The construction industry is one of the largest contributors to carbon emissions, abiotic depletion of natural resources, and waste generation due to the vast quantity of concrete produced. Concrete's main components have a significant environmental impact. The manufacturing of cement is responsible for 8% of global carbon emissions. In 2019, over 45 billion tons of aggregates were produced. Furthermore, the production of concrete generated over 600,000 tons of concrete waste in 2018. Conversely, vegetation consumes 30% of the global carbon dioxide emissions. Recent studies indicated that cryptogrammic species, and in particular moss, present a CO_2 uptake of 6.43 billion metric tons more than bare soil. Cryptogamic covers, such as moss and other CO_2 sequestering organisms, are key for the global cycles of carbon and nitrogen. By promoting the growth of living cryptogamic organisms in concrete building facades and roofs, the carbon footprint of concrete can greatly decrease, potentially achieving sub-zero carbon footprint. To attain this solution, cementitious composites must be designed to have an improved bio-receptivity, defined as a material's ability to be colonized by living organisms, or as a substrate to grow living organisms.

Previous studies show that the bio-receptivity of cementitious composites depends on a material's acidity and ability to capture and retain water. Yet, the inter-relationship between these properties and bio-receptivity is currently not well understood. Additionally, existing methods to achieve enhanced bio-receptivity in cementitious composites in terms of are often either expensive or counterproductive in terms of sustainability. This thesis aims to investigate and develop new methods to create ultra-sustainable composites with enhanced bio-receptivity and low abiotic depletion of natural resources. Additionally, this thesis aims to understand the importance, inter-relationship, and influence of the water transportation properties and acidity of cementitious composites on their bio-receptivity.

The first portion of this thesis is focused on proposing a new method to enhance bioreceptivity of precast cementitious composites elements through accelerated CO_2 exposure treatment and elucidating the function of recycled concrete aggregate use to create ultra-sustainable composites with enhanced bioreceptivity and low abiotic depletion of natural resources. Thus, this study simultaneously tackles the reduction of waste generation and abiotic depletion of natural resources, as well as the promotion of bio-receptivity while reducing the net carbon footprint of the cementitious composites. Results suggested that the proposed accelerated CO_2 exposure treatment enhanced the bio-receptivity of mortars, especially in mortars with RCFA. The combined effect of the RCFA's high porosity plus the effect of accelerated CO_2 exposures decrease on pH drastically enhanced the ability of promoting moss growth on mortars, enabling the production of low carbon bio-receptive cementitious material with a sub-zero abiotic depletion of natural resources.

The purpose of the second portion of this thesis was focused on understanding of the inter-related role of the mortar's porosity, water absorption, and surface pH on the bio-receptivity of cementitious composites. This portion of this thesis also focused on creating a predictive model of bio-receptivity of mortars as a function of water transportation/storage properties and surface pH. By conducting this study, the extent of importance of the water transportation/storage properties and surface pH on bio-receptivity can be determined. Results suggested that w/c ratio heavily influences the bio-receptivity of mortar, in which a higher w/c ratio increases bulk porosity, water absorption, and decreases the average surface pH. The use of accelerated CO_2 exposure improved bio-receptivity due to and decrease in average surface pH. Additionally, the combined effects of high w/c ratio and accelerated exposure CO_2 exhibited even greater improvements in bio-receptivity. Furthermore, the increase in w/c ratio resulted in the mitigation of accelerated CO_2 exposure adverse effects on bulk porosity and absorption. The developed bio-receptive predictive model successfully predicts the bio-receptivity of mortars as a function of the average surface pH and bulk porosity. This bio-receptivity prediction model provides us with an instrument to assist in engineering concretes with a target bio-receptivity. The results of this study also show that, while previous literature indicated a maximum pH of 5.0-5.5 to produce a bio-receptive cementitious composite, the pH threshold to obtain a bio-receptive cementitious composite depends on other factors such as porosity of the material, and it is possible to create bio-receptive concretes with a surface pH of 6.2-8.3.

This research will contribute to creating target-by-design living-engineered concrete facades that can capture CO_2 while reducing the consumption of natural resources.