

PREDICTING DURABILITY OF GREEN CONCRETE USING INTEGRATED MATHEMATICAL MODELING AND BUILDING INFORMATION MODELING (BIM) WITHIN SUSTAINABLE CONSTRUCTION FRAMEWORK

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Abstract. As skyscrapers rise and the pace of construction accelerates, one pivotal question remains: how long will our building materials truly last? This study embarks on a scientific journey, merging the intelligence of mathematical modeling with the power of digital technology, to unravel the secrets behind the durability of green concrete – a material the very composition of which holds the promise of a more sustainable and environmentally conscious future. This study aimed to develop an advanced mathematical model to predict the long-term performance (up to 100 years) of green concrete (containing recycled materials or cementitious alternatives) and integrate it with a Building Information Modeling (BIM) environment to enhance decision-making in sustainable design and management. Exponential decay equations were employed to predict strength degradation, Fick's second law of diffusion to simulate water absorption, and a linear model to estimate changes in thermal conductivity. The degradation coefficients (k_1 , α , β) were calibrated through precise laboratory tests. The model was then implemented using Python within the Dynamo and Revit environments to simulate the behavior of various concrete mixes over 50 years. The results showed a variation in mix performance. The GC_{P30%} mix (with natural aggregates) achieved an optimal balance between compressive strength and thermal insulation, while pozzolanic mixes (GCS_{P50%}) demonstrated high thermal insulation efficiency despite lower structural strength. The study warned against using mixes (Basalt mixtures) like NCP in humid environments due to high absorption (>15%). This study provides a practical framework to support engineers in selecting appropriate materials based on environmental and structural requirements, thereby contributing to the efficiency of sustainable construction.

Keywords: green concrete, durability prediction, mathematical modeling, BIM, degradation coefficients, recycled aggregates.

Introduction

The construction sector holds great importance among economic sectors, playing a significant and vital role in supporting the national economy, advancing economic and social life, and achieving urban development in most countries of the world. This sector is expected to have particular importance and a multiplier effect in the upcoming phase, as the climate change crisis, the shortage of energy resources, as well as the natural disasters witnessed in the region and the world, compel architects, civil engineers, and property owners to examine the impact of their work on the environment and accelerate the use of sustainable tools and materials [1]. There is a compelling reason for this: nearly 40% of energy-related carbon dioxide emissions and 36% of global energy consumption come from the building and construction sector, according to a 2021 report by the United Nations Environment Programme and the International Energy Agency.

Amid the accelerating global trend towards sustainable construction, the development of durable and environmentally friendly building materials has become a top priority. Green concrete, which contains recycled materials or cementitious substitutes such as pozzolana, presents a promising solution to reduce the carbon footprint and achieve sustainability [2]. However, assessing the long-term durability of these materials poses a challenge due to the complexity of the chemical and physical interactions affecting their properties. Hence, there is a pressing need for accurate analytical tools capable of simulating material behavior under various environmental conditions, which is what this study seeks to achieve by integrating advanced mathematical modeling with Building Information Modeling (BIM) techniques.

In light of the growing global interest in sustainable construction and the pressing need to reduce the environmental impact of the building materials sector, predicting the performance of green concrete has become a fundamental challenge that requires innovative solutions, for instance, Mungle et al. [3] proposed a GBM-CNN methodology to model the complex interactions within supplementary cementitious material (SCM) compositions. Gradient boosting machines (GBMs) are employed to handle numerical features such as SCM proportions, curing time, and temperature, capturing nonlinear relationships inherent in tabular data. Concurrently, convolutional neural networks (CNNs) process microstructural images to extract spatial features correlated with mechanical properties. The outputs of

both models are integrated using an ensemble approach to predict concrete strength, with expected performance metrics reaching an R^2 of approximately 0.85 and an RMSE of around 2 MPa.

Artificial intelligence (AI) techniques, particularly machine learning, are now employed in almost every domain of human activity, ranging from material property prediction, and beyond [4-6]. Within civil engineering [7], and more specifically in concrete technology [8], the use of machine learning to predict the mechanical properties of concrete has gained significant traction, given that conventional experimental methods are often laborious, costly, and resource-intensive [9; 10]. Ahmad et al. [11] employed supervised machine learning techniques including AdaBoost, bagging, gene expression programming (GEP), and decision trees (DT) to forecast the compressive strength of pozzolanic concrete incorporating fly ash and blast furnace slag. The bagging model demonstrated superior performance with an R^2 value of 0.92, confirming the accuracy of the proposed approaches in predicting the strength development of pozzolanic concrete [12].

Meanwhile, Shishegaran et al. [13] sought to predict the compressive strength of concrete using three standalone models, namely step-by-step regression (SBSR), gene expression programming (GEP), and an adaptive neuro-fuzzy inference system (ANFIS).

The main challenge lies in the lack of practical tools that allow for accurate prediction of the long-term performance of green concrete, especially given the multiplicity of factors affecting its durability, such as humidity, acids, and mechanical loads. Furthermore, the lack of integration between mathematical models and modern design tools such as BIM hinders the application of theoretical results in real-world projects, which may lead to the selection of unsuitable materials or the miscalculation of a building's service life.

This study intends to explore the following hypotheses by analyzing how green concretes will perform over time according to specific environmental conditions according to the following three factors: the degradation of compressive strength, the increase of water absorption, and the variation of thermal conductivity of green concrete over a 50 to 100-year period. The purpose of the research is to investigate whether the degradation of green concrete can be predicted accurately based on three calibrated mathematical models: exponential decay, Fick's second law of diffusion, and linear deterioration models. Furthermore, the study tests whether all three above-mentioned models can be implemented in a Building Information Model (BIM) with a Revit/Dynamo interface, which will allow engineers to use these tools in creating a decision support system that will allow them to determine the most viable green concrete mix based on the predicted long-term performance of green concrete as it is expected to function in a specific environment and structural conditions.

Research significance and objectives

This research contributes to bridging a significant knowledge gap at both the scientific and applied levels by developing accurate and integrated mathematical models to simulate the degradation of green concrete properties. It introduces measurable and developable deterioration coefficients and transitions these models from the theoretical framework to practical application by integrating them with the Building Information Modeling (BIM) environment, specifically within the Revit and Dynamo platforms using the Python programming language. This integration enables engineers to simulate material performance in a visual and interactive manner. To achieve this, the research aims to: develop an integrated mathematical model for predicting the degradation of compressive strength, water absorption, and thermal conductivity of green concrete; calibrate the deterioration coefficients through laboratory testing of various mixtures, including natural and recycled aggregates as well as pozzolanic admixtures; and subsequently integrate this model into the BIM environment to create an interactive simulation capable of evaluating the performance of different mixtures over a fifty-year period. From an environmental perspective, the research supports the selection of sustainable building materials that enhance resource efficiency and reduce waste, while economically, it facilitates improved preventive maintenance planning and reduces long-term costs for construction projects.

Materials and methods

The experimental methodology relied on several main stages: starting with the preparation of laboratory samples by processing rubble and crushing it manually and mechanically, then characterizing the materials used (pozzolana, basalt, and recycled aggregates) through a series of physical and chemical

tests. Subsequently, sixteen concrete mixtures were designed, divided into four groups with different replacement ratios for aggregates (natural, recycled, and pozzolanic), in addition to replacing cement with ground pozzolana at the following weight percentages (10%, 30%, 50%), and natural sand with ground basalt or pozzolanic sand. It should be noted that the term “recycled aggregates” refers to the mixture composed of processed rubble in the following weight percentages: (60% concrete, 10% tiles, 20% blocks, 10% ceramics).

The performance of the mixtures was evaluated through tests that included measuring water absorption, thermal conductivity, compressive strength, and durability (including sulfuric acid exposure tests). These tests aim to determine the suitability of alternative materials for structural applications by accurately predicting the long-term performance of green concrete, especially given the multiplicity of factors affecting its durability such as humidity, acids, and mechanical loads.

Below, we detail the composition of these mixtures:

Table 1

Mixture compositions for all groups, $\text{kg}\cdot\text{m}^{-3}$

Component	Mixture Code	Pozzolana	Cement	Water	Normal stones	Fine sand	Lenticular coarse sand	Recycled gravel	Pozzolanic gravel	Basalt sand	Pozzolanic sand
Group 1 (Natural Agg.)	NC	0	350	210	1042	366	385	–	–	–	–
	GCP10%	35	315	210	1042	366	385	–	–	–	–
	GCP30%	105	245	210	1042	366	385	–	–	–	–
	GCP50%	175	175	210	1042	366	385	–	–	–	–
Group 2 (Recycled Agg.)	NCR	0	350	210	–	375	375	994	–	–	–
	GCRP10%	35	315	210	–	375	375	994	–	–	–
	GCRP30%	105	245	210	–	375	375	994	–	–	–
	GCRP50%	175	175	210	–	375	375	994	–	–	–
Group 3 (Basalt Sand)	NCP	0	350	210	–	–	385	–	658	340	–
	GCPP10%	35	315	210	–	–	385	–	658	340	–
	GCPP30%	105	245	210	–	–	385	–	658	340	–
	GCPP50%	175	175	210	–	–	385	–	658	340	–
Group 4 (Pozzolanic Agg.)	NCPS	0	350	210	–	–	–	–	658	–	666
	GCSP10%	35	315	210	–	–	–	–	658	–	666
	GCSP30%	105	245	210	–	–	–	–	658	–	666
	GCSP50%	175	175	210	–	–	–	–	658	–	666

Note: Dashes (–) indicate that the component was not used in that mixture. Group 1: natural aggregates; Group 2: recycled aggregates; Group 3: basalt sand + pozzolanic gravel; Group 4: fully pozzolanic aggregates (sand + gravel)

1. Casting of Concrete Mixtures

For casting the concrete mixtures, we relied on manual mixing. Each component of the dry mixture was weighed independently. The molds (10*10*10 cm) were then filled, demolded the following day, and the specimens were placed in water for 28 days.

2. Experiments on Hardened Concrete:

Measurement of Maximum Water Absorption

We weighed the specimens in both dry and saturated states. For the dry state, the specimens were placed in an oven at 105°C for 24 hours and then weighed. For the saturated state, the specimens were immersed in water for 24 hours and then weighed.

Measurement of Thermal Conductivity

The thermal conductivity test was conducted using the direct heat exposure method on the concrete specimens. An insulated thermal chamber was designed using fire bricks, with dimensions of 10 cm ×

10 cm and a height of 20 cm. It was equipped with a heat source at the bottom, and the top side was open to accommodate the test specimen.

The design of the chamber and the heat source allows for heating the specimen from one side only, in order to measure the heat transfer from this face to the opposite face after a period of time, as shown in Fig. 1.

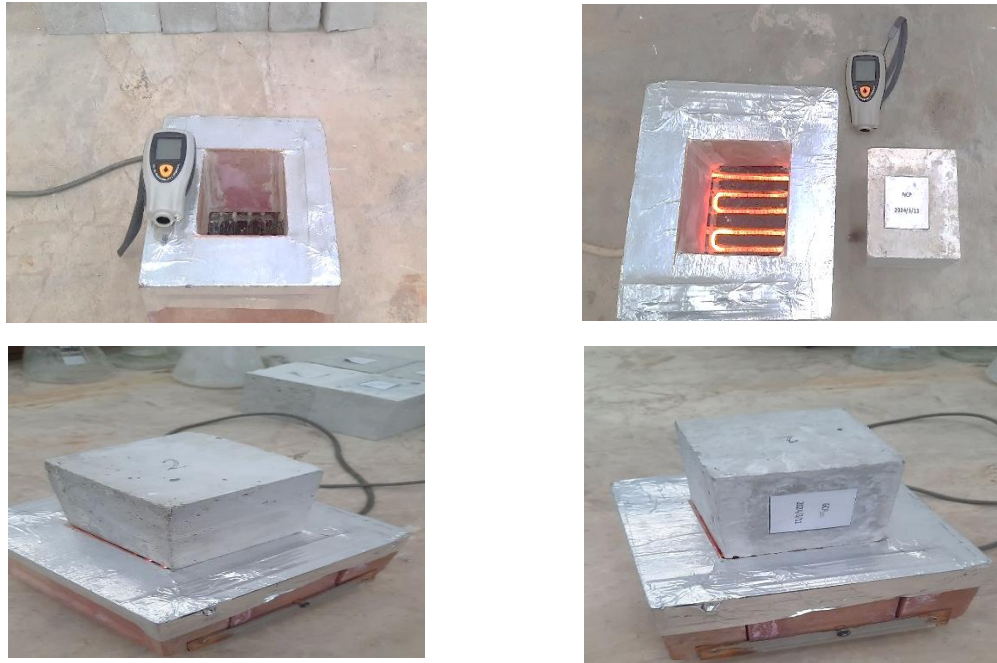


Fig. 1. Mechanism for measuring the thermal conductivity of concrete samples

Measurement of Compressive Strength

To determine the compressive strength of the concrete specimens at the age of (28 days), we applied a force to their surface. The compressive strength of the specimens is calculated by determining the compressive force that leads to the failure of the specimen and calculating the surface area subjected to that force. Table 2 shows the results of the three tests:

Table 2

Results of the three tests on hardened concrete

Mixture	Replacement ratio, %	Absorption rate, %	Thermal conductivity λ , $W \cdot (mK)^{-1}$	Compressive strength, $kg \cdot cm^{-2}$
NC	0	6.49	1.1024	330
GCP _{10%}	10	6.47	1.0934	244
GCP _{30%}	30	6.11	1.0872	180
GCP _{50%}	50	5.45	1.0540	162
NCR	0	9.08	1.0781	194
GCR _{P10%}	10	10.64	1.0221	186
GCR _{P30%}	30	11.92	0.9450	155
GCR _{P50%}	50	10.65	0.8444	154
NCP	0	15.68	0.6370	143
GCP _{P10%}	10	15.77	0.6469	132.5
GCPP _{30%}	30	14.58	0.6002	112.5
GCPP _{50%}	50	11.35	0.5764	77.5
NCPS	0	19.30	0.6126	41
GCSP _{10%}	10	16.33	0.5480	44
GCSP _{30%}	30	15.84	0.4319	59
GCSP _{50%}	50	15.14	0.4007	76.5

Predicting the Durability of Building Materials Using Mathematical Modeling and BIM

In light of the global trend towards sustainable construction, it has become necessary to develop accurate tools for predicting the long-term performance of building materials. Green concrete (containing recycled materials or cementitious substitutes such as pozzolana) is one of the promising solutions, but assessing its durability requires advanced mathematical modeling that integrates:

- the physical and mechanical properties of the materials;
- the capabilities of BIM software (such as Revit and Dynamo) for simulating temporal behavior.

Methodology Adopted

Phase 1: Building the Mathematical Model

The degradation of properties (strength, water absorption, thermal conductivity) is represented using a modified exponential decay model. This model was chosen for the following reasons:

- flexibility in representing temporal degradation (compressive strength, water absorption, durability);
- possibility of integrating it with data from accelerated tests (such as exposing specimens to acids and immersion in water);
- simplicity and accuracy in long-term prediction (up to 100 years).

Three mathematical models were used: prediction of compressive strength over time, prediction of water absorption over time and prediction of thermal conductivity.

Prediction of Compressive Strength over Time

The strength after time t (years) is predicted using the exponential decay model, due to its suitability for the deterioration behavior of concrete, which typically follows an exponential pattern (rapid initially, then slow over time). This behavior is attributed to the formation of micro-cracks that propagate gradually, in addition to chemical reactions, such as sulphate attack, which accelerate in the early stages and then stabilize over time [14].

$$R(t) = R_0 \cdot e^{-k_1 t}, \quad (1)$$

- where $R(t)$ – resistance (strength) after time t (in years);
 R_0 – initial resistance (strength);
 k_1 – deterioration coefficient (calculated from accelerated durability tests).

Prediction of Water Absorption Over Time

Water penetration in concrete follows a mechanism similar to the diffusion of liquids in porous materials, where water molecules move in proportion to the square root of time (\sqrt{t}) due to the gradual resistance provided by the porous structure of the concrete (ASTM C1585, 2013). Accordingly, the water absorption prediction model was derived from Fick's Second Law of Diffusion, which describes the process of mass transfer in porous media, according to the following mathematical relationship [15]:

$$W(t) = W_0 + \alpha \sqrt{t}, \quad (2)$$

- where W_0 – initial water absorption;
 α – depends on the porosity of the concrete (calculated from the water absorption test of the specimens).

Prediction of Thermal Conductivity

The thermal conductivity of concrete deteriorates over time due to two main factors: the formation of micro-cracks resulting from thermal fluctuations or mechanical loads, and changes in the pore structure caused by chemical reactions such as carbonation or sulphate attack. The international standard (ISO 10456:2007) indicates that thermal properties may change over time due to such cracking, which has led to the representation of the thermal conductivity prediction model using a linear model expressed by the equation [16]:

$$\lambda(t) = \lambda_0 \cdot (1 + \beta t), \quad (3)$$

- where λ_0 – initial conductivity;

β – thermal degradation coefficient.

Calibration of Deterioration Coefficients:

1. Compressive Strength Deterioration Coefficient (k_1) – a coefficient that determines the rate at which concrete loses its compressive strength over time, expressing the speed of deterioration due to environmental factors such as humidity, acids, and repeated loads [17].
2. Water Absorption Increase Coefficient (α) – a coefficient that determines the rate of increase in the concrete ability to absorb water over time, as a result of the development of micro-cracks and increased porosity [18].
3. Thermal Conductivity Deterioration Coefficient (β) – a coefficient that determines the rate of increase in the thermal conductivity of concrete over time due to the development of cracks and moisture accumulation [19].

Phase 2: Integrating the Model into the BIM Environment

Integrating the mathematical model for predicting the sustainability of building materials with the BIM (Building Information Modeling) methodology represents a fundamental step in transforming theoretical data into practical decisions in design and management. By embedding deterioration equations (exponential decay) into a software environment such as Revit and Dynamo, the long-term performance of materials can be simulated visually and dynamically, enabling engineers to assess the service life of buildings, optimize material selection, and plan preventive maintenance. The importance of this integration lies in its combination of scientific accuracy and applied efficiency, as it translates the complex mathematical model into easily understandable outputs (illustrating the deterioration of elements within the 3D model), thereby enhancing data-driven decision-making in sustainable construction projects.

The model was built entirely using the Python programming language within the Dynamo environment (in Revit). Data from laboratory test results (compressive strength, water absorption, and thermal conductivity) were processed. Subsequently, the mathematical model was executed using Python Script, and based on the input data, the three deterioration coefficients (for strength, absorption, and conductivity) were generated. Finally, the long-term properties of the green concrete were predicted. Fig. (2) illustrates the steps followed in this process.

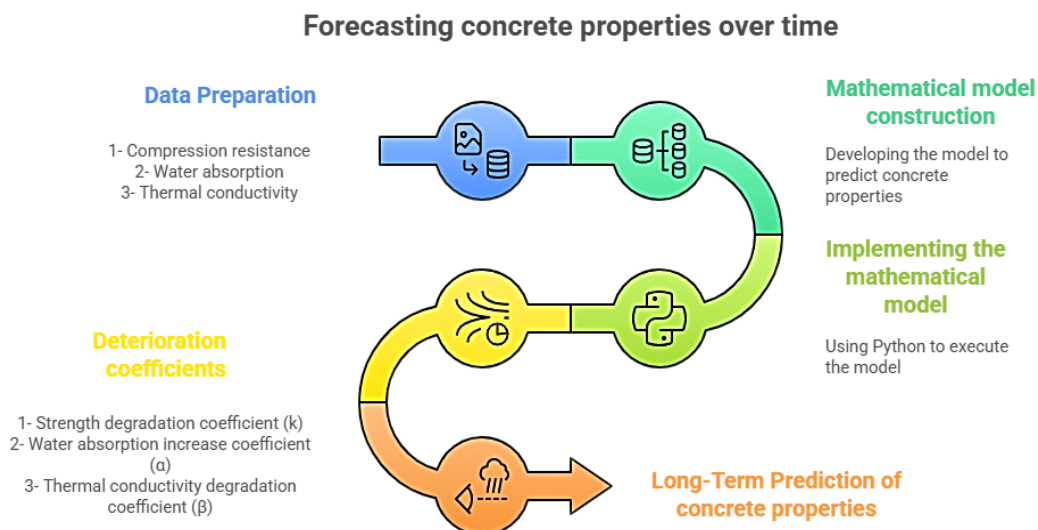


Fig. 2. Methodology adopted for predicting sustainability of concrete mixtures using the BIM approach (Researcher)

The following figures illustrate the core mechanism of the proposed predictive framework. Fig. 3 demonstrates the algorithm developed in Dynamo to simulate and predict the long-term sustainability performance of various concrete mixtures. This visual workflow integrates material data with degradation models. Complementing this, Fig. 4 presents a segment of the Python code utilized within

the Dynamo environment to execute complex calculations and automate the prediction process, enabling precise control over the simulation parameters.

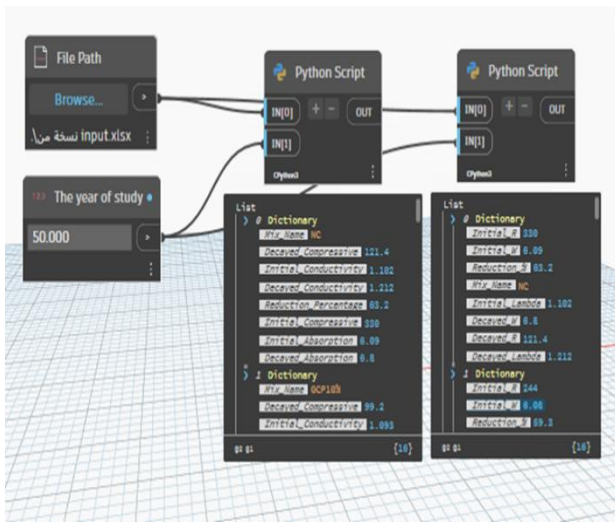


Fig. 3. Mechanism for predicting sustainability of concrete mixes using Dynamo

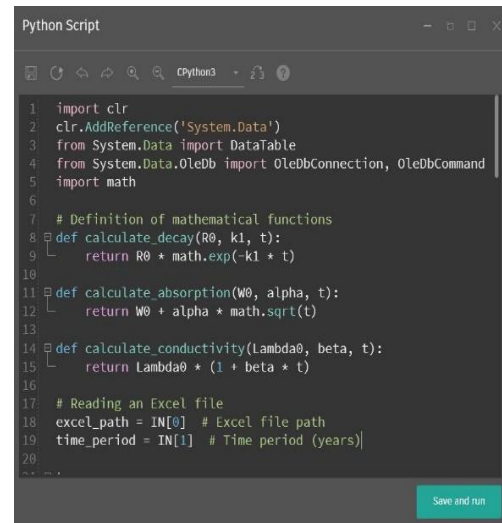


Fig. 4. Part of the Python code used in the prediction process

Results and discussion

Table 3 summarizes the results of this simulation, which will be discussed in detail below.

Table 3

Predicted long-term performance of mixtures in group one

Mixture	Compressive strength, kg·cm ⁻²	Absorption rate, %	Thermal conductivity λ, W·(mK) ⁻¹	Results
Group one				
NC	330 → 185	6.1 → 7.7	1.102 → 1.16	Reduction in strength 44%
GCP _{10%}	244 → 136	6.1 → 7.6	1.093 → 1.15	Better performance than NC
GCP _{30%}	180 → 118	5.8 → 7.2	1.087 → 1.14	Balance between sustainability and durability
GCP _{50%}	162 → 108	5.2 → 6.8	1.054 → 1.11	Low strength but good thermal insulation
Group two				
NCR	194 → 108	8.3 → 9.8	1.078 → 1.13	High absorption due to porosity
GCR _{P10%}	186 → 104	9.6 → 11.1	1.022 → 1.07	Significantly reduced resistance
GCR _{P30%}	155 → 112	10.7 → 12.2	0.945 → 0.99	Slight improvement in durability
GCR _{P50%}	154 → 110	9.6 → 11.1	0.844 → 0.89	Better thermal insulation but poor resistance
Group three				
NCP	143 → 98	13.6 → 15.1	0.637 → 0.67	Very high-water absorption
GCP _{P10%}	132.5 → 82	13.6 → 15.1	0.647 → 0.68	Not suitable for humid environments
GCP _{P30%}	112.5 → 109	12.7 → 14.2	0.600 → 0.63	High acid resistance
GCP _{P50%}	77.5 → 73	10.2 → 11.7	0.576 → 0.61	Poor resistance but excellent insulation
Group four				
NC _{PS}	41 → 30	16.2 → 17.7	0.613 → 0.64	Very weak under loads
GCS _{P10%}	44 → 33	14.0 → 15.5	0.548 → 0.58	Slight improvement in insulation
GCS _{P30%}	59 → 45	13.7 → 15.2	0.432 → 0.45	Excellent thermal insulation option
GCS _{P50%}	76.5 → 66	13.2 → 14.7	0.401 → 0.42	Highest resistance and best insulation

1. Evolution of Compressive Strength Over Time

The simulation results for all mixes showed a decrease in compressive strength over time, which is consistent with the exponential model used (Equation 1). The degradation coefficient (k_1) reflects the speed of this decline.

In Group One (containing natural aggregates), the mixes maintained relatively good structural performance. The reference mix NC experienced a 44% strength reduction from 330 to 185 kg·cm⁻² after 50 years, confirming its fundamental durability but with notable deterioration. In contrast, the GCP_{30%} mix (containing 30% pozzolana) demonstrated superior performance, with its strength decreasing from 180 to 118 kg·cm⁻², achieving the best balance between cement reduction and maintaining acceptable resistance. This suggests that adding pozzolana in optimal proportions (around 30%) can improve the microstructure of concrete in the long term, thereby reducing the degradation rate compared to the reference NC mix. This finding aligns with previous studies on pozzolanic reactions that fill voids and increase concrete density.

For Group Four, which used pozzolanic aggregates and pozzolanic sand, the initial strength values were very low (41 kg·cm⁻² for the NC_{PS} mix), rendering them unsuitable for load-bearing structural elements. However, increasing the pozzolana content (from GCS_{P10%} to GCS_{P50%}) led to a noticeable improvement in initial strength (from 44 to 76.5 kg·cm⁻²) and a reduced degradation rate, with the GCS_{P50%} mix strength decreasing by only 14% (from 76.5 to 66 kg·cm⁻²) over 50 years. This improvement is attributed to the fact that pozzolana, although it reduces early strength due to its slow reaction, contributes in the long term to the formation of additional cementitious compounds (C-S-H) that increase concrete cohesion, especially in mixes that initially suffer from significant structural weakness.

2. Evolution of Water Absorption Rate Over Time

Water absorption is a critical indicator of concrete durability, as it relates to resistance against weathering and chemicals. The models based on Equation (2) showed an increase in absorption over time, with the coefficient (α) reflecting the rate of this increase due to the development of micro-cracks.

Group Three (containing basalt) emerged as a cautionary example in this context. The reference mix NCP exhibited a very high initial absorption rate (15.68%), which increased over time to reach 15.1% after 50 years. This high absorption (>15%) renders these mixes completely unsuitable for humid environments or those exposed to sulfate attacks, as the high porosity allows water laden with harmful salts to penetrate, accelerating the deterioration of the concrete and reinforcing steel. Even with the addition of pozzolana (GCP_{P10%}), the absorption rate remained very high, confirming the significant negative impact of using basalt as an aggregate on the permeability property.

In contrast, Group One showed the best performance in terms of resistance to water absorption. The mixes recorded low and relatively stable values, with absorption decreasing as the pozzolana percentage increased, reaching 5.45% in GCP_{50%}. This reinforces the hypothesis that pozzolana, by reacting with calcium hydroxide, produces additional binding materials that block capillary pores and improve the pore structure, thereby reducing concrete permeability. A clear decrease in absorption with increasing pozzolana content is also observed in Group Four compared to the reference mix NC_{PS} (from 19.3% to 15.14%), confirming the positive role of pozzolana even in structurally weak mixes.

3. Evolution of Thermal Conductivity Over Time

Thermal conductivity represents the material ability to transfer heat; lower values indicate better thermal insulation. The linear model used (Equation 3) shows a slight increase in conductivity over time (coefficient β) due to the development of micro-cracks that may create additional pathways for heat or due to moisture accumulation.

The results show that mixes containing pozzolana and lightweight aggregates (especially pozzolanic ones) possess the best thermal performance. In Group Four, the fully pozzolanic mixes achieved the lowest thermal conductivity values, decreasing from 0.61 W·(m·K)⁻¹ for the NC_{PS} mix to 0.40 W·(m·K)⁻¹ for the GCS_{P50%} mix. This makes them an excellent choice for insulating walls or non-load-bearing elements in buildings requiring high thermal efficiency and energy savings.

Conversely, thermal conductivity was higher in Groups One and Two (containing natural or recycled aggregates), indicating their lower insulating capacity. However, what is noteworthy is the effect of adding pozzolana even in these groups; in Group Two (GCR_{P50%}), conductivity decreased significantly to 0.84 W·(m·K)⁻¹, demonstrating that pozzolana contributes to improving thermal properties alongside enhancing durability in some cases. This improvement is likely due to the denser

and more complex microstructure resulting from pozzolanic reactions, which limits heat transfer through the solid material.

Conclusions

This study aimed to develop an integrated mathematical model to predict the long-term performance of green concrete and integrate it with Building Information Modeling (BIM). The research relied on laboratory data from four groups of concrete mixes, each containing different proportions of alternative materials (pozzolana, recycled aggregates, basalt). This data was input into a mathematical model based on exponential decay equations (for compressive strength), Fick's second law of diffusion (for water absorption), and a linear model (for thermal conductivity). The degradation coefficients (k_1 , α , β) were calibrated based on laboratory tests, and the performance of these mixes was simulated over 50 years using Python within Revit and Dynamo environments.

Practical Implications

Based on this detailed discussion, several important practical conclusions can be drawn.

- For structural applications in normal environments, the GCP_{30%} mix (from Group One) stands out as an optimal choice, offering an excellent balance of good compressive strength, low water absorption, and acceptable improvement in thermal properties.
- For applications requiring high thermal insulation, such as building facades, pozzolanic mixes like GCS_{p50%} (from Group Four) or GCR_{p50%} (from Group Two) provide superior thermal performance, while considering that their mechanical strength is low and therefore unsuitable for heavy structural loads.
- The use of mixes containing basalt (such as NCP) is strongly cautioned against in humid environments or those exposed to water, due to the very high absorption rates (> 15%) which lead to rapid durability degradation.

This integrated framework, combining precise mathematical modeling with an interactive BIM environment, provides engineers and designers with a powerful tool for making informed decisions based on scientific evidence. It enables them to simulate material performance for decades to come and select the most appropriate ones according to the project's environmental and structural requirements, thereby contributing to the efficiency and sustainability of the construction sector.

References

- [1] Wassouf M.A., J.Y. Omran A.I. Kheirbek, Durability Assessment of Green Concrete Incorporating Volcanic Tuff Pozzolan, Basalt, and Recycled Aggregate. ARO-THE SCIENTIFIC JOURNAL OF KOYA UNIVERSITY. 13(2), 2025, pp. 64-74.
- [2] Wassouf M., J. Omran A. Kheirbek, Use of natural pozzolana as alternative to Portland cement with recycled pebbles for manufacture of concrete with environmental properties. 2025.
- [3] Mungle, N.P., et al., Applications of computational intelligence for predictive modeling of properties of blended cement sustainable concrete incorporating various industrial byproducts towards sustainable construction. Asian Journal of Civil Engineering. 25(8), 2024, pp. 5939-5954.
- [4] Amezquita-Sanchez J.P., et al., A new dispersion entropy and fuzzy logic system methodology for automated classification of dementia stages using electroencephalograms. Clinical Neurology and Neurosurgery. 201, 2021 p. 106446.
- [5] Afolayan A.H., B.A. Ojokoh A.O. Adetunmbi, Performance analysis of fuzzy analytic hierarchy process multi-criteria decision support models for contractor selection. Scientific African. 9, 2020, p. e00471.
- [6] Jiménez-Bravo D.M., et al., Multi-object tracking in traffic environments: A systematic literature review. Neurocomputing. 494, 2022, pp. 43-55.
- [7] Rafieizonooz M., et al., Testing methods and design specifications for FRP-prestressed concrete members: A review of current practices and case studies. Journal of Building Engineering. 73, 2023, p. 106723.
- [8] Alabi S.A., Mahachi J. Utilizing artificial neural network and multiple linear regression to model the compressive strength of recycled geopolymer concrete. International Journal of Integrated Engineering. 14(4), 2022, pp. 43-56.

- [9] Barkhordari M.S., et al., Hybrid wavelet scattering network-based model for failure identification of reinforced concrete members. *Sustainability*. 14(19), 2022, p. 12041.
- [10] Cao R., et al., Application of machine learning approaches to predict the strength property of geopolymers. *Materials*. 15(7), 2022, p. 2400.
- [11] Ahmad W., et al., Application of advanced machine learning approaches to predict the compressive strength of concrete containing supplementary cementitious materials. *Materials*, 14(19), 2021, p. 5762.
- [12] Mohammed A., et al., Prediction of compressive strength of concrete modified with fly ash: Applications of neuro-swarm and neuro-imperialism models. *Computers and Concrete*. 27(5), 2021, pp. 489-512.
- [13] Shishegaran A., et al., High correlated variables creator machine: Prediction of the compressive strength of concrete. *Computers & Structures*. 247, 2021, p. 106479.
- [14] Mehta P.K., Monteiro P.J., *Concrete microstructure, properties, and materials*. 2006: McGraw-hill.
- [15] ASTM_C1585, Standard test method for measurement of rate of absorption of water by hydraulic-cement concretes. C1585–13, 2020.
- [16] Kumar R., *Recent Advances in High-Performance Concrete for Sustainable Structural Engineering*.
- [17] Li S., et al., Degradation of reinforced concrete beams subjected to sustained loading and multi-environmental factors. *Buildings*. 12(9), 2022, p. 1382.
- [18] Wang Y., et al., Factors influencing the capillary water absorption characteristics of concrete and their relationship to pore structure. *Applied Sciences*. 12(4), 2022, p. 2211.
- [19] Lucio-Martin T., et al., Thermal conductivity of concrete at high temperatures for thermal energy storage applications: Experimental analysis. *Solar Energy*. 214, 2021, pp. 430-442.