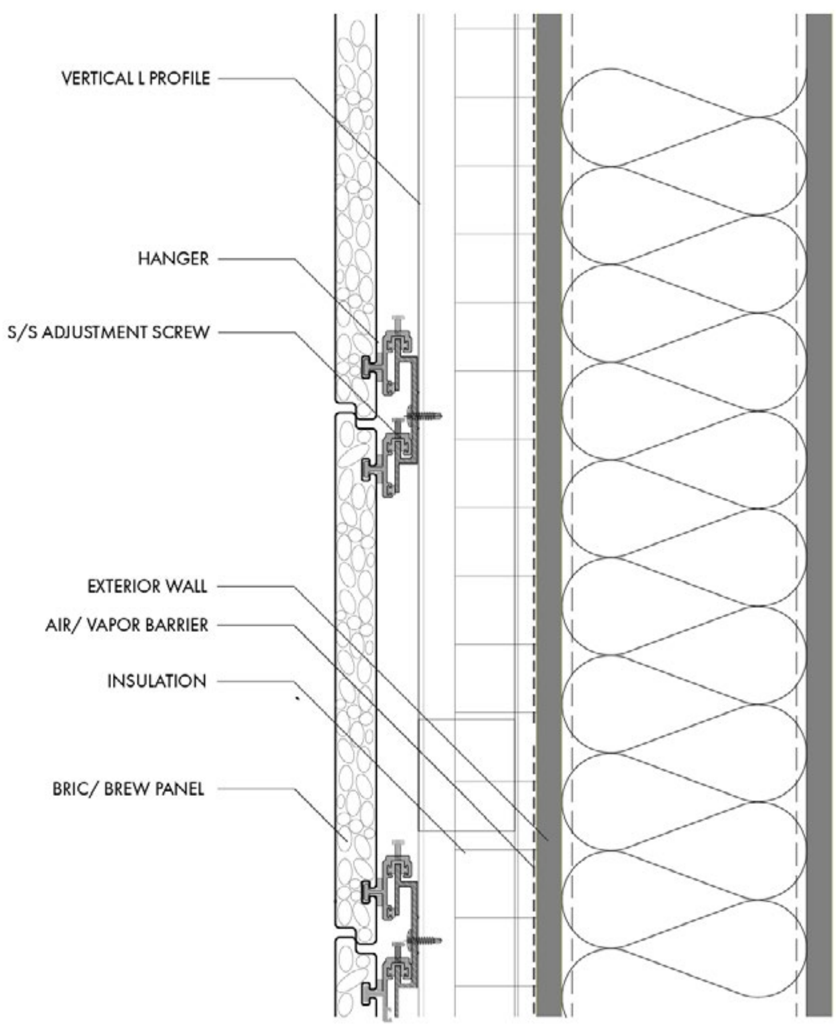

Figure 3: Proposed material assembly

METHODOLOGY

The methodology to fabricate BRIC and BREW involved a combination of Resin Transfer Molding and Hand Lay-Ups to give greater control over the final product in terms of its aesthetics and easier availability of fabrication tools.

One important thing to consider when fabricating the bio-composites was the water/ binder ratio and the filler/binder ratio, where the filler was the concrete or wood and the binder was the bio-resin. As Bumanis et al point out in their research, these are the two main parameters that are considered when designing the mixture composition of the composite that eventually affect the performance of the material. (Bumanis et al., 2020)

Due to unavailability of recycled concrete specifically, recycled stones were used, with the assumption that there would not be much of a difference in the final material properties other than potentially the aesthetics. For BREW, recycled wood chips were used as a filler component.

The bio-resin chosen for the study was a "high bio-based resin" by Entropy Resins, made using up to 50% renewable resources. Ideally, the test would have been carried out using a completely biodegradable resin, but due to lack of time and long shipping times, a high bio-based resin was used, with the assumption that the tactile experience of the final product would be the same or very similiar to that of a 100% bio-based resin.

Initially, a mockup sample of BRIC was created at a smaller scale to test the fabrication process. For this mockup, the ratio of binder to filler was kept at 50% each by volume, to get a general sense of curing times for the resin, and how the materai would behave during the curing process.

Once the mockup was succesfully created, the samples of BRIC and BREW were made at full scale but this time with a binder to filler ratio of 20% to 80% by volume respectively, to minimize the amount of resin used.

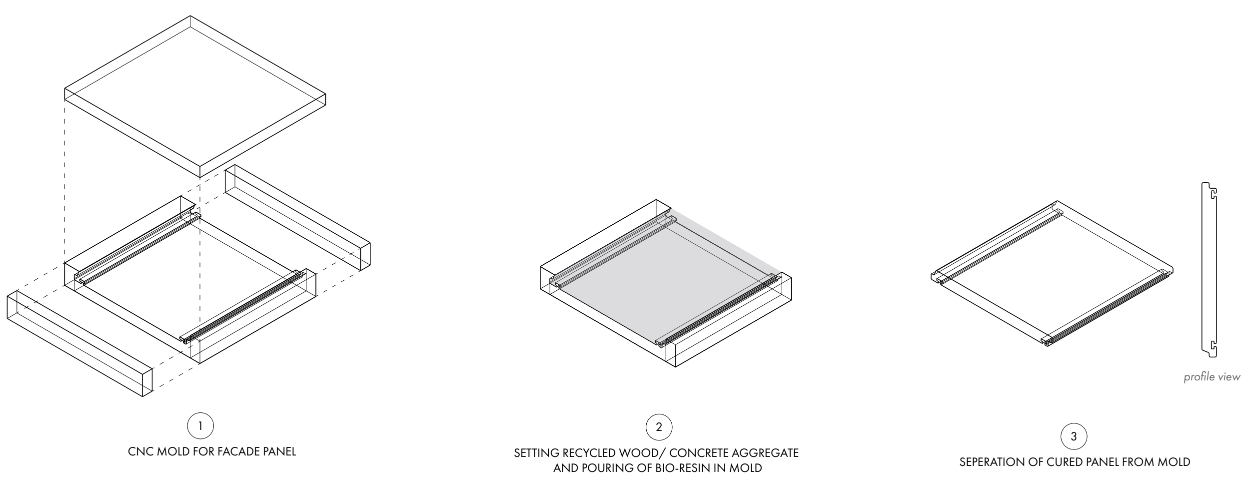

Figure 4: Fabrication process

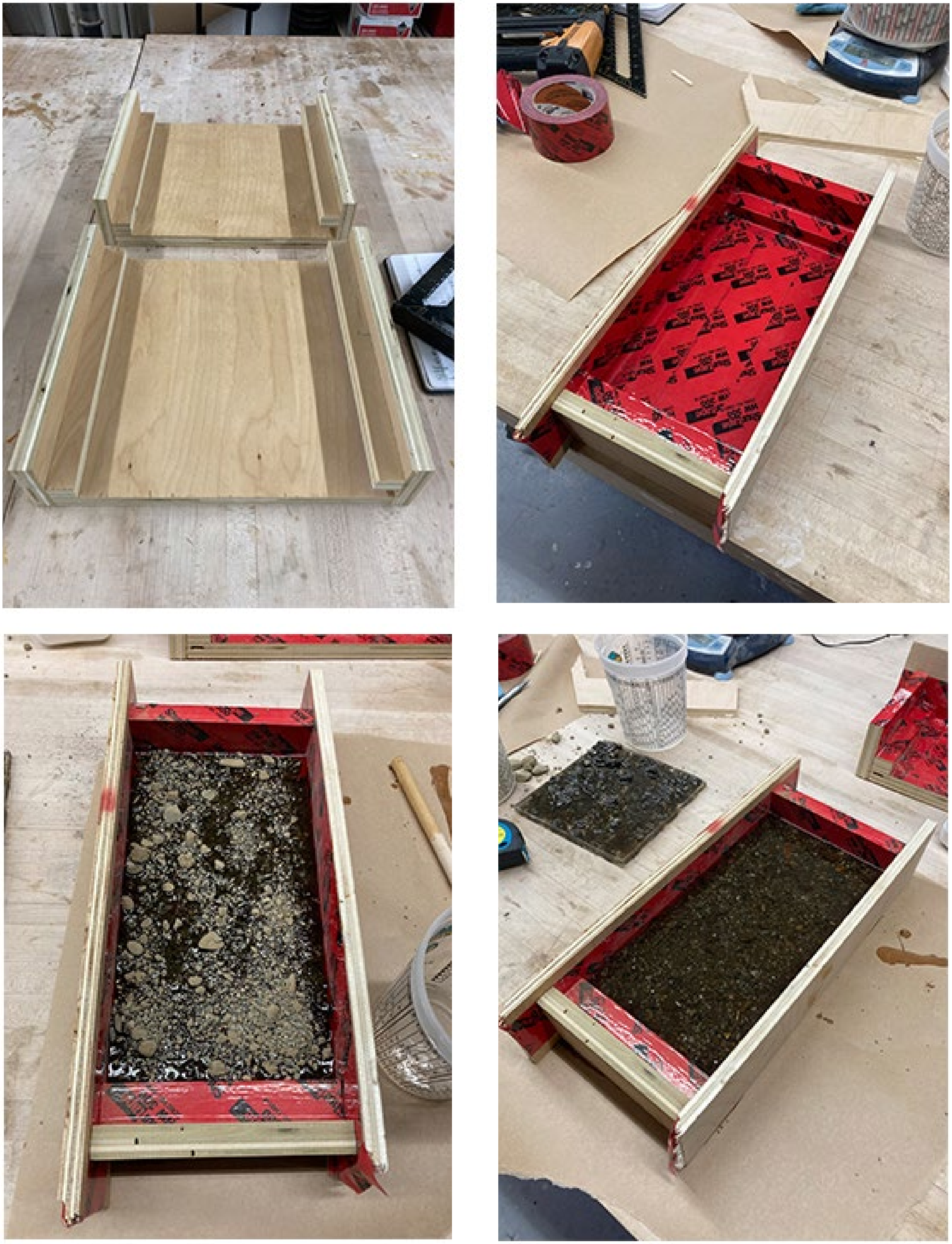

Figure 5: Fabrication process

RESULTS

Figure 6: BRIC mockup

Figure 7: BRIC mockup

Figure 8: BREW & BRIC full scale tests

Figure 9: BREW & BRIC full scale tests

DISCUSSION OF RESULTS

The tests were successful in the sense that they give a good idea of the aestheic qualities and potential of the proposed composite materials. The potential to use concrete and wood waste to create higher value composite materials, in my opinion, is very promising, and this research begins to ask pertinent questions on the feasability of such a methodology. The potential to create a cascade use of such products could fundamentally change how we deal with and percieve C&D "waste" materials, allowing for a more cyclical approach to material flows.

There are however, several technical limitations in the results which I hope to resolve through further research. For instance, more research needs to be done on 'bio-resins'. For the products to truly have multiple material lives and low embodied energy, the binder, in this case the bio-resin has to be compostable or biodegradable so that the fillers (concrete and wood) can re-enter into the manufacturing stream once they reach the end of their useful life. It is probably same to assume, that the product in its current stte is not biodegradable or compostable ,since the resin is only partially bio-based. There is also a concern that bio-resins require specific conditions and industrial equipment to be biodegraded, meaning that they cannot breakdown in natural enviornments. This raises questions about bio-resins as effective binders, potentially raising the need for an alternative natural binder material.

There are also questions about the technical performance criteria of the composite materials, if they are to be effectively used as finishing materials on the facade or interior applications. Technical tests and studies need to be carried out on the materials to ensure that they meet the stipulated technical standards at the bare minimum.

Future research on the topic will hope to resolve these fundamental questions and concerns.

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