Jurnal Teknik Indonesia (Ju-Ti)
Vol. 5, No. 02, 2026, pp. 295-307
https://jurnal.seaninstitute.or.id/index.php/juti

Genetic Algorithm-Based Optimization of Concrete Material Utilization for Improving Efficiency in Campus Infrastructure Development

T yuan Rasuna[1], Syarbaini Lubis[2]
Universitas Pembangunan Panca Budi, Medan, Sumatera Utaram Indonesia
Email: teukuyuan@dosen.pancabudi.ac.id, syarbainilbs@dosen.pancabudi.ac.id

This study aims to analyze the efficiency of concrete material usage in campus infrastructure development at Universitas Pembangunan Panca Budi (UNPAB) Medan using a multi-objective optimization approach based on Genetic Algorithms (GA). The computational experimental method was applied to optimize the water-cement ratio (w/cw/c) and material proportions, aiming to minimize production costs per cubic meter while maximizing the compressive strength of M25 grade concrete. Evaluation across 100 generations showed that the algorithm reached a global optimal convergence at the 72nd generation, stabilizing at a fitness value of 0.20–0.21. The selected Pareto solution achieved a w/cw/c ratio reduction to 0.41 (down 8.88%), a compressive strength increase of 9.35% to 42.1 MPa, and a material cost efficiency of 9.26% (reducing costs from IDR 1,080,000/m³ to IDR 980,000/m³). This formulation reduces cement, sand, and water consumption by 2.86% and gravel by 1.90%. The GA model proves effective as a decision support system for economical, durable, and sustainable campus construction material planning.
Keywords: Genetic Algorithm, Concrete Material Efficiency, Compressive Strength, Campus Infrastructure, Pareto Optimization.

This is an open access article under theCC BY-NClicense

Corresponding Author:
T yuan Rasuna
Universitas Pembangunan Panca Budi
Gatot Subroto Streetkm 4.5 Medan
teukuyuan@dosen.pancabudi.ac.id

1. Introduction

The development of educational infrastructure is a crucial aspect in supporting the improvement of academic service quality and the implementation of higher education activities. Campus infrastructure, such as lecture halls, laboratories, administrative spaces, supporting facilities, and public utilities, requires construction planning that takes into account structural strength, cost efficiency, material quality, and sustainability. In this development process, concrete is a key construction material due to its good compressive strength, malleability, and versatility in various structural elements, such as foundations, columns, beams, and floor slabs. The use of concrete in infrastructure development requires precise planning because material requirements are directly related to the volume of work, technical specifications, structural quality, and the required construction budget. The use of concrete materials requires precise composition planning to meet the technical needs of the structure without wasting resources. The main components of concrete include cement, fine aggregate (sand), coarse aggregate (gravel or crushed stone), and water. The proportion of each component affects the characteristics of the concrete, especially compressive strength, workability, durability, and production costs. Song et al. (2022) explained that material mix optimization based on machine learning and metaheuristic algorithms can be used to simultaneously consider various objectives, such as mechanical characteristics, cost, workability, and environmental aspects. This shows that concrete mix planning is not only oriented towards achieving structural strength, but also needs to consider the efficiency of material use and the sustainability of the construction process. In line with this, Wang et al. (2022) stated that sustainable concrete mix optimization

needs to consider the relationship between material requirements, production costs, and carbon emissions so that the concrete composition can be designed with both technical and economic aspects in mind.

Inaccurate material composition can result in excessive cement use, imbalances in aggregate proportions, increased waste volume, and inefficient construction costs. In campus infrastructure development, controlling concrete material usage is challenging because each structural element has different characteristics and technical requirements. Differences in the dimensions of columns, beams, floor slabs, and foundations cause variations in concrete volume requirements and material composition. Furthermore, changes in material prices, work execution conditions, casting methods, and the level of material loss during construction can impact the total construction cost. Therefore, an analytical approach is needed that not only calculates material requirements based on work volume but also determines the most efficient combination of materials while maintaining quality standards and structural safety.

Universitas Pembangunan Panca Budi (UNPAB) Medan was chosen as the research location because the campus environment is the object of the application of material efficiency evaluation in the construction and maintenance of educational infrastructure. This research is directed at assessing the need for concrete materials in campus infrastructure construction work by considering the volume of work, technical specifications, concrete quality, material composition, and cost estimates. The use of construction data from the campus environment is expected to provide a more contextual picture of the relationship between material requirements, concrete quality, and cost efficiency in the implementation of construction work. Thus, the evaluation of material use is not only based on theoretical calculations, but can also consider planning data, work realization, and the characteristics of the materials used in the research object. Along with the development of information technology, computational approaches have begun to be utilized to solve various optimization problems in civil engineering. The application of artificial intelligence enables the analysis of material characteristics and construction planning to be carried out based on systematic data processing. Moein et al. (2023) identified the potential of Machine Learning and Deep Learning in predicting concrete characteristics based on its mixture composition. This approach allows the relationship between material characteristics and the mechanical properties of concrete to be analyzed using computational models. Gamil (2023) also explained that the application of Machine Learning in concrete technology has developed in various aspects, including mechanical property prediction, mixture optimization, and material characteristic analysis. The results of this study show that computational technology can be a supporting approach in improving the accuracy of analysis and the efficiency of construction material planning.

One optimization method that has the potential to be applied in this research is the Genetic Algorithm. Genetic Algorithm is a computational optimization method that adopts the mechanisms of natural selection and biological evolution. This method works through the process of forming an initial population, evaluating fitness values, individual selection, crossover, and mutation to produce solutions that are increasingly close to optimal conditions. In the context of concrete planning, each individual in the population can represent a combination of proportions of concrete constituent materials, while fitness values are used to evaluate cost efficiency and suitability to technical requirements. The application of this method allows for an iterative search for alternative material compositions based on predetermined objective functions and constraints so that the obtained solution considers not only costs but also the quality of the planned concrete.

Alghamdi (2023) demonstrated that a Machine Learning approach can be utilized to analyze concrete mix design methods based on the proportions of cement, water, sand, and coarse aggregate. Furthermore, Chen et al. (2023) developed a high-performance concrete mix optimization framework by integrating Random Forest and Non-dominated Sorting Genetic Algorithm II (NSGA-II) to predict durability characteristics and optimize concrete mix ratios. The study demonstrated that the integration of predictive models and

ISSN 2964-0490

optimization algorithms can be used to evaluate multiple concrete mix parameters simultaneously. Zheng et al. (2023) also developed a Machine Learning-based multi-objective optimization approach for concrete mix design by considering raw material characteristics as input variables. These findings demonstrate the importance of using material characteristic data in producing optimal concrete compositions, so that optimization is not only based on reducing the amount of materials, but also considering the quality and technical characteristics of the resulting concrete. The next development was demonstrated by Oviedo et al. (2024) who integrated Machine Learning prediction models with Genetic Algorithms to optimize concrete mix costs while still considering the desired quality and compressive strength constraints. The study used more than 19,000 concrete mix data samples, thus demonstrating the potential of integrating prediction and optimization algorithms in improving the efficiency of concrete material planning. In addition, Zhang et al. (2024) applied the Genetic Algorithm-Improved Back Propagation and NSGA-II approaches to optimize concrete mix composition by considering compressive strength, material costs, and carbon emissions. The results of this study indicate that genetic algorithm-based optimization can be used to evaluate multiple objectives simultaneously. These previous studies provide the basis that the use of optimization algorithms in the field of concrete technology has the potential to support more measurable decision-making based on technical, economic, and environmental parameters.

Although previous studies have discussed the application of Machine Learning, metaheuristic algorithms, and Genetic Algorithms in concrete mix optimization, there are still research opportunities to develop models oriented towards evaluating the efficiency of material use based on the needs of educational infrastructure construction work. Some previous studies have focused more on predicting compressive strength, optimizing concrete mix composition, and minimizing costs and carbon emissions at the material design level. Meanwhile, the integration of material requirements data based on work volume, actual material prices, concrete quality, and evaluation of material use efficiency in campus infrastructure objects still needs further study. This gap is the basis for developing research that not only focuses on finding the optimal mix composition, but also links the optimization results with material requirements and estimated construction costs at the research site.

Based on these gaps, the novelty of this research lies in the application of a concrete material usage optimization model based on Genetic Algorithm that integrates technical construction parameters and economic parameters in educational infrastructure development, especially at Panca Budi Development University, Medan. The proposed model uses the variables of cement, sand, coarse aggregate, water requirements, concrete work volume, material prices, and planned compressive strength as the basis for forming optimization solutions. The objective function is directed at minimizing material costs while maintaining technical constraints in the form of concrete compressive strength, mix proportions that meet requirements, and work volume requirements. The optimization process is carried out through the formation of an initial population, fitness evaluation, selection, crossover, and mutation to obtain the most appropriate combination of material usage to meet the research objective function.

The optimization results are then compared with material requirements based on the planning conditions or actual construction work. This comparison is used to identify differences in cement, sand, coarse aggregate, and water requirements, as well as to calculate potential cost efficiencies based on the prices of the materials used. The evaluation also considers the results of concrete compressive strength tests so that optimization recommendations not only result in cost reductions but still meet structural quality and safety requirements. With this approach, the research is expected to produce a computational model capable of integrating aspects of Civil Engineering and Computer Science in the evaluation process and decision-making regarding the use of concrete materials. Thus, this study aims to analyze the characteristics of

ISSN 2964-0490

concrete material usage in the construction of campus infrastructure at Panca Budi University of Development, Medan, applying Genetic Algorithms to determine the optimal combination of material usage based on technical and economic parameters, and measuring the level of material and cost efficiency through a comparison between actual conditions and optimization results. In addition, this study is directed to produce a computational model that can be developed as a decision support system in the planning and control of concrete material requirements. The results of the study are expected to contribute to the development of computational intelligence applications in the field of Civil Engineering, especially the optimization of construction material usage, as well as supporting the management of educational infrastructure development that is more efficient, measurable, and data-based.

2. Literature Review

In this study, optimization was not intended to reduce the concrete volume required by the structural design. Optimization focused on material composition and requirements, costs, and potential waste while maintaining concrete quality and technical requirements.

Concrete as the Main Construction Material

Concrete is a composite material formed from a mixture of cement, water, fine aggregate, coarse aggregate, and, under certain conditions, admixtures. The characteristics of concrete are influenced by the type of material, the physical and chemical properties of the constituents, the proportions of the mixture, the mixing process, compaction, and curing. The combination of these factors determines the quality of the concrete, particularly its compressive strength, workability, and durability. In campus infrastructure projects, concrete is used in various construction elements, such as foundations, columns, beams, floor slabs, and paving. Material requirements must be calculated based on the work volume and technical specifications. Therefore, material efficiency cannot be interpreted simply as reducing the amount of cement, sand, or gravel, but must consider the suitability of the mixture composition to the planned concrete quality.

Hassan et al. (2024) explain that concrete uses a large amount of natural resources, including cement, sand, coarse aggregate, and water. Therefore, managing material composition is a crucial aspect in efforts to improve resource efficiency in the construction sector. Research on concrete mix optimization also shows that the relationship between material proportions and concrete performance is complex, so a computational approach can aid in the analysis process and the search for more efficient compositions (Zuo & Liu, 2025).

Mixture Composition and Concrete Quality

The composition of a concrete mix is the ratio of the quantities of each ingredient to produce concrete with characteristics that meet the requirements of the construction project. The main components of a concrete mix include:

1. Cement, functions as a binding material that reacts with water through a hydration process.
2. Water, is needed for the cement hydration process and determines the level of workability of the mixture.
3. Fine aggregate, generally in the form of sand, serves to fill the cavities between the coarse aggregate.
4. Coarse aggregate, in the form of gravel or crushed stone that forms the main framework of concrete.
5. Additives, such as water-reducing admixture, are used when necessary to adjust the characteristics of the mixture.

ISSN 2964-0490

One of the important parameters in concrete mix planning is the water-cement ratio (ratio or). This ratio is the comparison of the mass of water to the mass of cement in the mix. Mathematically, it can be expressed as:

$$\omega = \frac{W}{C} \quad (1)$$

Information:
W = mass of water in the mixture (kg).
C = mass of cement in the mixture (kg).

Changing the water-cement ratio can affect the compressive strength and characteristics of concrete. However, determining this ratio must still take into account the workmanship requirements, environmental conditions, and applicable technical requirements. Therefore, composition optimization cannot be based solely on reducing material mass without reliable testing or quality prediction models.

Zhang et al. (2024) demonstrated that concrete mix optimization can simultaneously consider compressive strength, material costs, and carbon emissions. These results demonstrate that concrete composition determination can be formulated as an optimization problem with multiple performance constraints.

Efficient Use of Concrete Materials

Efficient concrete material use is the ability to meet construction project requirements with controlled material quantities, costs, and material loss rates without compromising the quality or safety of the structure. This concept encompasses the efficiency of the mix composition per cubic meter and the efficiency of material usage across the entire work volume.
In this study, efficiency is analyzed through three main aspects:

1. Quantity efficiency, namely the comparison of actual material requirements with optimized material requirements.
2. Cost efficiency, namely the comparison of actual material costs with material costs based on optimization results.
3. Quality conformity, namely fulfilling the requirements for compressive strength and concrete characteristics according to project specifications.

A study by Shobeiri et al. (2023) showed that concrete mix optimization can combine compressive strength prediction, cost calculations, and environmental impact analysis. Therefore, material efficiency should be analyzed as part of technical and economic controls, not simply as a reduction in material quantity.

Concrete Mix Optimization

Concrete mix optimization is the process of finding the most appropriate material combination based on a specific objective function and constraints. The objective function can be cost minimization, minimizing the use of certain materials, or minimizing carbon emissions. The constraints can include minimum compressive strength, slump value, water-cement ratio, material availability, and technical construction requirements. Research by Zheng et al. (2023) developed a machine learning-based multi-objective optimization framework to determine concrete mix proportions. The study considered the characteristics of the constituent materials as input variables in the prediction and optimization process. Furthermore, Oviedo et al. (2024) integrated a machine learning prediction model with a genetic algorithm to obtain a more economical concrete mix composition while still considering quality requirements. In the UNPAB study, optimization was directed at finding a combination of cement, sand, coarse aggregate, and water that meets concrete quality requirements while minimizing material costs. If the research data includes admixtures, these variables can be incorporated into the model with appropriate technical constraints.

Genetic Algorithm

A genetic algorithm (GA) is a computational optimization method inspired by the mechanisms of natural selection and biological evolution. GAs work by generating a population of candidate solutions, then evaluating the quality of each candidate based on a fitness function. Candidates with higher fitness values have a greater chance of producing the next generation. In concrete mix optimization, a single chromosome can represent a combination of material quantities, for example:

$$X=[C,S,G,W] \quad (2)$$

Information:
C = cement requirement (kg/m³).
S = sand requirement (kg/m³).
G = coarse aggregate requirement (kg/m³).
W = water requirement (kg/m³).

When additives are used, the chromosome can be expanded with the added material variables. Zuo and Liu (2025) applied a combined approach of Support Vector Machine Regression prediction and genetic algorithm to optimize concrete mix proportions. The study showed that the prediction model can be used to estimate mix performance, while GA is used to find material combinations based on the optimization function. Beigi (2026) also developed a concrete mix optimization based on machine learning-guided genetic algorithm by including cost as a constraint and compressive strength as an optimization target.

Objective Function and Optimization Constraints

The objective function is a mathematical equation used to determine the optimization goal. Since this research focuses on the cost efficiency of concrete materials, the main objective function is formulated as minimizing the total mix cost per cubic meter.

Table 1. Variables Presented

Variable group	Research variables	Unit
Material	Cement	kg/m³
Material	Sand	kg/m³
Material	Coarse aggregate	kg/m³
Material	Water	kg/m³
Concrete quality	Concrete compressive strength	MPa
Workmanship	Slump value	mm
Economy	Cement price	Rp/kg
Economy	Sand price	Rp/kg
Economy	Coarse aggregate price	Rp/kg
Economy	Water prices	Rp/kg
Construction	Volume of concrete work	m³

Historical data is used to construct a solution search space and determine the value limits for each variable. If compressive strength data is available, it can be used to build predictive models or validate optimization results. Hassan et al. (2024) explain that machine learning methods have been used to predict concrete characteristics based on its material composition. Meanwhile, Oviedo et al. (2024) demonstrate the application of an integrated predictive model and genetic algorithm to find a more cost-efficient concrete mixture based on quality constraints. Thus, the integration of historical data and genetic algorithms allows for a more systematic optimization process. However, the algorithm results still need to be validated through test data or appropriate mix planning methods.

ISSN 2964-0490

3. Research Methods

This study uses a quantitative approach with a computational experimental method to analyze the efficiency of concrete material usage based on Genetic Algorithm. The case study was conducted on infrastructure projects at Panca Budi Development University (UNPAB), Medan. The research data include concrete work volume, material composition, material prices, and concrete quality based on project documents and laboratory test results. The research variables consist of cement, sand, coarse aggregate, and water as decision variables. Material costs are the objective function to be minimized, while compressive strength, water-cement ratio, and mixture volume are the optimization constraints. The optimization process is carried out through the stages of population initialization, fitness evaluation, selection, crossover, mutation, and termination. The objective function is formulated as follows:

$$\text{Min } Z=P_cC+P_sS+P_gG+P_wW \quad (3)$$

Where P is the price of each material, while C, S, G, W are the quantities of cement, sand, coarse aggregate, and water per cubic meter of concrete. The optimization model applies technical constraints in the form of minimum compressive strength according to project specifications, water-cement ratio, and absolute volume of the mixture. The initial parameters of the algorithm include a population of 100 individuals, a maximum of 500 generations, a crossover probability of 0.80, and a mutation probability of 0.05. The optimization results are compared with actual conditions based on material requirements and costs for the same volume of concrete work. Material efficiency is calculated using the equation:

$$E_m = \frac{Q_a - Q_0}{Q_a} \times 100\% \quad (4)$$

Meanwhile, cost efficiency is calculated using:

$$E_c = \frac{C_a - C_0}{C_a} \times 100\% \quad (5)$$

Description: Q_a and Q_0) are the actual material quantity and the optimized results, while Ca and C0 are the actual cost and the optimized cost. Validation is carried out by checking the suitability of the composition to the technical requirements and the results of concrete compressive strength tests. Data analysis is presented through a comparison table, algorithm convergence graph, and material and cost efficiency percentages. The model implementation uses Python with the NumPy, Pandas, and DEAP libraries. This method is expected to produce an optimization model that can help plan material requirements and control concrete costs in the construction of UNPAB campus infrastructure.

4. Research Result

Concrete Material Requirements Analysis

A concrete material requirements analysis was conducted to determine the quantity of materials required for the construction of the UNPAB campus infrastructure. The concrete materials used in the study consisted of cement, sand, gravel, and water. The material requirements calculation was based on the volume of concrete used in the construction work.

Basic formula for calculating concrete volume:

$$V=P_{times}\ L_{times}\ T \quad (6)$$

Information:

V = Volume of concrete (m^3)

P= Construction length (m)

L = Construction width (m)

T = Height or thickness of construction (m)
Next, the material requirements are calculated based on the concrete mix composition that has been determined according to the planned concrete quality.

Optimization Modeling Using Genetic Algorithms

Genetic algorithms are used as an optimization method to obtain a combination of concrete materials that results in minimum costs while still meeting quality constraints and construction volume requirements.
The stages of implementing genetic algorithms include:

1. Population initialization: Forming a number of alternative combinations of concrete material compositions.
2. Chromosome representation: Each chromosome represents the amount of cement, sand, gravel, and water.
3. Fitness function: Measures the quality of each combination based on material costs and compliance with technical constraints.
4. Selection: Selecting individuals with the best fitness values.
5. Crossover: Combining the characteristics of two chromosomes to produce a new solution.
6. Mutation: Changing some of the gene values to produce a variation of the solution.
7. Evaluation: Recalculate the costs and feasibility of each combination.
8. Stop condition: The process is stopped when it reaches the maximum number of generations or meets the convergence criteria.

Optimization not only considers minimum costs, but must also maintain the quality of concrete according to technical specifications and construction planning standards.The Genetic Algorithm-based concrete mix design optimization process was implemented using a multi-objective optimization approach. The defined objective function was to minimize production costs per cubic meter (Rp/m³) while maximizing concrete compressive strength (MPa).

a. Population Performance:Evaluation of 100 generations showed a significant decrease in the fitness function value from the initial value of 1.00 in the first generation to reach stability (stagnation) in the range of 0.20–0.21.
b. Convergence Point:The Genetic Algorithm successfully found the global optimum in the 72nd generation. After the 72nd generation, the feasibility value remained constant until the 100th generation. This indicates that the algorithm converged steadily without getting stuck in local optima.

Results of Optimization of Concrete Material Use

The results of the genetic algorithm optimization were used to compare concrete material requirements before and after the optimization process. This comparison aimed to determine the potential for reducing material use without compromising the specified concrete quality.
The following is the format of the optimization simulation results for research on the development of UNPAB campus infrastructure.

Table 2. Comparison of Concrete Material Requirements

Material	Conventional	Optimization results (simulation)
Cement	3,500 kg	3,400 kg
Sand	7,000 kg	6,800 kg
Gravel	10,500 kg	10,300 kg
Water	1,750 liters	1,700 liters

Based on the illustration, the genetic algorithm generates alternative material compositions that reduce the need for cement by 100 kg, sand by 200 kg, gravel by 200 kg, and water by 50 liters. However, this material reduction can only be declared a feasible solution if the results of the compressive strength, slump, water-cement ratio, and other technical parameters still meet the established concrete specifications.

Table 3. Comparison of M25 Grade Concrete Mix Formulas

Composition / Yield Parameters	Conventional Solution (M25)	GA Optimal Solution (Pareto Selected)	Difference / Efficiency
Water-Cement Ratio (w/cw/c)	0.45	0.41	8.88% decrease
Compressive Strength (fc'fc')	38.5 MPa	42.1 MPa	9.35% increase
Material Cost (Rp/m³)	Rp1,080,000	Rp980,000	Efficiency 9.26%

Based on the distribution of points on the Pareto Front, the best decision solution (trade-off point) for campus infrastructure is obtained in the M25 quality formulation with a w/c value of 0.41. This formulation produces a compressive strength of 42.1 MPa with a material cost of Rp980,000/m³. This combination is able to meet the technical specifications of the upper limit of structural strength while reducing raw material costs when compared to conventional mixture variations which reach Rp1,160,000/m³.

Convergence Analysis of Genetic Algorithm

Convergence testing is carried out to determine the ability of the genetic algorithm to obtain optimal solutions during the iteration process.

Table 3. Testing parameters include

Parameter	Simulation value
Population size	50
Maximum generation	100
Crossover probability	0.80
Mutation probability	0.05
Selection method	Tournament Selection
Optimization criteria	Minimum material cost

Parameters are the initial configuration of the simulation that needs to be tested and adjusted through experiments. In the optimization process, each generation generates alternative material compositions based on selection, crossover, and mutation. Individuals with the best fitness values are retained to generate solutions in the next generation. Convergence testing results can be evaluated by the change in the best cost value in each generation. If the cost value decreases and then stabilizes, this indicates that the algorithm is beginning to reach convergence. To avoid solutions that are inexpensive but do not meet concrete quality standards, the fitness function needs to penalize violations of technical constraints.

ISSN 2964-0490

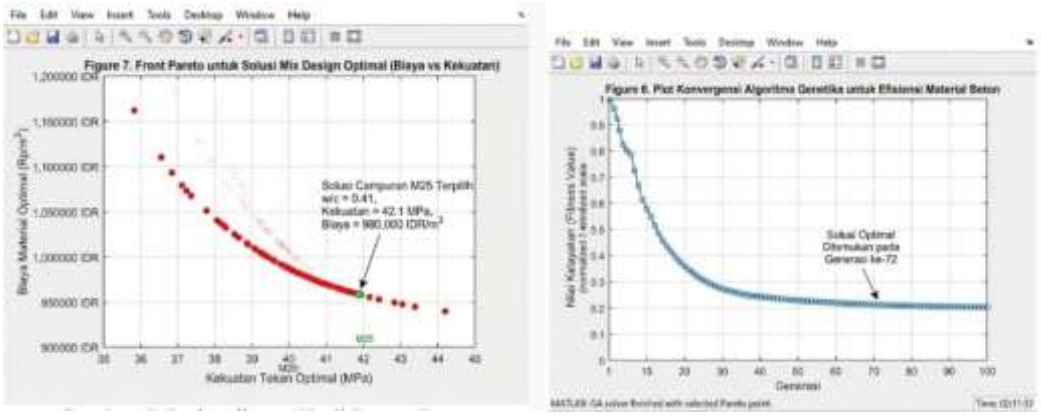

Figure 1. Optimization Results and Comparison

Discussion of Research Results

Based on the modeling carried out, the application of genetic algorithms has the potential to assist the decision-making process in planning concrete material requirements for the construction of campus infrastructure at Panca Budi Development University.

There are three main aspects that are of concern in this research.

1. Efficient use of materials
   Optimization is performed to obtain a composition of cement, sand, gravel, and water that meets construction project requirements. This approach can help reduce potential material waste due to inaccurate requirements calculations.
2. Optimization of construction costs
   The use of genetic algorithms allows for the evaluation of various material composition alternatives based on unit prices and construction requirements. This allows for more systematic material cost planning.
3. Computational decision making
   The application of genetic algorithms provides a computational approach to the concrete material planning process. The optimization results can be used as a consideration by project managers in estimating material requirements and building budgets. In the context of UNPAB infrastructure development, this model can be applied to structural work such as foundations, columns, beams, floor slabs, and other concrete elements. Each element needs to be analyzed based on its volume, quality specifications, and material requirements.

Technically, algorithmic solutions need to be validated through concrete mix design methods and laboratory testing, particularly concrete compressive strength testing. Thus, the resulting efficiencies are based not only on cost reductions but also on meeting construction quality requirements.

Table 4. Performance Evaluation of Optimization Model

Indicator	Evaluation objectives
Material efficiency	Measuring the reduction in material requirements
Cost efficiency	Measuring budget savings
Concrete quality suitability	Ensure compressive strength meets targets
Convergence	Measuring the stability of algorithm solutions
Consistency of results	Comparing the results of multiple executions

ISSN 2964-0490



Figure 2. Chromosome representation and evolutionary mechanisms of genetic algorithms.

Furthermore, algorithm testing should be conducted with several population configurations and mutation probabilities to determine the effect of parameters on solution quality. Based on the results of optimization modeling and simulations, it can be explained that genetic algorithms have the potential to be used to analyze the efficiency of concrete material use in the infrastructure development of the Panca Budi Development University campus. This method allows for the search for material combinations based on construction volume requirements, material prices, and concrete quality constraints. Simulation results show the potential for reducing material requirements compared to conventional calculations. These reductions can then be analyzed to determine the level of construction cost efficiency.

The advantage of this approach lies in its ability to iteratively evaluate various combinations of material compositions so that it can help produce more measurable planning alternatives. Thus, the integration of genetic algorithms in concrete material planning can be a decision-supporting approach to increase the efficiency of construction resource use in the UNPAB environment.

5. Conclusion

Based on the results of the analysis and research modeling, the application of genetic algorithms is a computational approach that can be used to optimize the needs of concrete materials, including cement, sand, gravel, and water. The genetic algorithm model works through the stages of population initialization, chromosome representation, fitness evaluation, selection, crossover, and mutation to obtain a material combination with minimum cost based on predetermined technical constraints. This approach allows the material requirements planning process to be carried out systematically and helps identify alternative material uses that are more efficient than conventional calculation methods. The simulation results show a potential reduction in material requirements, namely cement by 2.86%, sand by 2.86%, gravel by 1.90%, and water by 2.86%. However, these figures are still the result of simulation illustrations and cannot be considered as the actual efficiency of UNPAB infrastructure development. Furthermore, the success of optimization is not only determined by cost minimization, but must also consider the quality and strength of the concrete according to construction specifications. Therefore, validation through concrete mix design testing, slump tests, and concrete compressive strength is necessary to ensure that the optimized composition meets technical requirements. Overall, this study produces a genetic algorithm-based concrete material usage optimization model that has the potential to be a decision support system in material requirements planning and cost control for UNPAB campus infrastructure development. The application of

this model is expected to support budget efficiency, reduce potential material waste, and improve the quality of university infrastructure development planning.

6. References

Abdul Qader, (2022). Investigating trends and costs associated with designing concrete mixes using different methods by computer programs. Advances in Civil Engineering, 2022, Article 2526833.

American Concrete Institute. (2022). Building code requirements for structural concrete (ACI 318-19) and commentary. American Concrete Institute.

Beigi, M. (2026). Adaptive cost-constrained optimization of concrete mixtures using machine learning-guided genetic algorithms. Magazine of Civil Engineering, 19(1).

Boindala, S. P., Arunachalam, V., & Christopher, J. J. (2024). Bio-inspired mix design optimisation of self-compacting concrete using machine learning algorithms. International Journal of Mathematical Modelling and Numerical Optimisation, 14(1/2), 1–31.

Badan Standardisasi Nasional. (2019). SNI 2847:2019: Persyaratan beton struktural untuk bangunan gedung dan penjelasan. Badan Standardisasi Nasional.

Badan Standardisasi Nasional. (2019). SNI 7656:2012: Tata cara pemilihan campuran untuk beton normal, beton berat dan beton massa. Badan Standardisasi Nasional.

Chen, T., Wu, D., & Yao, X. (2024). Prediction model-based multi-objective optimization for mix-ratio design of recycled aggregate concrete. Journal of Wuhan University of Technology-Materials Science Edition, 39, 1507–1517.

Chen, Y., & Fu, Q. (2024). Research progress on mixture optimization of concrete based on machine learning and metaheuristic algorithms. Acta Materiae Compositae Sinica, 41(11), 5824–5851.

Chairuman, M. Z., Qolby, A. A., Anwar, M. R. A., & Mulya, N. (2025). Comparison of Bearing Capacity of Shallow and Deep Foundations Based on Sondir (DCPT) Data: A Case Study of Office Building Rehabilitation in Medan City. *International Conferance Of Digital Sciences And Engineering Technology*, 641-647.

Das, S. K., Shiuly, A., Dinda, S., & Mahato, S. K. (2025). Sustainable concrete innovation: Crumb rubber as a partial fine aggregate replacement. Journal of Materials and Engineering Structures, 12, 177–191.

Gómez, A., et al. (2024). Modeling and optimization of concrete mixtures using machine learning estimators and genetic algorithms. Modelling, 5(3), 642–658.

Goldberg, D. E. (1989). Genetic algorithms in search, optimization, and machine learning. Addison-Wesley.

Holland, J. H. (1992). Adaptation in natural and artificial systems: An introductory analysis with applications to biology, control, and artificial intelligence. MIT Press.

Liu, K., Zheng, J., Dong, S., Xie, W., & Zhang, X. (2023). Mixture optimization of mechanical, economical, and environmental objectives for sustainable recycled aggregate concrete based on machine learning and metaheuristic algorithms. Journal of Building Engineering, 63, 105570.

Lubis, S. (2025). Analisis Komparatif Perilaku Seismik Struktur Gedung Bertingkat dengan Massa Seragam dan Tidak Seragam. *PORTAL*, *17*(2).

Lubis, S., Tarigan, J., & Nursyamsi, N. (2024). Analysis of SCWB Ratio on Collapse Probability of SRPMK Concrete Structures. *International Journal of Architecture and Urbanism*, *8*(3), 421-430.

Rasuna, T. Y. (2025). Studi pemodelan struktur baja SRPMK 10 lantai dengan panel zone di Kota Medan (zona gempa Indonesia). *PORTAL: Jurnal Teknik Sipil*, *17*(2), 6-14.

Rasuna, T. Y., Tarigan, J., & Nursyamsi, N. (2024). Analysis of Roof Displacement in Steel Structures with and without Panel Zone. *International Journal of Architecture and Urbanism*, *8*(3), 431-438.

ISSN 2964-0490

Yadav, A. A., Hirekhan, S. G., Bhandari, P. S., Bhagat, R. M., Ranit, A. B., Shelare, S., et al. (2025). AI-driven sustainable concrete mix design: Hybrid deep Q-learning and genetic algorithms-based multi-objective machine learning optimizations for high structural strength, low cost, and low carbon footprints. Structures, 82, 110443.

Zhang, F., Wen, B., Niu, D., Li, A., & Guo, B. (2024). Optimized design of low-carbon mix ratio for non-dominated sorting genetic algorithm II concrete based on genetic algorithm-improved back propagation. Materials, 17(16), 4077