https://doi.org/10.1051/e3sconf/202454601005

Strategies and solutions to green concrete construction material

Julia Nerantzia Tzortzi[1*], and *Rola A.* Hasbini[1*]

[1]Department of Architecture, Built Environment & Construction Engineering, Politecnico Di Milano, Piazza Leonardi Da Vinci, 32, 20133 Milan, Italy

Abstract. With escalating adverse effects, climate change is, presently, a critical global issue. The primary agent is the atmospheric high level of carbon dioxide and other pollutants. Concrete significantly contributes to greenhouse gas emissions. Green building is, therefore, a professional responsibility. This analysis briefly proposes various possibilities for reverting to green concrete in construction, advising strategies and solutions implementable at the several life cycle phases of the construction material. Multi-faceted sustainable aspects would pertain to eco-friendly extraction and manufacturing processes, thermal energy-efficient layout, scrubbing of pollutants, and recyclability. In particular, the study sheds light on an important experimental possibility of symbiosing the inert building material with the biological realm: the Living Concrete. At Politecnico Di Milano – Department of Architecture, Built Environment & Construction Engineering, we, first, realized a symbiotic concrete tile with macro-algae Ulva lactuca; then, we developed the experiment to conceive a novel "living concrete" construction finish material designed to absorb/scrub carbon dioxide from the atmosphere. This material consists of concrete blocks with Chlorella vulgaris cultivated on their surface. C. vulgaris is common microalgae with photosynthetic activity. This new photosynthetic concrete finish material was further developed and realized at the University of Verona – Department of Biotechnology with the help of expert professors. Researching effective negative greenhouse gas emissions techniques (NGHGET) from the chemical, physical and/or biological realm presents a valid approach to address and solve climate change problem.

1 Introduction

Marked by escalating adverse effects, climate change is, currently, a global concern. The primary agent is the elevated atmospheric level of carbon dioxide (CO_2) and other pollutants such as methane (CH_4) and nitrous oxide (N_2O) [1]. Concrete, the widely adopted construction material, significantly contributes to greenhouse gas emissions (GHGE). Therefore, the adoption of green concrete building practices becomes imperative. Accordingly, this paper briefly presents green strategies and solutions implementable across the life cycle phases of the construction material to promote more sustainable building practices. This aligns with scientists' research for optimal techniques to reduce greenhouse gas emissions resulting from concrete construction, whether during the manufacturing, the built, or the disposal phases [2, 3, 4, 5]. Multi-faceted sustainable aspects would pertain to eco-friendly extraction and manufacturing processes, thermal energy-efficient layout, scrubbing of pollutants, and recyclability. In particular, the study sheds light on an important experimental possibility of symbiosing the inert building material with the biological realm producing an innovative photosynthetic construction finish material: the "Living Concrete."

2 Methods

Compared to standard concrete, green concrete is defined as eco-friendly concrete used for the same purpose. Green concrete produces fewer noxious greenhouse gas emissions to the environment; it possesses a greener footprint [6], across the life cycle phases of the material. The life cycle of concrete extends over three phases: the production/execution phase (Phase A), the use phase (Phase B), and the end-of-life phase (Phase C) [6]. Aiming to define the best applicable strategies for greener concrete across the three phases, we applied three methods: literature review, virtual laboratory setting, and experimentation. A thorough literature review was conducted using advanced research tools. The virtual laboratory was set in COMSOL Multiphysics®, version 6.2, to analyze the energy performance of concrete walls layout. Experimental studies were conducted, first, on plain concrete tiles, then, on concrete blocks which are certified according to the standards of the American Society for Testing and Materials (ASTM). On plain concrete tiles, macro-algae *Ulva lactuca* was cultivated for eighteen days, in a non-controlled environment; on the ASTM-certified concrete blocks, micro-algae

* Corresponding author: julia.georgi@polimi.it, rola.hasbini@polimi.it

Chlorella vulgaris was cultivated for eighteen days, with technical filming and measurements of the photosynthetic activities [7], in dedicated laboratories. We conducted the latter experiment at the University of Verona, in the Department of Biotechnology, with the technical support and guidance of Professors Dr. Matteo Ballottari and Dr. Francesco Bellamoli. The photosynthetic activities were measured with a closed FluorCam FC 800-C instrument [8].

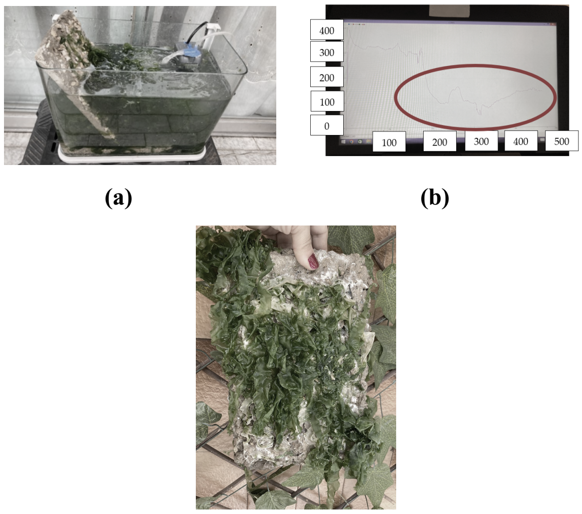
3 Strategies, solutions, and results brief

Based on the above, two main strategies were assessed adequate. The first strategy pertains to a strategy of optimization of the GHGE while the second one pertains to a strategy of scrubbing the main greenhouse gases (GHG) present in the contextual atmosphere. The latter strategy can be defined as a strategy of developing negative (removal, absorption and/or scrubbing) techniques. These techniques can be researched within the chemical, physical and/or biological realms. Negative thinking would refer to methodological research for applicable solutions to scrub CO_2 and other pollutants from the prevailing atmosphere. It also implies the research of efficient and affordable technical solutions for this GHG removal. A thorough technical literature review is a prime procedure for both strategies.

Optimization of the GHGE, through Phase A of concrete life cycle, refers to an eco-friendlier extraction and manufacturing processes, and/or an eco-friendlier mixture. The latter may contain one or more recycled components such as blast furnace slag, fly-ash, or silica fume, and/or may be composed of one or more less depletable components such as water. It would also involve production using techniques that consume lower energy [2]. Through Phase B, optimization of GHGE would refer to a thermal energy-efficient layout [9]. This can be virtually tested through advanced computerized platforms such as COMSOL Multiphysics®; the impact of every parametric modification can be assessed to infer the optimum contextual solution. These parameters encompass studying the impact of various composite layering of concrete construction materials, analyzing the effect of variations in physical properties, and adjusting indoor/outdoor environmental conditions. An effective improvement of the building envelope thermal performance was assessed by implementing a double-wall concrete layer instead of a single-layer concrete wall [10]. Through Phase C, bacterial treatment can reduce the GHGE at the disposal phase [11]. Recycling basic concrete components is an efficient procedure, as it reduces manufacturing energy consumption from 1450 °C to 300 °C [12,13]. Through all the three phases A, B and C, minimizing transport reduces GHGE [14].

Negative greenhouse emissions techniques (NGHGET) involve methods to remove, scrub, or absorb the main GHG present in the atmosphere. These techniques may pertain to the chemical, physical or the biological realms. Strategically, these NGHGET could be considered at Phase B. From the chemical realms, available techniques include the utilization of photocatalytic concrete [15] and the natural carbonation phenomenon [16]. From the physical realm, electrical systems can be devised to draw GHG into porous disposable absorbing films. These devices would be applied to the concrete building envelope. From the biological realms, the "living concrete" is a finish block symbiosing the concrete inert material with the living micro-algae, resulting in photosynthetic activities with increasing amounts [7].

To test the NGHGET effectivity, within the biological realm, we conducted, first, an experiment in a non-controllable environment, in an outdoor space, at a temperature ranging between 18 ◦C to 23 ◦C. We prepared two manually poured concrete tiles - each dimensioned 20 cm x 10 cm x 2 cm. The concrete composition of each tile was: 11% Portland cement; 40% coarse aggregate; 40% fine aggregate; 9% batch water; with no admixtures. The tiles were left to symbiose with the macro-algae *Ulva lactuca* (sea lettuce) [17], in sea-water aquarium for ten days. One tile was fully submerged in the aquarium; the second one was half submerged – Fig. 1(a). After ten days, the CO_2 level was measured using Arduino sensor; the measurement on Arduino platform indicated a drop from 430 ppm – 7 m away from the aquarium - to around 100 ppm next to the aquarium - Fig. 1(b). Fig. 1(c) shows the symbiotic concrete tile with *Ulva lactuca.*



(a) (b)

(c)

Fig. 1. (a) The two tiles in the aquarium: one half-submerged and one fully submerged **(b)** Measurements on Arduino platform **(c)** The symbiotic concrete tile with *Ulva lactuca.*

For a technical enhancement of the experiment, an ASTM-certified concrete blocks of 10 cm x 10 cm x 7 cm was left to symbiose with micro-algae *Chlorella vulgaris* in a controlled laboratory environment; the compressive strength of the concrete blocks is 250 kg/cm^2 in twenty-eight days. Humidity level ranged from 40% to 60%; however, the light was maintained at 23 ◦C. *C. vulgaris* is common microalgae species exhibiting photosynthetic activity. These organisms rely on water, light carbon dioxide, and nutrients for sustenance while simultaneously producing oxygen. The photosynthetic measurements indicated an increase in the photosynthetic activities from Day 0 on [7] – Fig. 2.

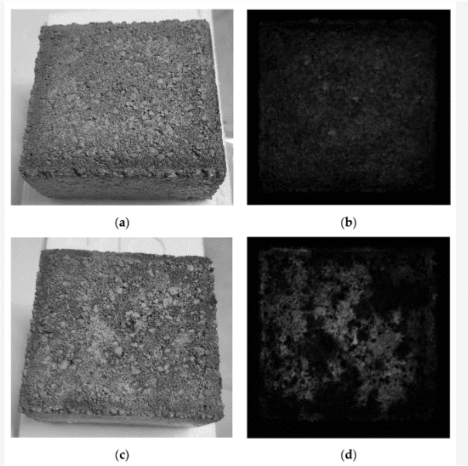


Fig. 2. Increase in chlorophyll fluorescence on the "wet" partially immersed living concrete ASTM-certified finish block sample, **(a)** The "wet" block on Day 0, **(b)** Day 0 chlorophyll fluorescence emissions **(c),** The "wet" block on Day 4, **(d)** Day 4 chlorophyll fluorescence emissions

4 Discussion

Greener concrete is the result of the production, the construction, the use, and/or the disposal of a concrete with lower GHGE than a standard concrete adopted for the same usage. It is essential to thoroughly examine each stage of the material life cycle to optimize greenhouse gas emissions (GHGE). However, given that greenhouse gas (GHG) can persist in the atmosphere for hundreds of years once released [18], it is imperative to develop methods for absorbing the predominant GHGs present in the environmental atmosphere, particularly the most prevalent ones: these methods are the net greenhouse gases emissions techniques or NGHGET. These techniques can be researched within the chemical, the physical and the biological realms. Concerning the biological realm, we conceived at Politecnico Di Milano – Department of Architecture, Built Environment and Construction Engineering, an innovative efficient solution: the Living Concrete experiment. This was realized in the laboratories of Verona University, at the Department of Biotechnology, with the support of expert professors.

The proposed external application assembly, whether integrated into a new or pre-existing building envelope, would extend up to a height of three meters to mitigate anthropogenic street-level emissions. Alternatively, it can be installed horizontally on rooftops. This innovative concrete/biological composite material effectively scrubs carbon dioxide emissions and release oxygen. It, thus, reverses the current CO_2 pollution trend. Therefore, it offers a promising solution to address climate change concerns in urban areas with moderate climates.

The methodology proposed defines the procedure to obtain greener concrete. It may very well be applied to other materials such as limestone. Taking into consideration the ability of limestone ($CaCO_3$) to react chemically with the harmful carbon dioxide (CO_2) to obtain the non-harmful calcium bicarbonate ($Ca(HCO_3)_2$), in the presence of water (H_2O) [19], i.e. to abate CO_2 into a non-harmful element in the presence of water, this applied methodology should shed light on this important property.

This paper addressed strategies concerning the environmental sphere. However, achieving a balanced solution necessitates not only environmental considerations, but also acceptance within the other two sustainability spheres: the economic and the social ones [20]. Analysing the economic impact of an environmental green concrete solution is a well-established procedure, supported by advanced tools. However, evaluating the social aspects of an architectural greener concrete building envelope, for example, demands a distinct approach. The social and architectural significance of the concrete building envelope must be thoroughly evaluated before implementation.

Finally, both the field of green concrete and the methodology of negative thinking are relatively new topics, still in their embryonic stages. Achieving satisfactory results in these areas demands global significant concerted effort.

5 Conclusion

While the scientists and the professionals are researching to optimize and to reduce the greenhouse gas emissions to the environment, we elaborated a further methodological thinking to find practical cost-effective ways to absorbs those greenhouse gas. These techniques would pertain to the chemical, physical, or biological realm. Concerning the latter, we conceived a living concrete block that we realized at the laboratories of Verona, at the Department of Biotechnology with the help of expert professors. This concrete/biological composite material effectively reverses carbon dioxide emissions. Consequently, it is a promising viable solution addressing climate change challenges in urban areas characterized by moderate climates.

Patent: E-Soleau - 92 Institut National de la Propriété Industrielle (INPI) - DSO2023012898.

Acknowledgments: The Authors would like to extend their sincere gratitude to Professor Dr. Carlo Andrea Castiglioni for his invaluable support and guidance throughout the process of the research. His technical expertise was instrumental in shaping the direction of the research and refining the methodologies. The authors would like also to acknowledge the academic society of Politecnico Di Milano – Department of Architecture, Built Environment and Construction Engineering for their rich intellectual environment. The conducive atmosphere and resources provided by the department have greatly facilitated the research endeavors, contributing to the depth and breadth of the findings. Additionally, the Authors are deeply grateful to Professors Dr. Matteo Ballottari and Professor Dr. Francesco Bellamoli, from the Department of Biotechnology - University of Verona, for their dedication and expertise to realize the "Living Concrete" experiment. Finally, the Authors are thankful to Derviche

Haddad PPB Structures for providing the ASTM-certified block samples as necessary to conduct the experiment. Their contribution has been indispensable in ensuring the reliability of our experimental results.

References

1. Agents of Global Warming, Ask NASA, NASA Global Climate Change, Last Modified 8 February 2010. Available online: https://climate.nasa.gov/explore/ask-nasa-climate/260/agents-of-global-warming/ (accessed on 31 March 2024).
2. J. N. Tzortzi, R. Hasbini, A classification review on green concrete. Adv. Mater. Res. 1166: 113–123 (2021)
3. J. N. Tzortzi and R. Hasbini, A classification review on green concrete. In Green Concrete: 3–13; P. Kryvenko and S. Kolisnychenko, Eds. (Trans Tech Publications Ltd, Stafa-Zurich, 2023)
4. K.M. Liew, A.O. Sojobi, L.W. Zhang, Green concrete: Prospects and challenges. Constr. Build. Mater. 156: 1063-1095 (2017)
5. A. K. Mohammed et al., Green concrete predicting the compressive strength of green concrete at various temperature ranges using different soft computing techniques. *Sustainability.* 15 (15), 11907 (2023)
6. BSI (British Standards Institution), Standards publications environmental management for concrete and concrete structures – Part 8: Environmental labels and declarations (BS ISO 13315- 8:2019 (E): 5-12, London. U.K 2019)
7. J.N. Tzortzi, R. Hasbini, M. Ballottari, F. Bellamoli, The living concrete experiment: cultivation of photosynthetically active microalgal on concrete finish blocks. *Sustainability* 16, 2147 (2024)
8. Photon System Instruments, Czech Republic. Available online: https://fluorcams.psi.cz/ (accessed on 10 December 2023)
9. Y.H. Lee, M. Amran, Y.Y. Lee, A.B. Hong Kueh, S.F. Kiew, R. Fediuk, N. Vatin, Y. Vasilev, Thermal behavior and energy efficiency of modified concretes in the tropical climate: A systemic review. *Sustainability* 13 (21), 11957 (2021)
10. J.N. Tzortzi and R. Hasbini, Simulating heat transfer performance for double-walls concrete residential building envelope in Mediterranean climate, in Proceedings of RE-DWELL - Housing Co-creation for Tomorrow's Cities conference, Grenoble, France, December 8-9, (2022)
11. A. Rowell, T. Ghebrab, R. Jeter, Bacterial treatment of recycled concrete aggregate. *Recycling* 8 (5), 68 (2023).
12. A. Naqi, J. Cook Jang, Recent progress in green cement technology utilizing low-carbon emission fuels and raw materials: A review. *Sustainability* 11 (2), 537 (2019)
13. M. Wimala, Environmental impact of waste concrete treatment in precast concrete production, in Proceedings of the Annual Conference Japan Concrete Institute, Japan (2011)
14. Z. Xiaoyi, IoT driven framework based efficient green energy management in smart cities using multi-objective distributed dispatching algorithm. Environ. Impact Assess. Rev. 88, 106567 (2021)
15. L. Yang, A. Hakki, F. Wang, D. E. MacPhee, Photocatalyst efficiencies in concrete technology: The effect of photocatalyst placement. Appl. Catal.: B. 222: 200-208 (2018)
16. K. Tongaria, S. Mandal, D. Mohan, A review on carbonation of concrete and its prediction modelling. J. Environ. Nanotechnol. 7 (4): 76 – 91 (2018)
17. G. Bitar, A. Ramos-Esplá, O. Ocaña, Y. Sghaier, A. Forcada, C. Valle, H. Shaer, M. Verlaque, Introduced marine macro-flora of Lebanon and its distribution on the Levantine coast. Mediterr. Mar. Sci. 18 (1): 138-155 (2017)
18. US Environmental Protection Agency (EPA), Climate Change Indicators: Greenhouse Gases. https://www.epa.gov/climate-indicators/greenhouse-gases / (accessed on 31 March 2024).
19. Wikipedia. Calcium Carbonate. https://en.wikipedia.org/wiki/Calcium_carbonate. (accessed on 31 March 2024).
20. The three pillars of Sustainability: Environmental, Social & Economic. Enel, Stories / Moving Energies / Last modified June 15, 2023. https://www.enel.com/company/stories/articles/2023/06/ three-pillars-sustainability / (accessed on 31 March 2024).