ZeCRoCo: Zero Carbon Roadmap for Concrete

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Executive summary

India faces a significant challenge in providing affordable housing due to rapid population growth and urbanization, with concrete being a primary construction material. However, concrete production has a high environmental impact, particularly in CO_2 emissions. The ZeCRoCo project aims to enhance the environmental sustainability of a 28-storey social housing building by focusing on two main areas: reduction of Embodied Carbon and reduction of Operational Carbon. The project explores eco-friendly concrete by substituting 20% of cement with Rice Husk Ash (RHA), maintaining traditional concrete properties while reducing carbon emissions by 12.5%. The project evaluates insulation materials from rice byproducts, i.e. rice straw (RS) and rice husk (RH), showing that added insulation can significantly improve indoor conditions and lower energy consumption during the build lifetime. Through an in-depth Life-Cycle-Approach (LCA) and Life-Cycle-Cost (LCC) analysis, the project considers the entire lifespan of the building showing a reduction of 38.6% of the overall carbon emissions maintaining low costs. The project aims at integrating solutions and community needs and effectively involving regional facilities and local suppliers to reduce transportation costs and emissions. The ZeCRoCo project successfully integrates sustainable practices into prefabrication techniques, hence introducing the Precast Concrete Construction (PCC) technique in the favourable Indian market. It serves as a blueprint for future developments in India, promoting sustainability and resilience in affordable housing initiatives.

Key Words

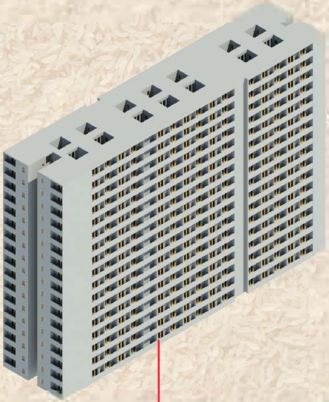
Carbon footprint; Rice husk ash concrete; Thermal analysis; LCA and LCC

Modular housing prototype, façade

ZeCRoCo

Planet Smart City
Alta Scuola Politecnica XIX Cycle

Zero Carbon Roadmap for Concrete



Pre-cast cement model

Planet Smart City's social housing projects in Pune, Maharashtra, India, responding to the growing demand for affordable housing.

Modular Housing prototype

Our **Project**: reduces carbon emissions (both embodied and operational) whilst maintaning timeliness and cost-efficiency

1) Reduce Embodied Carbon by exploring innovative local materials and mix design

Rice Husk Ash as a cement substitute in a circular approach, reducing the carbon footprint while leveraging a local supply chain.

2) Reduce Operational Carbon by improving thermal performance of the envelope

Panel insulation layer to cater for current and future needs of thermal isolation due to extreme temperature increase

-38%

CARBON EMISSIONS IN 50 YEARS

- **IMPROVED EFFICIENCY**
- **MAINTAINED HOUSING AFFORDABILITY & PRICING**

Zero Carbon Roadmap for Concrete

Project description written by the Principal Academic Tutor

The project represents a particularly complex challenge as it seeks to innovate and make sustainable production processes with very low technological content and added value such as those of heavy concrete prefabrication for the construction sector. Furthermore, the application context is represented by a particularly complex reality from the socio-economic point of view and the organization of production processes and the supply chain such as India. Through a transdisciplinary approach, the team managed to overcome the limits of prefabrication and materials normally used, identifying significant supply chain, technical, construction and production innovations which synergistically contribute to obtaining environmental and social benefits with reference also to the local economy and end users. Benefits that will amplify with the evolution of user demand, clearly clarified by in-depth analyzes of current trends. As requested by the partner company that had proposed the topic of investigation, the project is able to reconcile technology, materials, typology, morphology and social aspects, while preserving the cost-effectiveness and affordability of the housing solution, obtaining potential environmental, social and economic benefits also measured through specific indicators.

Team description by skill

The ZeCRoCo project team consisted of 6 members from diverse academic backgrounds, ensuring a multidisciplinary approach:

Cecilia Francardo (Environmental Engineering) - Conducted LCC and LCA analysis of the proposed solution.

Michele Laurante (Management for the Built Environment) - Assisted with LCC and LCA analysis, leading the economic analysis.

Alessandro Di Miscio (Space Engineering) - Analyzed risk factors, economic variables, and provided insights from living in India.

Adriana Magli (Urban Planning and Policy Design) - Studied the Indian context and assisted with architectural design.

Filippo Ferrari (Architecture of the Built Environment) - Created the Builidng Information Modeling (BIM), analyzed thermal conduction within the building and materials.

Luca Piemontese (Material Engineering) - Researched and analyzed RHA and RH solutions for the concrete modules, implemented changes in the BIM.

Goal

The ZeCRoCo project aims to improve the current construction paradigm adopted by Planet Smart City in the social housing context in response to the urgent need for affordable housing in rapidly urbanizing countries. India has been used as a benchmark, in particular the Pune district in Maharashtra. It addresses the dual challenge of maintaining economic efficiency while enhancing sustainability in construction practices. The project focuses on using sustainable materials and local resources while providing energy-efficient and improving comfort standards. Additionally, it seeks to mitigate the impacts of extreme heatwaves in India by promoting passive cooling strategies and reducing reliance on energy-intensive air conditioning systems.

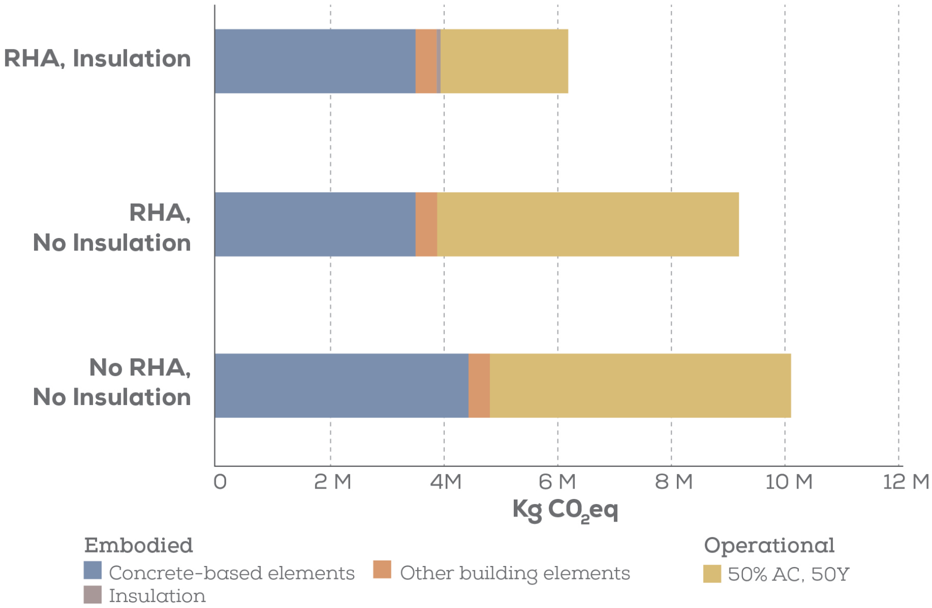
Problem

India, the world's most populated nation, is at a tipping point, with its urban population set to nearly double by 2050, adding over 400 million new urban dwellers. Uncontrolled urbanization and rapid economic growth are intensifying an already severe housing crisis, with a current shortage of 19 million homes. Housing prices have made it difficult for middle and lower-income families to afford homes, prompting government initiatives to prioritize affordable housing solutions. This calls for a building model that prioritizes economic efficiency while also ensuring compliance with local building standards.

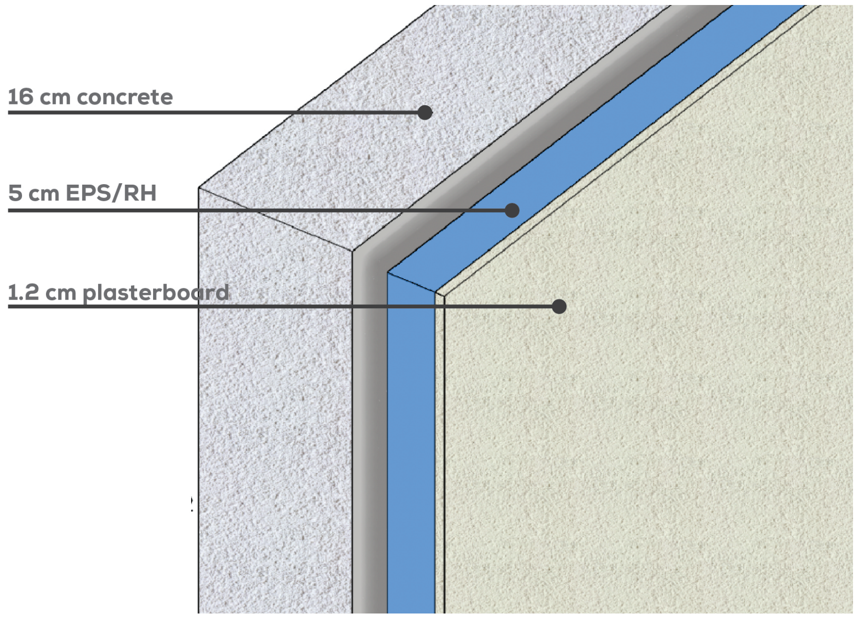
However, while housing is a fundamental human need, its entire lifecycle has significant environmental impacts, stemming from both embodied and operational carbon. Cement production is a major challenge during construction, responsible for 8% of global emissions. The operational phase can be even more impactful, often producing more than twice the embodied carbon due to design inefficiencies. The extreme heat waves currently affecting India further complicate the situation, as rising temperatures force residents to rely heavily on air conditioning systems, which increases the overall energy consumption and further affects the climate issue. To face this problem, the Indian government, together with many stakeholders, has committed to reducing cooling energy demands through energy-efficient building designs that minimize reliance on air conditioning to both mitigate the economic and environmental problem.

Moreover, in large cultivating countries like India there is a necessity of integrating sustainable practices to reduce pollution and environmental damages due to the wastes and dumps of agriculture byproducts, such as rice husk, rice straw and rice husk ashes, promoting a circular economy.

ZeCRoCo seeks to reconcile these pressing issues by focusing on sustainable materials, energy-efficient designs, and local resources, ensuring that affordable housing developments do not contribute to long-term environmental degradation.



Total carbon emission over a 50 year life-cycle



Details of the panel with technical specifications

Exploring the opportunities

Precast concrete construction (PCC), which involves manufacturing concrete elements in a controlled factory setting before transporting them to the construction site, offers significant advantages over traditional cast-in-place methods. These include more efficient material use, quicker construction times due to parallel processes and pre-finishing options, and increased safety for workers. PCC also leads to lower long-term costs through increased durability and reduced maintenance needs.

However, in India, PCC's adoption is currently limited, with only a 2% market share. This low adoption rate is attributed to several challenges, such as high transportation costs, the need for substantial initial investments in manufacturing infrastructure, and a shortage of skilled labor. Additionally, technical difficulties, logistical hurdles, and regulatory constraints further complicate its widespread use. The project considered several alternative eco-friendly building materials (Hempcrete, reclaimed wood, bamboo, etc. ...) to be used together with traditional concrete. This set of innovative materials are widely spread in the Indian subcontinent and provide many advantages to the local community and its industrial framework. However, they lack mechanical characteristics for the final applications in advanced building structures and a robust product supply chain. These considerations strongly limit their final application hence additional work is required to match the traditional materials performances.

Generating a solution

The ZeCRoCo project conducted an in-depth research in innovative building materials together with an economic assessment of the Indian context for the next few years. A BIM-model of the considered building case, together with analysis of its thermal behavior were conducted and the efficiency of the provided solutions were validated with LCA and LCC methods. As a result of the above mentioned analysis the team focused on two complementary routes: the reduction of embodied carbon and the reduction of operational carbon. The first route concerns the adoption of an eco-friendly concrete where 20% of cement is substituted with RHA (rice husk ashes), a byproduct of the Indian rice paddy industry. This material has the same functional properties of traditional concrete but a reduction of 12.5% in CO2 emissions. This not only makes use of a readily available material but also reduces the energy-intensive production of cement. To further address energy use, the second route introduces an insulation panel that improves indoor comfort by maintaining more stable temperatures and reduce the need for air conditioning, therefore cutting the operational CO2 emissions along a 50 year life-cycle by 58.0% (in the hypothetical scenario in which half of the dwellings implement air conditioning). Additionally, the insulation panels can be made from rice husk, leveraging the same supply chain as the rice husk ash used to replace cement. Overall, CO2 emissions considering a 50-year building life-span would be cut by 38.6% by joining both embodied and operational solutions proposed. These measures represent a forward-thinking approach to sustainable building practices, particularly suited to the needs and resources of the Indian market.

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