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Life-Friendly Engineering and Life-Oriented Engineering Education in Indonesia: Integrating Professional Ethics, Safety Culture, Sustainability Awareness, Digital Responsibility, and Social Responsibility

Syamsul Arifin Hamidah [1,*]

[1] College of engineering, Universitas Negeri Malang, Malang, Indonesia .Email: syamsul_arif.ha@um.ac.id
* Corresponding Author: Syamsul Arifin Hamidah, syamsul_arif.ha@um.ac.id

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ABSTRACT

Engineering has become an indispensable foundation of modern human civilization, supporting mobility, housing, energy production, communication, healthcare, industry, and public services. However, engineering activities do not affect human society alone. Engineering planning, construction, operation, and maintenance interact continuously with ecosystems, biodiversity, animals, plants, and natural resources. Consequently, engineering education should move beyond the conventional transmission of technical knowledge and incorporate a broader life-oriented perspective that recognizes safety, ecological integrity, human dignity, sustainability, and social responsibility as integral dimensions of engineering practice.

This conceptual study develops a framework for Life-Friendly Engineering (LFE) and Life-Oriented Engineering Education (LOEE) in Indonesia. Building on interdisciplinary literature analysis, conceptual synthesis, and engineering practice cases, the study integrates five contemporary educational dimensions—professional ethics, safety culture, sustainability awareness, digital responsibility, and social responsibility—with additional dimensions derived from the original life-friendly engineering framework, including biodiversity protection, human-centered engineering, environmental responsibility, inclusive engineering design, and risk-management competence. The Indonesian context is used as the institutional setting because engineering education and professional engineering practice increasingly require outcome-oriented competencies and broader responsibility toward society and the environment.

The proposed framework conceptualizes Life-Oriented Engineering Education as an upstream educational mechanism that strengthens ethical awareness, safety culture, sustainability awareness, digital responsibility, and social responsibility. These dimensions contribute to risk-management competence, environmental responsibility, inclusive engineering design, and human-centered engineering, which subsequently shape engineers' Life-Friendly Engineering Orientation. The framework further proposes that life-friendly engineering should be implemented throughout the engineering life cycle, including planning, design, construction, operation, maintenance, and decommissioning. Particular attention is given to human safety, vulnerable populations, biodiversity, animal movement, vegetation, ecological connectivity, climate resilience, and responsible application of artificial intelligence and Building Information Modeling. The study concludes by proposing an Indonesian Life-Friendly Engineering Education framework that connects humanistic education, life education, ecological education, professional engineering education, and digital responsibility. The framework provides a conceptual foundation for future empirical research, curriculum development, professional training, and life-friendly engineering assessment in Indonesia.

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1. Introduction

Engineering is one of the principal material foundations of human civilization. From roads, bridges, buildings, water systems, and energy infrastructure to digital networks, transportation systems, and advanced manufacturing, engineering activities profoundly shape the conditions under which individuals and communities live [1]. Engineering therefore cannot be understood solely as the application of mathematical, scientific, and technological knowledge. It is also a social and ecological activity that produces consequences for human beings and other forms of life [2].

The relationship between engineering and life is multidimensional [3]. Engineering originates from natural resources, operates within natural environments, serves human needs, and simultaneously modifies ecological systems [4]. Construction activities may consume land, water, minerals, energy, and biological resources. Roads can fragment wildlife habitats; dams can alter aquatic ecosystems; buildings can create collision risks for birds; intensive urban development can reduce vegetation and increase heat exposure; and poorly designed infrastructure can increase risks for children, older adults, persons with disabilities, and other vulnerable groups [5,6].

These relationships indicate that engineering performance cannot be evaluated only according to technical functionality, economic efficiency, construction time, or structural reliability [7]. An engineering project may be technically successful while simultaneously producing undesirable consequences for biodiversity, ecological connectivity, community well-being, or vulnerable populations [8]. Consequently, engineering requires a broader value framework in which the protection of life becomes an explicit consideration throughout the engineering life cycle [9].

This study develops the concept of **Life-Friendly Engineering (LFE)** as an engineering value orientation based on respect for, protection of, and responsibility toward life. The concept extends conventional ideas of sustainable engineering, green engineering, safe engineering, and human-centered design by explicitly connecting human life with other biological and ecological systems.

The concept is particularly relevant to engineering education. Engineers are the principal actors responsible for translating scientific knowledge into physical and technological interventions. Their decisions influence project location, design, materials, construction methods, environmental impacts, safety systems, maintenance strategies, and long-term operation. Therefore, the development of life-friendly engineering cannot be separated from the education and professional formation of engineers.

The Indonesian context provides an appropriate setting for developing this framework. Indonesia's engineering profession is institutionally associated with professional standards, engineering education, professional development, public protection, and sustainable development [10]. Indonesian engineering accreditation also emphasizes outcome-based education, learning outcomes, stakeholder needs, and continuous quality improvement. These features provide an institutional foundation for integrating life-oriented competencies into engineering education [11].

The objective of this study is therefore to develop a conceptual framework for Life-Friendly Engineering and Life-Oriented Engineering Education in Indonesia by integrating:

1. professional ethics;
2. safety culture;

3. sustainability awareness;
4. digital responsibility;
5. social responsibility;
6. risk-management competence;
7. environmental responsibility;
8. biodiversity protection; and
9. inclusive and human-centered engineering.

The study addresses three principal questions:

RQ1: What are the conceptual foundations and dimensions of Life-Friendly Engineering?

RQ2: How can Life-Oriented Engineering Education cultivate the competencies required for life-friendly engineering practice?

RQ3: How can professional ethics, safety culture, sustainability awareness, digital responsibility, and social responsibility be integrated into engineering education in Indonesia?

2. Conceptual Foundations of Engineering and Life

2.1 Engineering as a Human–Nature Interface

Engineering is fundamentally connected to nature because its materials, energy sources, spatial environments, and functional objectives are derived from or operate within natural systems [12]. Human beings transform natural materials into infrastructure through technological knowledge and organized labor [13]. Thus, engineering is not external to nature; rather, it is a human-mediated form of interaction with nature [14].

Historically, engineering has frequently learned from natural structures and processes[15]. Biomimetic architecture, bio-inspired materials, ecological infrastructure, and nature-based solutions demonstrate how biological systems can provide inspiration for engineering innovation[16].

This relationship can be represented as:

Natural systems → Human knowledge → Engineering design → Built environment → Feedback to natural systems

T[illegible]s, water systems, habitats, atmospheric conditions, or resource consumption patterns, these modifications may generate feedback effects on humans and other species [17].

Therefore, engineering should be understood as a **human–nature interface**, rather than an isolated technological activity[18].

2.2 Engineering and Human Life

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Engineering exists fundamentally to serve human needs. Buildings provide shelter, transportation systems enable mobility, water infrastructure supports health, energy systems support economic activity, and communication infrastructure connects communities [19].

However, serving human needs requires more than providing technical functionality. Engineering should consider[20]:

- physical safety;
- public health;
- psychological well-being;
- accessibility;
- comfort;
- resilience;
- affordability;
- environmental quality;
- social inclusion; and
- long-term usability.

Particular attention should be given to vulnerable populations, including older adults, children, persons with disabilities, people with limited mobility, and communities exposed to environmental or disaster risks.

Consequently, human-centered engineering should evolve toward **life-centered engineering**, in which the well-being of human users is considered together with the ecological systems on which human life depends [21].

2.3 Engineering and Biodiversity

Engineering activities can affect biodiversity through habitat conversion, fragmentation, pollution, noise, artificial lighting, changes in hydrological systems, and direct wildlife mortality[22].

Road infrastructure, for example, may fragment habitats and create wildlife–vehicle collision risks. Buildings with highly reflective glass surfaces may increase bird-collision risks. Water infrastructure can alter aquatic migration routes. Large construction projects may also remove vegetation or modify soil conditions[23].

These impacts demonstrate that biodiversity should not be treated as an external environmental issue considered only after engineering decisions have been made. Biodiversity protection should be incorporated during project planning and design[24].

3. Defining Life-Friendly Engineering

3.1 Conceptual Definition

Life-Friendly Engineering can be defined as:

An engineering philosophy and practice that integrates respect for life, human safety, ecological integrity, biodiversity protection, sustainability, ethical responsibility, and social well-being into engineering decisions throughout the entire project life cycle.

The concept contains three fundamental dimensions.

Value dimension

Engineering should recognize the intrinsic importance of life and establish respect for human beings, animals, plants, and ecological systems as a core professional value.

Technical dimension

Engineering should transform these values into concrete design, construction, operation, maintenance, monitoring, and risk-management practices.

Institutional dimension

Engineering organizations, educational institutions, professional bodies, regulations, standards, and assessment mechanisms should provide systematic support for life-friendly practices.

3.2 Core Principles

The original conceptual framework can be developed into five principles for the Indonesian context.

Principle 1: Life Priority

Protection of human life and ecological integrity should be considered a fundamental engineering priority.

Principle 2: Whole-Life Integration

Life-friendly considerations should be integrated into:

Planning → Design → Construction → Operation → Maintenance → Renewal/Decommissioning

Principle 3: Long-Term Responsibility

Engineering decisions should consider not only immediate project benefits but also long-term effects on communities, ecosystems, resource availability, and future generations.

Principle 4: Inclusive Responsibility

Engineering should respond to diverse human needs and should avoid systematically excluding vulnerable populations.

Principle 5: Digital and Technological Responsibility

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Artificial intelligence, digital twins, BIM, sensors, automation, and other digital technologies should be used responsibly, transparently, safely, and in ways that protect people and the environment.

4. Dimensions of Life-Friendly Engineering

Table 1 presents the expanded conceptual dimensions.

Table 1. Dimensions of Life-Friendly Engineering

Dimension	Core concern	Engineering implication
Human safety	Protection from injury and hazards	Risk assessment, safe design and emergency preparedness
Professional ethics	Moral and professional responsibility	Ethical decision-making and accountability
Safety culture	Organizational commitment to safety	Reporting, prevention, monitoring and continuous improvement
Sustainability awareness	Long-term environmental and resource impacts	Resource efficiency, low-carbon and resilient solutions
Digital responsibility	Responsible use of digital technologies	AI transparency, data protection and human oversight
Social responsibility	Relationship with communities	Stakeholder participation and equitable outcomes
Biodiversity protection	Protection of species and habitats	Ecological assessment and biodiversity-sensitive design
Environmental responsibility	Prevention of ecological degradation	Pollution control and environmental monitoring
Inclusive engineering	Accessibility and vulnerable groups	Universal and inclusive design
Risk-management competence	Anticipation and mitigation of hazards	Identification, assessment, treatment and monitoring of risk

These dimensions collectively define the proposed **Life-Friendly Engineering Orientation (LFEO)**.

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5. Professional Ethics and Life-Friendly Engineering

Professional ethics represents the moral foundation of engineering practice. Engineering decisions can influence human safety, public resources, environmental conditions, and community welfare. Consequently, engineers require more than technical competence.

A life-friendly ethical framework requires engineers to ask:

1. Who benefits from the project?
2. Who may be exposed to risk?
3. Which environmental systems may be affected?
4. Which groups may be disadvantaged?

5. What are the long-term consequences?
6. What uncertainties remain?
7. What alternative designs could reduce harm?

Professional ethics therefore functions as a decision-making mechanism that connects technical knowledge with social and environmental responsibility.

In Indonesia, this dimension is particularly compatible with the professional framework established under the national engineering law, which addresses professional standards, professional development, rights and obligations, and public protection [25].

6. Safety Culture as a Core Engineering Competency

Safety should not be treated merely as compliance with technical regulations. A strong safety culture involves attitudes, organizational practices, communication, leadership, learning, reporting, and continuous improvement.

The proposed framework distinguishes between:

Safety knowledge → Safety awareness → Safety behavior → Safety culture → Safety performance

Engineering education should therefore provide students with opportunities to understand real-world hazards and practice risk identification.

Examples include:

- structural failure;
- fire;
- flooding;
- landslides;
- earthquakes;
- industrial accidents;
- transportation accidents;
- extreme weather;
- occupational hazards; and
- technological failures.

For Indonesia, disaster-resilient engineering is particularly relevant because engineering curricula and professional practice must address diverse hazard environments.

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The engineering education process should consequently include scenario-based risk analysis rather than relying exclusively on theoretical examinations.

7. Sustainability Awareness

Sustainability awareness represents the engineer's ability to understand the long-term consequences of engineering decisions.

It includes:

- resource efficiency;
- energy efficiency;
- carbon reduction;
- circular economy principles;
- waste minimization;
- water conservation;
- biodiversity protection;
- climate resilience;
- ecosystem services; and
- intergenerational responsibility.

Sustainability should not be treated as a separate elective topic. Instead, it should become a cross-cutting engineering competency.

For example, a civil engineering student should evaluate not only whether a bridge satisfies structural requirements but also:

- its material footprint;
- construction waste;
- maintenance requirements;
- resilience to extreme events;
- impacts on surrounding ecosystems; and
- accessibility for different users.

8. Digital Responsibility in Engineering Education

Digital transformation introduces a new dimension of engineering responsibility.

Engineers increasingly use:

- artificial intelligence;

- machine learning;
- Building Information Modeling;
- digital twins;
- remote sensing;
- automated monitoring;
- geographic information systems;
- Internet of Things technologies; and
- predictive analytics.

These technologies can improve safety, efficiency, environmental monitoring, and decision-making. However, they can also create new risks related to inaccurate models, biased algorithms, cybersecurity, privacy, data misuse, and excessive dependence on automated systems.

Digital responsibility therefore requires five competencies:

8.1 Data literacy

Engineers should understand where data originate, how they are processed, and what limitations they contain.

8.2 Algorithmic awareness

Engineers should recognize that AI-generated outputs may contain errors or systematic biases.

8.3 Human oversight

Critical engineering decisions should retain appropriate professional oversight.

8.4 Data ethics

Sensitive data should be collected, stored, analyzed, and shared responsibly.

8.5 Technological sustainability

Digital technologies themselves should be evaluated in terms of energy consumption, resource requirements, and environmental impacts.

9. Social Responsibility and Community-Centered Engineering

Engineering projects affect communities in different ways. A technically efficient project may nevertheless generate social conflicts if communities are excluded from decision-making.

Social responsibility requires engineers to consider:

- local community needs;
- accessibility;

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- affordability;
- cultural context;
- livelihood impacts;
- displacement;
- public participation;
- environmental justice; and
- distribution of project benefits and risks.

Engineering education should therefore introduce students to stakeholder analysis and participatory design.

The engineer becomes not merely a technical problem solver but also a mediator between:

Technology ↔ Community ↔ Environment ↔ Institutions

10. Biodiversity-Friendly Engineering

The original framework identifies five principal strategies for reducing engineering impacts on animals. These strategies can be generalized into an Indonesian Life-Friendly Engineering model.

10.1 Avoidance

Avoid environmentally sensitive areas whenever technically and economically feasible.

Examples include:

- changing project locations;
- avoiding critical habitats;
- rerouting roads;
- reducing construction footprints.

10.2 Ecological Connectivity

Where infrastructure divides habitats, ecological connections should be restored through:

- wildlife crossings;
- ecological bridges;
- underpasses;
- fish passages;
- habitat corridors.

10.3 Substitution

Where engineering and animal activity conflict, alternative solutions should be developed.

For example, infrastructure can be redesigned to provide alternative nesting or habitat opportunities while preserving operational safety.

10.4 Mitigation and Compensation

Where impacts cannot be completely avoided, engineers should apply mitigation measures and, where appropriate, ecological restoration.

10.5 Information and Warning

Engineering systems can incorporate signs, sensors, cameras, intelligent transportation systems, and real-time warnings to reduce wildlife and human risks.

11. Plant-Friendly Engineering

Plants are essential components of ecological systems and human settlements.

Life-friendly engineering should therefore:

- minimize unnecessary vegetation removal;
- protect mature and ecologically valuable trees;
- reduce soil sealing;
- preserve soil quality;
- increase urban vegetation;
- incorporate green roofs;
- develop vertical greenery;
- establish ecological corridors; and
- use native or ecologically appropriate plant species where suitable.

Green infrastructure can simultaneously contribute to biodiversity, thermal comfort, stormwater management, air quality, and urban well-being.

Thus, plant-friendly engineering is not merely an aesthetic concern. It represents an integrated environmental engineering strategy.

12. Inclusive Human-Centered Engineering

A life-friendly engineering framework should recognize differences among users.

Table 2. Inclusive Engineering Requirements

User group	Key engineering requirement

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Older adults	Accessibility, mobility support and safe circulation
Children	Protection from falls, traffic and unsafe infrastructure
Persons with disabilities	Universal design and accessible information
Workers	Occupational safety and ergonomic conditions
General public	Safe, healthy and reliable infrastructure
Local communities	Participation and equitable access
Future generations	Resource conservation and long-term resilience

This approach transforms the principle of “human-centered design” into a broader **life-centered design** philosophy.

13. Life-Oriented Engineering Education

13.1 Concept

Life-Oriented Engineering Education (LOEE) is defined in this study as:

An educational approach that develops engineers who combine technical competence with respect for life, professional ethics, safety awareness, ecological responsibility, digital responsibility, and social responsibility.

LOEE does not replace conventional engineering education. Rather, it expands its objectives.

The traditional model can be represented as:

Science → Technology → Engineering → Technical Solution

The proposed model becomes:

Science + Technology + Ethics + Safety + Ecology + Society + Digital Responsibility → Life-Friendly Engineering Solution

14. Proposed Indonesian Life-Oriented Engineering Education Framework

The framework consists of four interconnected educational layers.

Layer 1: Humanistic Education

Students develop:

- empathy;
- ethical reasoning;
- cultural awareness;
- social responsibility;

- understanding of human dignity.

Layer 2: Life and Ecological Education

Students learn:

- biodiversity;
- ecosystem relationships;
- environmental impacts;
- climate resilience;
- conservation;
- human–nature relationships.

Layer 3: Professional Engineering Education

Students acquire:

- engineering science;
- design;
- construction;
- risk assessment;
- safety management;
- project management;
- professional standards.

Layer 4: Digital Responsibility Education

Students develop:

- AI literacy;
- data ethics;
- cybersecurity awareness;
- digital modeling;
- responsible automation;
- human oversight.

The four layers converge in:

Life-Friendly Engineering Competence

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15. Proposed Conceptual Model

Figure 1. Conceptual framework of Life-Oriented Engineering Education

LIFE-ORIENTED ENGINEERING EDUCATION

Professional Ethics   Safety Culture   Sustainability Awareness

Digital Responsibility   Social Responsibility

Risk Management Competence

Human-Centered Engineering   Environmental Responsibility   Biodiversity Protection

LIFE-FRIENDLY ENGINEERING

ORIENTATION (LFEO)

▼ ▼ ▼

Human Safety | Ecological Integrity | Social Well-being

▼

SUSTAINABLE ENGINEERING

AND LIFE PROTECTION

16. Proposed Relationships Between the Variables

The conceptual framework allows the development of the following propositions for future empirical testing.

Proposition 1

Life-Oriented Engineering Education positively contributes to professional ethical awareness among engineering students.

Proposition 2

Professional ethics positively contributes to Life-Friendly Engineering Orientation.

Proposition 3

Safety culture positively contributes to risk-management competence.

Proposition 4

Sustainability awareness positively contributes to environmental responsibility.

Proposition 5

Digital responsibility positively contributes to responsible technology adoption in engineering practice.

Proposition 6

Social responsibility positively contributes to human-centered engineering orientation.

Proposition 7

Risk-management competence positively contributes to Life-Friendly Engineering Orientation.

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Proposition 8

Environmental responsibility positively contributes to biodiversity-sensitive engineering practice.

Proposition 9

Life-Oriented Engineering Education indirectly influences Life-Friendly Engineering Orientation through professional ethics, safety culture, sustainability awareness, digital responsibility, and social responsibility.

17. Proposed Measurement Framework

Because the present study is conceptual rather than survey-based, the following indicators are proposed for future empirical validation.

Table 3. Proposed Measurement Dimensions

Construct	Suggested indicators
Life-Oriented Engineering Education	life education, ecological education, ethical education, interdisciplinary learning
Professional Ethics	integrity, accountability, ethical decision-making, public interest
Safety Culture	hazard awareness, reporting, prevention, emergency preparedness
Sustainability Awareness	resource efficiency, climate awareness, circularity, environmental protection
Digital Responsibility	data ethics, AI awareness, cybersecurity, human oversight
Social Responsibility	stakeholder engagement, inclusion, community welfare
Risk-Management Competence	risk identification, assessment, mitigation, monitoring
Environmental Responsibility	pollution prevention, ecosystem protection, ecological monitoring
Inclusive Engineering	accessibility, universal design, vulnerable-user protection
Biodiversity Protection	habitat protection, wildlife connectivity, ecological mitigation
Life-Friendly Engineering Orientation	respect for life, long-term thinking, ecological integration, safety priority

A future empirical study could operationalize these constructs through a Likert-scale questionnaire and evaluate the measurement model using **PLS-SEM or covariance-based SEM**.

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18. Integration into Indonesian Engineering Curricula

The proposed framework can be incorporated into Indonesian engineering education without requiring the removal of existing technical courses.

Table 4. Curriculum Integration Framework

Educational stage	Proposed content	Learning activity
Foundation	Ethics and life awareness	Lectures and reflection
Engineering fundamentals	Safety and risk	Hazard-analysis exercises
Design courses	Inclusive and ecological design	Design projects

Environmental courses	Sustainability and biodiversity	Environmental assessment
Digital courses	AI and data responsibility	Digital case studies
Project courses	Community responsibility	Participatory projects
Internship	Professional responsibility	Workplace observation
Capstone project	Life-friendly engineering	Integrated design project

This approach transforms Life-Friendly Engineering from an abstract philosophical concept into an educational competency.

19. Project-Based Learning

Project-based learning can provide an effective mechanism for connecting engineering knowledge with life-friendly values.

Students could be asked to redesign a local engineering project while evaluating:

1. human safety;
2. accessibility;
3. ecological impacts;
4. biodiversity;
5. energy use;
6. material consumption;
7. climate resilience;
8. digital monitoring;
9. community needs; and
10. long-term maintenance.

For example, a road-design project could require students to simultaneously evaluate traffic safety, pedestrian accessibility, drainage, vegetation, wildlife movement, construction impacts, and long-term maintenance.

The final assessment would therefore not be based solely on technical correctness but on the project's overall life-friendly performance.

20. Digital Technologies and AI-Based Life-Friendly Engineering

Artificial intelligence and BIM can support the implementation of the proposed framework.

BIM applications

BIM can support:

- lifecycle information management;
- clash detection;

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- safety planning;
- energy analysis;
- maintenance planning;
- environmental assessment.

AI applications

AI can support:

- hazard prediction;
- wildlife detection;
- traffic-risk prediction;
- environmental monitoring;
- structural health monitoring;
- energy optimization;
- disaster early warning.

However, technology should remain a tool rather than a substitute for professional judgment.

A responsible AI framework should therefore follow:

Data quality → Algorithm validation → Human review → Decision accountability → Continuous monitoring

This principle is especially important when AI is used for safety-critical engineering decisions.

21. Institutional Implementation

Life-Friendly Engineering Education requires cooperation among multiple stakeholders.

Universities

Universities should:

- revise learning outcomes;
- introduce interdisciplinary courses;
- strengthen project-based learning;
- integrate ethics and sustainability;

- evaluate life-friendly competencies.

Professional organizations

Professional organizations should:

- develop continuing professional education;
- promote ethical standards;
- provide technical guidance;
- encourage biodiversity-sensitive engineering.

Engineering companies

Companies should:

- integrate life-friendly indicators into project management;
- provide safety and environmental training;
- monitor project impacts;
- establish feedback mechanisms.

Government agencies

Government institutions should:

- incorporate life-friendly principles into engineering standards;
- strengthen environmental assessment;
- support resilient infrastructure;
- establish monitoring and evaluation mechanisms.

Communities

Communities should:

- participate in relevant planning;
- communicate local needs;
- contribute local ecological knowledge;
- participate in monitoring.

22. Life-Friendly Engineering Across the Project Life Cycle

Table 5. Life-Friendly Engineering by Project Stage

Stage	Principal life-friendly questions

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Planning	Who and what may be affected?
Site selection	Can sensitive habitats and communities be avoided?
Design	Can risks and ecological impacts be reduced?
Construction	How can pollution, accidents and habitat disturbance be minimized?
Operation	Is the infrastructure safe, inclusive and environmentally responsible?
Maintenance	Are emerging risks continuously monitored?
Renewal	Can materials and resources be reused?
Decommissioning	Can ecological and social impacts be minimized?

This life-cycle perspective prevents environmental and social considerations from being treated as late-stage corrective measures.

23. Proposed Life-Friendly Engineering Evaluation Index

Future research can develop a multidimensional evaluation index.

Table 6. Proposed Evaluation Structure

Dimension	Example indicators	Weighting approach
Human safety	Accident prevention, emergency preparedness	To be empirically determined
Professional ethics	Accountability, transparency	To be empirically determined
Sustainability	Energy, resources, emissions	To be empirically determined
Biodiversity	Habitat protection, connectivity	To be empirically determined
Social responsibility	Participation, inclusion	To be empirically determined
Digital responsibility	Data quality, AI oversight	To be empirically determined
Resilience	Disaster preparedness and recovery	To be empirically determined
Accessibility	Universal design	To be empirically determined

No fixed numerical weights are assigned at this conceptual stage because such weights should be derived through empirical expert assessment, stakeholder surveys, AHP, entropy weighting, Delphi methods, or other validated approaches.

24. Discussion

The central contribution of this study is the conceptual expansion of engineering responsibility from a primarily technical orientation toward a broader life-oriented framework.

Traditional engineering education emphasizes scientific knowledge, technical analysis, design competence, and professional practice. These remain essential. However, engineering decisions increasingly occur under conditions of ecological uncertainty, climate change, technological transformation, population growth, urbanization, and complex social expectations.

Under these conditions, technical competence alone cannot fully determine whether an engineering intervention is desirable or responsible.

The concept of Life-Friendly Engineering introduces an additional question:

Does the engineering solution improve human well-being while minimizing unnecessary harm to other forms of life and ecological systems?

This question does not imply that all engineering impacts can be eliminated. Infrastructure inevitably transforms environments. Instead, Life-Friendly Engineering seeks to establish a structured decision-making process for avoiding unnecessary harm, reducing unavoidable impacts, restoring damaged systems, and continuously improving engineering practices.

The Indonesian context further highlights the importance of integrating professional responsibility with engineering education. Outcome-oriented engineering education provides an institutional mechanism through which technical, ethical, environmental, and social competencies can be incorporated into learning outcomes and assessment.

The proposed framework also extends the original life-friendly concept by adding **digital responsibility**. This addition is important because contemporary engineering increasingly depends on data and computational technologies. A life-friendly engineer must therefore understand not only physical risks but also the consequences of digital decisions.

For example, an AI-based infrastructure monitoring system may improve safety if its data and algorithms are reliable. However, inaccurate data may generate false alarms or missed hazards. Therefore, digital responsibility becomes part of safety responsibility.

Similarly, sustainability awareness cannot remain limited to environmental courses. It should influence engineering decisions concerning materials, energy, land use, construction methods, maintenance, and end-of-life management.

Social responsibility provides another essential dimension. Infrastructure exists within communities. Consequently, engineers should understand that technical optimization may conflict with community needs if social impacts are ignored.

25. Theoretical Contributions

This study makes four principal conceptual contributions.

First

It conceptualizes **Life-Friendly Engineering** as a multidimensional engineering value system rather than merely an environmental protection strategy.

Second

It connects Life-Friendly Engineering with **engineering education**, establishing a direct relationship between educational inputs and professional engineering values.

Third

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It expands the original framework by incorporating **professional ethics, safety culture, sustainability awareness, digital responsibility, and social responsibility**.

Fourth

It proposes an integrated framework suitable for future empirical testing in Indonesia.

26. Practical Contributions

The framework can support:

- engineering curriculum development;
- accreditation preparation;
- professional development;
- engineering-company training;
- environmental assessment;
- safety management;
- sustainable infrastructure planning;
- biodiversity-sensitive design;
- AI and BIM governance;
- community-centered engineering.

It can also provide a basis for developing a future **Life-Friendly Engineering Index for Indonesia**.

27. Future Empirical Research Design

The conceptual framework can subsequently be converted into a quantitative study.

A future study could survey:

- undergraduate engineering students;
- postgraduate engineering students;
- engineering educators;
- practicing engineers;
- engineering managers.

The proposed constructs could be measured through five- or seven-point Likert scales.

The analytical sequence could be:

Exploratory Factor Analysis → Confirmatory Factor Analysis → Reliability Testing → Validity Testing → PLS-SEM → Mediation Analysis

The hypothesized structural model would test whether Life-Oriented Engineering Education influences Life-Friendly Engineering Orientation through the five principal dimensions:

Professional Ethics

Safety Culture

Sustainability Awareness

Digital Responsibility

Social Responsibility

Risk-management competence could then be examined as an intermediate mechanism.

Importantly, these empirical steps should be implemented in future research rather than presented as findings of the present conceptual study.

28. Limitations

This study has several limitations.

First, the framework is conceptual and does not report original survey or experimental data.

Second, the proposed relationships among the constructs have not yet been statistically validated in an Indonesian engineering student population.

Third, the proposed measurement indicators require empirical reliability and validity testing.

Fourth, Life-Friendly Engineering may vary across engineering disciplines. Civil, mechanical, electrical, environmental, chemical, mining, and software engineers encounter different forms of risk and environmental impact.

Fifth, the relative importance of the proposed dimensions may differ among universities, industries, regions, and communities in Indonesia.

Sixth, digital responsibility is a rapidly developing field, meaning that AI-related engineering competencies will require continuous updating.

These limitations provide opportunities for subsequent empirical research rather than weaknesses that invalidate the conceptual framework.

29. Conclusions

Engineering is not an isolated technical activity. It is a form of human intervention that interacts continuously with people, communities, natural resources, ecosystems, animals, plants, and technological systems.

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This study developed the concept of **Life-Friendly Engineering** as an integrated engineering value orientation based on respect for life, human safety, ecological integrity, sustainability, professional responsibility, and social well-being.

The study further proposed **Life-Oriented Engineering Education** as a mechanism for developing engineers capable of translating these values into professional practice.

The proposed framework integrates five principal educational dimensions:

1. **Professional Ethics**
2. **Safety Culture**
3. **Sustainability Awareness**
4. **Digital Responsibility**
5. **Social Responsibility**

These dimensions are complemented by risk-management competence, environmental responsibility, biodiversity protection, inclusive engineering, and human-centered design.

The framework proposes that engineering education should move from a narrow model of:

technical knowledge → technical solution

toward:

technical knowledge + ethics + safety + sustainability + digital responsibility + social responsibility → life-friendly engineering solution.

Life-Friendly Engineering should be implemented throughout the complete engineering life cycle, from planning and site selection to design, construction, operation, maintenance, renewal, and decommissioning.

For human users, this means developing safe, accessible, healthy, inclusive, and resilient infrastructure. For animals, it means avoiding habitat destruction where possible, maintaining ecological connectivity, developing wildlife passages, applying mitigation measures, and using intelligent warning systems. For plants and ecosystems, it means protecting vegetation, minimizing land degradation, reducing unnecessary soil sealing, and integrating green infrastructure. For communities, it means meaningful participation, equitable access, transparency, and long-term social responsibility. For digital systems, it means responsible data use, algorithmic awareness, human oversight, and accountability.

In the Indonesian context, the framework is compatible with the broader direction of professional engineering development and outcome-oriented engineering education. It therefore provides a conceptual foundation for universities, professional organizations, engineering companies, and public institutions seeking to strengthen the humanistic, ecological, ethical, and technological dimensions of engineering education.

The ultimate objective is not to separate engineering from technological progress, but to redefine technological progress in a broader sense: engineering should create infrastructure and technological systems that are technically competent while simultaneously protecting human life, respecting biodiversity, supporting communities, conserving resources, and maintaining the ecological conditions upon which future generations depend.

Accordingly, the future engineer should not be educated merely as a designer, constructor, analyst, or technology specialist. The engineer should also become a **guardian of safety, an ethical professional, a responsible digital actor, an environmental steward, and a contributor to social well-being**.

Life-Friendly Engineering therefore represents a possible transition from **engineering for functionality** toward **engineering for life**, while Life-Oriented Engineering Education provides the educational pathway through which this transition can become part of professional engineering culture in Indonesia.

Ethical Considerations

Not applicable. This study did not require ethical approval because it does not include human or animal subjects and does not involve any personal or sensitive data.

List of Abbrevations:

Acknowledgment:

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Declaration of generative AI and AI-assisted technologies in the writing process

The authors hereby declare that no generative artificial intelligence or AI-assisted technologies were used at any stage during the preparation of this manuscript, including language editing, proofreading, or content development. The authors take full responsibility for the originality and integrity of the work presented in this publication.

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Conflicts of Interest:

"The authors declare no conflict of interest."

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