

# Key Factors Influencing the Use of Coal Ash as Construction Material in Vietnam

Le Van Tuan<sup>1</sup>, Le Hai Yen<sup>1</sup>, Nguyen Thi Thuy<sup>1\*</sup>, Nguyen Thi My Hanh<sup>1</sup>

<sup>1</sup> Faculty of Construction Economics and Management,  
Hanoi University of Civil Engineering, No. 55 Giai Phong Street, Bach Mai Ward, Hanoi, VIETNAM

\*Corresponding Author: [thuynt3@huce.edu.vn](mailto:thuynt3@huce.edu.vn)  
DOI: <https://doi.org/10.30880/ijscet.2025.16.02.006>

## Article Info

Received: 18 February 2025  
Accepted: 3 August 2025  
Available online: 6 September 2025

## Keywords

Ash and slag, fly ash, coal-fired power plants, construction materials, construction contractors

## Abstract

The accumulation of ash and slag resulting from thermal power plants's generation poses significant environmental risks to soil, water, and air. The Government of Vietnam has shown particular concern regarding the treatment and management of ash and slag produced by coal-fired power plants. In pursuit of sustainable development goals, the government aims for 80% of the total amount of ash and slag produced by these plants to be reused, recycled, or transformed into raw materials for manufacturing, building materials, and landfilling while complying with environmental standards. Initial programs and support have been introduced to encourage investors and construction contractors to encourage the utilization of coal combustion ash and slag in construction applications. However, the widespread adoption of ash and slag utilization remains limited due to various challenges including technical, economic, and institutional challenges. This study examines the elements that affect the decision-making processes of construction contractors in Vietnam regarding the use of coal combustion ash and slag as construction materials. Based on prior studies, 18 influencing factors were identified and categorized into five groups. Data were collected from 42 construction contractors. The Fuzzy Analytic Hierarchy Process (FAHP) method was employed to assess the relative importance of these factors in influencing contractors' decisions. The findings reveal that the most influential factors include: government support programs and policies; unit prices and technical-economic norms of ash and slag; physical properties of ash and slag; financial advantages of utilizing ash and slag as building materials in construction; environmental assurance; and technological innovation.

## 1. Introduction

In Vietnam, operational coal-fired thermal power plants generate more than 13 million tons of the ash and slag every year, with emissions primarily concentrated in the northern region (accounting for 65%), followed by the central region (23%) and the southern region (12%) of the total waste volume [1]. The accumulation of ash and slag presents significant risks of environmental pollution to soil, water, and air. These by-products contain components such as alumina, silica, calcium, and sulfur (especially in CFB and FGD ash/slag), as well as trace amounts of heavy metals. Ash and slag contain hazardous elements, including lead, mercury, cadmium, copper, and tin. These can leach into surface and groundwater, causing contamination. Ammonium leached from storage sites can transform into nitrates, which infiltrate groundwater sources, contributing to water pollution.

Fly ash, a fine powdery material, typically has particle sizes ranging from 0.5 to 300  $\mu\text{m}$ . Toxic elements tend to concentrate in fine particles, particularly those around 2  $\mu\text{m}$  in size, which can be inhaled and deposited in

human respiratory systems, increasing health risks [2]. In dry disposal areas, airborne fly ash particles can degrade local air quality. Due to such environmental concerns, the Hai Duong BOT Thermal Power Plant was instructed by the Hai Duong Provincial People's Committee to halt external transport of ash and slag outside the plant premises. Residents living near thermal power plants and ash disposal sites are exposed to high risks from airborne toxic dust. Monitoring data from areas surrounding the Vinh Tan Power Center showed that dust concentrations exceeded regulatory limits by 1.19 to 1.63 times, and nighttime noise levels were 1.05 times above permissible standards [3].

Processed ash and slag are most commonly used as mineral additives for cement production—an estimated 24 million tons, accounting for 70% of usage. Approximately 4 million tons (12%) are used for the production of fired clay bricks and non-fired bricks; around 3 million tons (9%) serve as additives for ready-mix concrete and concrete used in irrigation, transportation infrastructure (e.g., rural cement roads), and civil construction (e.g., large foundation structures with low heat emission); and about 3.5 million tons (9%) are used as backfilling and road embankment materials [1].

Some coal-fired power plants have achieved high consumption rates of ash and slag. In the North, notable examples include the Uong Bi and Ninh Binh plants (100%), Hai Phong (98%), Thai Binh, and Pha Lai (72%). In the Central region, the Nghi Son 1 (85%) and Formosa Ha Tinh plants have good utilization rates, while in the South, Duyen Hai 3 reports a rate of 85.5%. Conversely, several plants with high ash and slag outputs show relatively low consumption rates, such as Mong Duong I, Cam Pha I and II, and Quang Ninh I and II in the North; Vung Ang I, Vinh Tan I, II, and IV in the Central region; and Duyen Hai I in the South.

Despite government-issued regulations and initiatives promoting the utilization of ash and slag produced by coal-fired power plants as building materials, multiple challenges persist in their implementation:

1. **Inadequate Quality of Ash and Slag for Construction Use:** The quality of ash and slag depends heavily on the combustion technology and fuel characteristics. Ash and slag from plants utilizing circulating fluidized bed (CFB) combustion technology tend to be of lower quality. Consequently, they can only be used as limited mineral additives for cement and concrete, restricting their market potential.
2. **Competition from Locally Available Traditional Construction Materials:** These materials are often cheaper and more readily accessible, making them more appealing to contractors.
3. **Institutional and Policy Challenges in Promoting Ash and Slag Use:** According to Decree No. 08/2022/ND-CP dated January 10, 2022 [4], which details the execution of certain provisions of the 2020 Law on Environmental Protection, ash and slag are classified as ordinary waste. Once standardized, they are managed similarly to other products and goods. However, in practice, organizations and individuals intending to use ash and slag for land reclamation or as raw materials for building materials often face legal ambiguities and policy inconsistencies. Furthermore, limited public awareness and understanding of ash and slag contribute to ongoing difficulties in their transfer and consumption.

## 2. Literature Review

Globally, especially in developed countries, considerable attention has been directed towards the utilization of coal-fired power plant ash and slag to minimize environmental emissions and promote the circular economy. For instance, C. Heidrich and colleagues conducted research on coal combustion by-products from a circular economy perspective [5]; C.H. Benson and S. Bradshaw [6] provided guidance on the use of coal bottom ash and boiler slag in the construction of green infrastructure; D. Harris, C. Heidrich, and J. Feuerborn [7] emphasized the substantial environmental impact of unprocessed ash and slag; A. Horvath [8] assessed the economic efficiency and environmental effects of using recycled materials in construction; Behera [9] focused on the origin and physicochemical properties of ash and slag, as well as their environmental implications; Rossow [10] explored the effective utilization of ash and slag in building materials in concrete components and cement production; and Jayaranjan [11] investigated alternative reuse options for commercial applications, including construction. These international studies have clarified several key issues: (1) the origin and basic physicochemical and mechanical properties of ash and slag from coal-burning power plants; (2) the negative environmental impacts of coal combustion by-products; (3) the limitations of current applications of ash and slag in building projects; and (4) the evaluation of usage effectiveness and sustainability of such materials in the construction industry.

In Vietnam, a number of studies have examined the application of ash and slag from coal-fired power plants. For example, Cao Tien Phu and Truong Duc Tiep [12] investigated the consumption of ash and slag from municipal solid waste incinerators as raw materials for construction materials; Nguyen Thi Bich Thuy and colleagues [13] studied the application of fly ash with a high loss on ignition as a sand replacement in mortar; Vu Hai Nam [14] explored the application of highly refined fly ash from Pha Lai in mass concrete typically used in gravity dams; Hoang Thi Phuong and Vu Quoc Vuong [15] evaluated the potential of ash and slag as building materials, proposing recycling solutions to ensure environmental protection and economic efficiency; and Le Van Tuan [16] assessed the effectiveness of coal combustion ash and slag as replacement materials in various types of construction projects in Vietnam. Domestic studies have shed light on the mechanical and physical characteristics of ash and

slag when used as construction materials, the implementation of the “circular economy” model in assessing the advantages of using coal-fired power plant by-products, and the practical effectiveness of using ash and slag as replacement materials in construction.

It is clear that the incorporating of ash and slag in the construction has garnered research interest both internationally and domestically. However, despite support and promotion from the Vietnamese government, their actual application in construction remains limited. Contractors still rarely incorporate ash and slag into their construction methods or material choices.

Synthesizing findings from both international and domestic research, a total of 18 factors have been identified that influence the decision to use ash and slag from coal-fired power plant as materials for construction (Table 1).

**Table 1** Factors influencing the decision to use coal-fired power plant ash and slag as construction materials

Code	Factor	Description and Explanation	Source
<b>A. Legal Regulations</b>			
A1	Unit prices and technical-economic norms for ash and slag	Regulations on pricing and technical norms for using ash and slag as construction materials	[17]
A2	Construction standards and acceptance regulations	Standards, codes, and technical guidelines for handling and using ash and slag as raw materials and in construction works.	[17]
A3	Government support programs and policies	Policies regarding fund allocation, legal frameworks, guidance, and collaboration to promote the reuse of ash and slag in construction.	[17]
A4	Tax incentive policies	Preferential tax policies to promote the utilization of ash and slag, such as VAT exemptions for certain products and CIT reductions for manufacturers.	[16]
<b>B. Ash and Slag Characteristics</b>			
B1	Physical Properties	Ash and slag vary in physical composition depending on combustion technology (PC vs. CFB), including major oxide content ( $\text{SiO}_2$ , $\text{Al}_2\text{O}_3$ , $\text{Fe}_2\text{O}_3$ ), $\text{SO}_3$ , CaO, LOI, moisture, specific gravity, etc.	[2, 16, 17]
B2	Chemical Properties	Ash and slag differ in particle size, deformation/melting temperature, and color, all of which affect their suitability as construction materials.	[2]
B3	Material Usability	Replacing 50% of cement that incorporates high-calcium fly ash compound with steel slag and recycled aggregates can produce high-strength, eco-friendly concrete.	[17, 18]
<b>C. Cost/Economic Factors</b>			
C1	Economic Benefits	Fly ash used in high-performance concrete can extend the lifespan of concrete pavements to 30–60 years compared to the current design life of 20–25 years.	[17]
C2	Life Cycle Cost	Life cycle costing provides a framework for estimating the total incremental cost over the development, production, use, and disposal phases.	[19]
C3	Economic Feasibility	Using ash and slag as replacement materials in construction has been shown to be economically viable, particularly in transportation projects.	[20]
C4	Large-Scale Utilization	Ash and slag can be used in bulk for construction projects, especially for embankments and land reclamation, resulting in economic benefits.	[21, 22]

<b>D. Environmental Factors</b>			
D1	Environmental Assurance	Ash and slag are among the most complex anthropogenic materials, and improper disposal leads to environmental concerns and resource waste. Their reuse offers a green, sustainable solution with social benefits.	[17, 23]
D2	Resource Conservation	Fly ash reduces energy consumption, minimizes waste, and conserves natural resources.	[17]
D3	Sustainable Development Goals (SDGs)	SDGs emphasize managing waste across its full lifecycle, from generation to final disposal, including prevention, minimization, reuse, recycling, and treatment to protect health, environment, and adapt to climate change.	[24]
<b>E. Other Factors</b>			
E1	Training, Education, and Promotion	Awareness campaigns and professional education can significantly promote the use of fly ash.	[17]
E2	Technological Innovation	Innovation enhances efficiency, supports new product development, and creates both relative and absolute advantages.	[17, 25]
E3	Stakeholders' Perspectives	Project owners and contractors make material usage decisions based on their execution strategies and preferences.	[26]
E4	Designers' Awareness	Design units determine material use at the project design stage, depending on their understanding of ash and slag properties.	[26]

### 3. Research Methodology

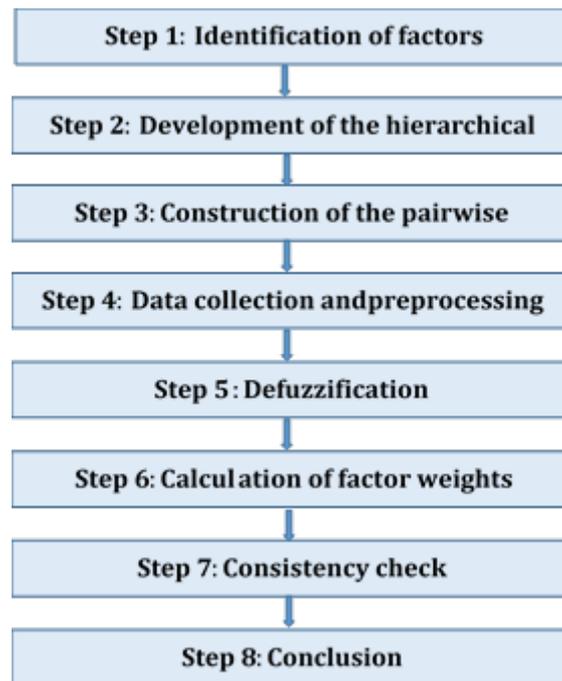
Analytical Hierarchy Process (AHP) is a decision making method based on hierarchical analysis. Basing on the comparison of pairs of criteria, the weight of each criterion is determined. Meanwhile, fuzzy set theory support to evaluate the membership relationship between an element and a set, this relationship is expressed by a membership function.

This study was applied by a mixture of AHP and fuzzy set theory, known as the Fuzzy Analytical Hierarchy Process (F-AHP). F-AHP overcomes several of the drawbacks associated with traditional AHP and is increasingly being applied in academic and applied research, especially this method is particularly suitable for addressing vagueness in expert evaluations.

The F-AHP method includes standard triangular fuzzy is chosen because of the following advantages:

- Linguistic evaluations by experts of the factors influencing contractors' decisions to use coal combustion ash and slag as construction materials more accurately reflect the nature of the problem than numeric scales. These linguistic terms are then encoded into triangular fuzzy numbers, allowing for objective expert assessments.
- The influencing factors are structured hierarchically, enabling pairwise comparisons between them. AHP calculates relative weights for each factor based on the degree of importance.
- By using F-AHP, interdependencies between factors are partially taken into account. Each factor's weight is calculated based on fuzzy pairwise relations, providing a comprehensive understanding of their influence.

Implementing the Research Steps using the F-AHP Method (Figure 1)



**Fig. 1** Implementing the research steps using the F-AHP method using F-AHP method

### 3.1 Step 1: Identification of Influencing Factors

Factors influencing the decision to use coal ash as construction material are summarized through previous studies (Table 1).

### 3.2 Step 2: Development of the Hierarchical Structure

The decision problem is organized within a three-level hierarchical model:

- Level 1 – Goal: To determine the factors influencing the decision to use coal combustion ash and slag as construction materials by construction contractors in Vietnam.
- Level 2 – Criteria Groups: Five groups of influencing factors are identified and categorized as follows:
  - Group A: Legal regulations;
  - Group B: Material characteristics of coal ash and slag;
  - Group C: Cost/Economic factors;
  - Group D: Environmental factors;
  - Group E: Other factors.

This level corresponds to Fuzzy Pairwise Comparison Matrix Level 1, where factor groups are compared relative to the goal.

- Level 3 – Sub-Criteria: This level includes specific factors within each group from Level 2. Each group of sub-criteria is evaluated through Fuzzy Pairwise Comparison Matrix Level 2, where individual elements within each group are compared to one another.

### 3.3 Step 3: Construction of the Fuzzy Pairwise Comparison Matrix

According to the findings from of Steps 1 and 2, fuzzy pairwise comparison matrices are developed. Unlike traditional AHP, these matrices incorporate triangular fuzzy values to account for uncertainty in expert evaluations. The fuzzy scales are derived from Saaty's fundamental scale [15], adapted to represent imprecise judgments using triangular fuzzy numbers.

Every fuzzy pairwise comparison matrix is denoted by  $J$ , where each element  $j_{ij}$  is a triangular fuzzy number indicating the relative importance of element  $i$  over element  $j$ .

$$\bar{J} = (\bar{J}_{ij})_{n \times n} = \begin{bmatrix} \bar{J}_{11} & \bar{J}_{12} & \dots & \bar{J}_{1n} \\ \bar{J}_{21} & \bar{J}_{22} & \dots & \bar{J}_{2n} \\ \dots & \dots & \dots & \dots \\ \bar{J}_{n1} & \bar{J}_{n2} & \dots & \bar{J}_{nn} \end{bmatrix} \tag{1}$$

**Table 2** Measurement scale

Level	Measurement Scale (l, m, u)	Definition	Explanation
1	(1, 1, 1)	Equally Important	The two factors exert the same level of influence
2	(1, 2, 3)	Between level 1 and level 3	
3	(2, 3, 4)	Moderately Important	The considered factor has a moderately greater influence than the other.
4	(3, 4, 5)	Between level 3 and level 5	
5	(4, 5, 6)	Strongly More Important	The considered factor has a strong influence compared to the other.
6	(5, 6, 7)	Between level 5 and level 7	
7	(6, 7, 8)	Very Strongly More Important	The considered factor is very strongly more influential than the other.
8	(7, 8, 9)	Between level 7 and level 9	
9	(8, 9, 9)	Extremely More Important	The considered factor has an overwhelming influence compared to the other.
1/x	1/(x+1), 1/x, 1/(x-1)	AHP Scale-1	

### 3.4 Step 4: Data Collection and Processing

Data Collection: Data were collected through expert interviews.

Data Aggregation and Processing: The data aggregation and processing were carried out with the aid of Microsoft Excel. Expert opinions were fuzzified before being aggregated. The pairwise comparison matrix was constructed using triangular fuzzy values [13, 14]. The aggregation of these triangular fuzzy values was performed as follows:

$$\bar{J}_{ij} = (l_{ij}, m_{ij}, u_{ij}); l_{ij} \leq m_{ij} \leq u_{ij}; l_{ij}, m_{ij}, u_{ij} \in \left[\frac{1}{9}, 9\right] \tag{2}$$

$$l_{ij} = \sqrt[n]{\prod_1^n l_{ijk}}$$

$$m_{ij} = \sqrt[n]{\prod_1^n m_{ijk}}$$

$$u_{ij} = \sqrt[n]{\prod_1^n u_{ijk}}$$

### 3.5 Step 5: Defuzzification

In order to revert to a crisp AHP pairwise comparison matrix for subsequent computation, the fuzzy values (lij, mij, uij) must be converted into real numbers Jij. Deng [17] suggested using the α-cut index and λ parameter, which represent the level of confidence and attitude of the respondents toward the evaluated criteria.

The α-cut index ranges from 0 to 1. A higher α value (closer to 1) demonstrates a higher degree of confidence in the respondent’s judgment. The λ parameter also ranges from 0 to 1, reflecting the respondent’s attitude:

- A value close to 1 implies an optimistic perspective,
- A value near 0 reflects a pessimistic view,
- A value of 0.5 represents a neutral state.

In this study, the authors adopt α = 0.5 and λ = 0.5, which indicates that the respondents were in an unbiased psychological state—neither overly optimistic nor pessimistic—during their participation in the evaluation. The defuzzification process is completed when the fuzzy numbers are encoded into crisp values through α and λ, as calculated by the subsequent equations:

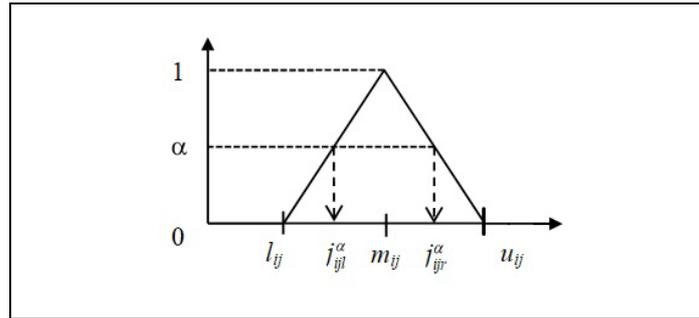


Fig. 2 Implementing the research steps using the F-AHP method using F-AHP method

$$j_{\alpha} = \begin{bmatrix} [j_{11l}^{\alpha}, j_{11r}^{\alpha}] & [j_{12l}^{\alpha}, j_{12r}^{\alpha}] & \dots & [j_{1ml}^{\alpha}, j_{1nr}^{\alpha}] \\ [j_{21l}^{\alpha}, j_{21r}^{\alpha}] & [j_{22l}^{\alpha}, j_{22r}^{\alpha}] & \dots & [j_{2ml}^{\alpha}, j_{2mr}^{\alpha}] \\ \dots & \dots & \dots & \dots \\ [j_{n1l}^{\alpha}, j_{n1r}^{\alpha}] & [j_{n2l}^{\alpha}, j_{n2r}^{\alpha}] & \dots & [j_{nml}^{\alpha}, j_{nmr}^{\alpha}] \end{bmatrix} \tag{3}$$

$$\begin{aligned} j_{ijl}^{\alpha} &= (m_{ij} - l_{ij}) \cdot \alpha + l_{ij} \\ j_{ijr}^{\alpha} &= u_{ij} - (u_{ij} - m_{ij}) \cdot \alpha \\ j_{ij\alpha}^{\lambda} &= \lambda \cdot j_{ijr}^{\alpha} + (1 - \lambda) \cdot j_{ijl}^{\alpha}; \lambda \in [0,1] \end{aligned} \tag{4}$$

$$j_{\alpha}^{\lambda} = \begin{bmatrix} j_{11\alpha}^{\lambda} & j_{12\alpha}^{\lambda} & \dots & j_{1n\alpha}^{\lambda} \\ j_{21\alpha}^{\lambda} & j_{22\alpha}^{\lambda} & \dots & j_{2n\alpha}^{\lambda} \\ \dots & \dots & \dots & \dots \\ j_{n1\alpha}^{\lambda} & j_{n2\alpha}^{\lambda} & \dots & j_{nn\alpha}^{\lambda} \end{bmatrix}$$

### 3.6 Step 6: Calculation of Weights

After defuzzification, the weight calculation is performed using the AHP method. The steps are as follows:

- Calculate the sum of each column in the matrix.
- Divide each element by the sum of the corresponding column, then calculate the sum of each row.
- On each row, calculate the sum and divide by the number of criteria. The resulting value is the weight of the criterion.

### 3.7 Step 7: Consistency Check

In the pairwise comparison method of AHP, it is essential to evaluate the uniformity of the data, i.e., whether the respondent’s judgments were logically coherent throughout the survey. This requirement is assessed using the Consistency Ratio (CR).

The CR value is computed using the formulas below:

$$CR = \frac{CI}{RI} \tag{5}$$

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{6}$$

Where:

CI (Consistency Index): Assesses the level of inconsistency in the pairwise comparisons.

N: The number of criteria (i.e., the order of the matrix)

$\lambda_{max}$  = Max (n), the largest eigenvalue of the comparison matrix

RI (Random Index): The average consistency index of matrices randomly generated of the same order n.

CR (Consistency Ratio): Indicates the level of consistency in the judgments. A value of  $CR \leq 0.1$  is generally considered acceptable.

Table 3 Values of the Random Index (RI)

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.4	1.45	1.49

If the Consistency Ratio (CR) is less than 10%, the comparison matrix is considered consistent and acceptable. If  $CR > 10\%$ , it indicates inconsistency in the respondents' judgments, and the data collection process must be repeated.

### 3.8 Step 8: Conclusion

After confirming the data's consistency, the determined weights are deemed trustworthy reliable for drawing conclusions regarding the factors influencing project implementation progress in Hanoi's construction sector

## 4. Research Results

### 4.1 Data Collection Results

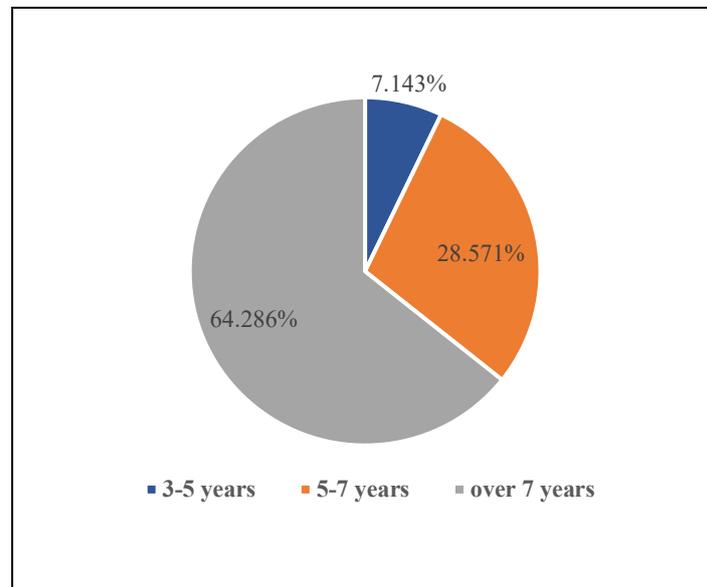
The criteria for selecting experts were based on the following conditions:

- Having formal education in the field of construction;
- Currently working at construction contractor companies;
- Having at least three years of professional experience;
- Having an understanding about the utilization of coal ash and slag as building materials.

According to the research team, the number of experts with sufficient understanding of ash and slag in building is still limited. A total of 42 experts, who are managerial personnel representing construction contractors, participated in the survey.

Among these respondents:

- 64.29% had over 7 years of experience and had previously served as site managers;
- 28.57% had 5 to 7 years of experience;
- The lowest proportion, 7.14%, had 3 to 5 years of experience.



**Fig. 3** Respondents' work experience statistics

Regarding project types, among the 42 surveyed experts:

- 38 out of 42 have participated in civil construction projects;
- 19 out of 42 have worked on industrial projects;
- 18 out of 42 have experience with transportation infrastructure projects.

In contrast, the least common project types among respondents were:

- Defense and security projects, with only 3 out of 42 participants;
- Agricultural and rural development projects, with 6 out of 42 participants.
-

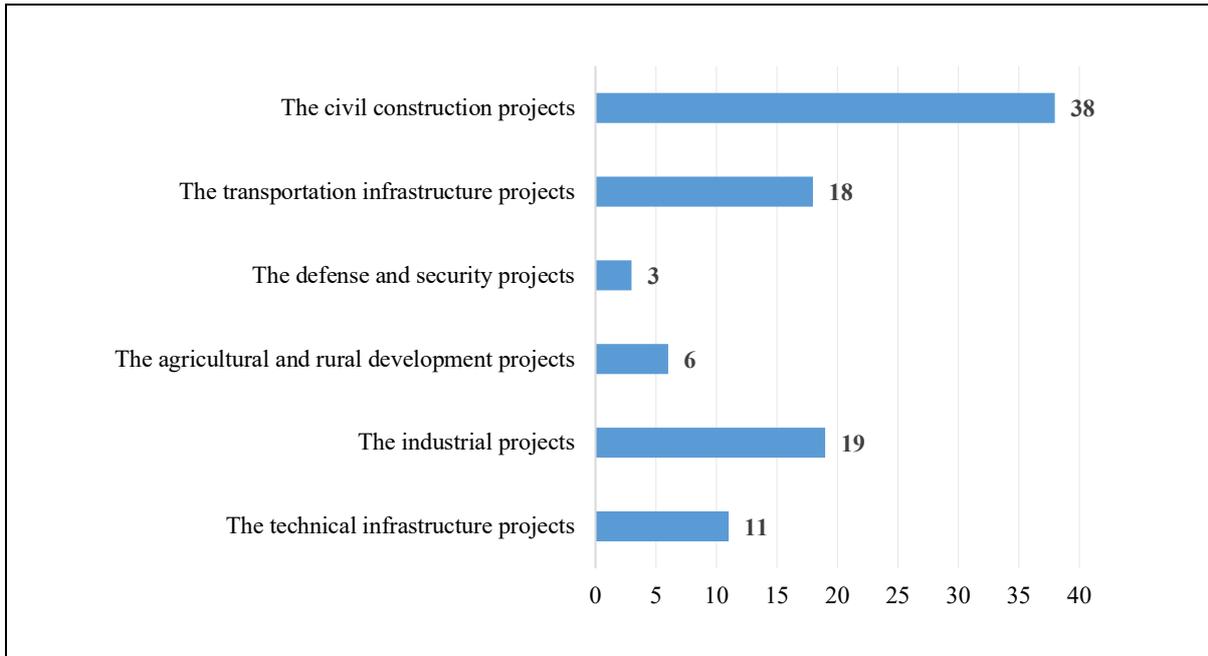


Fig. 4 Statistics on project types participated in by respondents

## 4.2 Data Analysis Results

### 4.2.1 Group of Legal Regulation Factors (Group A)

Table 4 Fuzzified matrix for group A

	A1			A2			A3			A4		
A1	1,00	1,00	1,00	1,01	1,19	1,38	1,68	2,12	2,57	2,51	3,07	3,57
A2	0,73	0,84	0,99	1,00	1,00	1,00	1,32	1,60	1,95	1,32	1,59	1,94
A3	0,39	0,47	0,59	0,51	0,63	0,76	1,00	1,00	1,00	0,90	1,16	1,48
A4	0,28	0,33	0,40	0,52	0,63	0,76	0,68	0,86	1,11	1,00	1,00	1,00

Table 5 Defuzzified matrix for group A

	A1		A2		A3		A4	
A1	1,00	1,00	1,10	1,29	1,90	2,34	2,79	3,32
A2	0,78	0,91	1,00	1,00	1,46	1,77	1,46	1,77
A3	0,43	0,53	0,56	0,69	1,00	1,00	1,03	1,32
A4	0,30	0,36	0,57	0,69	0,76	0,97	1,00	1,00

Table 6 Aggregated matrix for group A

	A1	A2	A3	A4
A1	1,00	1,19	2,12	3,06
A2	0,84	1,00	1,62	1,61
A3	0,47	0,62	1,00	1,18
A4	0,33	0,62	0,85	1,00

**Table 7** Weight matrix for group A

	A1	A2	A3	A4	Trọng số
A1	0,38	0,35	0,38	0,45	0,39
A2	0,32	0,29	0,29	0,24	0,28
A3	0,18	0,18	0,18	0,17	0,18
A4	0,12	0,18	0,15	0,15	0,15

**Table 8** Consistency check for group A

	A1	A2	A3	A4	Weighted sum value	Criteria Weights	Consistency vector	Lamda max	CI	RI	CR
A1	0,36	0,35	0,36	0,40	1,47	0,39	3,78	4,07	0,02	0,89	2,59%
A2	0,30	0,29	0,30	0,25	1,14	0,28	4,03				
A3	0,19	0,18	0,19	0,18	0,74	0,18	4,19				
A4	0,14	0,18	0,16	0,16	0,64	0,15	4,27				

The results from Tables 4 to 8 reflect the evaluation of factors related to legal regulations. The experts' consistency ratio of 2.59% indicates that the results are reliable and that there is a high level of consensus among the experts.

#### 4.2.2 Group of Ash and Slag Characteristics (Group B)

**Table 9** Fuzzified matrix for group B

	B1			B2			B3		
B1	1,00	1,00	1,00	1,20	1,42	1,70	0,86	1,04	1,31
B2	0,59	0,70	0,83	1,00	1,00	1,00	0,84	1,01	1,28
B3	0,76	0,96	1,17	0,78	0,99	1,20	1,00	1,00	1,00

**Table 10** Defuzzified matrix for group B

	B1		B2		B3	
B1	1,00	1,00	1,31	1,56	0,95	1,17
B2	0,64	0,76	1,00	1,00	0,92	1,00
B3	0,85	1,06	1,00	1,08	1,00	1,00

**Table 11** Aggregated matrix for group B

	B1	B2	B3
B1	1,00	1,44	1,06
B2	0,70	1,00	0,96
B3	0,94	1,04	1,00

**Table 12** Weighted criteria matrix for group B

	B1	B2	B3	Trọng số
B1	0,38	0,41	0,35	0,38
B2	0,26	0,29	0,32	0,29
B3	0,36	0,30	0,33	0,33

**Table 13** Consistency check for group B

	B1	B2	B3	Weighted sum value	Criteria Weights	Consistency vector	Lamda max	CI	RI	CR
B1	0,36	0,38	0,34	1,07	0,38	2,81				
B2	0,30	0,32	0,34	0,97	0,29	3,34	3,02	0,01	0,52	2,23%
B3	0,34	0,30	0,32	0,96	0,33	2,92				

The results from Tables 9 to 13 represent the evaluation of factors related to the characteristics of ash and slag. The experts' consistency ratio of 2.23% confirms the reliability of the results and a high degree of consistency among the evaluators.

#### 4.2.3 Group of Cost/Economic Factors (Group C)

**Table 14** Fuzzified matrix for group C

	C1			C2			C3			C4		
C1	1,00	1,00	1,00	0,57	0,73	1,03	0,56	0,71	0,96	0,55	0,69	0,92
C2	0,97	1,37	1,77	1,00	1,00	1,00	0,99	1,37	1,72	1,55	1,96	2,45
C3	1,04	1,41	1,78	0,58	0,73	1,01	1,00	1,00	1,00	0,83	1,05	1,30
C4	1,09	1,45	1,80	0,41	0,51	0,65	0,77	0,95	1,21	1,00	1,00	1,00

**Table 15** Defuzzified matrix for group C

	C1		C2		C3		C4	
C1	1,00	1,00	0,65	0,88	0,64	0,83	0,62	0,80
C2	1,13	1,54	1,00	1,00	1,18	1,55	1,75	2,20
C3	1,20	1,57	0,65	0,84	1,00	1,00	0,94	1,18
C4	1,24	1,60	0,45	0,57	0,85	1,06	1,00	1,00

**Table 16** Aggregated matrix for group C

	C1	C2	C3	C4
C1	1,00	0,77	0,73	0,71
C2	1,31	1,00	1,37	1,98
C3	1,36	0,73	1,00	1,06
C4	1,40	0,51	0,94	1,00

**Table 17** Weighted criteria matrix for group C

	C1	C2	C3	C4	Trong số
C1	0,20	0,25	0,18	0,15	0,20
C2	0,26	0,33	0,34	0,42	0,34
C3	0,27	0,24	0,25	0,22	0,25
C4	0,28	0,17	0,23	0,21	0,22

**Table 18** Consistency check for group C

	C1	C2	C3	C4	Weighted sum value	Criteria Weights	Consistency vector	Lamda max	CI	RI	CR
C1	0,32	0,24	0,31	0,50	1,38	0,20	7,03				
C2	0,36	0,27	0,24	0,18	1,04	0,34	3,08	4,23	0,08	0,89	8,46%
C3	0,21	0,24	0,21	0,15	0,81	0,25	3,29				
C4	0,11	0,26	0,24	0,17	0,78	0,22	3,50				

The results presented in Tables 14 to 18 reflect the evaluation of factors related to cost and economic considerations. The experts' consistency ratio of 8.46% indicates that the results are reliable and that there is reasonable consistency among the experts.

#### 4.2.4 Group of Environmental Factors (Group D)

**Table 19** Fuzzified matrix for group D

	D1			D2			D3		
D1	1,00	1,00	1,00	0,97	1,16	1,38	1,11	1,39	1,71
D2	0,73	0,86	1,03	1,00	1,00	1,00	1,09	1,53	2,03
D3	0,58	0,72	0,90	0,49	0,65	0,91	1,00	1,00	1,00

**Table 20** Defuzzified matrix for group D

	D1		D2		D3	
D1	1,00	1,00	1,07	1,27	1,25	1,55
D2	0,79	0,94	1,00	1,00	1,31	1,00
D3	0,65	0,80	1,00	0,76	1,00	1,00

**Table 21** Aggregated matrix for group D

	D1	D2	D3
D1	1,00	1,17	1,40
D2	0,86	1,00	1,16
D3	0,72	0,86	1,00

**Table 22** Weighted criteria matrix for group D

	D1	D2	D3	Trọng số
D1	0,39	0,39	0,39	0,39
D2	0,33	0,33	0,33	0,33
D3	0,28	0,29	0,28	0,28

**Table 23** Consistency check for group

	D1	D2	D3	Weighted sum value	Criteria Weights	Consistency vector	Lamda max	CI	RI	CR
D1	0,36	0,38	0,34	1,07	0,39	2,75				
D2	0,30	0,32	0,34	0,97	0,33	2,94				
D3	0,34	0,30	0,32	0,96	0,28	3,42	3,03	0,02	0,52	3,36%

The results presented in Tables 19 to 23 reflect the evaluation of factors related to environmental aspects. The experts' consistency ratio of 3.36% confirms the reliability of the evaluation and a high level of agreement among the experts.

#### 4.2.5 Group of Other Factors (Group E)

**Table 24** Fuzzified matrix for group E

	E1			E2			E3			E4		
E1	1,00	1,00	1,00	0,54	0,65	0,78	0,41	0,48	0,57	0,70	0,87	1,05
E2	1,29	1,54	1,84	1,00	1,00	1,00	1,31	1,58	1,93	1,58	1,88	2,19
E3	1,74	2,08	2,44	0,52	0,63	0,76	1,00	1,00	1,00	1,71	2,07	2,48
E4	0,95	1,15	1,44	0,46	0,53	0,63	0,40	0,48	0,58	1,00	1,00	1,00

**Table 25** Defuzzified matrix for group E

	E1		E2		E3		E4	
E1	1,00	1,00	0,60	0,71	0,45	0,53	0,78	0,96
E2	1,40	1,68	1,00	1,00	1,45	1,76	1,73	2,03
E3	1,89	2,24	0,57	0,69	1,00	1,00	1,89	2,27
E4	1,04	1,28	0,49	0,58	0,44	0,53	1,00	1,00

**Table 26** Aggregated matrix for group E

	E1	E2	E3	E4
E1	1,00	0,65	0,49	0,87
E2	1,53	1,00	1,60	1,88
E3	2,05	0,62	1,00	2,08
E4	1,15	0,53	0,48	1,00

**Table 27** Weighted criteria matrix for group E

	E1	E2	E3	E4	Trong số
E1	0,17	0,23	0,14	0,15	0,17
E2	0,27	0,36	0,45	0,32	0,35
E3	0,36	0,22	0,28	0,36	0,30
E4	0,20	0,19	0,13	0,17	0,17

**Table 28** Consistency check for group E

	E1	E2	E3	E4	Weighted sum value	Criteria Weights	Consistency vector	Lamda max	CI	RI	CR
E1	0,23	0,27	0,21	0,20	0,92	0,17	5,30	4,14	0,05	0,89	5,09%
E2	0,25	0,30	0,34	0,30	1,19	0,35	3,41				
E3	0,33	0,27	0,30	0,33	1,24	0,30	4,07				
E4	0,19	0,16	0,15	0,16	0,65	0,17	3,76				

The results from Tables 24 to 28 reflect the evaluation of other influencing factors. The experts' consistency ratio of 3.36% indicates that the results are reliable and demonstrate a high level of agreement among the respondents.

**Table 29** Final weights of factors influencing the decision to use coal combustion ash and slag as construction materials

No	Code	Factor	Weighted
	A	Legal Regulations	
1	A1	Unit prices and technical-economic norms for ash and slag	0,39
2	A2	Construction standards and acceptance regulations	0,28
3	A3	Government support programs and policies	0,18
4	A4	Tax incentive policies	0,15
	B	Characteristics of Ash and Slag	
5	B1	Physical Properties	0,38
6	B2	Chemical Properties	0,29
7	B3	Material Usability	0,33
	C	Cost/Economic Factors	
8	C1	Economic Benefits	0,20
9	C2	Life Cycle Cost	0,34
10	C3	Economic Feasibility	0,25
11	C4	Large-Scale Utilization	0,22
	D	Environmental Factors	
12	D1	Environmental Assurance	0,39
13	D2	Resource Conservation	0,33
14	D3	Sustainable Development Goals	0,28
	E	Other Factors	
15	E1	Training, Education, and Promotion	0,17
16	E2	Technological Innovation	0,35
17	E3	Stakeholders' Perspectives	0,30
18	E4	Designers' Awareness	0,17

Based on the evaluation of 18 factors (as presented in Table 29), expert assessments indicate that all factors have an impact on the decision to use coal combustion ash and slag as building materials in construction. Among them, several factors demonstrate a more significant influence compared to others, including:

- Unit prices and technical-economic norms for ash and slag
- Physical properties of ash and slag
- Economic benefits of using ash and slag as building materials in construction
- Environmental assurance
- Technological innovation

On the other hand, factors with relatively lower influence include:

- Tax incentive policies
- Government support programs and policies
- Training, education, and promotion
- Designers' awareness and understanding

## 5. Discussion on the Factors Influencing the Decision to Use Coal Combustion Ash and Slag as Construction Materials

Coal combustion ash and slag from thermal power plants possess characteristics similar to those of conventional construction materials such as cement and sand. In Vietnam, ash and slag are most commonly used as mineral additives in cement. Additionally, they are used for brick production, fresh concrete admixtures, and landfill materials. Several projects have successfully utilized ash and slag to address challenges in material supply, such as in site leveling for the VSIP Can Tho industrial zone and road construction projects in Tra Vinh.

Moreover, some enterprises have actively employed ash and slag in material production, including the Vietnam Cement Industry Corporation (VICEM) and Thao Trang Transport and Trading Co., Ltd. Survey responses indicate that the government has introduced policies supporting the reuse of ash and slag, including fund

allocation, regulatory frameworks, technical guidance, and incentives for public-private cooperation. These policies, in principle, provide a foundation for promoting the application of ash and slag in construction.

However, construction contractors still face significant difficulties in bidding and cost estimation, as the unit prices of ash and slag-based materials are neither clearly defined nor officially approved in the government's pricing database. In the absence of standardized prices, relying on market prices may expose contractors to financial risks, especially in competitive bidding situations. This explains why the factor "Unit prices and technical-economic norms for ash and slag" received the highest weight (0.39) among legal-related factors.

In Vietnam, two main combustion technologies are utilized in coal-fired power plants: Pulverized Coal Combustion (PC) and Circulating Fluidized Bed Combustion (CFB). The resulting ash and slag vary in physical composition, including aggregate quantity of main oxides ( $\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$ ),  $\text{SO}_3$ , CaO, LOI, moisture content, and bulk density. However, current combustion technologies remain unoptimized, leading to inconsistent ash and slag quality. Some plants produce ash with unburnt carbon levels above 12%, making it unsuitable for use in cement and concrete admixtures, such as in the cases of Vinh Tan 2 and Duyen Hai 1 plants.

Among factors related to material characteristics, "Physical properties of ash and slag" were highlighted by experts as the most challenging issue. They emphasized that combustion technology directly affects the quality of ash and slag, and consequently, the quality of construction works that use these materials.

Within the group of cost/economic factors, the "Life cycle cost of ash and slag as construction materials" received the highest weight (0.34). Although technical guidelines for the application of ash and slag in landfilling exist, these materials still struggle to compete on price with traditional fill materials. Moreover, some ash-generating facilities sell ash and slag instead of offering incentives to encourage consumption, thereby slowing down usage.

In many cases, ash and slag disposal sites are far from consumption points such as cement factories or major construction sites, resulting in high transportation costs. This reduces their appeal from an economic and technical perspective. Exceptions exist for projects where fly ash use is mandatory, such as in the mass concrete structures of hydropower dams.

Another challenge is the dustiness of ash and slag, which increases transportation requirements: the materials must be moistened, covered, and often packaged in jumbo bags or transported in bulk tankers. Additional transportation-related taxes and fees further raise overall costs, limiting their application in distant locations.

Numerous studies have confirmed that improperly managed ash and slag can cause serious environmental pollution. According to Vietnamese law, ash and slag must be classified and, if not hazardous and meeting technical standards and guidelines, may be used as raw materials for construction materials, landfill, or infrastructure projects and managed as commodities.

The Vietnamese government, ministries, and local authorities have issued various policies and legal instruments to promote the treatment and reuse of ash and slag, especially in construction. A consistent theme in these regulations is the emphasis on environmental protection and sustainable development. In line with this, surveyed experts widely agreed that the factor "Environmental assurance" plays a significant role in decisions to use ash and slag in construction.

The factor "Technological innovation" is also considered critical. According to experts, technological advancement must be addressed on two fronts: (1) Improving combustion technology to enhance ash and slag quality, and (2) Innovating material production technologies that incorporate ash and slag. However, such innovations require substantial investment and adequate preparation time.

## 6. Conclusion

Given Vietnam's increasing energy demand, the generation of electricity from coal is projected to keep increasing in the coming years, thereby generating greater volumes of ash and slag. As such, the management and utilization of ash and slag must be approached in a way that is advantageous to the environment, society, and economy.

Using ash and slag as construction materials stands out as one of the most practical and viable solutions. This study focuses on one key aspect of this approach—analyzing the factors influencing construction contractors' decisions to use coal combustion ash and slag in Vietnam.

The findings identify 18 key factors that influence contractors' decisions. Among these, the most impactful factors include:

- Unit prices and technical-economic norms for ash and slag
- Physical properties of ash and slag
- Economic benefits of using ash and slag as construction materials
- Environmental assurance
- Technological innovation

However, it is vital to understand that utilizing ash and slag in construction remains a current and evolving challenge. For ash and slag to be sustainably reused, they must be considered from a dual-benefit perspective: not only as a solution to environmental problems, but also as a source of economic value.

## Acknowledgements

This research is funded by Hanoi University of Civil Engineering (HUCE) under grant number 27-2024/KHXD-TĐ.

## Conflict of Interest

The authors declare that there are no any conflicts of interest relevant to the article. The authors' contributions were clear and consistent from the moment the authors had an idea the article.

## Author contributions

The authors reviewed the results and approved the final version of the manuscript with their contributions to the article as follows: **literature review and collect influencing factors:** Nguyen Thi My Hanh; **data collection and processing:** Nguyen Thi Thuy and Le Hai Yen; **analysis of results and draw conclusion:** Le Van Tuan; **preparation of the manuscript:** Nguyen Thi Thuy.

## References

- [1] Toan Thang. (2020, November 15). Thermal power waste ash treatment: Current situation and bottlenecks that need to be solved. *The Government Newspaper*.  
<https://baochinhphu.vn/xu-ly-tro-xi-thai-nhiet-dien-thuc-trang-va-nhung-nut-that-can-go-102282573.htm>
- [2] L. V. Tuan. (2020, May-June). Scientific basis for using coal-fired thermal power plant ash as an alternative material in construction. *Construction People*, 5–6.
- [3] K. T. M. Truong. (2021). Environment contaminated with dust... coal ash.  
<https://kinhthemoitruong.vn/moi-truong-nhiem-bui-tro-xi-than-54559.html>
- [4] C. Phu. (2022). Detailed regulations on a number of articles of the Law on Environmental Protection, Vietnam.
- [5] C. Heidrich, H.-J. Feuerborn, and A. Weir. (2013). Coal combustion products: a global perspective. *Proc. World of Coal Ash Conf*,
- [6] C. H. Benson and S. Bradshaw. (2011). User guideline for coal bottom ash and boiler slag in green infrastructure construction, *Recycled Materials Resource Center, Univ. of Wisconsin–Madison*.
- [7] D. Harris, C. Heidrich, and J. Feuerborn. (2019). Global aspects of coal combustion products.
- [8] A. Horvath. (2003). Life-cycle environmental and economic assessment of using recycled materials for asphalt pavements.
- [9] A. Behera and S. S. Mohapatra. (2018). Challenges in recovery of valuable and hazardous elements from bulk fly ash and options for increasing fly ash utilization. *Coal Fly Ash Beneficiation–Treatment of Acid Mine Drainage with Coal Fly Ash, IntechOpen*, pp. 19–39. doi:10.5772/intechopen.69469
- [10] M. Rossow. (2003). Fly ash facts for highway engineers, *Continuing Education and Development, New York, NY*.
- [11] M. L. D. Jayaranjan. E. D. Van Hullebusch, and A. P. Annachhatre. (2014). Reuse options for coal-fired power plant bottom ash and fly ash. *Rev. Environ. Sci. Biotechnol.*, vol. 13, pp. 467–486, 2014.  
doi:10.1007/s11157-014-9358-2
- [12] C. T. Phu and T. D. Tiep. (2021). Research on the use of ash and slag from domestic solid waste incinerators as raw materials for the production of construction materials. *Materials & Construction Magazine*, vol. 11, no. 6, pp. 95–102.
- [13] N. T. B. Thuy \*et al.\*. (2022). Using wet fly ash with high loss on firing to replace sand in mortar. *HCMCOJS–Conf*,
- [14] V. H. Nam, (2012) Research on the use of high-content Pha Lai ash in conventional mass concrete for gravity dams, *M.S. thesis, Hanoi Univ. of Civil Engineering, Vietnam*.
- [15] H. T. Phuong and V. Q. Vuong. (2020). Potential of construction materials from ash and slag - Recycling solutions to protect the environment and achieve economic efficiency. *Journal of Science and Technology of Water Resources and Environment g*, no. 70, pp. 118–123.

- [16] L. V. Tuan. (2021). Evaluation of the effectiveness of using coal-fired thermal power plant ash as a substitute material in some types of construction works in Vietnam, *M.S. thesis, Hanoi Univ. of Civil Engineering, Vietnam*.
- [17] A. Haleem et al. (2016). Critical factors for the successful usage of fly ash in roads, bridges, and embankments: Analysis of Indian perspective. *Resources Policy, vol. 49, pp. 334–348*.  
doi: 10.1016/j.resourpol.2016.07.011
- [18] F. Baho. (2024). Analyzing the factors influencing sustainable decision-making of construction contractors," *M.S. thesis, [Institution]*.
- [19] Y. Asiedu and P. Gu. (1998). Product life cycle cost analysis: state-of-the-art review. *Int. J. Prod. Res., vol. 36, no. 4, pp. 883–908*.  
doi: 10.1080/002075498193371
- [20] A. P. Black et al. (2011). The economic impacts of prohibiting coal fly ash use in transportation infrastructure construction.
- [21] N. Pandian. (2004). Fly ash characterization with reference to geotechnical applications. *J. Indian Inst. Sci., vol. 84, no. 6, p. 189*.
- [22] J. Alam and M. Akhtar. (2011). Fly ash utilization in different sectors in Indian scenario. *Int. J. Emerg. Trends Eng. Dev., vol. 1, no. 1, pp. 1–14*.
- [23] I. Ponsot et al. (2015). Recycling of pre-stabilized municipal waste incinerator fly ash and soda-lime glass into sintered glass-ceramics. *J. Clean. Prod., vol. 89, pp. 224–230*.  
doi: 10.1016/j.jclepro.2014.10.071
- [24] T. T. C. Phu. (2018). Decision No. 491/QĐ-TTg approving the adjusted national strategy for integrated solid waste management to 2025, vision to 2050, Vietnam.
- [25] S. A. Zakaria \*et al.\* (2018). Key factors influencing the decision to adopt industrialized building systems technology in the Malaysian construction industry: An inter-project perspective. *Architectural Eng. Des. Manag., vol. 14, no. 1–2, pp. 27–45*.  
doi:10.1080/17452007.2017.1298318
- [26] I. Ogunkah and J. Yang. (2012). Investigating factors affecting material selection: The impacts on green vernacular building materials in the design-decision-making process. *Buildings, vol. 2, no. 1, pp. 1–32*.  
doi:10.3390/buildings2010001