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Predicting mechanical properties of marble powder concrete using artificial neural networks and blockchain-rock for sustainable construction

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Use of marble powder—an industrial by-product—serves as a supplementary cementitious material (SCM) and ensures sustainability by minimizing environmental impacts of cement manufacturing. This paper suggests a novel use of artificial neural networks (ANN) and Blockchain-Rock technology to enhance predictive accuracy and assure tracking of data in concrete mix optimization. Using an ANN model trained on 629 data sets, the proposed approach achieved high predictive accuracy for mechanical properties of marble powder concrete: Model I reached R^2 = 0.99 and RMSE = 1.63 on the test set, while Model II achieved R^2 = 1.00 and RMSE = 0.21. These results are superior or comparable to those of other machine learning models, such as a feedforward ANN (R^2 = 0.985, RMSE = 1.12) and a general regression neural network (GRNN) (R^2 = 0.92, RMSE = 4.83), highlighting the effectiveness of the proposed ANN architecture. This demonstrates the ANN's ability to efficiently predict compressive and tensile strength of marble powder concrete, substantially reducing the need for standard long-duration tests. Additionally, Blockchain-Rock ensures secure and tamper-free tracking of material origin and concrete mixes, enabling transparency and efficiency in the supply chain. Experiments demonstrate that the addition of marble powder improves concrete strength and durability. Furthermore, ANN-based predictions enable real-time optimization of the concrete mix design. This dual approach offers an extended solution for sustainable construction by leveraging AI-based efficiency and blockchain-based data security. Future work can explore additional enhancements by real-time IoT integration and larger data sets to further improve predictive accuracy and industrial applicability.

KEYWORDS

marble powder, artificial neural networks, blockchain-rock, mechanical properties, supplementary cementitious materials (SCMs), concrete durability, cement replacement, sustainable concrete

1 Introduction

Marble powder is one of the Supplementary Cementitious Materials (SCMs) that used to replace cement for more sustainable concrete, while compressive and Tensile concrete tests are important for us to know the quality of

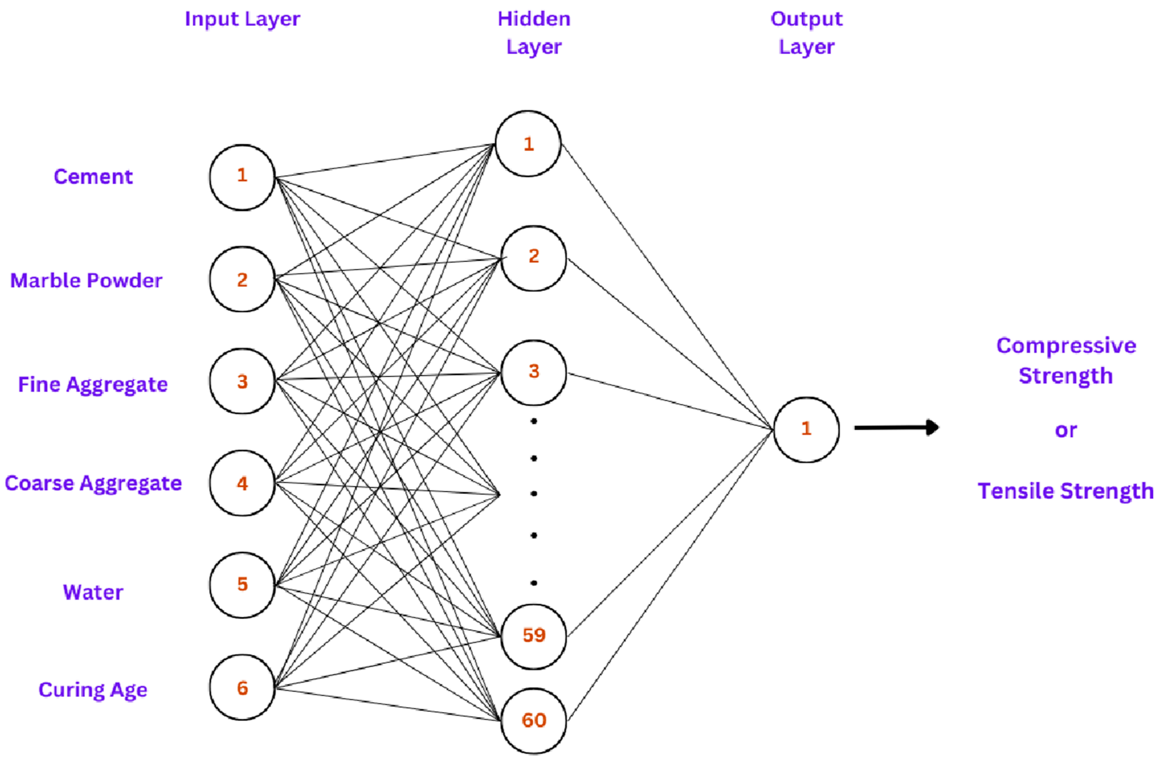

FIGURE 1
Artificial neural network architecture.

TABLE 1 Artificial neural network layers details.

Neural network	Input layer	Hidden layer	Output layer
I-ANN	6	60	1
II-ANN	6	60	1

the concrete that we use to build, the testing samples process itself takes at least 28 days for concrete to have its maximum strength to have more reliable results.

The construction industry requires, for sustainability, more natural building materials; the CO_2 emissions are tremendously high, affecting the environment due to the manufacturing of cement (Abbas and Muntean, 2025). The effective solution for the problems considered above will consist in the search for methodologies that minimize excessive consumption of natural materials. Among them, one may list the rational application of industrial waste during the preparation of concrete mixes (Abbas and Muntean, 2025; González-Vallejo et al., 2020; Woź niak et al., 2022; Agarwal and Gulati, 2006; Latawiec et al., 2018). Marble industry generates substantial amounts of waste that can be utilized as a by-product along with cement to produce environmentally friendly concrete (Molnar and Manea, 2016).

Construction waste management (CWM) is a complex adaptive system and a holistic strategy that involves controlled treatment, reduction, reuse, and recycling (Jueyendah et al., 2021), and effective final disposal of waste generated from building, converting waste from the building and manufacturing sectors into valuable products (Trtnik et al., 2009). Simultaneously, it promotes sustainability and cost reduction. Successful CWM reduces damage through avoidance of soil and water contamination, pollution of the atmosphere, and habitat disruption, and avoidance of methane gas emitted by landfill sites (Kelechi Enobie et al., 2024), Through diversion of waste and employment of recycled materials, natural materials and energy are conserved based on the principle of circular economy, where material is kept in circulation over a considerable amount of time (Kelechi Enobie et al., 2024).

A Circular Economy (CE) principle in CWM represents a paradigm shift from a linear “take-make-consume-dispose” model of a conventional economy to a restorative one. The circular process aims to have assets in service for longer, getting the highest value from them with minimal waste generation (Gherman et al., 2023; E. Parliament, 2023). The paradigm is termed a core new sustainable principle to optimize waste management in the construction industry. The advantages of embracing a CE in CWM are. It reduces the amount of waste to landfill sites, saves on natural resources, and even reduces greenhouse

TABLE 2 Comparison of traditional and digitalized construction methods.

Aspect	Traditional methods	Digitalized methods	Impact
Project Planning	Manual calculations, 2D drawings	BIM, 5D modeling, AI-driven simulations	Faster, more accurate planning and resource allocation
Resource Management	Manual tracking, paper-based records	IoT sensors, cloud-based platforms	Real-time tracking, reduced waste, and optimized resource use
Safety Monitoring	Reactive safety measures, manual inspections	AI-powered hazard detection, drones	Proactive safety measures, reduced accidents, and improved compliance
Sustainability	High carbon footprint, material waste	AI-driven material optimization, green tech	Reduced environmental impact, improved energy efficiency
Cost Management	Manual cost estimation, frequent overruns	AI-based cost prediction, real-time analytics	Reduced cost overruns, better budget control

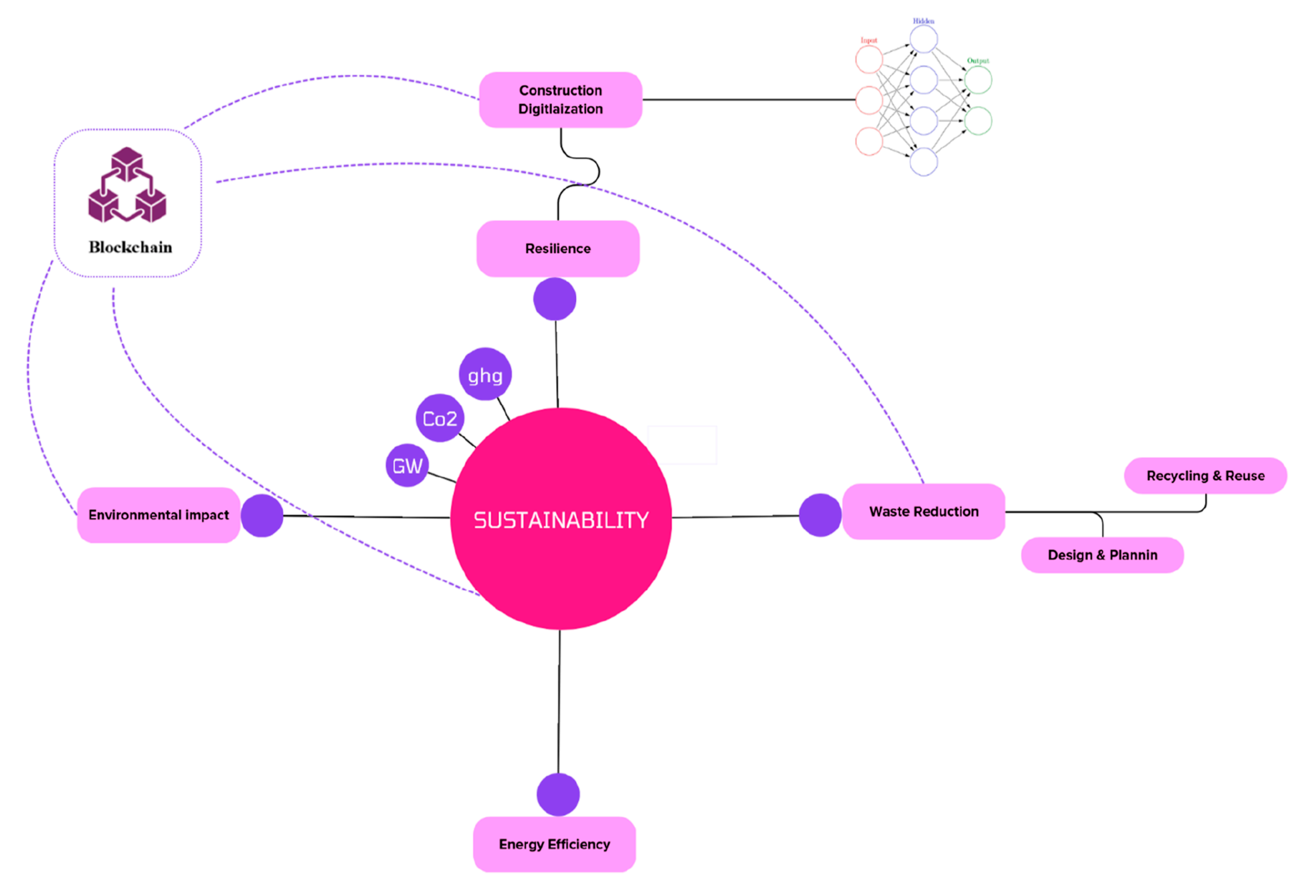

FIGURE 2
Digitalization towards sustainability, [Global worming (GW), Greenhouse gases (GHG)].

gases through reduced new production energy demands. The methodology fosters a more robust building industry that is not so dependent on volatile global supply chains and subject to material shortages.

Blockchain (BC) Technology is one of the best methods that can be used in Waste Management (WM) permanently because BC keeps data inside a chained sequence of blocks, thereby making it simple to track changes through calculating a single-block's hash value and comparing it with recorded hash value inside a nearby block (Motasem 2024) Researchers proceeded to elaborate on how BC today is used in WM in payment facilitation, tracking, waste monitoring. There are also BC applications that are already in place like Swachhcoin (BC mechanism for effective and eco-friendly micromanagement of trash from homes and businesses and making them into valuable commodities), Recereum (BC platform for recycling wastes and turning them into real value),

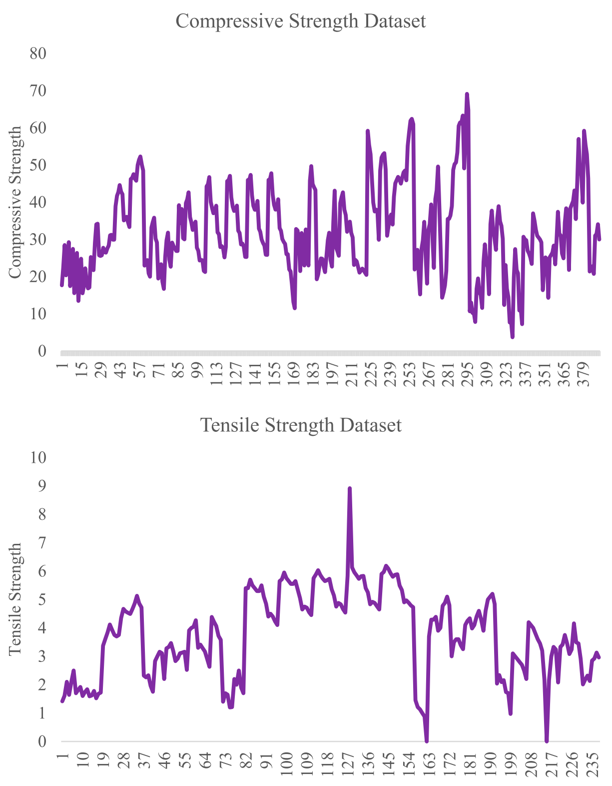

FIGURE 3
Graphical presentation of the dataset.

and Plastic Bank (BC program that focuses on monetizing users in order to keep trash out of ocean). Furthermore, BC can also be used in a cloud system to give a boost to the security of WM making it possible for individuals to participate actively within WM through mobile phone and personal computer (Taylor et al., 2020; Researchgate, 2019). BC even has solutions to core areas named, fraud and manipulation, incorrect/loss of data, manual processing and absence of knowledge and control found within WM practices (França et al., 2020).

In CWM, blockchain integration has a lot of potential by allowing harmonious platforms for managing data and accelerating circular economy CE concepts by means of improved collaboration. That potential can be boosted by drawing on integration strategy applicable to construction. A key strategy involves using smart contracts on platforms like Ethereum to achieve a secure peer-to-peer network within waste processing streams. While references provided do not directly refer to blockchain-based solutions like Swachhcoin, Recereum, Plastic Bank, or DanKu protocol specially applied to waste within construction, the references lay emphasis on blockchain nature like decentralization, immutability, and openness to play a vital role in effective waste tracking and measurement optimization, crucial to CE methods. In addition to that, blockchain's ability to integrate other digital technologies like BIM, IoT, and RFID, explored to apply to the general context of construction, also supports its contribution to overall waste handling by simplifying real-time tracking, furthering improved data exchange, and automated verifications along waste lifecycle (Mahmudnia et al., 2022; Perera et al., 2020; Yang et al., 2020; Souza Barreto et al., 2020).

By applying ANN (see Figure 1) on the prediction of compressive and tensile strength: This will reduce the amount of time wasted in procedures. It will eliminate such long curing and physical testing activities by directly assessing the quality of concrete. With a well-trained ANN model, decisions can be made quickly over mix design optimization in real time to improve project efficiencies.

The current study aims to provide an ANN model that would be able to predict the compressive and tensile strength of marble concrete. In this respect, 629 data from previous works have been selected with much care, and factors like cement, coarse and fine particles, water, and specimen curing age were taken as a number of these parameters is considered significant determinants of compressive and tensile strength of conventional concrete.

ANN systems have lately become popular, and many researchers have used them for different engineering applications. Laboratory tests are carried out to get the physical and mechanical properties of concrete. By simulating human brains, ANNs may learn from experience the connections between certain inputs and outputs (Molnar and Manea, 2016; Bilim et al., 2009; Demir, 2008; Topçu and Sarıdemir, 2008a; Sarıdemir et al., 2009; Lee, 2003; Parichatprecha and Nimityongskul, 2009; Özcan et al., 2009; Topçu and Sarıdemir, 2008b; Tanyildizi, 2009). An ANN uses an activation function to generate an output, a learning algorithm to modify the weights, and a set of patterns from a training database as input (Cevik and Guzelbey, 2008; Hou et al., 2008; Topçu and Sarıdemir, 2008c).

The ANN is a biologically inspired computational technique that will map the relations of n-dimensional input and output vectors very accurately. In this architecture, the so-called hidden layers composed of hidden neurons are sandwiched between an input and an output layer, where the input layer represents nodes for the input variables and the output layer is utilized to express the outputs of the model. How these three layers are combined is demonstrated in Table 1 (Zadeh, 1965).

These are the connections between the three layers, linked to weights initially set by the network creator but changed iteratively for every "epoch" that the network goes through. Because it reduces the error function of the network output to a predetermined threshold or limit-as instructed by the gradient descent optimization-it provides weight after weight which, in the end, converges with respect to the final values. Or in other words, the number of converged epochs reaches to its maximum until convergence is attained. Each hidden neuron has an associated activation function acting on the weighted sum of inputs it gets from the preceding layer for feeding the result of this function to the subsequent layer and so on until the final output layer. This procedure from the input layer to the output layer is called the feed-forward step. The Backpropagation technique helps in re-adjusting the weights of the network during the learn phase such that the input gets mapped with a more accurate output with a reduced Mean Squared Error. In the process, this results in converging the error to a reasonable margin below a certain threshold (Zadeh, 1965).

TABLE 3 Dataset samples.

Cement (kg/m3)	MP (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)	Water (kg/m^3)	Age (Days)	Compressive strength (kg/m^3)
383	54.6	546	1,187	191.6	7	20.34
369.35	41.04	605.58	1235.78	196.57	90	17.1
319	106.67	671.87	1092.92	192	7	26.45
263.25	87.75	858	1,183	158	90	25.28
358.7	63.3	689	1,278	148	180	47.35
500	156	680	725	255	90	63.3
360	40	644.58	1,199	184	56	52.29
315.2	78.8	707.2	1257.2	158	28	27.78
						Tensile Strength (kg/m3)
405.34	21.33	671.87	1092.92	192	7	3.61
362.67	64	671.87	1092.92	192	14	4.67
320	80	644.58	1,199	184	7	1.75
423.3	22.28	651.76	1172.4	191.6	28	4
337.6	84.4	689	1,278	148	360	6.09
377.65	30	538.09	1194.4	191.6	28	2
380	20	684	1,026	200	28	4.29
316.2	55.8	719.39	1143.528	186	28	2.96

It is this mapping capability of ANNs in complex nonlinear relations that have made them quite applicable in fields like engineering and material sciences, including concrete property predictions. While the number of hidden layers and the number of neurons within each layer are problem-dependent, more complicated problems are modeled with deeper architectures. The model is very sensitive to network performance for proper preprocessing of the data, which must at least involve one step of normalization or standardization, in a way that it could make sure the input features must be well scaled to avoid over-problems within exploding or vanishing phases during backpropagation, including diverse activation functions that will be leveraged for capturing complex conditions, Recent breakthroughs in machine learning add the additional capabilities of accurately predicting concrete characteristics, thereby optimizing material performance by reducing the need for excessive physical tests (Trtnik et al., 2009).

Overall, the training of the ANN should be performed on a partition of data into training, validation, and testing subsets so as not to have any generalization problem or overfitting. The model generalization might get improved by applying some regularization techniques, including dropout, or L2 regularization methods. Generally speaking, more sophisticated optimization algorithms, such as the adaptive methods Adam or RMSprop, should be used, since they ensure faster convergence and improvement in general performance. ANNs are flexible in that they can fit into a wide range of problem domains by changing their architecture and hyperparameters, making them a mighty tool for predictive modeling and pattern recognition.

Recent research has explored the use of artificial intelligence to predict the mechanical properties of various sustainable concretes. For example, Jiang et al. (2023) applied AI to forecast the properties of banana peel-ash and bagasse blended geopolymer concrete, demonstrating the versatility of machine learning in sustainable materials. Other studies have proposed simplified AI-based methodologies for geopolymer concrete mix design (Alaneme et al., 2024a), and critical reviews have highlighted the growing role of AI in optimizing geopolymer concrete production (Alaneme et al., 2024b). Additionally, systematic reviews emphasize the eco-friendly potential of agro-waste-based geopolymer concrete (Alaneme et al., 2023a). Compared to these works, this study integrates marble powder as a cement replacement and combines ANN prediction with blockchain-based material tracking, addressing both performance optimization and supply chain transparency.

TABLE 4 Chemical composition of marble.

SiO_2	CaO	MgO	Al_2O_3	Fe_2O_3	SO_3	Na_2O	LOI	[Ref.]
28.35	-	16.25	0.42	9.7	-	-	-	Abbas (2025)
0.67	53.79	0.71	0.49	0.2	0.09	-	43.72	Selvasofia et al. (2020)
4.99	32.23	18.94	1.09	1.09	0.02	0.63	10.63	Kanhar et al. (2021)
0.94	-	-	-	0.46		-	-	Shukla and Gupta (2019)
0.8	58.1	0.1	0.1	0.2	0.1	-	-	Sharma et al. (2023)
62.48	4.83	2.56	18.72	6.54	-	-	0.48	Mishra et al. (2013)
0.48	55.09	0.4	0.17	0.12	0.06	0.2	43.48	Ali and Hashmi (2014)
28.35	40.45	16.25	0.42	9.7	-	-	-	Kumar and Kumar (2015)
8.38	61.83	14.36	0.67	0.65	0.33	0.6	13.02	Vaidevi (2013)
4.99	32.23	18.94	1.09	1.09	0.02	0.63	40.63	Zhang et al. (2020)
-	51.49	0.36	0.7	0.33	0.1	0.19	44.6	Chavhan and Bhole (2014)
1.29	52.46	0.54	0.39	0.78	-	-	-	Sounthararajan and Sivakumar (2013a)
-	55.45	-	-	0.67	-	-	43.58	Ofuyatan et al. (2019)

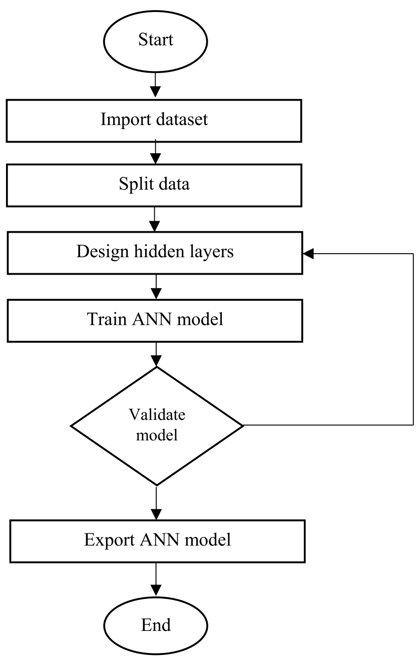

FIGURE 4
Flowchart of training.

Though previous work on ANN-based concrete strength prediction exists, few have brought together AI-based prediction and blockchain technology for tracking and sustainability in material sources and construction. This paper presents a novel approach by combining ANN with Blockchain-Rock to predict the mechanical characteristics of marble powder concrete as well as providing transparency and security in material sources and construction. This dual approach encourages real-time mix design decision-making and addresses sustainability challenges in construction.

2 Construction materials digitalization

Future megatrends, that is, urbanisation, resource efficiency, as well as globalisation, are transformative drivers with far-reaching social, economic, business, culture, as well as human impacts. Specifically, digital technologies are remaking these areas in all industries as well as on all continents. Work methods (see Table 2) in design as well as construction have been changed by digitalization (see Figure 2) with highly accurate models that allow planning, designing, constructing, assembling, operation, as well as maintenance (Papayianni and Pachta, 2017).

However, construction material development as well as construction methods have not followed that of architecture and civilizations. All construction technologies developments have in turn relied on construction material (Rajesh et al., 2024), although its sustainability is not always prioritized. The impact buildings have on nature is not realized by society (Papayianni et al., 2016) as much as it is supposed to be. In consideration of digitalization as well as sustainability, construction material as well as construction technologies increasingly have to be reevaluated with consideration towards a more healthy environment.

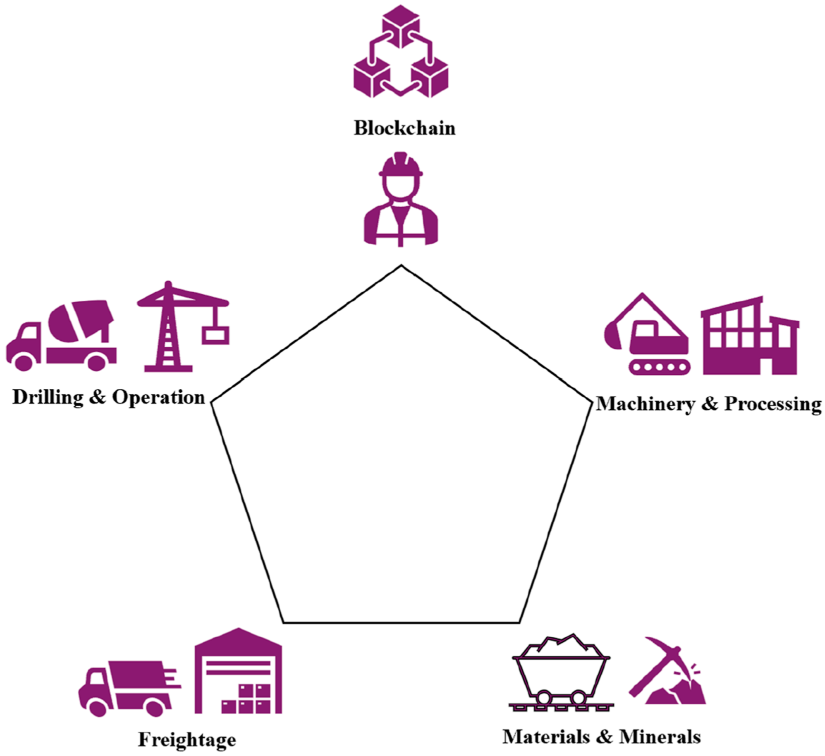

FIGURE 5
Minerals industry blockchain-rock processes.

TABLE 5 Emerging technologies in construction.

Technology	Application	Benefits
Artificial intelligence (AI)	Predictive analytics, risk management, design optimization, safety monitoring	Reduces costs, improves accuracy, enhances safety, and optimizes resources
Building information modeling (BIM)	3D modeling, clash detection, 5D cost and time integration	Improves collaboration, reduces errors, and enhances project planning
Robotics and automation	Bricklaying, welding, site inspections, autonomous drones	Addresses labor shortages, improves precision, and reduces human error
Digital twins	Virtual project replicas, real-time monitoring, predictive maintenance	Enhances decision-making, reduces downtime, and improves project outcomes
IoT and sensors	Real-time data collection, equipment monitoring, environmental tracking	Improves resource management, reduces waste, and enhances safety
Generative AI	Automated design, 3D modeling, compliance checking	Reduces design time, improves accuracy, and ensures regulatory compliance
Cloud-based collaboration	Real-time data sharing, project management, workflow optimization	Enhances collaboration, improves efficiency, and streamlines communication

Several innovations have been made known, and scholars from a variety of disciplines are enthusiastic. Some are developments in deep learning, having big data available for benchmarks, as well as algorithmic developments in terms of activation functions, initialization schemes in weights, as well as improved schemes in terms of optimization. To sense damage in structures (Selvasofia et al., 2020) (Kanhar et al., 2021), cracking in concrete (Shukla and Gupta, 2019) (Sharma et al., 2023), structural elements in bridges (Mishra et al., 2013), in asphalt (Ali and Hashmi, 2014), tunnels (Kumar and Kumar, 2015), towers in transmission

(Vaidevi, 2013), as well as ceiling (Zhang et al., 2020), civil engineers have utilized new computer science. The construction sector is far from leading in terms of innovation as a sector because it lacks creativity as well as innovation, as well as more importantly, poor sustainability performances (Chavhan and Bhole, 2014). Innovations involve a broad spectrum of transformative systems such as AI as well as ANN, which can assist in the growth of the construction sector, but whose prospect is eroded by a lack of internet-based data.

Use of marble powder as cement substitute is critical in light of environmental impacts from dumping marble waste as well as construction sector sustainability objectives construction sector is increasingly interested in sustainability. In cement, marble powder, a high surface area material that is a by-product from marble grinding, can be a cement substitute, application of marble powder as cement substitute holds promise in terms of cost as well as environmental impacts in conformity with sustainable construction (Khodabakhshian et al., 2018; Khan et al., 2022; Nega et al., 2023).

629 entries (see Figure 3 and Table 3) (Shukla and Gupta, 2019; Sharma et al., 2023; Mishra et al., 2013; Ali and Hashmi, 2014; Kumar and Kumar, 2015; Vaidevi, 2013; Zhang et al., 2020; Chavhan and Bhole, 2014; Ofuyatan et al., 2019; Ghani et al., 2020; Lezzerini et al., 2022; Chandrasekaran, 2017; Gopi et al., 2017; Rao, 2016; Dhanalakshmi et al., 2022; AshaLak et al., 2019; Chandrakar and Singh, 2017; Majeed et al., 2021; Sharma et al., 2019; Shirule et al., 2012; Pal et al., 2016; Singh et al., 2019; Ris et al., 2014; Southararajan and Sivakumar, 2013b; Latha et al., 2015) from available studies on Marble powder (MP) effects on cement as well as durability in concrete have been utilized in this research. Waste management. To promote not just the mechanical properties but also sustainability in concrete, cement in varying ratios replaced these. The output parameter in the database was concrete strength, with input parameters consisting of cement quantity, quantity of fine aggregate (FA), quantity of coarse aggregate (CA), water, Marble powder substitute ratios as well as age in curing.

2.1 Blockchain-rock

Blockchain is an integrated decentralized database made up of multiple technologies in which every node in the chain stores the entire database and ensures data consistency through hash algorithms, digital signatures, consensus protocols, smart contracts, and peer-to-peer networks (Hautala et al., 2017; Wu and Margarita, 2024). Consensus algorithms enable all the nodes to verify blocks and ensure secure and transparent data management. With its distributed data storage architecture and cryptography-based security features, blockchain provides open, tamper-evident, and trackable access to data and thus is a disruptive technology that decentralizes the management of trust and redefines cyber technology (Hautala et al., 2017; Kaur et al., 2021). It has drawn significant interest in cryptocurrencies, smart cities, and the Internet of Things. Technologically, blockchain redefines the recording, storage, and management of data and enables the shift from an information-based Internet to a value-based Internet. Marketwise, its decentralized and transparent nature reduces the use of intermediaries and the costs of trust and encourages economic efficiency (Hautala et al., 2017).

Blockchain technology can facilitate in-depth end-to-end tracing of minerals and ores. This involves marking sealed containers or ore and concentrate bags with a special number later to be entered into the blockchain. This number will be updated regularly with a constant timeline tracking and recording movement and information on the quality and quantity of each parcel of ore or concentrate. This will have two immediate applications: first, it will bring confidence to clients in the movement of valuable minerals, and secondly, it will make it easy to verify that minerals purchased are from conflict- and law-abiding sources (Ali et al., 2020).

Blockchain-Rocks focuses on utilizing blockchain technology in the sedimentary rock layers supply chain. This use ensures transparency, security, and efficiency in tracking the distribution and sales of rock formations and other minerals. Some of the key principles involved are:

1. Cryptography–Ensures confidentiality and integrity of transactions.
2. Decentralization–Takes away centralized power, allowing users to independently validate transactions.
3. Consensus Mechanism–All transactions are confirmed as a group to ensure accuracy and prevent unauthorized modifications.

Construction and demolition waste (CDW) in the European Union (EU) accounts for approximately a third of all the waste in the region. This issue is further aggravated by inadequate treatment and management where much of the waste is unable to be reused in the value chain. Efficient management of CDW by appropriate handling and material recycling can reap huge dividends in sustainability, quality of life, and economic development. Strengthening the demand for recycled materials can further contribute to the construction and recycling industries. One of the principal barriers, however, lies in the lack of digital competences—44% of the population and 37% of the workforce in the EU lack the basic level of digital competences as per the European Commission (Onifade et al., 2024).

The rising rate of waste production poses difficulties in identifying appropriate destinations for proper waste management. While technological advancement in the shape of the Internet of Things (IoT) and smart sensors can facilitate data collection, it does not necessarily imply correct and secure data handling on its own. The immense amount of data requires credibility and security in information transfer between the stakeholders where the use of Blockchain technology becomes essential (Cristóbal García et al., 2024).

Blockchain has been widely applied in recent times in a number of fields, most prominently in environmental sustainability. It offers huge advantages in strategic planning, environmental tracking, logistics, and green supply chain management. Besides this, the application of Blockchain in urban circular economies ensures data integrity and security in smart cities (Casino et al., 2019).

The basis of 21st-century social and economic development will be digital technology. Therefore, it becomes essential to make use of their full potential in order to sustain an economy in favor of society and the environment (Kshetri, 2018).

3 Materials & methods

3.1 Research and data retrieval methodology

The ANN data were manually gathered by looking at several Marble publications. A thorough literature study was carried out in order to develop a reliable framework for forecasting the compressive and tensile strength of concrete using artificial neural networks (ANNs) see Figure 2 and Table 4. Targeted were important research that highlighted the function of supplemental cementitious materials (SCMs) in environmentally friendly building. The following standards were met by the data collection:

- Publications with peer review
- Research must be published within the recent years.
- Studies that specifically examined the use of marble powder in the mix design.

The following retrieval method was used to create a dataset of 629 items from different academic journals:

3.2 Data selection criteria

Several important criteria served as a guide for the inclusion of works in this domain:

3.2.1 Relevance to sustainable construction

- The research must address critical issues such as of Marble for enhanced concrete durability, mechanical strength, and eco-friendliness.
- Studies providing insights into optimizing concrete mix designs using ANNs were prioritized.

3.2.2 Methodological consistency

- The chosen research must use strong, repeatable procedures, such as cutting-edge data science methods.
- Studies showing creative ANN uses to capture intricate nonlinear correlations in concrete characteristics were highly regarded.

3.2.3 Significance and practical impact

Studies that offered workable answers—like lessening the need for physical testing or improving real-time decision-making in concrete mix design—were given preference.

3.3 Information sources

The following sources were considered reliable and relevant for the study:

- Studies carried out in laboratory or real-world conditions, as long as they met strict quality requirements.
- Research from reputable scholarly publications, conferences, and organizations that focus on sustainable building and civil engineering.
- Data and reports from recognized organizations, such as industry standards committees and environmental authorities, that are accessible to the public.

3.4 Algorithm

The algorithm used is Levenberg-Marquardt as shown in Equations 1, 2 which is driven from Gauss Newton method the algorithm workflow shown in Figure 4.

J_0 The Jacobian matrix:

$$J_0 = \begin{bmatrix} \frac{\partial f}{\partial \beta_1}(x_1, b_0) & \cdots & \frac{\partial f}{\partial \beta_p}(x_1, b_0) \\ \vdots & \ddots & \vdots \\ \frac{\partial f}{\partial \beta_1}(x_n, b_0) & \cdots & \frac{\partial f}{\partial \beta_p}(x_n, b_0) \end{bmatrix} \quad (1)$$

Levenberg–Marquardt algorithm:

$$w_{k+1} = w_k - \left(J_k^T J_k + \mu I\right)^{-1} J_k e_k \quad (2)$$

The research is based on a dataset of 629 entries collected from literature reviewing previous research in marble powder usage in concrete with the aim of enhancing concrete durability. Marble powder was partially replaced with cement in varying proportions with the aim of rendering sustainability and improving the mechanical properties of concrete. These include cement, FA, CA, water, SCMs, and curing age as input parameters, while the output parameter is the tensile strength of the concrete. Examples of some of the dataset used are shown in Table 2.

Figure 5 Graphical representation of the data collected marble powder was replaced with variable percentage of cement in studies and subsequently, the properties tested include the compressive strength and tensile strength test for their concrete samples. Such tests had given an indication of the possibility of usage of SCMs as a means to increase eco-friendliness in structural concretes by showing even longer service life.

4 Results

It is represented that the ANN models based on I-ANN and II-ANN architecture are trained and tested concerning two metrics-Mean Squared Error and correlation coefficient see Table 5 using 60 hidden neurons which resulted in minimum MSE with maximum predictive accuracy.

Results have shown that the addition of Marble powder increases the Compressive and tensile strength of concrete and generally enhances the durability of concrete. The curing time and water-to-cement ratio were the critical factors in controlling the compressive and tensile strength. ANN performance with testing data turned out to be excellent; hence, this approach is applicable (see Figures 6–10 and Table 6).

4.1 ANN training state plot

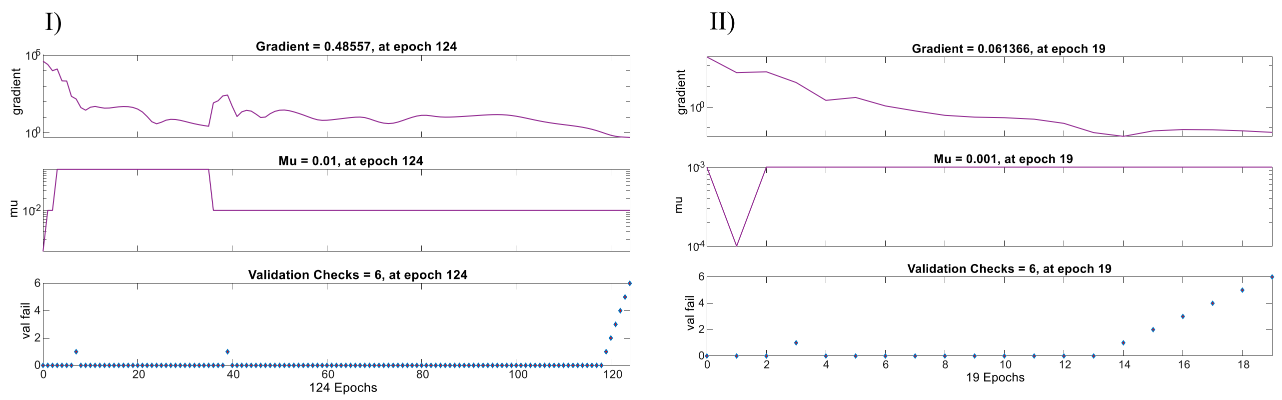

FIGURE 6
Neural network I and II training state.

4.2 ANN Performance plot

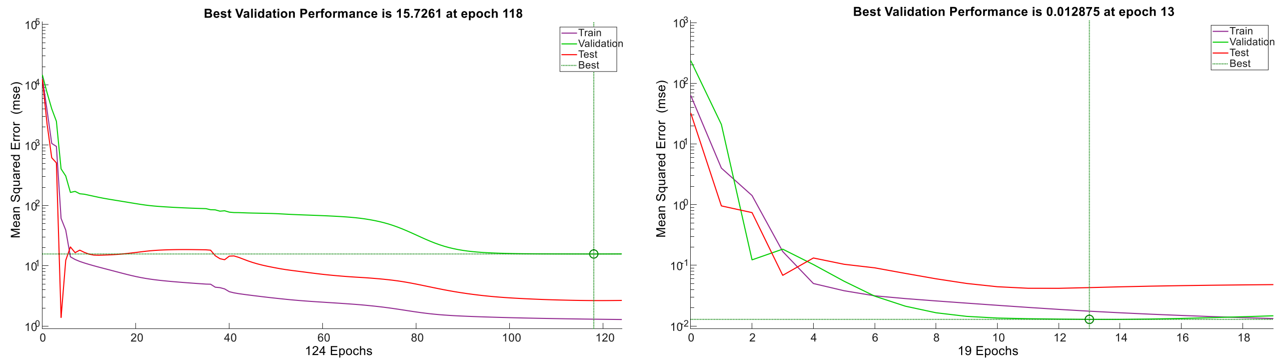

FIGURE 7
Neural network I and II performance plot.

4.3 ANN Error histogram

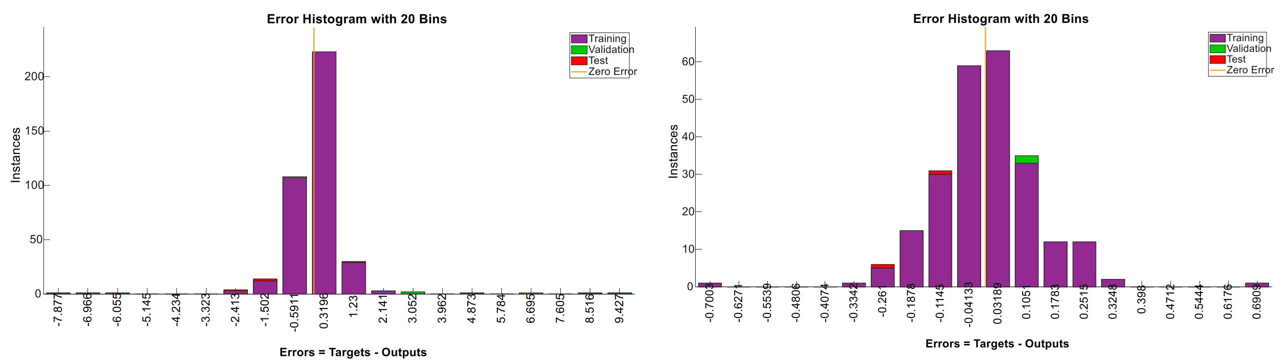

FIGURE 8
Neural network I and II error histogram.

4.4 ANN Bivariate histogram

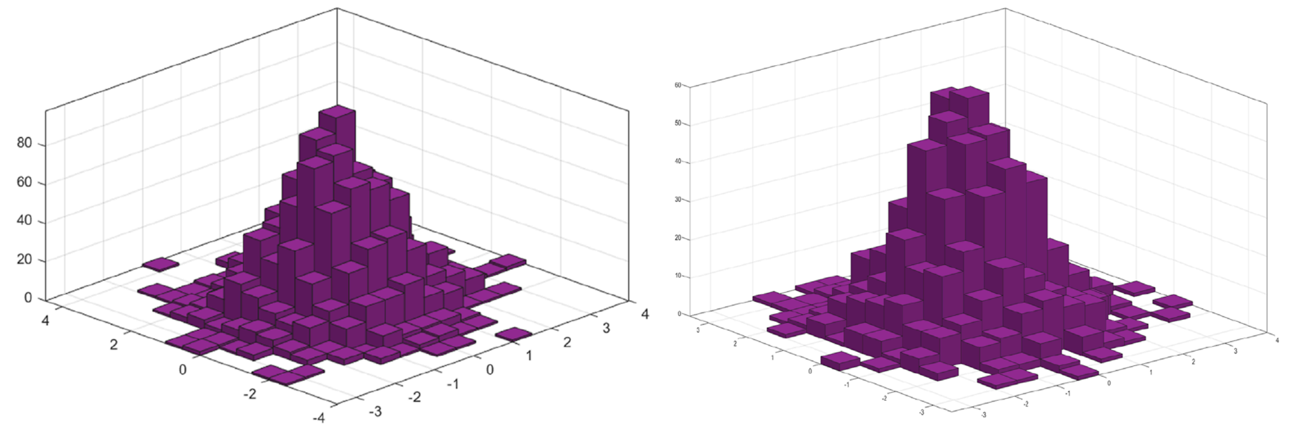

FIGURE 9
Neural network I and II bivariate histogram.

4.5 ANN Regression plot

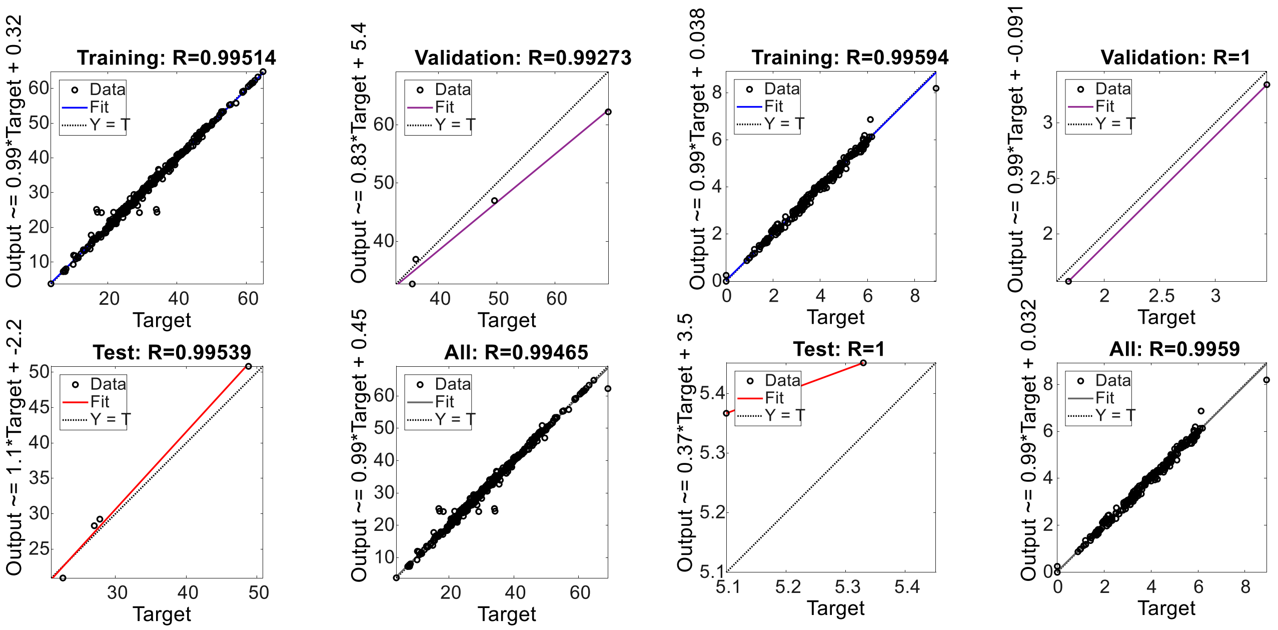

FIGURE 10
Neural network I and II regression plot.

TABLE 6 ANN traning results.

ANN	Training (MSE)	Validation (MSE)	Test (MSE)	Training (R)	Validation (R)	Test (R)
I	1.3056	15.7261	2.6576	0.9951	0.9927	0.9954
II	0.0176	0.0129	0.0430	0.9959	1	1

TABLE 7 Performance comparison of ANN predictive models.

Models	MSE	RMSE	R2
ANN I (proposed)	2.6576	0.9908	0.9954
ANN II (proposed)	0.0430	0.207	1
ANN (Alaneme et al., 2024a)	1.251	1.118	0.985
GRNN (Alaneme et al., 2023b)	-	4.830	0.9198

4.6 Model Comparison

To evaluate the performance of the proposed ANN model, its results were compared with those of a Feedforward ANN model and a General Regression Neural Network (GRNN) regressor. Table 7 summarizes the comparative performance in terms of R^2 and RMSE for compressive strength prediction.

5 User interface

For better usability, an application model was further developed upon the trained ANN. It further allows users to input certain values: marble powder in percentage, cement, time of curing, and finally water to cement ratio against which concrete compressive and tensile strength is predictable. Figure 11 presents the tool providing immediate insight so as to optimize concrete mixing designs and thereby reduce the current dependence on time-consuming, conventional test methods.

6 Summary and conclusion

This study developed and validated an artificial neural network (ANN) model for predicting the compressive and tensile strength of marble powder concrete, using a dataset of 629 samples. The model demonstrated high predictive accuracy, outperforming other machine learning techniques. In addition, the study introduced Blockchain-Rock technology to record and verify data related to material sources, mix designs, and predicted properties, thereby enhancing transparency and traceability in the concrete supply chain.

The integration of ANN and Blockchain-Rock offers a comprehensive solution for sustainable construction. ANN enables rapid and reliable prediction of concrete properties, reducing reliance on lengthy laboratory tests, while Blockchain-Rock ensures secure and tamper-proof documentation of all relevant data. This dual approach improves efficiency, quality assurance, and sustainability in the construction industry. Future research may explore real-time IoT integration and expansion to larger datasets to further enhance predictive accuracy and practical applicability.

By leveraging ANN, construction professionals can make real-time, data-driven decisions that improve material performance and structural reliability. The incorporation of marble powder as a supplementary cementitious material (SCM) further aligns with global sustainability efforts by minimizing waste and reducing cement consumption. Additionally, Blockchain-Rock enhances trust and accountability in material sourcing, reducing environmental and economic risks, for further research approaches:

- Expand the dataset to include a wider range of material properties and mix designs.
- Further optimize ANN architectures to enhance predictive accuracy.
- Explore deeper integration of Blockchain-Rock into construction workflows for improved quality control and lifecycle monitoring.
- Investigate real-time IoT integration to enable dynamic data collection and model updates.
- Continue to advance the combined use of AI and blockchain to drive smarter, more sustainable, and efficient construction practices.

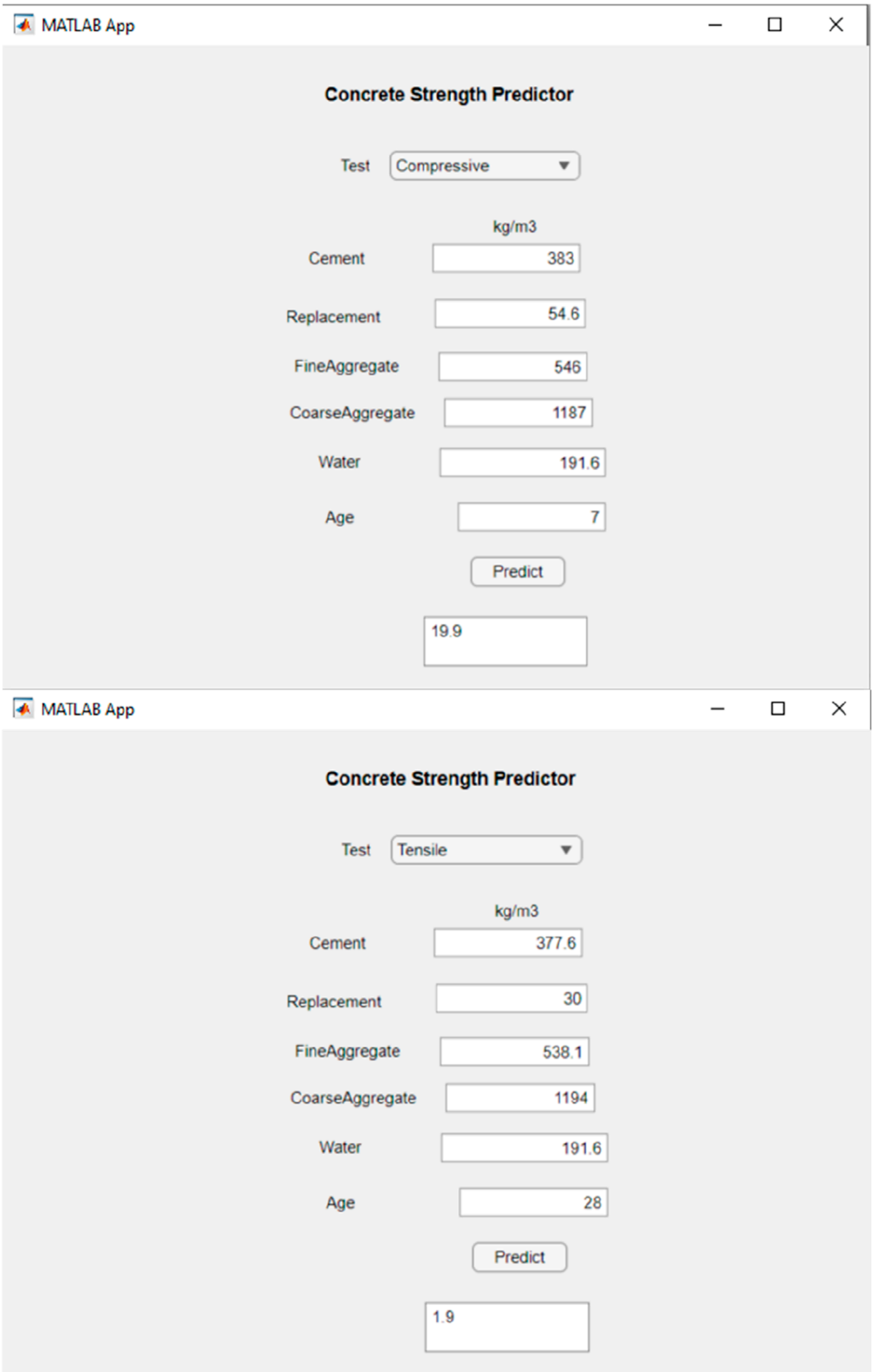

FIGURE 11
The developed application for predicting the compressive and tensile strength of concrete.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

MA: Writing – original draft, Visualization, Software, Investigation, Methodology, Conceptualization. RM: Project administration, Resources, Validation, Formal Analysis, Data curation, Supervision, Writing – review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Generative AI was used in the creation of this manuscript.

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