Multidisciplinary Engineering Science Open

Barriers to Implementing Sustainable Engineering Solutions in Multidisciplinary Contexts: A Qualitative Study of Engineering Professionals in Tehran

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Citation: Sadeghi, N. (2026). Barriers to Implementing Sustainable Engineering Solutions in Multidisciplinary Contexts: A Qualitative Study of Engineering Professionals in Tehran. *Multidisciplinary Engineering Science Open,* 3, 1-15.

Abstract

This study aimed to explore the major barriers that hinder the implementation of sustainable engineering solutions in multidisciplinary project contexts from the perspectives of engineering professionals, project managers, sustainability consultants, and public-sector technical experts in Tehran. A qualitative descriptive design was adopted. Data were collected through semi-structured interviews with 24 participants selected through purposive maximum-variation sampling from engineering consulting firms, construction and infrastructure companies, environmental advisory units, energy-related organizations, and municipal technical bodies in Tehran. Participants had direct experience in designing, managing, evaluating, or implementing sustainable engineering solutions across multidisciplinary projects. Interviews continued until theoretical saturation was reached, which occurred after the twenty-first interview; three additional interviews were conducted to confirm conceptual adequacy. Interviews were audio-recorded with permission, transcribed verbatim, anonymized, and analyzed using thematic analysis. NVivo software was used to organize transcripts, develop initial codes, compare patterns across participant groups, and construct final categories. Analysis generated five main categories of implementation barriers: fragmented disciplinary logics and weak cross-functional communication; economic and procurement constraints; regulatory ambiguity and institutional inertia; limited sustainability knowledge, data, and lifecycle assessment capacity; and stakeholder misalignment, risk perception, and weak accountability. Participants emphasized that sustainable engineering solutions often fail not because of technical impossibility, but because engineering, financial, managerial, legal, and social actors evaluate project success through different criteria. High initial costs, short-term budgeting, uncertain incentives, fragmented approval procedures, limited access to reliable lifecycle data, and insufficient client demand weakened implementation. Sustainable engineering implementation in multidisciplinary contexts requires more than technical design competence. It depends on integrated governance, lifecycle-based evaluation, interdisciplinary communication, supportive regulations, financial incentives, stakeholder engagement, and organizational accountability. The findings suggest that sustainable engineering should be embedded into project planning, procurement, education, and performance evaluation systems rather than treated as an optional design feature.

Keywords: sustainable engineering; multidisciplinary projects; implementation barriers; qualitative research; thematic analysis; Tehran; NVivo; sustainability transition

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1. Introduction

Sustainable engineering has become an essential paradigm for addressing environmental degradation, climate change, resource scarcity, urban pressure, infrastructure vulnerability, and the social consequences of technological development. Traditional engineering approaches have often emphasized technical efficiency, functionality, cost reduction, and compliance with immediate client requirements. Although these criteria remain important, they are no longer sufficient for engineering practice in societies facing complex sustainability challenges. Sustainable engineering requires engineers and project stakeholders to integrate environmental protection, social responsibility, economic feasibility, lifecycle thinking, resilience, and intergenerational equity into the design, implementation, operation, and decommissioning of systems, products, infrastructure, and technologies (Allen & Shonnard, 2012; Anastas & Zimmerman, 2003; Glavič, 2022). In this sense, sustainable engineering is not merely a set of "green" technical choices, but a systems-oriented professional orientation that connects engineering decisions to broader ecological, social, institutional, and economic consequences.

The conceptual roots of sustainable engineering are closely linked to the broader notion of sustainable development, commonly defined as development that meets present needs without compromising the ability of future generations to meet their own needs (World Commission on Environment and Development, 1987). The United Nations 2030 Agenda further expanded sustainability into a global framework of interdependent goals, including clean water, affordable energy, sustainable cities, responsible consumption, climate action, innovation, and strong institutions (United Nations, 2015). Engineering is directly implicated in these goals because engineers design and manage the material and technological systems through which energy is produced, water is distributed, buildings are constructed, transportation is organized, waste is treated, digital infrastructures are deployed, and industrial processes are optimized. Therefore, sustainable development cannot be achieved without engineering solutions that are technically sound, environmentally responsible, economically viable, socially acceptable, and institutionally implementable.

However, the implementation of sustainable engineering solutions remains difficult, particularly in multidisciplinary contexts. Engineering projects rarely occur within the boundaries of a single discipline. Sustainable infrastructure, renewable energy systems, low-carbon buildings, smart urban technologies, water-resource systems, waste-management platforms, and circular production processes require cooperation among civil, mechanical, electrical, environmental, chemical, industrial, software, architectural, managerial, legal, financial, and policy actors. While such collaboration is necessary, it also increases complexity. Each discipline brings its own assumptions, performance indicators, technical language, risk perceptions, timelines, and professional priorities. As a result, sustainable engineering implementation often encounters coordination problems, communication failures, fragmented responsibilities, and conflicting definitions of value. In multidisciplinary projects, sustainability may be understood by environmental experts as ecological impact reduction, by engineers as resource efficiency, by managers as long-term cost control, by clients as reputational advantage, by regulators as compliance, and by communities as safety and quality of life.

This fragmentation is consistent with sustainability transition theory, which emphasizes that sustainable transformation requires changes not only in technologies, but also in institutions, markets, user practices, regulations, infrastructures, cultural meanings, and professional routines (Geels, 2002; Markard et al., 2012). From this perspective, sustainable engineering solutions often fail because they are introduced into socio-technical systems that are still organized around conventional design standards, short-term economic evaluation, risk avoidance, fragmented procurement, and disciplinary specialization. Even when a sustainable technology is available, its adoption may be limited by weak incentives, lack of lifecycle data, uncertain return on investment, inadequate regulations, client resistance, insufficient professional capacity, or poor coordination among project actors. Therefore, barriers to sustainable engineering implementation must be studied as systemic and relational phenomena rather than as isolated technical deficiencies.

A growing body of research has identified barriers to sustainability implementation in construction, infrastructure, project management, and engineering design. Common barriers include high initial costs, lack of incentives, insufficient technical knowledge, resistance to change, weak regulations, fragmented stakeholder engagement, limited sustainability assessment tools, and inadequate integration of sustainability into project management processes (Fathalizadeh et al., 2021; Fathalizadeh et al., 2022; Kivilä et al., 2017; Krechowicz, 2022; Martens & Carvalho, 2017). In the Iranian construction sector, previous studies have shown that economic and institutional barriers can strongly inhibit sustainable project management, particularly when resources are scarce and project stakeholders prioritize immediate cost reduction over long-term sustainability value (Fathalizadeh et al., 2021, 2022). These findings are important because developing and middle-income urban contexts often face simultaneous pressures: rapid urbanization, aging infrastructure, environmental pollution, energy inefficiency, regulatory complexity, and financial constraints. In such settings, sustainable engineering is highly needed but often difficult to institutionalize.

Tehran provides a relevant context for examining these issues. As a large metropolitan city, Tehran faces serious sustainability challenges related to air pollution, water stress, transportation congestion, energy consumption, seismic risk, waste management, urban expansion, and infrastructure renewal. Engineering projects in Tehran frequently involve multiple organizations, including private engineering firms, contractors, municipal departments, clients, consultants, regulators, suppliers, and community stakeholders. These projects require technical integration across different fields and coordination across organizational boundaries. Yet, the practical implementation of sustainable engineering solutions may be constrained by cost pressures, fragmented decision-making, inconsistent enforcement, limited data availability, and uneven sustainability awareness among actors. Understanding these barriers from the perspective of professionals directly involved in multidisciplinary engineering work can provide context-sensitive insights for improving implementation.

Despite the increasing attention to sustainable engineering, several gaps remain. First, much of the existing literature focuses on identifying and ranking barriers through quantitative surveys, while less attention has been given to the lived experiences and interpretive perspectives of professionals who negotiate these barriers in real projects. Second, many studies focus on a single sector, such as construction or green building, whereas sustainable engineering solutions increasingly cut across multiple disciplines and sectors. Third, implementation barriers are often reported as separate factors, although practitioners may experience them as interconnected problems. For example, lack of lifecycle data may reinforce financial uncertainty; weak regulation may reduce client demand; poor interdisciplinary communication may produce design conflicts; and procurement rules may discourage innovation. Fourth, there is a need for qualitative evidence from urban contexts such as Tehran, where sustainability implementation is shaped by specific institutional, economic, regulatory, and professional conditions.

A qualitative approach is appropriate for addressing these gaps because it allows researchers to explore how professionals interpret sustainability, how barriers emerge during project processes, and how multidisciplinary interactions shape implementation outcomes. Semi-structured interviews are especially useful because they provide enough flexibility to capture participants' experiences while maintaining focus on the research problem. Through qualitative analysis, it becomes possible to move beyond listing barriers and instead examine the mechanisms through which barriers are produced, reinforced, negotiated, or overcome.

Accordingly, the aim of this study was to explore the perceived barriers to implementing sustainable engineering solutions in multidisciplinary contexts among engineering professionals, project managers, sustainability consultants, and public-sector technical experts in Tehran.

2. Methods and Materials

This study used a qualitative descriptive design to explore the barriers that hinder the implementation of sustainable engineering solutions in multidisciplinary project contexts. A qualitative design was selected because the research aimed to understand professional experiences, perceptions, meanings, and contextual mechanisms rather than to test predetermined hypotheses. The study followed an inductive thematic analysis approach, allowing categories to emerge from participants' accounts while remaining informed by the literature on sustainable engineering, sustainability transitions, and project implementation barriers (Braun & Clarke, 2006; Creswell & Poth, 2018).

Participants were selected through purposive maximum-variation sampling. The inclusion criteria were: being an engineering professional, project manager, sustainability consultant, technical expert, or policy-related professional working in Tehran; having at least five years of professional experience; and having direct involvement in projects where sustainable engineering solutions were proposed, assessed, designed, implemented, or rejected. Participants were recruited from engineering consulting firms, infrastructure and construction companies, municipal technical departments, environmental advisory units, energy-related organizations, and multidisciplinary project teams.

The final sample included 24 participants. The sample size was determined by theoretical saturation. Saturation was reached after 21 interviews, when no substantially new codes or categories emerged from the data. Three additional interviews were conducted to confirm the stability and adequacy of the categories. The participants included civil engineers, environmental engineers, mechanical engineers, electrical engineers, project managers, sustainability consultants, urban infrastructure specialists, and public-sector technical experts. This variation was intended to capture different disciplinary perspectives on sustainable engineering implementation.

Data were collected through semi-structured interviews. An interview guide was developed based on the research aim and relevant literature. The guide included open-ended questions about participants' understanding of sustainable engineering, their experiences with multidisciplinary projects, barriers encountered during implementation, conflicts among stakeholders, regulatory and financial challenges, data and assessment limitations, and recommendations for improving implementation. Example questions included: "Can you describe a project in which a sustainable engineering solution was proposed but faced difficulties during implementation?" "What types of barriers most commonly prevent sustainable solutions from being adopted?" "How do different disciplines or organizations affect the implementation process?" and "What changes would make sustainable engineering solutions easier to implement in Tehran?"

Interviews were conducted face-to-face or online depending on participant availability. Each interview lasted between 45 and 75 minutes. With participants' consent, interviews were audio-recorded and later transcribed verbatim. Field notes were also written after each interview to document contextual observations, preliminary analytical impressions, and emerging questions for subsequent interviews. All participants were assured that their identities and organizational affiliations would remain confidential.

Data were analyzed using thematic analysis. The analysis followed six general stages: familiarization with the data, generation of initial codes, searching for themes, reviewing themes, defining and naming themes, and producing the final report (Braun & Clarke, 2006). First, transcripts were read several times to gain an overall understanding of participants' narratives. Second, meaningful units related to implementation barriers were coded line by line. Third, related codes were grouped into preliminary categories. Fourth, categories were compared across participants and disciplinary groups to identify similarities, differences, and relationships. Fifth, categories were refined and named based on their conceptual meaning. Finally, findings were organized into five main categories representing the central barriers identified in the data.

NVivo software was used to organize the data, store transcripts, manage codes, retrieve relevant excerpts, compare coding patterns, and develop thematic structures. The use of NVivo supported systematic data management but did not replace interpretive analysis. To enhance trustworthiness, the study used prolonged engagement with the data, peer debriefing among the research team, memo writing, comparison of cases, and member-checking of summarized findings with several participants. Credibility was strengthened by using direct quotations to illustrate categories. Dependability was supported through an audit trail documenting coding decisions and category development. Transferability was addressed through thick description of the research context, participants, and analytical categories (Lincoln & Guba, 1985).

Participation was voluntary. All participants received information about the study purpose, interview procedure, confidentiality, and their right to withdraw at any time. Written or verbal informed consent was obtained before each interview. Participants' names and organizational details were removed from transcripts, and each participant was assigned a code such as P1, P2, or P3. Audio files and transcripts were stored securely and used only for research purposes.

3. Findings

The study included 24 participants from Tehran. Of these, 15 participants were male and 9 were female. Participants' ages ranged from 29 to 58 years, with the largest group aged 35–44 years. Regarding educational level, 6 participants held a bachelor's degree, 14 held a master's degree, and 4 held a doctoral degree. In terms of professional background, 6 participants were civil engineers, 4 were environmental engineers, 3 were mechanical engineers, 3 were electrical engineers, 4 were project managers, 2 were sustainability consultants, and 2 were public-sector technical experts. Professional experience ranged from 5 to 27 years; 7 participants had 5–10 years of experience, 11 had 11–20 years, and 6 had more than 20 years. Most participants had worked on projects involving buildings, urban infrastructure, energy systems, water and wastewater systems, transport facilities, industrial facilities, or environmental assessment. This disciplinary and professional diversity allowed the study to capture barriers across multidisciplinary engineering contexts.

The first major barrier was the fragmentation of disciplinary perspectives and weak communication among professionals involved in sustainable engineering projects. Participants explained that sustainability requires integration among technical, environmental, financial, managerial, legal, and social considerations, but project teams often operate through disciplinary silos. Civil engineers may focus on structural feasibility and execution speed, environmental specialists may emphasize impact reduction, mechanical or electrical engineers may focus on efficiency, project managers may prioritize schedule and budget, and clients may prioritize immediate cost. This fragmentation leads to late-stage conflicts, redesign, superficial sustainability measures, or abandonment of sustainable options. Participants reported that sustainability discussions often begin after major technical decisions have already been made, making integration difficult. One participant stated, “Sustainability is usually invited to the project after the main design has been fixed. At that stage, we can only decorate the project with green words, not change its logic” (P7, environmental engineer). Another participant noted, “Each discipline speaks its own language. The environmental team talks about lifecycle impact, the finance team talks about payback, and the contractor talks about speed. Nobody translates these concerns into one shared decision model” (P14, project manager). Participants emphasized that multidisciplinary meetings often function as reporting sessions rather than spaces for joint problem-solving. As a result, sustainable engineering solutions are treated as additional requirements rather than as integrated design principles. This category shows that the absence of shared language, early collaboration, and integrated decision-making weakens implementation even when technical expertise exists.

The second category concerned economic barriers, especially high initial costs, short-term budgeting, procurement rules, and uncertainty about financial returns. Participants repeatedly stated that sustainable engineering solutions are often rejected because decision-makers focus on capital cost rather than lifecycle value. Although sustainable technologies may reduce energy use, maintenance costs, environmental harm, or long-term operational risks, these benefits are not always visible within conventional budgeting and procurement systems. Participants explained that clients and contractors frequently select the lowest initial bid, which discourages innovative materials, renewable technologies, water-saving systems, lifecycle assessment, and high-performance design. One participant said, “When the tender is based on the lowest price, sustainability loses before the project starts. A sustainable option may be better over ten years, but the decision is made on the first invoice” (P3, civil engineer). Another participant observed, “The problem is not always that green solutions are impossible; the problem is that nobody wants to carry the first cost when the benefit appears later and maybe for someone else” (P19, sustainability consultant). Participants also mentioned unstable prices, imported equipment costs, limited financial incentives, and uncertainty about maintenance capacity as reasons for rejecting sustainable options. Some participants argued that the market does not yet reward sustainability sufficiently, and therefore project owners may view sustainable design as a risk rather than an investment. This category indicates that economic barriers are not limited to lack of money; they are embedded in procurement models, cost-accounting practices, incentive structures, and the separation between short-term project delivery and long-term system performance.

The third barrier was regulatory ambiguity and institutional inertia. Participants believed that sustainable engineering implementation is weakened when regulations are unclear, inconsistent, weakly enforced, or disconnected from actual project conditions. Some participants stated that sustainability standards exist in general policy language but are not translated into binding design requirements, practical approval criteria, or measurable project indicators. Others emphasized that approval processes can be fragmented across organizations, creating uncertainty about who has authority to evaluate sustainability-related decisions. One participant explained, “There are many documents that say sustainability is important, but when you go to get approval, the checklist is still conventional. The system asks for traditional documents, not real sustainability performance” (P11, public-sector technical expert). Another participant stated, “Sometimes the regulation is not absent; it is ambiguous. You do not know which organization has the final word, and because of this uncertainty, the safest choice is the old method” (P22, project manager). Participants also described institutional inertia, meaning that organizations continue using familiar procedures even when better sustainable alternatives are available. In some cases, professionals feared that proposing unfamiliar solutions would delay approval, increase liability, or create conflict with inspectors and contractors. This category shows that sustainable engineering implementation depends on institutional readiness. Without clear standards, aligned approval systems, enforcement mechanisms, and organizational willingness to change routines, sustainable solutions remain vulnerable to delay, dilution, or rejection.

The fourth category involved knowledge, data, and assessment limitations. Participants reported that many engineering teams have general awareness of sustainability but lack practical tools for evaluating and implementing sustainable solutions. Sustainability is often understood as energy saving or use of environmentally friendly materials, while broader issues such as lifecycle impacts, embodied carbon, social effects, circularity, resilience, maintenance, user behavior, and end-of-life consequences receive less attention. Participants also noted limited access to reliable local data on material performance, environmental impacts, lifecycle costs, energy behavior, water consumption, and maintenance outcomes. Without credible data, sustainable alternatives are difficult to justify to clients, regulators, and contractors. One participant said, “We talk about lifecycle analysis, but in many projects we do not have local databases. We use assumptions from other countries, and then the client says the numbers are not convincing” (P5, mechanical engineer). Another participant stated, “Many engineers support sustainability in principle, but they have not been trained to calculate it, defend it, or translate it into drawings, specifications, and contracts” (P16, sustainability consultant). Participants also highlighted gaps in university education and professional training, stating that many engineers graduate with strong technical skills but limited exposure to sustainability assessment methods, interdisciplinary collaboration, stakeholder engagement, or systems thinking. This category demonstrates that implementation barriers are partly epistemic and methodological: sustainable engineering requires not only motivation, but also data infrastructures, assessment tools, professional competencies, and practical translation mechanisms.

The fifth category concerned stakeholder misalignment, perceived risk, and weak accountability. Participants emphasized that sustainable engineering projects involve multiple stakeholders with different interests, including clients, designers, contractors, consultants, regulators, suppliers, investors, users, and communities. When these stakeholders are not aligned, sustainability goals become vulnerable to compromise. Some participants explained that clients may request sustainability in early discussions but later remove sustainable features because of cost, delay, or uncertainty. Contractors may resist unfamiliar methods because they fear execution problems, warranty claims, or supply-chain delays. Regulators may hesitate to approve innovative designs. Users may not understand how to operate sustainable systems effectively. One participant stated, "Everyone agrees with sustainability in meetings, but when responsibility and cost are assigned, the agreement disappears" (P8, project manager). Another participant explained, "A sustainable system needs someone to remain accountable after construction. If operation and maintenance are ignored, even a good design becomes unsustainable" (P20, electrical engineer). Participants also discussed the role of public trust and community acceptance. Sustainable engineering solutions can fail when local stakeholders are not involved or when social impacts are poorly communicated. For example, changes in transport systems, waste systems, water reuse, or energy infrastructure may require behavioral adaptation and public understanding. This category suggests that sustainable engineering implementation is not a purely technical decision; it requires governance arrangements that distribute responsibility, manage risk, engage stakeholders, and maintain accountability across the project lifecycle.

4. Discussion

This study explored the barriers to implementing sustainable engineering solutions in multidisciplinary contexts among professionals in Tehran. The findings revealed five main categories: fragmented disciplinary logics and weak cross-functional communication; economic and procurement constraints; regulatory ambiguity and institutional inertia; limited sustainability knowledge, data, and lifecycle assessment capacity; and stakeholder misalignment, risk perception, and weak accountability. Together, these findings indicate that sustainable engineering implementation is not prevented by a single barrier. Rather, it is constrained by a network of interrelated technical, economic, organizational, institutional, and social factors. This interpretation is consistent with sustainability transition theory, which argues that sustainability transformation requires changes across socio-technical systems, including technologies, markets, policies, infrastructures, user practices, professional norms, and institutional arrangements (Geels, 2002; Markard et al., 2012). The findings therefore support the view that sustainable engineering must be understood as a systemic implementation challenge rather than as a narrow design problem.

The first finding showed that fragmented disciplinary logics and weak cross-functional communication create major barriers to sustainable engineering implementation. Participants emphasized that sustainability requires early integration of diverse disciplinary perspectives, but project teams often work in silos. This result aligns with the literature on design for sustainability, which argues that sustainability challenges cannot be solved only at the product or component level and increasingly require systems thinking, cross-sector collaboration, and integration across technical and social domains (Ceschin & Gaziulusoy, 2016). It is also consistent with sustainable engineering principles, which emphasize holistic thinking, lifecycle orientation, stakeholder engagement, and integration of social, environmental, and economic considerations (Allen & Shonnard, 2012; Glavič, 2022). In multidisciplinary contexts, barriers arise when different actors use different criteria to define success. A technically efficient solution may be rejected if it is not financially justified; an environmentally superior solution may fail if it is not constructible; and a socially beneficial solution may be ignored if community concerns are not incorporated into engineering decisions. Therefore, the finding suggests that sustainable engineering requires boundary-spanning competencies, shared decision frameworks, and collaborative design processes.

The second finding concerned economic and procurement constraints. Participants reported that sustainable solutions are frequently rejected because of high initial costs, short-term budgeting, lowest-price tendering, and uncertain financial returns. This finding strongly aligns with previous studies on sustainable construction and sustainable project management. Fathalizadeh et al. (2021) found that barriers to sustainable project management in the Iranian construction sector are interconnected and cannot be addressed effectively in isolation. Fathalizadeh et al. (2022) further showed that economic and institutional barriers are particularly important in Iran, where resource constraints require careful prioritization of remedial strategies. Similarly, Martens and Carvalho (2017) emphasized that sustainability in project management depends on strategic alignment, stakeholder commitment, and integration of sustainability into project success criteria. The present study extends these insights by showing how economic barriers operate within multidisciplinary engineering projects. Participants did not describe cost simply as lack of funds; instead, they described a deeper mismatch between lifecycle value and project-level financial decision-making. When procurement systems reward the lowest initial cost, they discourage sustainability options whose benefits emerge over longer time horizons. This suggests that financial tools such as lifecycle costing, total cost of ownership, green procurement criteria, performance-based contracts, and sustainability incentives are necessary to support implementation.

The third finding identified regulatory ambiguity and institutional inertia as major barriers. Participants explained that sustainability policies may exist at a general level, but they are often not translated into clear standards, enforceable criteria, or coordinated approval procedures. This finding is consistent with research showing that policy, regulation, and institutional support are central to sustainable project implementation (Fathalizadeh et al., 2022; Kivilä et al., 2017; Krechowicz, 2022). Kivilä et al. (2017) argued that sustainability in infrastructure projects requires project control mechanisms that connect sustainability objectives with monitoring, governance, and decision-making throughout the project lifecycle. The findings of the present study show that when approval systems remain conventional, project actors may avoid innovative sustainable solutions because they fear delay, liability, or rejection. This finding is especially important in contexts where multiple institutions influence project approval and implementation. Regulatory ambiguity does not merely create administrative inconvenience; it shapes professional behavior by encouraging risk-avoidance and conventional design. Therefore, clearer sustainability standards, integrated approval procedures, and institutional capacity-building are needed to reduce uncertainty and legitimize sustainable alternatives.

The fourth finding related to limited sustainability knowledge, data, and lifecycle assessment capacity. Participants reported that professionals often support sustainability in principle but lack reliable local data, practical tools, and training to implement it effectively. This finding aligns with green engineering and sustainable engineering literature emphasizing that sustainability requires lifecycle analysis, systems thinking, environmental performance assessment, social indicators, and integration of economic, environmental, and social criteria (Allen & Shonnard, 2012; Anastas & Zimmerman, 2003; Glavič, 2022). The lack of local databases is especially problematic because sustainable engineering decisions often depend on contextual information, including material supply chains, energy systems, climatic conditions, maintenance capacity, user behavior, and local environmental priorities. When data are unavailable or unreliable, sustainability claims become difficult to defend. This finding also suggests that sustainable engineering education should go beyond awareness-raising and provide practical competence in lifecycle assessment, sustainability indicators, interdisciplinary communication, environmental modeling, circular design, and stakeholder analysis. Without these competencies, sustainability remains rhetorical rather than operational.

The fifth finding showed that stakeholder misalignment, risk perception, and weak accountability weaken implementation. Participants noted that sustainable solutions often require cooperation across clients, contractors, consultants, regulators, suppliers, operators, and users. When responsibilities are unclear, stakeholders may verbally support sustainability while resisting its costs, risks, or operational implications. This finding is consistent with the stakeholder-oriented view of sustainable project management, which emphasizes that project success should include long-term social and environmental value, not only short-term delivery performance (Martens & Carvalho, 2017; Silvius & Schipper, 2014). It also aligns with sustainability transition theory, which emphasizes that new technologies and practices require alignment among actors, institutions, users, and markets (Geels, 2002; Markard et al., 2012). The present study adds that weak accountability across the lifecycle can undermine even technically sound sustainable solutions. For example, a building may be designed with efficient systems, but if users are not trained or maintenance responsibilities are unclear, expected sustainability benefits may not be achieved. Therefore, stakeholder engagement should not be limited to consultation at the beginning of a project; it should continue through design, procurement, construction, operation, monitoring, and feedback.

Overall, the findings suggest that sustainable engineering implementation in multidisciplinary contexts depends on the alignment of four conditions. First, project teams need integrated design processes that bring disciplines together early and create a shared language for sustainability. Second, financial and procurement systems must recognize lifecycle value rather than only initial cost. Third, regulations and institutions must provide clear, enforceable, and coordinated support for sustainable solutions. Fourth, organizations must develop knowledge infrastructures, data systems, and accountability mechanisms that allow sustainability to be measured, justified, implemented, and maintained. These conditions are mutually reinforcing. For example, lifecycle costing requires reliable data; reliable data support financial justification; financial justification strengthens client commitment; client commitment encourages contractors and designers to accept sustainable options; and regulatory clarity reduces perceived risk. Conversely, weakness in one condition can reinforce barriers in others.

The findings have theoretical implications for sustainable engineering research. They support a socio-technical understanding of implementation barriers, showing that sustainable engineering solutions are shaped by interactions among technologies, institutions, professional cultures, economic incentives, and stakeholder relationships. The study also contributes to qualitative knowledge by showing how professionals experience barriers in practice. Rather than treating barriers as static variables, the findings show that barriers emerge through project processes, communication patterns, decision rules, and institutional routines. This processual understanding can help researchers develop more realistic models of sustainable engineering implementation.

The findings also have practical implications. Engineering organizations should embed sustainability into early project definition, feasibility studies, procurement documents, risk analysis, and performance evaluation. Project teams should use interdisciplinary workshops, integrated design charrettes, shared sustainability indicators, and lifecycle-based decision tools. Clients and public agencies should revise procurement criteria to reward long-term performance, energy efficiency, resource efficiency, maintainability, and social value. Regulators should clarify sustainability requirements and reduce uncertainty around innovative solutions. Universities and professional associations should strengthen sustainability training for engineers, especially in lifecycle assessment, systems thinking, stakeholder engagement, and interdisciplinary collaboration. Finally, accountability should extend beyond project delivery to include operation, maintenance, user behavior, and post-occupancy performance.

This study has several limitations. First, the research was conducted only in Tehran, and the findings may not fully represent sustainable engineering implementation barriers in other Iranian cities or international contexts. Second, the study relied on semi-structured interviews, meaning that the findings reflect participants' perceptions and experiences rather than direct observation of project processes. Third, although maximum-variation sampling was used, some engineering sectors may have been represented more strongly than others. Fourth, because sustainability implementation is highly context-dependent, barriers may vary according to project type, project scale, ownership model, regulatory environment, and client priorities. Fifth, the qualitative design does not allow statistical generalization; however, it provides conceptual and contextual insights that can inform further research and practice.

Future studies should compare sustainable engineering implementation barriers across different cities, sectors, and project types. Comparative research could examine whether barriers differ between public and private projects, infrastructure and building projects, large and small organizations, or conventional and innovation-oriented firms. Mixed-method studies could build on the present qualitative findings by developing and validating a quantitative instrument to measure the relative importance and interrelationships of the identified barriers. Longitudinal case studies are also recommended to examine how barriers emerge and change across project stages from concept design to operation. Future research should also investigate the role of procurement models, lifecycle costing tools, digital technologies, regulatory reforms, and professional training programs in reducing implementation barriers.

Engineering firms, public agencies, and project owners should treat sustainability as a core project requirement from the earliest planning stage rather than as an optional feature added after design decisions are finalized. Multidisciplinary project teams should establish shared sustainability goals, clear responsibilities, integrated communication routines, and lifecycle-based performance indicators. Procurement systems should move beyond lowest-price selection and include lifecycle cost, environmental performance, maintainability, resilience, and social value. Organizations should invest in sustainability training, local data systems, lifecycle assessment tools, and post-implementation monitoring. Finally, clients, regulators, designers, contractors, operators, and users should be engaged throughout the project lifecycle to ensure that sustainable engineering solutions are not only designed but also implemented, operated, and maintained effectively.

5. Conclusion

This qualitative study explored barriers to implementing sustainable engineering solutions in multidisciplinary contexts among engineering professionals and related experts in Tehran. The findings showed that implementation is constrained by fragmented disciplinary communication, economic and procurement barriers, regulatory ambiguity, institutional inertia, limited sustainability knowledge and data, stakeholder misalignment, risk perception, and weak accountability. These barriers are interconnected and operate across technical, organizational, economic, institutional, and social dimensions.

The study demonstrates that sustainable engineering implementation requires more than technical innovation. It depends on integrated project governance, interdisciplinary collaboration, lifecycle-based evaluation, supportive regulations, reliable data, financial incentives, stakeholder engagement, and accountability across the full project lifecycle. In multidisciplinary contexts, sustainability can be achieved only when different actors develop a shared understanding of value and coordinate their decisions around long-term environmental, social, and economic performance. Therefore, sustainable engineering should be institutionalized within design processes, procurement systems, professional education, regulatory frameworks, and organizational performance measures. By addressing the barriers identified in this study, engineering organizations and policymakers can improve the practical implementation of sustainable solutions and contribute more effectively to urban sustainability and socio-technical transition.

Ethical Considerations

All procedures performed in this study were under the ethical standards.

Acknowledgments

Authors thank all who helped us through this study.

Conflict of Interest

The authors report no conflict of interest.

Funding/Financial Support

According to the authors, this article has no financial support.

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