Research Paper Review: Machine Learning Predictions for Optimal Cement Content in Sustainable Construction

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ABSTRACT :. The designated concrete compressive strength at 28 days plays an important role in determining the quantity of cement (water to cement ratio) needed in concrete mix designs. Whilst a 28-day target is common, some structural elements receive deferred loads during construction, allowing a reduced cement content and the possibility to optimize the concrete mix to target full strength at 90 days. Machine learning techniques are used in this study to optimize the concrete mix de- sign of structural elements that commonly receive deferred loads, e.g., foundation and pavements, targeting a 90-day full strength. Specifically, the compressive strength of concrete samples cured for 28 and 90 days are considered to estimate the cement content per m^3 of concrete using Artificial Neural Network and Regression algorithms. The proposed machine learning and deep learning methods are proved to be capable of predicting the cement content with 94% and 90% accuracy, respectively. The Elastic Net algorithm shows the best performance in cement content optimization to a target 90-days compressive strength. This algorithm is hence employed to assess the carbon reduction benefits in a real case study: a typical mid-sized reinforced concrete structure is considered as a baseline to quantify the environmental benefit of optimizing the cement content for a 90-days target compressive strength. Results of the case study show that the proposed method may result in a reduction of approximately 10% in cement usage, consequently leading to a parallel reduction of about 10% in carbon emissions.

Keywords — Concrete, compressive strength, cement content, machine learning , structural element, sustainability, carbon reduction.

1. Introduction : The effects of climate change on the environment have become more severe in the recent years, raising the need to globally reduce carbon emissions and mitigate their negative consequences on our planet. According to the Environmental Protection Agency (EPA), more than 20% of global greenhouse gas (GHG) emissions in 2021 came from the industrial sector, amongst which the cement industry is the third largest energy consumer, with approximately 7% of global GHG emissions. As a reference, the total GHG emissions by the cement industry were roughly 1.50 Gt CO_2 in 2018, with a large participation of concrete production processes requiring carbonate decomposition, fuel combustion, and electricity usage. With an estimated 10 Bt production, concrete is indeed one of the most used cement-based construction products due to its accessibility and affordability, as well as favorable mechanical, thermal and insulation properties, often superior to other conventional construction materials.

2. Objective of study : The main objective of the study titled " Machine learning predictions for otptimal cement content in sustainable construction" is to thoroughly examine cement content for sustainable construction to develop and evaluate machine learning models that predict optimal cement content in concrete mix designs, balancing structural performance and sustainability while minimizing environmental impact, thereby contributing to sustainable construction practices and reducing the environmental footprint of the construction industry and

3. **Need for sustainable construction :** The need for sustainable construction has become increasingly critical in the face of rapid urbanization, resource depletion, and environmental degradation. Traditional construction practices often rely heavily on non-renewable resources, generate significant amounts of waste, and contribute substantially to greenhouse gas emissions. These impacts have led to a growing awareness of the importance of adopting environmentally responsible and resource-efficient construction methods.

4. **Scope and limitations of the study :** The study explores machine learning predictions for optimal cement content in sustainable construction, focusing on predicting cement content using techniques like Artificial Neural Networks and Regression Analysis. However, it has limitations, including reliance on available data, complexity of concrete mix design, potential lack of generalizability, and challenges in interpreting complex models. Future research should address these limitations by collecting large-scale datasets, improving model interpretability, expanding the scope to other sustainable construction aspects, and integrating domain knowledge to enhance accuracy and reliability. concrete.

5. **Literature Review :** The construction industry is one of the largest consumers of natural resources and contributors to greenhouse gas emissions. With the increasing demand for sustainable construction practices, optimizing cement content in concrete has become a critical area of research. Machine learning (ML) techniques have emerged as a promising approach to predict optimal cement content, reducing waste and environmental impact. This literature review explores the current state of research on ML predictions for optimal cement content in sustainable construction.

Machine learning algorithms can analyze complex relationships between variables, making them suitable for predicting cement content. Studies have applied ML techniques to various construction-related problems, including material properties prediction, structural health monitoring.

5. **Methodology :**

The In this section, the methodology used to determine the concrete mixture for targeting the 90-day compressive strength is presented in detail. First, the dataset used in this research is described to understand the available features and their distribution. All the different algorithms are then briefly presented to clarify the approach of the methodology. In this research, 261 different batches of concrete were cured in fresh water and tested at 7, 28, and 90 days to determine the com- pressive strength of concrete by conducting a compression test on standard cylindrical specimens. Two, three, and one sample are used to determine the 7-day, 28-day, and 90-day compressive strength of concrete, respectively and the correspondent average values indicate the compressive strength at these ages. For each batch of concrete, the concrete slump test is also conducted, and the results reported. The mix proportions of each concrete batch are thus characterized by eight properties, namely the 28-day compressive strength, 90-day compressive strength, concrete slump test, nominal maximum aggregate size, water content, cement content, coarse aggregate content, and fine aggregate content. shows the statistical parameters for the dataset. The 90-day compressive strength value ranges from 26.7 to 55.0 MPa, indicating a low to medium compressive strength of the experimental concrete batches.

6. **Observations And Results :**

The results of the regression models developed in section are presented in. The Elastic Net algorithm shows the highest test accuracy, hence the best performance, and is selected for further tuning. The tree-based algorithms, instead, show a substantial gap between train accuracy and test accuracy, i.e., they are susceptible to overfitting to a high degree

7. Conclusion :

A new approach to reduce carbon emissions related to concrete constructions and mitigate global warming is proposed in this study. Considering that concrete compressive strength grows within 90 days after pouring, and that some structural elements receive deferred full loads, cement savings can be obtained when a 90-days concrete compressive strength is targeted.

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