Scientific Research Publishing

Open Journal of Civil Engineering, 2025, 15(3), 545-562
https://www.scirp.org/journal/ojce
ISSN Online: 2164-3172
ISSN Print: 2164-3164

The Role of Engineers in Implementing Water-Efficient Technologies in Sustainable Building Projects

Nawar Berro

MEP Department, Bay Air Systems, Concord, CA, USA
Email: Nawar@bayairsystems.com, Nawar.berro@gmail.com

How to cite this paper: Berro. N. (2025) The Role of Engineers in Implementing Water-Efficient Technologies in Sustainable Building Projects. *Open Journal of Civil Engineering*, **15**, 545-562.
https://doi.org/10.4236/ojce.2025.153029

Received: July 24, 2025
Accepted: September 14, 2025
Published: September 17, 2025

Abstract

This paper traces the importance of engineers in the application of water-efficient technologies in sustainable buildings. With the rising number of global voices regarding the issue of water scarcity and the environmental effects of construction, the necessity of the sustainable management of water in buildings has also arisen. The study of the dissertation focuses on the roles and duties of engineers in terms of adopting and adapting advancements like greywater systems, rainwater collection, and low-flow fixtures. Qualitative type of research was used, together with semi-structured interviews of accomplished engineers in the building industry. The evidence suggests that engineers play an important role as facilitators in the making of suitable selections, designing, and implementing of water-efficient solutions, but encounter obstacles such as resistance by clients, price limits, and regulation requirements. Suggestions are an improvement of training, policy changes, and promotion of collaboration across disciplines. The study provides important information about the engineering techniques in green management and indicates ways of efficiency in conserving resources in the construction sector.

Keywords

Engineers' Responsibility in Construction, Role of Engineers in Sustainable Design, Water-Efficient Construction Practices, Water-Efficient Technologies, Sustainable Buildings, Rainwater Harvesting, Greywater Systems, Water Management in Construction, Green Building Standards (LEED, BREEAM), Life Cycle Assessment

1. Introduction

1.1. Background

The water crisis has become one of the greatest environmental problems of the 21st century worldwide. As the impacts of climate change become manifold, with the ever-accelerating rate of urbanization, the burden on the water resources grows in pressure. The shortage of freshwater is no longer a problem constrained to the arid/semi-arid areas; it has moved on to urban and industrial regions around the world, as explained by Yao [1]. The construction industry is among the industries that consume much water, besides affecting the environment. The industry also plays a significant role in the use of water and wastewater production at the sites developed for the running of the building. That being the case, a greater focus has been created due to sustainable construction methods that decrease water utilization and encourage environmental responsibility. At the core of these is the replacement of water-efficient technology being incorporated into current sustainable building structures. Such technologies do not only reduce the consumption of fresh water but also provide innovative ideas in water reuse and saving.

Practical use of water-efficient technologies can hardly be achieved without the participation of engineers. The engineers are invaluable members of the team of technical experts and facilitators in the sustainable building planning, designing, and management of the constructed and operating buildings. Their expertise and choices have a direct relationship with the successful integration of such technologies and successful attainment of desired performance results. Systematically, the role of engineers in the process is of the essence in the development of sustainable water management in the built environment.

Table 1, extracted from Global Green Building Council Reports, World Bank (estimates), Marzouk [2], shows the water usage trend per industry.

Table 1. Water usage statistics in the construction sector.

Construction Activity	Average Water Use (L/m^2)	Efficiency Opportunity
Site Preparation (e.g., dust control)	1030	Use of recycled water for spraying and soil stabilization
Concrete Mixing	150 - 200	Optimize batching; recycle process water
Sanitary and Plumbing Installations	50 - 100	Install low-flow fixtures, dual-flush
Landscaping	20 - 60	Implement rainwater harvesting and smart irrigation systems
Building Maintenance (post-handover)	100 - 300 annually	Greywater reuse and leak detection technologies

1.2. Research Objectives

- To consider the functions an engineer fulfills when designing sustainable building projects, executing them, and sustaining water-efficient technologies.

- To reveal the key obstacles engineers, have to overcome in the process of promoting or integrating the water-saving technologies in construction.
- To identify how organizational, regulatory, and client-related factors can affect the ability of engineers to introduce solutions that are water-efficient.
- To suggest some measures that can be used in ensuring that engineers become more effective in the promotion of sustainable water use practices within the construction industry.

1.3. Research Questions

- How do engineers work along the lifecycle of the sustainable building projects relating to water-efficient technologies?
- What are the technical, economic, and institutional obstacles that prevent engineers from achieving water-efficient systems?
- What is the role of client preferences and organizational policies in the ability of engineers regarding the aspect of water conservation?
- How can the input of engineers to sustainable water management be enhanced?

1.4. Sustainable Building Technologies Adoption

The growing trend of the use of water-efficient technologies in the construction of buildings mirrors a larger movement toward sustainable development. The article by Marzouk [2] mentions various technologies that are coming to be a norm in sustainable buildings, particularly green-pursuing building systems such as LEED (Leadership in Energy and Environmental Design) and BREEAM (Building Research Establishment Environmental Assessment Method). Some of these technologies include low-flow plumbing fixtures, which save water used in kitchens and bathrooms; greywater recycling systems, which allow water used in sinks and showers to be reused for non-potable actions; rainwater harvesting systems, which collect and store rainwater that can be used for landscaping or flushing; and smart metering systems, which track real-time water usage so that potential leaks can be found and consumption optimized.

Although these technologies are available and can be proven to have wonderful, positive effects, implementing these technologies in practice is not always easy. The specialists who choose, design, and incorporate important technology into construction projects are the ones who make a difference in the implementation process, as explained by Brand [3]. In particular, engineers are the most important change agents who can assist in converting sustainable principles into practical construction solutions. Their technical expertise, problem-solving skills, and project team leadership put them in a strategic position to advocate for and execute water-efficient innovations.

However, the role of engineers is defined by a variety of internal and external factors that impact clients. These may include how they view sustainable technology, their organizational support, project budgets, client priorities, and legal requirements. Building water efficiency is therefore a profession that requires not only the creative development of new technologies but also the deep comprehension of engineers working in complex project environments.

2. Literature Review

2.1. Theoretical Underpinnings

In order to learn more about how the engineers can adopt water-efficient technologies, it is important to learn more about theoretical aspects that can be used to explain behavior patterns, motivation, and professional commitments of engineers.

Role theory is one such framework, as it assists in the explanation of the expectations that are set towards individuals in particular professional settings. Biddle states that practitioners accomplish their roles based on the expectations of their roles conceived by society, an organization, or the profession itself. Such roles influence the perception of engineers as to what they are supposed to do, and this can also apply to participation in sustainability practices [4]. When engineers consider sustainability to be one of their central functions, it is much easier to promote and apply technologies that can save water in the construction sector.

The Technology Acceptance Model (TAM), which was developed by Davis (1989), is also another useful framework [5]. This model assumes that there are two items that affect the willingness of an individual to embrace a new technology, and these are the perceived usefulness and the perceived ease of use. When it comes to sustainable construction, in case engineers have an assumption that their installation of water-efficient technologies will perform successfully in terms of reducing its impact on the environment (usefulness) and will also be easy to incorporate into the existing systems (ease of use), they will be more willing to promote the adoption of such technologies. In contrast, once these technologies are perceived to be expensive, complicated, or challenging to the current practices, an engineer might not promote them, even where a tangible environmental gain is observed.

The mutual reinforcement of those perspectives grants a better understanding of the ways and the reasons for which engineers turn to sustainable technologies. Although role theory provides answers to such aspects of engineering practice as normative and occupational, TAM allows us to have answers to aspects of individual decision-making and behavioral intentions on technology use. **Table 2** below shows this distribution.

Engineers have more to do within the scope of facilitating water efficiency in construction than a basic technical one. It is reckoning the professional expectations, measuring the feasibility of technology, and impacting the project results based on informed decision-making. Consequently, it is important to provide engineers with information, mechanisms, and positive institutional platforms to practice the deployment of water conservation technologies in projects of sustainable building services.

Table 2. Theoretical models and key concepts.

Theory/Model	Key Concepts	Application to Engineers
Role Theory (Biddle, 1986) [4]	Roles are defined by societal, organizational, and professional expectations	Engineers perceive sustainability as part of their professional duty
Technology Acceptance Model (TAM) (Davis, 1989) [5]	Adoption depends on perceived usefulness and ease of use	Engineers adopt water-saving tech if they believe it's effective and easy to implement
Institutional Theory	Organizations act based on norms, rules, and legitimacy pressures	Engineering practices are shaped by industry standards and regulatory frameworks
Systems Thinking	Holistic understanding of interactions between system components	Engineers consider water efficiency in relation to energy, cost, and occupant behavior

2.2. Sustainable Building and Water Efficiency

The built environment places an enormous consequence on nature. Sustainable construction is fast becoming a requirement in achieving sustainable outcomes to counter its negative effect on the environment. Following the conception of Adetayo and Oladipupo, sustainable construction concerns practices that reduce the adverse environmental impacts of activities in regard to the whole lifecycle of a building, including planning, designing, operating, and deconstructing [6]. The main element of sustainability in building industries is water efficiency. According to water efficiency manual published by North Carolina Department of Environment and Natural Resources, Water efficiency involves cutting consumption of clean water in order to prevent excessive water use, as well as wastewater generation [7]. These entail the installation of low-flow fittings, greywater recycling, rain collection systems, and intelligent water meters. These technologies reduce the use of freshwater and remove the burden on the local source of water; hence, they are part and parcel of the application of sustainable building measures.

2.3. Role of Engineers in Sustainable Projects

Engineers are very crucial and dynamic in the process of incorporating the water-efficient technology in green building. Their competence guarantees the application of sustainability principles at all stages of the project's existence, including the planning process and long-term operation. Engineers, as discussed in Yao research, actively participate in all phases of the project development, having input on technical expertise and being innovative in solving problems to fulfill the environmental targets [1].

During the design stage, the engineers start with the assessment of the environmental situation, such as available water, climate, and laws. They list existing opportunities in conserving water and suitable technologies such as low-flow fixtures, greywater recycling, rainwater harvesting, and smart irrigation controls. Feasibility studies are also conducted by engineers to evaluate the technical and economic feasibility of such systems, and the opted solutions are appreciated in terms of their sustainability and client demands. The documents contain most of their recommendations that are the basis of water-saving strategies incorporated in the design of the building.

In the stage of construction work, the engineers take the role of supervision and quality assurance. They make sure that water-saving technologies are installed according to the recommended patterns and requirements and according to the principles of sustainability. Engineers liaise with contractors and subcontractors to ensure that materials and systems are well implemented and are at performance standards. Their management aids to avoid costly mistakes guarantee government regulation and certainty that installed systems will work as per purpose when in use.

During the operational phase, engineers do not give up on the project, as they still collaborate with managers of the facility and maintenance crews. They assist in setting up a maintenance regimen, tie into the performance of water systems, and follow up on recommendations based on these data to achieve maximum efficiency. This constant presence is essential in early detection of performance problems, ensuring long-term savings, and in order to make corrections related to changes in building occupancy or the environment.

In general, engineers act as a connective point between the concept of sustainability and its actual application. The technical capacity supported by their collaborative roles in the multidisciplinary teams guarantees that the choice of water-efficient technologies is not only prudent but also along with the execution and maintenance. The overall scope of this method is very effective in mitigating water usage, reducing operating expenses, and promoting the wider objectives of sustainable development in the built environment (refer to **Table 3**).

Table 3. Engineers' roles across project phases.

Project Phase	Engineers' Roles
Design	Technology evaluation, specification, integration planning
Construction	Installation supervision, system commissioning, QA/QC
Operation	Performance monitoring, maintenance planning, technical support

2.4. Inhibitors to Implementation

Although engineers play a significant role, they are usually confronted by several issues when applying water-efficient technologies in green buildings. Economic constraints are by far one of the more urgent obstacles. Nguyen and Macchion [8] point out that the price of the water-saving technologies is a big factor sending off clients, especially in developing countries, such as Kenya. These technologies tower just under long-term savings, but, during budget planning, the initial investment usually presents an area of debate.

The other one is the technical knowledge gap. Osuizugbo [9] notes that most engineers, especially engineers with training in between disciplines, might lack the expert knowledge needed to install high-tech water-efficiency systems. The shortcoming may be manifested in optimally suboptimal solutions or failed innovations.

There is a challenge of client priorities, too. According to the report by Adetayo and Oladipupo, the clients may be results-driven and are confined to temporal aesthetics or cash gains without minding sustainability goals [6]. Such goal conflict may lead to opposition to adopting new sources of water that are efficient in conservation and are technically viable and beneficial to the environment.

Also, the regulatory systems in most of these countries are nothing to reckon with as far as the enforcement of standards in water efficiency is concerned. According to Shoushtarian and Negahban-Azar [10], in some countries, water-saving technology integration is not often required by building regulations. The absence of strict, enforceable guidelines undermines the policy and provides less incentive to the developers and clients to maintain water efficiency.

These barriers are listed in **Table 4**.

Table 4. Key barriers to ımplementation and sources.

Barrier	Description	Source
Economic Constraints	High initial costs discourage investment	Nguyen & Macchion [8]
Technical Knowledge Gaps	Lack of specialized training among engineers	Osuizugbo [9]
Client Priorities	Emphasis on aesthetics or short-term gains over sustainability	Adetayo & Oladipupo [6]
Weak Regulatory Frameworks	Limited or absent legal requirements for water efficiency	Shoushtarian & Negahban-Azar [10]

In addition to structural and technical issues, the role of professional responsibility and institutional factors also has a considerable impact on the ability of engineers to promote water-saving approaches in sustainable building projects. Dindorf and Wos emphasize that professional institutions such as the Institution of Civil Engineers require ethical engineers to contribute to the program of sustainability [11]. However, in the actual world, the constraints of financing, the lack of client interest, and the lack of regulatory frameworks at large are common factors that can limit how far these ethical pledges may be conformed with by the engineers. Even the best-intentioned professionals may face these obstacles, preventing them from coming up with environmentally conscientious solutions.

Professional development and lifelong learning are two of the potential directions by which these shortcomings can be overcome. Brand notes that scientific and technological breakthroughs in society must be integrated into everyday engineering activities, which need continuous training and collaboration between various disciplines [3]. All engineers can stay informed on the latest developments in water-efficient systems and sustainable technologies to become more advocate-like in their design choices. To play a more convincing role in the discussions about the project, technical knowledge and communication may be improved to enable engineers to play such a role despite the possible opposition on the part of clients or limited budgets.

Moreover, the establishment of partnerships among engineers, architects, and sustainability consultants can create a stronger sense of resource efficiency. A gap between ethical responsibility and practical implementation can be filled when engineers are provided with the necessary instruments and knowledge to realize the potential in full. By doing so, they do not only carry out their professional responsibilities, but they also end up playing a fruitful role towards the greater aims of sustainable development. Therefore, the further education and empowerment of the engineers play a crucial role in the minds of those breaking the stereotype and being water efficient in the design of buildings.

3. Research Methodology

3.1. Research Design

In order to examine these problems in more detail, this research obtained a qualitative research design. This research was based on semi-structured interviews as a technique to gain insights on the roles, experiences, and perceptions of engineers in terms of water-efficient technologies in green building.

3.2. Measurement

This research carried out twelve interviews with practicing engineers with a civil, environmental, and mechanical engineering course background. All the respondents were directly involved in the durable construction industry. The interview questions have focused on what they worked on in different stages of the project, the difficulties that they encountered, and their opinion about the success and viability of water-saving technologies.

The participants were identified in order to attract participants on behalf of professional engineering organizations, personal acquaintances, and recommendations in the construction sector. The geographical area that the research was conducted within was restricted to California, United States, which represents the context within which sustainable construction practice is just being brought forward, just like the conventional building practices. The number of participants, twelve engineers, was found to be adequate by this qualitative research study because it was also able to review the experience of a wide range of professionals and arrived at thematic saturation. This is in line with the norms concerning qualitative research, which focus on depth rather than on statistical considerations of generalizability.

Table 5 shows the data collected from participants.

Table 5. Interview participant profiles.

Participant ID	Engineering Discipline	Years of Experience	Role in Sustainable Projects
ENG-01	Civil	12	Design and implementation lead
ENG-02	Environmental	9	Water system specialist
ENG-03	Mechanical	15	HVAC and water systems integration

3.3. Analysis of Data

This paper conducted thematic analysis following the widely recognized framework of Braun and Clarke [12] in order to draw out, code, and make conclusions on patterns using the interview material on the role engineers play in the process of application of water-efficient technologies in the implementation of sustainable building projects. Thematic analysis offered an accommodating methodological approach to studying the manner in which the participants characterized their professional duties, limitations, and experiences. Their encoding of data into themes and subthemes, including advocacy roles, technological barriers, and organizational influences, allowed details of this multifaceted and sometimes competing nature of the factors that affect the work of engineers on building projects contributing to water efficiency to be realized in finding solutions to realizing water efficiency.

This took place in six orderly steps: familiarization with data, preliminary coding, searching themes, theme review, definition and naming of themes, and final report of the analysis. Interviews were translated and checked several times to guarantee the context and accuracy. In order to come up with the codes, some were done inductively (recurring in the data) and some deductively (guided by the research questions of the study). The emerging themes were not just technical and professional, but these highlighted sociopolitical, economic, and institutional determinants of engineering practice that was happening in the context of sustainable development.

3.4. Ethics and Ethical Considerations

This research has been carried out within the frames of strictly adhered and well-known ethical standards of research. All interviewees have received thorough informed consent forms before and after participation, describing the purpose of the research, its procedures, and the use of the data, as well as the allowance of withdrawal, which carries no punishment. The participants have signed consent forms acknowledging the fact that they were participating voluntarily.

The questionnaires were also coded to each participant instead of being identified with their names, and this was to ensure anonymity and confidentiality. Information on any project-specific or company-specific reference was made anonymous or generalized with the aim of preventing identification. Information was put in coded, password-protected electronic forms, which only the research team could access. The research was subjected to ethical approval by the respective institutional review board, with the study having been in line with the set guidelines for conducting qualitative research on human subjects.

4. Discussion and Findings

Key findings arising out of the thematic analysis of the interviews are presented and discussed here by drawing their relationship with theoretical constructs like the Role Theory and the Technology Acceptance Model (TAM). The analysis unifies five major themes that include the multidimensionality of the engineering role in sustainable water practices, the effect of organizational priorities and its client priorities, the importance of technical training, the obstacles to implementation, and the theoretical explanation of these dynamics.

4.1. Roles of Engineers in Sustainable Practices

The interviewed engineers characterized their sphere of action in popularizing and realizing the water-efficient technologies as wide-ranging, dynamic, and contemporary throughout project phases. They are involved in:

1) Promoting water-saving systems at the very initial stages of project development.

2) Doing site-specific analysis to find out the viability and appropriateness of the implementation of technologies like low-flow fixtures, greywater recycling, rainwater harvesting, and smart irrigation.

3) The involvement in the processes of design, specification, and procurement to make sure that the selected technologies will correspond to the sustainability objectives and project budgets.

4) The supervision of installation, commissioning, and following up on the installation experience of the building operators and occupants.

This goes out ahead and keeps engineers not only as technical consultants but also as important translators of sustainability objectives into reality. Based on my personal experience as a senior lead MEP engineer with 20 years of consultancy experience, I have concluded that engineers play an important role in being advocates for sustainability. Their input and participation in the design phases, before construction, establish them engineers as key agents of sustainable changes in the built environment. Nonetheless, there are external factors that normally limit their potential, and these include such factors as client resistance or cost-related restraint.

According to Nguyen and Macchion [8], the engineers do not always have the right to make a final decision, and this reduces their authority even in those situations when they suggest creative solutions (Refer to **Table 3**).

4.2. Client and Organizational Influences

The other important theme relates to how the organizational culture and priorities of the clients lead to decisions on whether more efficient technologies involving water will be considered or actually put in place. The results show the obvious trend, *i.e.*, the companies that have integrated the strategy and sustainability policies are much more prone to make use of these technologies in all their projects. Commercially oriented companies or companies with no formal environmental targets, on the other hand, tend to focus on upfront cost savings to the detriment of long-term resource efficiency.

Awareness and values of the clients also have a crucial part. Brand points out the crucial role of client education; when clients learn about the environmental and economic advantages of the water-saving systems, including lower water bills, increased property value, and suitability to the regulations, they are more likely to accept their implementation in the project designs [3]. This has been reiterated by other engineers in the study as having been proven to be adaptable in projects where the clients were active contributors and knew what was going on early on in the process. Also, the typology of projects was important. The institution and other government work, such as schools and government buildings, commonly showed more sustainable requirements than the residential or commercial construction of real estate, which can be aimed at quick profit. The above is presented in **Table 6**.

Table 6. Key Findings on the influence of organizations and clients.

Influence Factor	Key Findings
Organizational Policies	Organizations with formal sustainability policies are more likely to adopt water-efficient systems.
Client Awareness and Education	Clients who understand long-term cost savings and environmental benefits are more receptive.
Project Typology	Public sector projects show stronger sustainability mandates than private commercial ones.
Financial Priorities	Commercial clients often prioritize short-term ROI over long-term water efficiency.

4.3. Techniques and Training

The third theme is associated with the technical knowledge and unending learning of engineers. Specific training was listed as an important facilitator of the capability of many participants to recommend, evaluate, and implement water-efficient technologies. Those engineers who had already participated in workshops, certificated programs, or projects with innovative technologies felt more confident discussing the advanced systems with clients or contractors, as presented in **Table 7**.

According to Dindorf and Wos, the professional growth in new green technologies is directly linked to the ability of the engineers to make necessary contributions to the sustainability goals [11]. This was especially so in the adoption of greywater systems and smart irrigation technologies that do not only need technical knowledge but also possess the skills to track how the regulatory standards work and the cost-benefit analysis.

Conversely, other interviewees admitted that there was no exposure or any institutional reinforcement in technical upskilling. Those organizations that did not make continuing education a priority left knowledge gaps in their way that did not allow proactive innovation. Refer to **Table 7**.

Table 7. Engineers' training background and technology acceptance.

Training Background	Impact on Technology Acceptance
Formal training in sustainable technologies	Engineers are more confident in recommending and implementing advanced water-efficient systems.
Participation in workshops or certifications	Increases awareness of emerging solutions like greywater recycling and smart irrigation systems.
On-the-job exposure through past projects	Enhances practical knowledge and credibility when advising clients and contractors.
Lack of institutional support for upskilling	Leads to limited understanding of new technologies and reluctance to promote innovative solutions.
Organizational encouragement of professional development	Fosters a culture where engineers feel empowered to drive sustainability initiatives.

4.4. Implementation Hindrances

Even though there are envisioned positive roles that engineers would like to achieve, there are also some key implementation obstacles. Cost was the most quoted challenge. Engineers were dissatisfied that although application of water-efficient technologies is likely to bring savings in the life cycle of a building, the investment involved puts off many developers and clients, particularly in price-conscious markets. Such economic factors were compounded by inflation, supply chain fluctuations, and poor economic incentives.

Osuizugbo note that cost-based limitations regarding water efficiency are not a one-of-a-kind situation but rather an overall barrier to sustainable building [9]. On the same note, the lack of sufficient technical expertise on the part of the engineers and other stakeholders was also a common theme. According to Nguyen and Macchion [8], engineers will tend not to popularize or even recommend the use of such solutions when they are themselves insecure or unaware of the entire range of existing solutions.

The other major obstacle is the regulatory environment. Other respondents expressed that building codes and regulations regarding planning are either out of date or unclear about water-saving technologies. It is known that not all cities provide incentives or want to comply with green standards, and when they do, policies are not uniform, and enforcement frequently fails. According to Shoushtarian and Negahban-Azar [10], without effective frameworks of policy, there is no great incentive for market actors to do more than the minimum. Cultural resistance and the inability of stakeholders to agree also became minor yet significant obstacles. The engineers claimed that there was cynicism among the contractors or the building operators who are not knowledgeable about the non-traditional systems.

4.5. Analysis and Interpretation of Results

The results of this research can be additionally situated in the contextual frameworks provided by Davis's (1989) Technology Acceptance Model (TAM) [5] and Biddle's Role Theory [4], according to which the evolution of technologies in relation to their adoption (or non-adoption) within an organizational environment could be viewed.

In TAM, it is believed that the probability of adopting a technology is dependent on two perceptions, which are the perception of usefulness and the perception of ease of use. Looking at water-efficient technologies, the paper established that the majority of engineers acknowledge their practicality, citing low operational costs, ability to meet environmental standards, and imperviousness to water shortages, among others. Nevertheless, implementation complexities, unavailability of support structures, and inadequate training reduce the perceived ease of use. Subsequently, it is possible that even very valuable technologies will not be embraced until such secondary obstacles are resolved.

TAM also emphasizes the importance of extrinsic factors, including support of the organization, economic drivers, and government regulation, as contributing factors determining the attitudes towards technology. All of these factors were apparent in the study at hand, and this added supporting evidence to the validity of the idea of TAM as a prism that may be used to analyze the information further.

In addition to TAM, role theory, as described by Biddle [4], will assist in explaining the social relationship that determines the behavior of engineers and the decision-making process. Institutional arrangements often compromise the capacity of engineers to play advocate of sustainability, even though they tend to identify themselves as such. Role strain: When there is a conflict between organizational norms, client demands, or economic pressures and sustainable goals, engineers may develop a situation of role strain, which is a mismatch between what is expected of them and the power or means at their disposal.

Such tension may result in frustration or disengagement, especially when the professional is young in the career and may feel underserved in the strategic decision-making unit. On the other hand, engineers who led their activities in favorable settings outlined a sense of agency and satisfaction in their statuses.

Collectively, the above theoretical perspectives highlight that environmental or technical competence is not the only thing needed to implement the successful and efficient implementation of water-efficient technologies in sustainable-building projects. It requires systemic convergence, both on policy, market, organizational, and cultural levels, in order that engineers can be enabled to perform as technical experts and as sustainability trendsetters.

5. Conclusion and Recommendations

5.1. Conclusion

Engineers come in very crucially in ensuring that water-efficient technologies are developed within the sustainable building projects in terms of technical input during the designing stages and also during the running stages. They directly fuel the growth of systems like the recycling of grey water, rainwater harvesting, and low-flow fixtures. But they suffer a limited impact because of resistance to them by clients, their high start-up costs, the lack of technical expertise, and poor regulation. The targeted interventions to overcome these barriers should be through collaboration between engineers, policymakers, and stakeholders of industries. The results of the research are regionally specific and globally applicable, as they fit into the global sustainability agenda, including the sustainability goals in the United Nations Sustainability Goals development and national policies aiming to manage water resources (Refer to **Table 8**).

Table 8. Summary of key study conclusions.

Category	Key Findings
Roles of Engineers	- Design and specify water-efficient technologies - Supervise installation and commissioning - Monitor system performance and provide technical support
Barriers Identified	- High initial costs - Limited technical training - Client resistance - Weak regulatory enforcement
Current Industry Gaps	- Lack of sustainability training in engineering curricula - Inconsistent policy incentives - Limited collaboration among disciplines - Insufficient awareness among clients

5.2. Recommendations

Addressing the problems found in this study by pursuing a more active role of engineers would require a multipronged and multicentric strategy of action. Some of the strategic suggestions follow below and are coupled with corresponding actors and implementation procedures.

5.2.1. Advanced Engineering Education and Professional Training

It is necessary to develop the capacity of engineers to make them learn and acquire knowledge and expertise to consider water-saving technologies in building design. Designing an engineering curriculum at the undergraduate level and graduate level should be revised according to the requirements to incorporate courses about sustainability, namely a water resource management course and an eco-efficient design course [3]. Lifetime professional development training should also be made available to the existing engineers in practice.

5.2.2. Enforce and Empower Building Codes and Offer Financial Incentives

Marzouk believes that both national and regional governments should take the forefront by amending building codes and construction policies to ensure that there are minimum water-efficiency levels [2]. Besides the requirements set by existing regulators, governments should consider providing financial incentives (tax credits, grants, or subsidies) for the projects implementing certified water-efficient technologies. This would lessen the economic load on the clients and developers, and the sustainable options would be attractive.

5.2.3. Learn and Involve Clients

A major coin in changing the attitude back in the market is educating the clients. Awareness programs among building owners, investors, and developers could be used to convey the message that using water-efficient technology would be economically viable and environmentally friendly [1]. Showing the returns on investment with regard to case studies and performance statistics may change minds and raise the readiness to invest in sustainable solutions.

5.2.4. Encourage Academic Innovation

Integrating the water-efficient technologies successfully needs the contribution of the broad palette of specialists such as architects, urbanists, construction managers, and environmental consultants. The Water efficiency Manual published by N.C. Department of Environment and Natural Resources, put a strong emphasis on the need to encourage interdisciplinary work during the project life cycle, including design and planning, implementation, and maintenance [7]. The establishment of cross-functional design teams will result in better and transformative solutions to water-saving innovations.

5.2.5. Strengthen the Local Supply Chains and Access to Technologies

To achieve widespread use, there is a need to have access to freely available, as well as affordable, high-quality, water-efficient technologies. Dindorf and Wos propose policies and programs that encourage local manufacturing and distribution of technologies of sustainable construction [11]. Localized supply chains

Table 9. Recommended actions and responsible stakeholders.

Recommended Action	Responsible Stakeholders
Enhance engineering education and training	Universities, professional bodies, engineering institutions
Strengthen building codes and offer incentives	Government agencies, regulatory bodies, municipal councils
Educate and engage clients	Engineers, construction firms, sustainability consultants
Promote interdisciplinary collaboration	Project managers, architects, engineers, environmental consultants

have the potential to cut the cost lower, add supply facilities, and encourage regional innovative use of green construction.

These recommendations are addressed to various stakeholders, as shown in Table 9. Each stakeholder has a role to play in contributing to the green construction, the engineers, educational institutions, government agencies, construction firms, clients, and technological providers. Collaborating with one another, these parties will help overcome multifaceted challenges that have been outlined in this study and speed up the process of building sector water-efficient technology adoption.

5.3. Recommendations on Future Studies

Although the study carried out in this paper gives an insight into the opportunities and issues related to the role of engineers in water-efficient practices in building, some issues need to be explored further at the academic level.

5.3.1. Quantitative Cost-Benefit Analyses

In the future, similar detailed cost-benefit analyses of different water-efficient technologies in different types of buildings are needed. Such research, by making available empirical data of the cost of installation, savings in water, maintenance, and returns in the longer run, may be able to build the business case around sustainable investments.

5.3.2. Comparative Studies—By Region

Comparative studies would be beneficial considering the variances in regulatory conditions and availability of resources and ways of construction between the areas. The comparison of water-efficient technology implementation in various countries or cities may point at the presence of the most effective practices, strategies that can be transferred, and the problem areas peculiar to the context.

5.3.3. Longitudinal Performance Tests

The performance of water-efficient buildings is not well monitored on a long-term basis regarding the amount of savings on water, user satisfaction, maintenance costs, and general sustainability of the building. Such longitudinal studies that follow buildings throughout their lives, during design, occupation, and long-term use, may be essential to revealing how successful the design and engineering choices and applied technology were.

5.3.4. Behavioral Research on Client Decision Making

It would be useful to learn about the psychological and behavioral aspects that are affecting the attitude of the clients toward sustainable water technologies. The studies can be conducted to examine the effect of marketing tactics, economic messaging, or indications of policies on the decision-making process, which can inform more efficient outreach and communication.

5.3.5. Interaction with Greater Sustainability Measures

Lastly, the interactions between water efficiency strategies and other sustainability objectives (*i.e.*, energy performance, carbon emissions, or indoor environmental quality) could be investigated by future research. Comprehensive sustainability modeling would assist engineers and project teams to make more comprehensive design decisions.

To conclude, sustainable water management requires the input of engineers, and it is a very multifaceted task. Institutional, technical, and market barriers can be overcome by making specific recommendations and conducting additional studies to release the maximum potential of engineering knowledge to push water-efficient building practices into the mainstream of sustainable construction.

5.4. Limitations to the Study

Despite the findings of the study, it is valuable to admit a number of limitations. The qualitative sample is quite small (twelve participants) and, therefore, not representative of the entire range of experiences of the engineers in various environments. The geographical focus, which was narrowed down to California, United States, may also add regional bias since regulatory systems, market environments, and availability of resources that occur in these areas are diversified. Furthermore, disciplinary representation was also biased toward civil, environmental, and mechanical engineering, and this might also be a disadvantage to other engineering fields engaged in developing sustainable buildings.

Acknowledgements

My appreciation goes to my colleagues at Bay Air Systems, the project managers and the CEO Bert Morgan for their encouragement.

I am deeply grateful to my family for their unwavering support and encouragement.

I would like to dedicate this work to my Daughter Serena Berro, and to my company Bay Air Systems.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] Yao, F., Liu, G., Ji, Y., Tong, W., Du, X., Li, K., *et al.* (2020) Evaluating the Environmental Impact of Construction within the Industrialized Building Process: A Monetization and Building Information Modelling Approach. *International Journal of Environmental Research and Public Health*, **17**, Article 8396. https://doi.org/10.3390/ijerph17228396

[2] Marzouk, O.A. (2024) Evolution of the (Energy and Atmosphere) Credit Category in the LEED Green Buildings Rating System for (building Design and Construction: New Construction), from Version 4.0 to Version 4.1. *Journal of Infrastructure*, *Policy and Development*, **8**, Article ID: 5306. https://doi.org/10.24294/jipd.v8i8.5306

[3] Brand, B.R. (2020) Integrating Science and Engineering Practices: Outcomes from a Collaborative Professional Development. *International Journal of STEM Education*, **7**, Article No. 13. https://doi.org/10.1186/s40594-020-00210-x

[4] Biddle, B.J. (1986) Recent Developments in Role Theory. *Annual Review of Sociology*, **12**, 67-92. https://doi.org/10.1146/annurev.so.12.080186.000435

[5] Davis, F. (1987) User Acceptance of Information Systems: The Technology Acceptance Model (TAM). https://quod.lib.umich.edu/b/busadwp/images/b/1/4/b1409190.0001.001.pdf

[6] Adetayo, O.O. and Oladipupo, O. (2021) Drivers and Barriers to the Implementation of Green Building Development. *PM World Journal*, **VIII**, 1-15. https://pmworldlibrary.net/wp-content/uploads/2019/10/pmwj86-Oct2019-Ono-sosen-Osanyin-Adeyemo-green-building-development.pdf

[7] Water Efficiency Manual, N.C. Department of Environment and Natural Resources Division of Pollution Prevention and Environmental Assistance Division of Water Resources Land-of-Sky Regional Council, Waste Reduction Partners. https://www.deq.nc.gov/watereducation/water-efficiency-business/download

[8] Nguyen, H.D. and Macchion, L. (2022) Risk Management in Green Building: A Review of the Current State of Research and Future Directions. *Environment*, *Development and Sustainability*, **25**, 2136-2172. https://doi.org/10.1007/s10668-022-02168-y

[9] Chigozie Osuizugbo, I., Oyeyipo, O., Lahanmi, A., Morakinyo, A. and Olaniyi, O. (2020) Barriers to the Adoption of Sustainable Construction. *European Journal of Sustainable Development*, **9**, 150-162. https://doi.org/10.14207/ejsd.2020.v9n2p150

[10] Shoushtarian, F. and Negahban-Azar, M. (2020) Worldwide Regulations and Guidelines for Agricultural Water Reuse: A Critical Review. *Water*, **12**, Article 971. https://doi.org/10.3390/w12040971

[11] Dindorf, R. and Wos, P. (2024) Challenges of Robotic Technology in Sustainable Construction Practice. *Sustainability*, **16**, Article 5500. https://doi.org/10.3390/su16135500

[12] Braun, V. and Clarke, V. (2006) Using Thematic Analysis in Psychology. *Qualitative Research in Psychology*, **3**, 77-101. https://doi.org/10.1191/1478088706qp063oa