SUSTAINABLE MACHINE INTELLIGENCE JOURNAL

A Neutrosophic Multi-Criteria Model for Evaluating Sustainable Soil Enhancement Methods and their Cost Implications in Construction

Ahmed A. El-Douh[1,*], SongFeng Lu[2], Ahmed Abdelhafeez[3], and Alber S. Aziz[4]

[1] Faculty of Information, Systems and Computer Science, October 6th University, Cairo, 12585, Egypt; ahmed.eldouh.csis@o6u.edu.eg.

[2] School of Cyber Science and Engineering, Huazhong University of Science and Technology, Wuhan 430074, China; lusongfeng@hust.edu.cn.

[3] Faculty of Information Systems and Computer Science, October 6th University, Cairo, 12585, Egypt; aahafeez.scis@o6u.edu.eg.

[4] Faculty of Information, Systems and Computer Science, October 6th University, Cairo, 12585, Egypt; albershawky.csis@o6u.edu.eg.

* Correspondence: ahmed.eldouh.csis@o6u.edu.eg.

Event	Date
Received	08-06-2023
Revised	03-09-2023
Accepted	18-10-2023
Published	25-10-2023

Abstract: This paper provides a comprehensive overview of the application of life cycle assessment (LCA) to promote sustainable soil practices in construction foundation projects. The aim is to evaluate the environmental impact and long-term sustainability of soil-related activities in construction through the lens of LCA. This assessment encompasses a wide array of factors, including soil quality, erosion control, contaminant remediation, soil stability, conservation, drainage management, and compliance with regulatory standards. To address this multifaceted evaluation, we employ a multi-criteria decision-making (MCDM) model, specifically introducing the Multi-Attributive Border Approximation Area Comparison (MABAC) method. This MCDM technique is utilized to appraise the sustainability of soil practices and is integrated with a neutrosophic set to handle imprecise information. Our study incorporates nine criteria and eight alternative methods. Through the application of LCA, construction professionals can uncover strategies to minimize the carbon footprint of their projects, optimize soil utilization, and enhance the long-term resilience of their structures. Achieving a comprehensive LCA tailored to the specific requirements of each project and local regulations necessitates close collaboration between soil engineers, environmental experts, and construction practitioners.

Keywords: Sustainability, Life Cycle Assessment, multi-criteria decision-making (MCDM), Neutrosophic set, Multi-Attributive Border Approximation Area Comparison (MABAC), Environmental Impacts, Construction Foundation.

1. Introduction

Responsible and long-lasting building methods need the careful and long-term management of soil for use in foundations. The quality, stability, and long-term performance of the soil directly affect the structural integrity and sustainability of the built environment, since the soil is the primary support system for buildings and structures. Soil quality, erosion control, contaminant cleanup, soil stability, conservation, drainage management, and regulatory compliance are just a few of the aspects of building foundations that must be considered while assessing sustainable soil practices [1], [2].

By evaluating sustainable soil practices in building foundations, we can lessen the negative effects on the environment and make better use of soil materials. In addition to preserving the foundation's strength and longevity, sustainable soil management also takes into account the soil's fertility, biodiversity, and ecosystem services. Sustainable soil practices may help construction sites avoid soil erosion, lessen the likelihood of soil contamination, improve compaction and stabilization methods, and exercise more conscientious water management [3], [4].

Physical, chemical, and biological aspects of the soil, as well as its background and potential for contamination, are all taken into account throughout the assessment process. Soil erosion may be avoided before, during, and after building by using erosion control methods including retaining walls and vegetation cover. Soil stabilization methods including compaction, stabilizing chemicals, and geosynthetic reinforcements are also used in sustainable soil practices to increase the soil's load-bearing capacity and structural stability [5], [6]. In addition, sustainable soil practices rely heavily on drainage management to forestall water collection, waterlogging, and structural damage. Maintaining healthy ecosystems and ensuring enough soil moisture may be achieved via the use of drainage systems and sustainable drainage practices [7], [8].

Soil recycling and reuse are included as part of the evaluation of sustainable soil practices for building footings. Construction projects may promote resource efficiency and decrease environmental effects by analyzing the quality and appropriateness of excavated soil to avoid the need for further soil extraction and waste creation. Evaluating sustainable soil practices in building footings is essential to advancing eco-friendly, long-lasting building methods. Construction projects can reduce their environmental impact, maximize soil use, and improve the foundation's long-term performance and sustainability by paying attention to aspects like soil quality, erosion control, contamination remediation, soil stability, conservation, drainage management, and regulatory compliance. Sustainable soil practices not only aid in the conservation of soil resources, but they also pave the way for the creation of a robust constructed environment that doesn't compromise the natural balance of its surroundings [9], [10].

We are unable to offer accurate assessment values of options to choose the best problem in actual MCDM challenges due to the uncertainty of DM's and decision-making concerns. This shortcoming was addressed in the initial definition of fuzzy set theory by Zadeh in 1965, which relied on the membership function to express estimated outcomes rather than precise real numbers [11], [12]. Atanassov introduced a supplementary index of measurement dubbed the non-membership function. Pythagorean fuzzy sets (PFS) have recently been established to handle more complex MCDM situations; its most distinguishing feature is that the total of squares of membership and non-membership is constrained to 1. The neutrosophic set was proposed to deal efficiently with indeterminacy, vague, and uncertain information. The neutrosophic set has three membership functions to deal with uncertainty like truth, indeterminacy, and falsity membership degrees.[13], [14]. Initially defined by Pamucar and Cirovic in 2015, the MABAC (multi-attributive border approximation area comparison) system calculates the distance measure among every option and the bored approximation area (BAA) [15], [16]. It has many valuable features, including the following:

- the calculation outcomes by the MABAC technique are constant
- the formulas for calculating formulas are easy:
- it takes the latent values of both advantages and disadvantages into account;
- it is accessible for integration with other models.

Therefore, the MABAC technique is an effective means of producing sound decisions. The goal of this study, integrate the single valued neutrosophic set with the MABAC method for the assessment of sustainable soil in foundation construction.

2. Life Cycle Assessment in Construction Foundation

To examine the environmental effect and long-term sustainability of goods, processes, and systems, life cycle assessment (LCA) is a useful tool. LCA is essential in the construction industry for evaluating the environmental friendliness of products including lumber, electricity, and garbage disposal. The assessment of building footings is one area where LCA is finding growing use [17], [18].

The stability and support of a building or structure is dependent on its foundation. The extraction and use of construction materials, energy consumption, soil disturbance, erosion, and trash creation are only some of the major environmental aspects of building and maintaining foundations. LCA is used to evaluate the environmental performance of building foundations from birth to death to solve these issues and encourage sustainable construction practices [19], [20].

Several important considerations go into an LCA analysis of a building's footing. Construction-related factors include material procurement and extraction, transportation effects, building procedures, upkeep needs, and decommissioning issues. When applied to building foundations, LCA allows for a more thorough knowledge of environmental implications and aids in identifying areas for improvement [21], [22]. Stability, durability, and long-term performance of buildings are all strongly impacted by how well the soil underneath them is managed and maintained. Sustainable soil practices may be evaluated using LCA, including those related to evaluating soil quality, preventing soil erosion, stabilizing soil, conserving soil, managing drainage, and cleaning up soil pollution. Construction projects may reduce their ecological footprints, maximize their soil usage, and strengthen their long-term sustainability by incorporating LCA into their soil management methods [23]–[25].

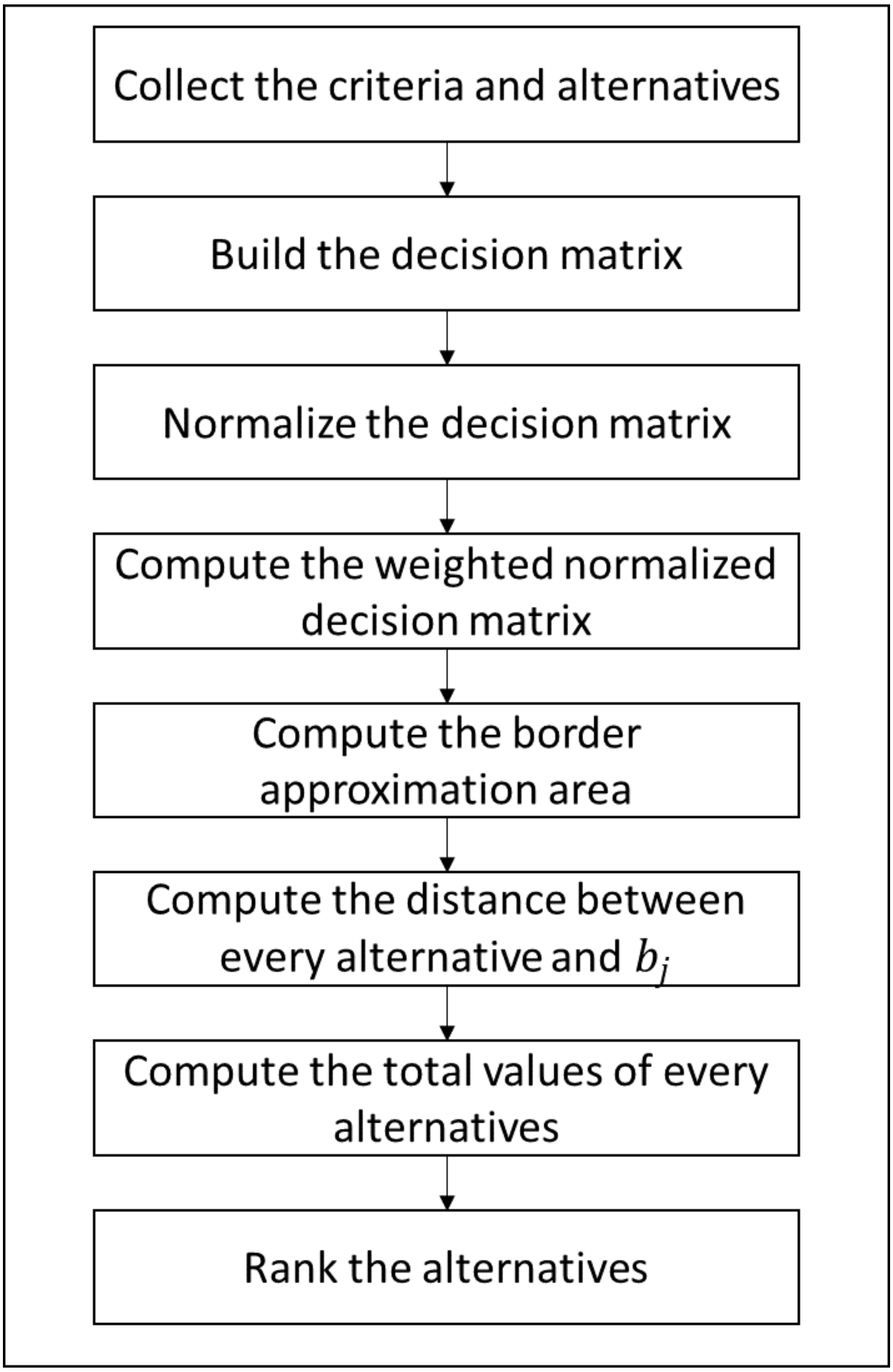

Figure 1. The steps of the integrated framework.

3. Methodology

This section introduces the MABC method with a single-valued neutrosophic set. Figure 1 shows the framework of the proposed method [26], [27].

Step 1. Build the decision matrix.

The decision matrix between criteria and alternatives is built based on the opinions of experts. Three experts built the decision matrix based on the single-valued neutrosophic numbers. Then these numbers are used to build the evaluation matrix.

$$A = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \quad (1)$$

Where $m = 1,2,3, \dots i \ (alternatives); n = 1,2,3, \dots . j \ (criteria)$

Step 2. Combine the decision matrices.

We combined the opinions of experts to obtain the one decision matrix.

Step 3. Normalize the decision matrix.

$$Z_{ij} = \max x_{ij} \ for \ beneficial \ criteria \quad (2)$$

$$Z_{ij} = \max x_{ij} \ for \ cost \ criteria \quad (3)$$

Step 4. Compute the weighted normalized decision matrix.

$$WZ_{ij} = w_j * Z_{ij} \quad (4)$$

Where w_j refers to the weights of the criteria.

The weights of the criteria are computed based on the average method.

Step 5. Compute the border approximation area.

$$b_j = \left(\prod_{i=1}^{m} WX_{ij}\right)^{1/m} \quad (5)$$

Step 6. Compute the distance between every alternative and b_j

$$E_{ij} = \begin{cases} E(WZ_{ij}, b_j) \ if \ WZ_{ij} > b\_j \\ 0 \quad if \ WZ_{ij} = b\_j \\ -E(WZ_{ij}, b_j) \ if \ WZ_{ij} < b\_j \end{cases} \quad (6)$$

Step 7. Compute the total values of every alternative

$$U_i = \sum_{j=1}^{n} E_{ij} \quad (7)$$

Step 8. Rank the alternatives.

The alternatives are ordered based on the maximum value in U_i.

4. Application

We applied the proposed method to a sustainable oil assessment in foundation construction. We gathered nine criteria and eight alternatives. Several criteria may be used to evaluate the environmental effect and long-term sustainability of a project when examining sustainable soil practices in building foundations. Key evaluation factors may include the following:

- Examine the soil's texture, fertility, compaction, permeability, organic matter concentration, and pH to get a sense of its physical, chemical, and biological qualities. Determining whether or not the soil is suitable for building and whether or not it can sustain healthy plant and ecosystem activities requires an evaluation of the soil's quality.

- Controlling soil erosion requires an evaluation of the methods used to keep the ground stable before, during, and after building. Evaluate how well sediment barriers, retaining walls, and vegetative cover prevent soil from washing away and settling into nearby water sources.
- Heavy metals, petroleum products, and other harmful substances may be present in the soil, therefore it's important to assess the level of contamination there. Determine the level of pollution, the dangers it poses to people and the environment, and how well the methods used to clean it up are working.

Think about the soil's stability in light of your load-bearing needs and the possibility of settling. Make sure the building foundation is solid and secure by analyzing soil compaction, soil stabilization methods, and geotechnical factors. It is important to evaluate current soil conservation and preservation methods. This involves taking measures to preserve topsoil, maintain soil fertility, and safeguard biodiversity, as well as reducing soil disturbance during construction. To lessen the need for further soil extraction and the resulting environmental effect, it is important to assess the potential for and scale of reusing the excavated soil on-site or recycling it for future projects. Stormwater runoff management, waterlogging prevention, and optimal soil moisture levels are all aspects of drainage management. To encourage natural water infiltration and lessen the load on traditional drainage infrastructure, sustainable drainage alternatives like infiltration basins and rain gardens should be considered.

Set up a method to track post-construction changes to the soil, erosion controls, and drainage systems. By keeping a close eye on things, we can catch any signs of wear and tear quickly and go to work fixing them. Soil management, erosion control, and contaminant cleanup must all be carried out by applicable environmental rules, building codes, and sustainability requirements for a successful construction project. Think about how the building project will affect the environment across its whole life cycle, from the mining of raw materials to the disposal of waste products. Evaluate the project's long-term viability and look for ways to reduce the negative impacts on the environment from soil-related tasks. Sustainable soil practices, reduced environmental effects, and a sturdy, long-lasting structure are all made possible when these factors are taken into account during building. Soil engineers, environmentalists, and construction experts should all be included to undertake a thorough evaluation that is suited to the needs of the project and the rules of the area.

Step 1. We built the decision matrix between nine criteria and eight alternatives by using single-valued neutrosophic numbers using Eq. (1).

Step 2. Then we combined the opinions of experts into one matrix.

Step 3. Then we normalized the decision matrix by using Eqs. (2 and 3) as shown in Table 1.

Table 1. The normalized decision matrix between criteria and alternatives.

	SSF_1	SSF_2	SSF_3	SSF_4	SSF_5	SSF_6	SSF_7	SSF_8	SSF_9
$SSFA_1$	0	0.649058	0.448418	0.918052	1	0.546979866	0.107847	0.288095	0
$SSFA_2$	0.885484	0.99855	0.328748	1	0.473684	1	1	0.753571	0.066067
$SSFA_3$	0.214516	0.744081	0	0.478622	0	0.441275168	0.014085	1	0.456935

SSFA₄	0.65	0.637784	0.628611	0.134204	0.779727	0.630872483	0.549296	0.872619	0.066067
SSFA₅	1	0	0.3989	0.244656	0.531189	0.166107383	0.32998	0	1
SSFA₆	0.65	1	1	0.608076	0.808967	0	0	0.240476	1
SSFA₇	0.745161	0.649058	0.3989	0	0.389864	0.268456376	0.32998	0.605952	0.456935
SSFA₈	0.737097	0.348365	0.85282	0.292162	0.643275	0.994966443	1	1	1

Step 4. Then multiply the weights of criteria by the normalization matrix to obtain the weighted normalized decision matrix by using Eq. (4) as shown in Table 2.

Table 2. The weighted normalized decision matrix between criteria and alternatives.

	SSF₁	**SSF₂**	**SSF₃**	**SSF₄**	**SSF₅**	**SSF₆**	**SSF₇**	**SSF₈**	**SSF₉**
SSFA₁	0.093036	0.242052	0.123412	0.306442	0.151802	0.20439331	0.121874	0.179672	0.057689
SSFA₂	0.175417	0.293352	0.113216	0.319534	0.111854	0.264248184	0.220019	0.2446	0.0615
SSFA₃	0.112993	0.256	0.085205	0.236235	0.075901	0.190427173	0.111559	0.278973	0.084049
SSFA₄	0.153509	0.240398	0.138765	0.181209	0.135083	0.215477546	0.170438	0.261205	0.0615
SSFA₅	0.186071	0.146782	0.119193	0.198855	0.116219	0.154070879	0.146311	0.139487	0.115378
SSFA₆	0.153509	0.293564	0.170409	0.256918	0.137303	0.132124092	0.11001	0.17303	0.115378
SSFA₇	0.162362	0.242052	0.119193	0.159767	0.105492	0.167593647	0.146311	0.224009	0.084049
SSFA₈	0.161612	0.197916	0.157869	0.206445	0.124726	0.26358313	0.220019	0.278973	0.115378

Step 5. Then compute the b_j by using Eq. (5).

Step 6. Then compute the distance between every alternative and b_j by using Eq. (6) as shown in Table 3.

Table 3. The distance between every alternative and b_j.

	SSF₁	**SSF₂**	**SSF₃**	**SSF₄**	**SSF₅**	**SSF₆**	**SSF₇**	**SSF₈**	**SSF₉**
SSFA₁	-0.92986	-0.84235	-0.87996	-0.77461	-0.8429	-0.85544615	-0.90606	-0.89506	-0.89784
SSFA₂	-0.84748	-0.79105	-0.89015	-0.76152	-0.88285	-0.79559128	-0.80791	-0.83013	-0.89402
SSFA₃	-0.9099	-0.8284	-0.91816	-0.84482	-0.9188	-0.86941229	-0.91637	-0.79576	-0.87148
SSFA₄	-0.86938	-0.844	-0.8646	-0.89984	-0.85962	-0.84436191	-0.85749	-0.81353	-0.89402
SSFA₅	-0.83682	-0.93762	-0.88417	-0.8822	-0.87848	-0.90576858	-0.88162	-0.93525	-0.84015
SSFA₆	-0.86938	-0.79084	-0.83296	-0.82413	-0.8574	-0.92771537	-0.91792	-0.9017	-0.84015
SSFA₇	-0.86053	-0.84235	-0.88417	-0.92128	-0.88921	-0.89224581	-0.88162	-0.85073	-0.87148
SSFA₈	-0.86128	-0.88648	-0.8455	-0.87461	-0.86997	-0.79625633	-0.80791	-0.79576	-0.84015

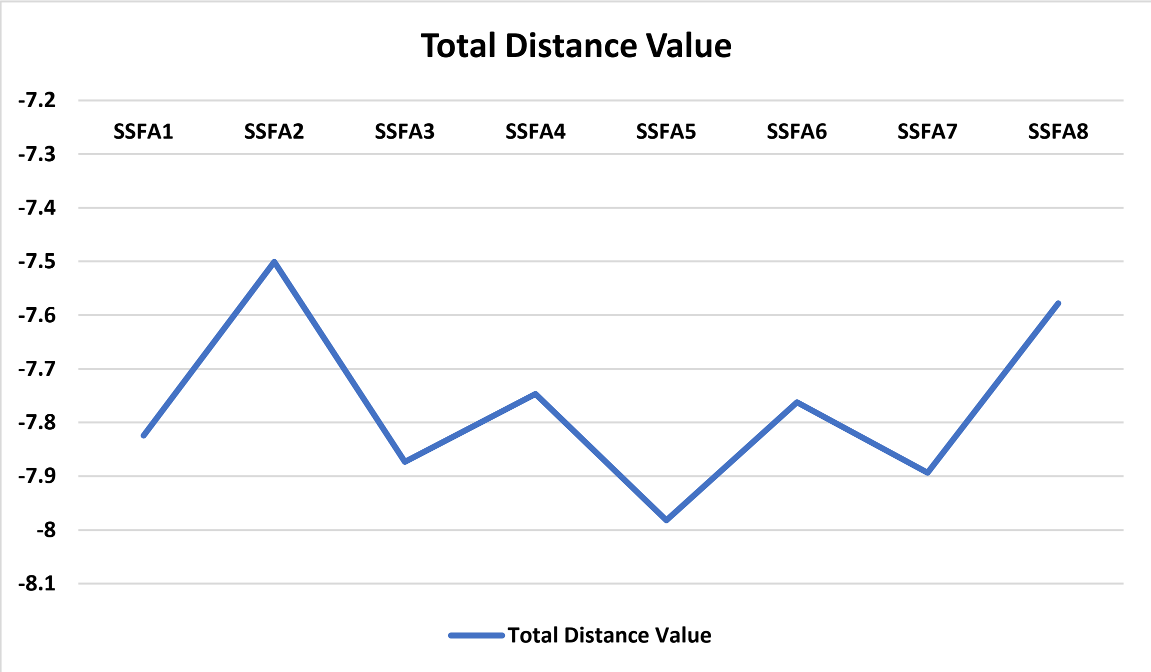

Figure 2. The total values of every alternative.

Step 7. Then compute the total values of every alternative by using Eq. (7) as shown in Figure 2.

Step 8. Then rank the alternatives as shown in Figure 2.

5. Conclusions

When used for sustainable soil practices in building foundations, life cycle assessment (LCA) yields important insights into the environmental effect and long-term viability of soil-related activities. The environmental impact of construction projects can be reduced and their sustainability improved with a comprehensive evaluation of issues like soil quality, erosion control, contamination remediation, soil stability, conservation, drainage management, and regulatory compliance. Using LCA, you can find better ways to do things at every step of the building process, from digging the foundation to keeping it in good repair. Projects may lessen their ecological footprint and protect soil resources for future generations by maximizing soil usage, putting in place erosion control measures, controlling soil pollution, and encouraging soil conservation.

Responsible water management and reduced risk of soil deterioration owing to waterlogging or erosion are other benefits of implementing sustainable drainage systems and meeting environmental laws. Soil engineers, ecologists, and builders should all work together as much as possible throughout the LCA phase. Their knowledge allows us to evaluate the project's unique needs, the applicable local rules, and the most efficient methods of sustainable soil management. This study used the MABAC method as an MCDM method to assess sustainable soil in construction foundations. The MABAC method is integrated with the neutrosophic set to deal with uncertain data. This study used nine criteria and eight alternatives. The use of LCA in the evaluation of environmentally friendly soil practices for building foundations is a boon to the creation of environmentally conscious initiatives. Construction projects may aid in soil quality preservation, promote ecological integrity, and improve the long-term sustainability of the built environment by applying the suggested approaches.

Supplementary Materials

Not applicable.

Author Contributions

The authors contributed equally to this work.

Funding

This research was conducted without external funding support.

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

Conflicts of Interest

The authors declare that there is no conflict of interest in the research.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

All data used to support the findings of this study are available upon request.

References

[1] A. J. Sánchez-Garrido, I. J. Navarro, and V. Yepes, "Evaluating the sustainability of soil improvement techniques in foundation substructures," *Journal of Cleaner Production*, vol. 351, p. 131463, 2022.

[2] G. C. Ezeokpube *et al.*, "Assessment of mechanical properties of soil-lime-crude oil-contaminated soil blend using regression model for sustainable pavement foundation construction," *Advances in Materials Science and Engineering*, vol. 2022, pp. 1–18, 2022.

[3] C. C. Ladd, "Stability evaluation during staged construction," *Journal of geotechnical engineering*, vol. 117, no. 4, pp. 540–615, 1991.

[4] C. Zhao and D. Zhao, "Application of construction waste in the reinforcement of soft soil foundation in coastal cities," *Environmental Technology & Innovation*, vol. 21, p. 101195, 2021.

[5] J. Elam and C. Björdal, "A review and case studies of factors affecting the stability of wooden foundation piles in urban environments exposed to construction work," *International Biodeterioration & Biodegradation*, vol. 148, p. 104913, 2020.

[6] T.-Y. Liu, S.-J. Ho, H.-P. Tserng, and H.-K. Tzou, "Using a unique retaining method for building foundation excavation: A case study on sustainable construction methods and circular economy," *Buildings*, vol. 12, no. 3, p. 298, 2022.

[7] D. F. McCarthy and D. F. McCarthy, *Essentials of soil mechanics and foundations*. Reston Publishing Company Reston, 1977.

[8] A. G. Correia, M. G. Winter, and A. J. Puppala, "A review of sustainable approaches in transport infrastructure geotechnics," *Transportation Geotechnics*, vol. 7, pp. 21–28, 2016.

[9] F. I. Shalabi *et al.*, "Cement-stabilized waste sand as sustainable construction materials for foundations and highway roads," *Materials*, vol. 12, no. 4, p. 600, 2019.

[10] G. Li *et al.*, "Freeze–thaw properties and long-term thermal stability of the unprotected tower foundation soils in permafrost regions along the Qinghai–Tibet Power Transmission Line," *Cold Regions Science and Technology*, vol. 121, pp. 258–274, 2016.

[11] P. Ji, H. Zhang, and J. Wang, "Selecting an outsourcing provider based on the combined MABAC–ELECTRE method using single-valued neutrosophic linguistic sets," *Computers & Industrial Engineering*, vol. 120, pp. 429–441, 2018.

[12] R. Şahin and F. Altun, "Decision making with MABAC method under probabilistic single-valued neutrosophic hesitant fuzzy environment," *Journal of Ambient Intelligence and Humanized Computing*, vol. 11, pp. 4195–4212, 2020.

[13] H. Ran, "MABAC method for multiple attribute group decision making under single-valued neutrosophic sets and applications to performance evaluation of sustainable microfinance groups lending," *Plos one*, vol. 18, no. 1, p. e0280239, 2023.

[14] L. Xu, Y. Liu, and F. Liu, "Improved MABAC method based on single-valued neutrosophic 2-tuple linguistic sets and Frank aggregation operators for MAGDM," *Computational and Applied Mathematics*, vol. 40, pp. 1–32, 2021.

[15] D. Xu, H. Xian, X. Cui, and Y. Hong, *A new single-valued neutrosophic distance for TOPSIS, MABAC and new similarity measure in multi-attribute decision-Making*. Infinite Study, 2020.

[16] C. Jana and M. Pal, "Multi-criteria decision making process based on some single-valued neutrosophic Dombi power aggregation operators," *Soft Computing*, vol. 25, pp. 5055–5072, 2021.

[17] R. Horn, S. Ebertshäuser, R. Di Bari, O. Jorgji, R. Traunspurger, and P. von Both, "The BIM2LCA approach: An industry foundation classes (IFC)-based interface to integrate life cycle assessment in integral planning," *Sustainability*, vol. 12, no. 16, p. 6558, 2020.

[18] F. Ardente, M. Beccali, M. Cellura, and V. Lo Brano, "Energy performances and life cycle assessment of an Italian wind farm," *Renewable and Sustainable Energy Reviews*, vol. 12, no. 1, pp. 200–217, 2008.

[19] N. Mithraratne and B. Vale, "Life cycle analysis model for New Zealand houses," *Building and environment*, vol. 39, no. 4, pp. 483–492, 2004.

[20] E. G. Hertwich, J. K. Hammitt, and W. S. Pease, "A theoretical foundation for life-cycle assessment: Recognizing the role of values in environmental decision making," *Journal of Industrial Ecology*, vol. 4, no. 1, pp. 13–28, 2000.

[21] A. Elsing *et al.*, "Comparative life cycle assessment of geosynthetics versus conventional construction materials, a study on behalf of the EAGM, Case 2, Foundation stabilization," in *Proceedings Eurogeo*, 2012, pp. 60–64.

[22] S. Junnila, A. Horvath, and A. A. Guggemos, "Life-cycle assessment of office buildings in Europe and the United States," *Journal of infrastructure systems*, vol. 12, no. 1, pp. 10–17, 2006.

[23] L. Schleisner, "Life cycle assessment of a wind farm and related externalities," *Renewable energy*, vol. 20, no. 3, pp. 279–288, 2000.

[24] J. Peng, L. Lu, and H. Yang, "Review on life cycle assessment of energy payback and greenhouse gas emission of solar photovoltaic systems," *Renewable and sustainable energy reviews*, vol. 19, pp. 255–274, 2013.

[25] S. Theißen *et al.*, "BIM integrated automation of whole building life cycle assessment using German LCA data base ÖKOBAUDAT and Industry Foundation Classes," in *IOP Conference Series: Earth and Environmental Science*, IOP Publishing, 2020, p. 32025.

[26] D. Pamučar and D. Božanić, *Selection of a location for the development of multimodal logistics center: Application of*

single-valued neutrosophic MABAC model. Infinite Study, 2019.

[27] X. Peng and J. Dai, "Approaches to single-valued neutrosophic MADM based on MABAC, TOPSIS and new similarity measure with score function," *Neural Computing and Applications*, vol. 29, pp. 939–954, 2018.