CivilEng

Review

Managing Sustainability and Resilience of the Built Environment in Developing Communities

Mariham Iskandar [1], Denise Nelson [2] and Fariborz M. Tehrani [1,*]

1 Department of Civil and Geomatics Engineering, California State University, Fresno, 2320 E. San Ramon Avenue, Fresno, CA 93740, USA; miskanda@mail.fresnostate.edu
2 Launch! Consulting, 1710 Allied Street, Suite 23, Charlottesville, VA 22903, USA; denise@launch-consulting.com
* Correspondence: ftehrani@csufresno.edu; Tel.: +1-559-278-1762

Abstract: Sustainable built environment has been the primary focus in academic and industrial fields in recent years. The major forces behind sustainable engineering are the rise in climate-related disasters, constant challenges in the energy sector, and a substantial shift in consumers' consciousness toward conserving natural resources. Further, many professional bodies have developed guidelines and specifications to implement sustainable practices and rate their impacts. Regardless, promoting analytical procedures for creating a context-sensitive design requires professionals to become familiar with standard sustainable practices and feel comfortable implementing more innovative materials and techniques in civil engineering design. In addition, the socio-political environment and macro-economic culture interact with engineering decisions. Hence, these considerations are necessary to deploy these elements in developing communities through best management practices during the lifecycle of sustainable and resilient projects. This paper endeavors to review these practices using lessons learned from applied examples and existing literature. Discussions cover various aspects of project development, from planning to demolition. Recommendations address challenges and opportunities in the sustainable development of resilient built infrastructure in developing regions.

Keywords: sustainable development; infrastructure resilience; project management; developing communities

Citation: Iskandar, M.; Nelson, D.; Tehrani, F.M. Managing Sustainability and Resilience of the Built Environment in Developing Communities. *CivilEng* **2022**, *3*, 427–440. https://doi.org/10.3390/civileng3020025

Academic Editors: Domenico Asprone and Zenonas Turskis

Received: 8 January 2022
Accepted: 11 May 2022
Published: 14 May 2022

1. Introduction

1.1. Backgrounds and Motivation

Sustainability and resilience are essential aspects of developing high-performance infrastructure in developing communities with limited resources. This paper reviews the link between project management and sustainable infrastructure development from basic research to planning, design, implementation, and assessment, focusing on developing regions and communities. In recent years, the sustainable built environment has been the primary focus in academic and industrial fields. The major forces behind sustainable engineering are the rise in climate-related disasters, constant challenges in the energy sector, and a substantial shift in consumers' consciousness toward conserving natural resources. In addition, the United Nations estimates the world population will reach 9.6 billion by 2050 and 10.9 billion by 2100 [1,2]. The world population demands engineering infrastructure to provide clean water, sanitary waste removal, energy, transportation systems, data systems, etc. Since infrastructure is long-lived (20 to over 75 years and even centuries), today's decisions will establish the energy, water, and materials efficiencies and ecosystem impacts for decades to come.

1.2. Research and Practice Gaps

Many professional bodies have developed guidelines and specifications, such as Envision®® from the Institute for Sustainable Infrastructure, to implement sustainable practices and rate their impacts [3]. Although many professionals are familiar with standard sustainable practices recognized by these resources, they are not comfortable implementing more innovative materials and techniques in civil engineering design. This hesitation may have roots in the socio-political environment and the macro-economic culture that may drive innovation in engineering. Moreover, appraising the feasibility of any sustainable approach requires knowledge of analytical procedures applied to a context-sensitive design. Project managers must evaluate technical criteria and performance through the lens of the host community's needs and natural environment. One solution does not fit all, especially in developing communities where social justice and equity are typically significant concerns. Success is achievable with a collaborative approach that identifies context-sensitive parameters, targets, and milestones [4,5]. Figure 1 exhibits the hierarchy of sustainability measures adopted by different rating frameworks focusing on equity and justice as the primary goal. Table 1 provides suggestive components for each measurement.

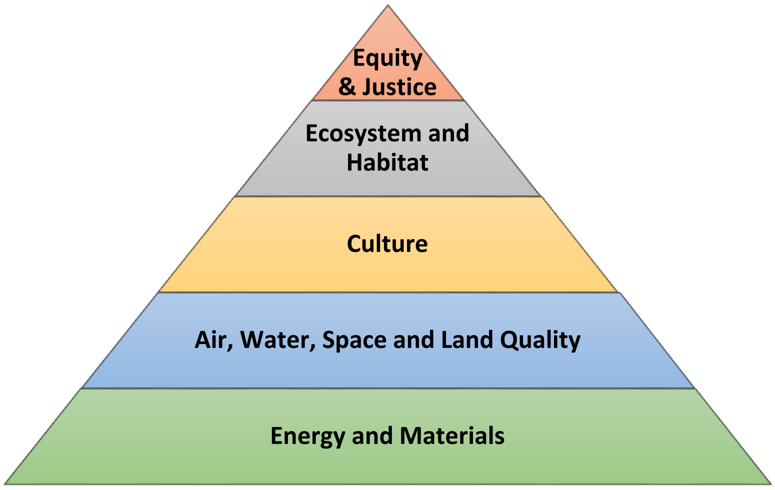

Figure 1. Hierarchy of substantiality measures.

Table 1. Sustainability measures.

Performance Measure	Details and Examples
Equity and Justice	Environmental and Social Justice, Livable Communities
Ecosystem and Habitat	Biodiversity, Conservation, Land Preservation
Culture	Aesthetics, Historic and Cultural Preservation
Air, Water, Space, and Land Quality	Greenhouse gases, Storm-water runoffs, Wetlands, Hazardous Waste, Noise, Health
Energy	Consumption and Efficiency
Materials	Hazardous Waste and Recycle

1.3. Significance

The United Nations Development Program (UNDP) defines developing communities as communities where members cannot develop to their fullest potential and lead productive and creative lives according to their needs and interests [6]. To improve living conditions, developing communities are expanding infrastructure and are exploiting resources at a high rate, which has proved ineffective [3]. Developing communities are still struggling to meet their desired needs and interests. This struggle increases maintenance costs, deterioration of infrastructure, and causes a decrease in the quality of service life provided by the infrastructure. They have also negatively impacted the surrounding environment, exacerbating poor living conditions [7,8].

1.4. Objectives

A sustainable engineering solution is required to meet community needs and improve living conditions. In this area, it is vital to note the significance of the order of priority for (1) environmental resilience, (2) social equity, and (3) techno-economic sufficiency aspects of sustainable development (Figure 2). This order emphasizes that projects not addressing climate change threats will not sustain community needs in the long term and will eventually fail, disregarding their technical, economic, or even societal fitness.

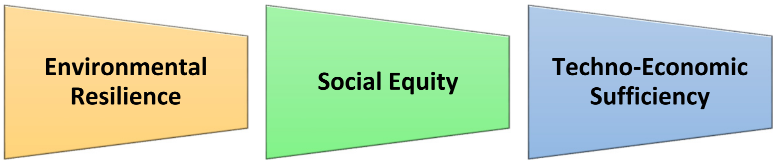

Figure 2. Inclusivity of development.

2. Challenges

Various factors, including lack of resources and funding, a wrong technical solution, and lack of community involvement in the project life cycle, prevent a sustainable engineering solution.

2.1. Challenge 1: Lack of Resources and Funding

There is a gap between developing community needs and their financial ability to address those needs [7–9]. To implement a sustainable engineering solution for a project, the community must fund the project throughout its planning, design, construction, operation and maintenance, and demolition cycle. Previous work in developing communities has shown that initial public and private funds typically carry out a project up to its construction phase. This approach tends to neglect operation and maintenance costs [7]. Around the globe, we see a disconnect in the funding to construct infrastructure (CAPEX) and the funding to operate and maintain infrastructure (OPEX). This disconnect results in the CAPEX and OPEX budgets being optimized independently. Hence, there is no concern for options to increase CAPEX in favor of solutions to decrease the overall lifecycle costs (Figure 3); that is, the lowest first cost often prevails [9,10].

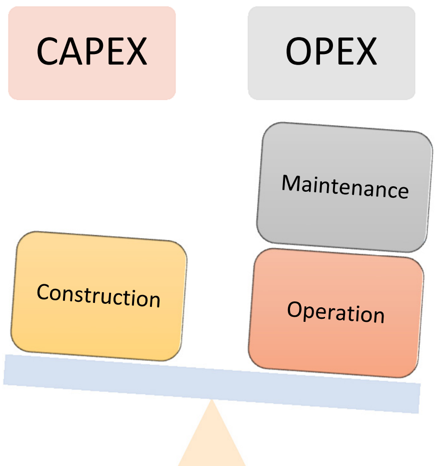

Figure 3. Schematic view of CAPEX versus OPEX.

A sustainable engineering solution requires an optimized allocation. Such allocation should consider initial and ongoing expenses and an evaluation of existing resources [10]. The bidding process and qualification criteria for bidders may also impact the quality of advanced planning for infrastructure funding [11,12].

2.2. Challenge 2: Applying the Right Technical Solution

Recognizing the "right problem" and incorporating the "right solution" is a technical challenge in developing a sustainable engineering solution [3]. Project design should reflect the appropriate level of technology for a developing community. A sophisticated construction, operation, and maintenance method that requires a specialized workforce or machinery may not be appropriate. The right technology level for a developing community will vary from a progressive society to a developing one and from one developing community to another [7].

A comprehensive study of the community in a site assessment will determine appropriate technology and local capacity to incorporate technology. It is essential to understand traditionally accepted local work methods, the extent and application of good international industry practices (GIIP), and the capacity of the market to support new products or services [13,14]. Figure 4 demonstrates a case for a water project in La Estanzuela, La Paz, Honduras, by the Engineers Without Borders Student Chapter at the University of Southern California [15]. This project involved upgrading local skills in building masonry dams to concrete dams with reinforcement techniques where needed.

Figure 4. Small dam construction in La Estanzuela, La Paz, Honduras: existing (**left**) and new (**right**) construction (Photo Credit: F. M. Tehrani 2011).

2.3. Challenge 3: Lack of Community Involvement

Lack of community involvement had prompted infrastructure sustainability failure even when the right technical engineering solution with enough resources and funds were available. For example, only 12% of well-designed drinking water supply and sanitation systems deployed to hundreds of villages during the 1980s by the International Drinking Water Supply and Sanitation remained operational by 2000 [16]. This failure resulted from a lack of community involvement in the infrastructure's maintenance, operation, and management support [16]. Lack of community involvement is due to a lack of community ownership and community participation in the early stages of the project [10].

3. Sustainable Engineering Solutions in Developing Communities

A sustainable engineering solution would address the above challenges. Sustainability is "development that meets the need of the present without compromising the ability of future generations to meet their own needs" [17]. Sustainability addresses the environmental, economic, and social aspects [16]. An engineering solution involves combining mathematics and science knowledge into a real-life problem and challenges [17]. Engineering sustainability combines technical sufficiency and economic feasibility for infrastructure system development. It also considers the social aspect of the project, including community participation and environmental elements that would contribute to the surrounding environment and community wellbeing. Envision (2018) measures the contributions of a sustainable engineering solution in five categories: (1) Quality of Life, (2) Leadership, (3) Resource Allocation, (4) Natural World, and (5) Climate and Resilience [2]. Each category involves a collection of credit points proportional to set levels of achievements. Mapping these points with best practices in project management hints toward optimized windows for implementing sustainable practices [18]. Figure 5 provides a breakdown of Envision categories regarding project management processes, indicating the significance of each process for developing sustainable solutions. The relationship between Envision Credits and project management processes highlights the project manager's relative control over various sustainability goals at each project stage. The significance of each goal is measured by the total Envision points available for the specified process and credit [3].

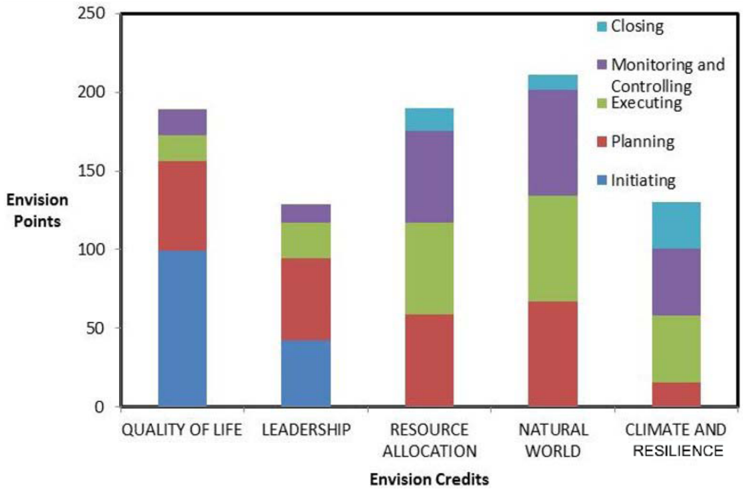

Figure 5. Mapping project management processes and sustainability performance measures.

4. Planning

Planning is the first step to developing a sustainable engineering solution. The planning phase involves proposing a general solution to the problem. The developed solution in the planning phase is tentative and subject to change. However, it is crucial to address research in this stage as thoroughly and accurately as possible because this stage will determine the project pathway. Planning considers general design, construction, operation, maintenance, and decommissioning. There are three stages in the planning phase: site assessment, prevalent solution alternatives, and community approval [7,8,18,19].

4.1. Stage 1: Site Assessment

Site assessment is research into the needs, risks, and impacts to define the root problems that the community may initially present. A project leader will look for issues and identify a sustainable opportunity to ensure a successful solution in the subsequent phases [19]. The World Bank offers guidance in its Environmental and Social Standards to enhance nondiscrimination, transparency, participation, accountability, governance, and the sustainable development outcomes of projects through ongoing stakeholder engagement [14].

There are no discrete or finite ways to carry out a site assessment. Hence, team members must allocate their time and efforts accordingly to obtain the most comprehensive overview of the community and the existing site [17]. Several suggested tools include interviews, house-to-house surveys, communication with local leaders, community workshops, focus groups, etc.

A site assessment, disregarding the methodology, must meet the following goals to address the challenges described earlier and present a sustainable opportunity:

1. To get an idea of the existing site's physical characteristics, including existing infrastructure and surrounding environment that could potentially interact with the infrastructure: The required resilience of the future infrastructure to be developed is a deduction from this information. Under this goal, the presented sustainable opportunity falls under the Envision categories of Natural World, and Climate and Resilience [3];
2. To get a good grasp on community resources (or limited resources) that include funding, labor, and material: The project team should be able to identify the community members and other organizations that will be able to assist in the design, construction phase, operation and maintenance phase, and demolition phase. Identifying community resources is the first attempt to deal with the lack of community resources and

resource funding. Envision categories of Resource Allocation and Leadership apply to this goal [3];
3. To understand regulations and laws that must be met to carry out a project and address any conflicting regulations and policies: The presented sustainable opportunity for this goal falls under the Envision category of Leadership [3];
4. To create a good relationship with the community via good communication: Proper communication improves the team's understanding of community preferences, priorities, and variables that affect their decision-making. Prompt communication also helps project leaders to involve community members in the project. Community makeup includes community members, local government, and any potential stakeholders. The presented sustainable opportunity falls under the Envision category of Leadership [3];
5. To identify community needs and the root problem that needs addressing to meet those needs by combining all data and analyzing information: This goal will facilitate the adaptability of technical solutions to the community's capacity. The presented sustainable opportunity falls under the Envision category of Quality of Life [3].

4.1.1. Communication

This phase is one of the first interactions with the community and an excellent opportunity to create good relationships that promote project acceptance and help ensure its success throughout its life cycle. Hence, good communication with the community is necessary for this stage, and the planning team should always have a member or members who are indigenous to the target community [7]. Intentional efforts to identify all the appropriate stakeholders, plan engagement methods suitable for various stakeholders, disclose information, consult with stakeholders in a meaningful way, facilitate a stakeholder grievance mechanism, and report outcomes to stakeholders are elements of a robust strategy [13].

4.1.2. Resources

Several resources are available for conducting a site assessment in the planning phase. Three critical tools include the CARE Handbook [17], the Site Assessment Checklist [16], and the Environmental and Social Impact Assessment (ESIA) [13]. These tools are essential when dealing with developing communities. The CARE handbook helps analyze the information to make conclusions about the community and meet the needs of a project. The Site Assessment Checklist addresses technical issues in different civil engineering project types (water, structural, transportation, etc.), deals with existing conditions, and collects general information relevant to the site. The EISA promotes investigating the relevant legal framework, the basis of design, baseline data, environmental and social risks, and impacts, and developing mitigation measures, analysis of alternatives, and design measures [13,14].

Other project guidelines are available according to the project type. For example, the Community-Led Urban Environmental Sanitation (CLUES) guideline focuses on water and sanitary issues in developing communities. Secondary resources that include historical reports found from previous groups are equally important. Such data will save time, money, and effort. Often there will be an information gap; team members can research to have a more comprehensive site assessment [17,19].

4.2. Stage 2: Development of General Solutions

Once team members have analyzed collected data and have identified the existing problem, they can develop general solutions to the current problem given community constraints that the community has communicated to the project team. Team members will collaborate with community leaders (representing community members) to select general alternative solutions to propose to the community [19].

Alternative Solution Characteristics

Alternative solutions are general approaches to the problems identified in the site assessment. Unless the community requests such specifications, these solutions are not overly detailed or specified. An alternative solution should demonstrate a clear understanding of project problems and constraints and approaches to addressing these problems. This approach should identify an appropriate technical solution, an overview of sustainable measures, a cost estimate of the project lifecycle, and a project scope of work for the project lifecycle that considers the design, construction, operation and maintenance, and demolition phases [19].

An engineer would consider construction materials, the level of maintenance and operation measures for a given infrastructure, required labor, required skillset, and available funding found in the site assessment. Evaluation of alternative options in a standard sustainable project assessment scheme, such as Envision, provides another mechanism for comparing options [3]. The evaluation may also include a comprehensive approach to include the performance of suppliers [20]. The results will not determine which project is more sustainable but will highlight sustainable practices in each alternative to aid decision making.

4.3. Stage 3: Community Presentation and Approval

Developed alternative solutions must be presentable to community members. This process must include all community groups; the consequence of community member exclusion is a social or economic gap that will negatively impact the quality of life for community members served [19].

Other Considerations in the Planning Phase

When dealing with a developing community, there will likely be inconsistencies in data and information derived from the site assessment because of lack of funding, technology, etc. These inconsistencies can change the project's outlook [18–21]. An interactive planning approach in planning a project mitigates these inconsistencies and uncertainty [19–21].

5. Design

Design is the second step to developing a sustainable engineering solution. The design phase uses the progress made in planning to create a detailed solution. The decisions made in design will impact the sustainability of construction, operations, maintenance, and decommissioning [21]. The designer is responsible for continuing stakeholder engagement and fostering an integrated team. Collaboration among diverse stakeholders and a multidisciplinary project team can resolve design conflicts, foster innovation, improve quality of life, decrease negative environmental impacts, and support integration with other community assets [22].

5.1. Stage 1: Schematic Design

Schematic design involves refining and building upon the scope of work, conceptual design, and cost estimate presented in the Planning Phase [19]. One of the main goals of this stage is to verify with the community representatives project requirements that were initially defined in the Planning Phase and review in detail the project plan and relationships of different components of the project. The change mechanism begins when community representatives disagree with the available alternative [21]. For example, if community members disagree on a design's long-term operation and maintenance costs, an option would be to design infrastructure with higher construction costs and lower operation and maintenance costs. The outcome of this stage is a preliminary report that includes schematic plans, schematic specifications, and a schematic cost estimate.

5.2. Stage 2: Design Development

The design development stage involves detailed conceptual design based on the schematic preliminary report [19]. Site plans detailing buildings, roads, drainage, utilities, etc., are developed. This stage also includes a sustainability review of the design, a detailed lifecycle cost analysis, and an operation and maintenance manual for infrastructure [7].

There is a limited opportunity to change design during this stage [21]. Thus, incorporation of lifecycle assessment in the schematic phase is vital to avoid lost opportunities concerning sustainable outcomes. The outcome of this stage is a design development plan, design development specifications, and design development cost estimate.

5.3. Stage 3: Development of Construction Documents

Construction documents provide the construction team with information on the project. Construction documents include a project manual, detailed drawings, technical specifications, resource quantity take-off, and refined probable construction costs [19]. The designer must provide a sustainable design solution, including [19]:

1. Project details. First, the designer must determine the "right project" for meeting the community's needs concerning sustainability objectives. This concept gets to the core of design for the most effective and efficient solution likely to be successful in the long term. Second, the designer must determine how to make the "project right" [3]. Designers should consider available technologies, materials, equipment, and social capacity.
2. Specific Location. While the approximate location is related to the basis of design, determining the location of construction works is instrumental in preserving sensitive environments, habitats, and social cohesion. In addition, the protection of the community is essential through assessing climate change effects such as sea-level rise and deforestation.
3. Risk and impact. Risk and impact assessment facilitated the development of measures to avoid, reduce, mitigate, or offset negative consequences, in that order. Risks may be associated with climate change, resource scarcity, natural disasters, or human threats.
4. Compliance. Compliance with local, regional, and global requirements is vital for new or innovative technologies, materials, or services.
5. Fund allocation. Designers may conduct a lifecycle cost assessment (LCCA) to understand the actual cost of infrastructure ownership. This assessment accounts for the cost of labor, materials, and other expenses over the entire lifecycle with a time-adjusted capital value. Optimizing the cost over the whole lifecycle is another way to promote innovative design decisions that reduce construction, operation, and maintenance costs.
6. Community endorsement. Sustainable development is about building more robust and resilient communities and ensuring the safety and reliability of services according to community values: identity, family, community, environment, and the future. The project's purpose is to provide a service to the population. Consider the short-term and long-term impacts on basic human needs. Delivery of these services shall be safe, diversified, universal, and without excessive time or financial burden. The final goal of community engagement is to create good relationships that will promote project acceptance and help ensure the project's success and community ownership.

5.3.1. Designing for Construction

The designer can influence the sustainability of construction in many ways. Design specifications directly impact the need for temporary structures and optimize resource allocation. Further, optimizing construction procedures may allow adequate safe workspaces for typical construction vehicles. When applicable, material specifications also contribute to the application of locally sourced materials. Similarly, a balanced geometric design minimizes earthwork cuts and waste [7]. Contractors are typically responsible for the means and methods [19]. Hence, they can incorporate sustainable construction practices, such as waste management procedures that include recycling and reusing materials using highly efficient or automated equipment and scheduling just-in-time delivery to reduce staging areas.

5.3.2. Designing for Operation and Maintenance

The designer can also impact the sustainability of the operations and maintenance phase by specifying low maintenance materials and plants, requiring the commissioning of electrical systems, and making the design adaptable for future potential changes in use. The designer should also prepare an operation and maintenance plan with instructions on procedures appropriate to optimize the design features. Specification of high-performing materials, often available at higher acquisition prices, significantly reduces operational costs, energy, emissions, and waste [21–25]. Assessing the input energy and emissions accurately compares various alternatives, such as local, recycled, or high-performance materials [25–27].

The operations and maintenance crew typically involve the infrastructure owner or community members. This team can incorporate sustainable operations and maintenance practices by sourcing parts and materials locally, if suitable, monitoring performance and conducting maintenance before necessary repairs, and sustainably managing waste products. The application of locally sourced materials should satisfy a balanced approach to achieve sustainability objectives such as durability and techno-economic sufficiency.

5.3.3. Designing for End of Life

The designer can impact the project's sustainability at the end of its useful life by specifying separable parts, reusable and recyclable materials, and non-toxic components [7]. Preparation of a Decommissioning Plan in the design phase helps to identify potential improvements in the design based on the concept of "reverse engineering" [19]. The purpose of the plan is to educate stakeholders on what to expect at the end of life. The program should be updated periodically during the operations and maintenance phase to account for changes to the local context, such as advancements in material recycling procedures, changes in waste disposal locations, or new types of demolition equipment and practices. The deconstruction or redevelopment team may also identify additional ways for waste recycling or reusing, structural repurposing, or managing hazardous contents.

6. Construction

In the construction phase, the design plans are put to work by the construction team. The construction manager, who leads the construction team, coordinates resources and people to ensure the project's success [21]. Critical features of construction management include management of skilled and unskilled labor, scheduling, risk management, safety, and reduction in construction impacts via management of construction waste and siltation control in waterways [19,28].

6.1. Management of Skilled and Unskilled Labor

A surplus of unskilled labor and shortage of skilled labor are common characteristics of developing communities. A long-term solution would be to implement some skillset courses to provide education for the surplus of unskilled labor. A short-term solution would be to hire a contractor by a development agency to be responsible for construction. This approach improves the contractor's selection using combined experience and lowest bid criteria [9]. Just-in-time training programs may address any gap in the knowledge and skills of hired contractors.

6.2. Scheduling and Risk Management

Scheduling is vital for effective project management in the construction phase. Scheduling must be detailed and likely requires frequent updating and scheduling. Scheduling is a tool for risk management. A reliable schedule will account for typical risks in a developing community, including unreliable infrastructure, unforeseen conditions, and other local challenges and constraints [9,21].

6.3. Health and Safety

Construction health and safety management involves addressing policies, procedures, and practices to prevent a wide range of injuries, accidents, and contaminations and promote the general welfare of the construction crew and public [7]. Construction health and safety management in construction is a primary concern for workers and community members that are not part of the construction process but near the construction site. The construction industry has the highest rate of accidents, including deaths and disabling injuries, worldwide [29]. Considering health and safety as a secondary or low priority issue in developing countries may have various reasons such as errors, omissions, or lack of knowledge or means required to perform tasks safely and socio-political factors and economic constraints. Additional causes, especially when dealing with a developing community, are possibly insufficient safety protocols or improper adoption of existing protocols due to other constraints [29].

The first step for construction safety management performance is to develop a corporate safety performance standard and means to measure set safety standards using objective measures such as injury frequency. This standard relies on the enterprise environment and public regulations at local and global scales [21]. A measure of performance will provide knowledge of existing safety procedures' strengths and weaknesses; this will guide the project manager in implementing different steps to improve existing practices. Potential room for improvements is enough safety training by project managers to increase knowledge of safety measures. Other enhancements may include the addition of a safety officer in the field responsible for carrying out safety tours and inspections and would identify potential safety hazards in the work environment [29].

6.4. Construction Waste Management

Reducing construction waste via recycling and reuse would reduce landfill uptake, the use of new raw material, and costs in the transportation of waste. In addition, proper handling of hazardous construction waste would improve the overall health of the environment and the community, and hence, it is linked to the broader concept of health and safety in construction. Thus, the waste management approach increases the overall sustainability of this project. Challenges faced in waste management when dealing with a developing community include lack of awareness about construction waste problems, lack of legislation and enforcement of recycling and reuse, illegal dumps of hazardous waste material, and lack of funds and technical equipment for hazardous construction waste. Numerous strategies are available to project managers to meet these challenges: promote construction waste problems in collaboration with established community leaders, create a payback incentive for recycling construction waste, develop a system to measure the level of performance of construction waste recycling, and adopt a set of rules and codes for handling hazardous waste [30–32].

7. Operation and Maintenance

Operation and maintenance involve sustaining infrastructure quality and function throughout its lifecycle [33]. There are three maintenance approaches: preventative, corrective, and reactive maintenance. Preventive maintenance refers to technical activities to keep the infrastructure in good condition; corrective maintenance refers to repairing and replacing the existing infrastructure components to keep it functional; reactive maintenance refers to required maintenance due to an emergency or public complaint [34].

Operation and maintenance substantially influence overall sustainability, especially in a developing community. Successful operation and maintenance require community involvement and leadership: community members must perform functions to operate and maintain the infrastructure system developed in this phase without external constraints. Achieving this goal is possible by facilitating community leadership through a locally elected board that would manage community members and collaborate with local agencies [9]. If community management and leadership strength are poor and cannot be improved, securing some external assistance may be possible. This phase requires both scheduling and risk management procedures. Sustainable opportunities in this phase include Leadership, Climate and Resilience, and Resource Allocation.

Figure 6 shows the installed water tanks in the Corral de Piedras, La Paz, Honduras, by the Engineers Without Borders Student Chapter at the University of Southern California [15]. Plastic water tanks required low cost for initial installation but needed coordinated maintenance efforts by the community, which caused challenges during the operation.

Figure 6. Water tanks in Corral de Piedras, La Paz, Honduras (Photo Credit: F. M. Tehrani, captured 2011).

8. Demolition

Demolition is the breakdown of the infrastructure that has reached the end of its lifecycle for complete removal or renewal. Every part of the infrastructure (roofing, piping, foundation, etc.) is considered demolition waste [30–32]. In this phase, infrastructure components are recycled (if possible) and invested in future projects in the community. These components are applicable for the assembly of new infrastructure, reprocessed to manufacture into new features, recycled and upcycled into new material, or downcycled as needed [35]. The benefits of sustainable demolition include minimizing waste, maximizing reuse and recycling, reducing environmental impact, minimizing negative social impact, and reducing waste transportation costs [30–32,36].

There are five stages to carrying out the demolition phase. These phases increase community awareness, develop deconstruction surveys, establish project goals and metrics, prepare plans and specifications, and monitor progress and performance.

8.1. Stage 1: Increasing Community Awareness of the Process

Community awareness of the demolition process is necessary for the demolition stage. Community awareness increases community understanding of safety measures during this stage and allows community members to participate in the demolition process. Advertisement is required because community involvement may not be as strong as during the first four phases since it is at the end of the project's lifetime. Suggested measures to increase community measures include creating information exchange and awareness celling campaigns that raise community awareness of the demolition phase through community meetings, flyers, and workshops that explain the process [30–32].

8.2. Stage 2: Deconstruction Survey

The deconstruction survey is a survey that identifies different materials for easy removal from the infrastructure, such as buildings, roads, treatment systems, etc., before being demolished, such as furniture, piping, windows, doors, brick, stone, and steel, etc. This survey also identifies hazardous material that needs to be removed from the infrastructure to prevent any hazardous material from contaminating the surrounding environment during the actual breakdown of the building, aligned with construction health and safety management. Materials in this phase can include but are not limited to lead-based paint, asbestos, mercury, and waste material [35,36].

8.3. Stage 3: Establishing Project Goals and Metrics

Setting goals for reuse and recycling follows identifying available material in the deconstruction phase. This approach extends to identifying contingency measures to address hazardous materials such as asbestos or lead. A means of measuring performance is also necessary to ensure meeting set goals. Some suggested performance measurements include but are not limited to a percentage of recycled material, percentage of reused material, and percentage of greenhouse gases reduction [35,36]. The latter requires expertise in emissions unless established documents such as environmental product declarations are available for identified materials. Setting goals and performance measurements follow decisions made collaboratively by community members and project team leaders.

8.4. Stage 4: Preparing Plans and Specifications

This stage aims to create a step-by-step process to ensure that goals are met [36]. Plans and specifications detail what—and how and when—will be removed, recycled, and reused.

8.5. Stage 5: Implementation and Monitoring of Progress

The final stage is to implement the set plans and specifications. Project management, scheduling, and risk management are involved, similar to the construction phase [35,36].

9. Broader Impacts

The broader impact of sustainable development in developing communities may incorporate education components. Engineering education recognizes the project-based approach as an essential tool [37–40]. Sustainable development of infrastructures in developing communities, such as Engineer Without Border projects, provides excellent opportunities for active groups and stakeholders to learn about the project's planning, design, and construction phases. The Nicaragua public elementary school project is an example of such development. The project involved 16 traveling students plus 40 additional supporting members of the Engineer Without Borders Student Chapter at California State University, San Luis Obispo (Cal Poly) [41]. This project incorporated the education of community members and students in all phases of planning, design, and construction. This approach positively impacted community leadership in Nicaragua and San Luis Obispo, where the team needed to organize and mobilize resources. Furthermore, educational outcomes were essential to sustain implemented practices, for Cal Poly students to lead similar projects, and for the local community in Nicaragua to carry out their future projects [42].

10. Conclusions

Sustainability is a continuum of options based on local baseline conditions. The key to context-sensitive design is understanding the local environment, community, and infrastructure systems. Accounting for variations in existing local practices and the capacity of the local marketplace makes it difficult to identify specific recommendations adaptable to all locations. More general process recommendations to understand the local context and mitigate risks to sustainability in an incremental fashion are more likely to be adopted and implemented. Community engagement may be the one universal specific practice for sustainable development. Engaging all stakeholders (owners, regulators, planners, designers, builders, operators, users, and others) early and throughout the project lifecycle might be the best approach for developing a successful context-sensitive design and managing sustainability and resilience in developing communities concerning climate change risks.

Author Contributions: Conceptualization, F.M.T. and D.N.; methodology, F.M.T. and D.N.; investigation, M.I.; resources, M.I., D.N. and F.M.T.; data curation, M.I. and F.M.T.; writing—original draft preparation, M.I., D.N. and F.M.T.; writing—review and editing, F.M.T. and D.N.; supervision, F.M.T.; project administration, F.M.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not Applicable.

Informed Consent Statement: Not Applicable.

Data Availability Statement: Not Applicable.

Acknowledgments: The corresponding author is thankful to students in the Engineers Without Borders Student Chapters at the University of Southern California and Cal Poly San Luis Obispo.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. United Nations. *World Population Projected to Reach 9.6 Billion by 2050*; UN News: New York, NY, USA, 2013. Available online: https://www.un.org/en/development/desa/news/population/un-report-world-population-projected-to-reach-9-6-billion-by-2050.html (accessed on 21 June 2017).
2. Bystroff, C. Footprints to singularity: A global population model explains late 20th century slow-down and predicts peak within ten years. *PLoS ONE* **2021**, *16*, e0247214. [CrossRef] [PubMed]
3. Institute for Sustainable Infrastructure. *Envision: Sustainable Infrastructure Framework*; Institute for Sustainable Infrastructure: Washington, DC, USA, 2018.
4. Nelson, D.; Tehrani, F.M. Is Resilience . . . Sustainable? *APWA Rep.* **2018**, *85*, 53–56. Available online: www3.apwa.net/Resources/Reporter/Articles/2018/8/Is-resilience-sustainable (accessed on 7 August 2018).
5. Tehrani, F.M.; Nelson, D. From Sustainability to Resilience: A Practical Guide to ENVISION®®. In *Objective Resilience Committee Manual of Practice*; Ettouney, M., Ed.; ASCE Press: Reston, VA, USA, 2022. [CrossRef]
6. United Nations Development Programme. *2021/22 Human Development Report*; UNDP: New York, NY, USA, 2021. Available online: https://hdr.undp.org/en/towards-hdr-2022 (accessed on 7 January 2022).
7. Goodman, A.S.; Hastak, M. *Infrastructure Planning Handbook*; McGraw Hill: Reston, VA, USA, 2006.
8. Vasquez, S.; Araya, F. Exploring Challenges to Implement an Integrated Urban Infrastructure Management Approach. In Proceedings of the Construction Research Congress 2022: Infrastructure Sustainability and Resilience, Arlington, VA, USA, 9–12 March 2022; pp. 240–248. [CrossRef]
9. Mihelcic, J.R.; Philips, L.D.; Myre, L.M.; Fy, L.M.; Barkdoll, B.D. *Field Guide to Environmental Engineering for Developing Workers*; American Society of Civil Engineers (ASCE): Reston, VA, USA, 2009.
10. Gwaka, L.; Haseki, M.; Yoo, C.S. Study Results from University of Pennsylvania Broaden Understanding of Engineering (Community Networks As Models To Address Connectivity Gaps In Underserved Communities). *Inf. Dev.* **2022**, *2*, 2395. [CrossRef]
11. Farshidpour, R.; Negoro, K.; Tehrani, F.M. A Statistical Approach to Analyzing Engineering Estimates and Bids. *Stats* **2021**, *4*, 62–70. [CrossRef]
12. Tehrani, F.M. Engineer's Estimate Reliability and Statistical Characteristics of Bids. *Cogent Eng.* **2016**, *3*, 1133259. [CrossRef]
13. The World Bank. *Environmental and Social Framework*; The World Bank: Washington, DC, USA, 2017. Available online: https://thedocs.worldbank.org/en/doc/837721522762050108-0290022018/original/ESFFramework.pdf (accessed on 7 January 2022).
14. Jokubauskaite, G. The World Bank Environmental and Social Framework in a wider realm of public international law. *Leiden J. Int. Law* **2019**, *32*, 457–463. [CrossRef]
15. Reed, J. Honduras H_2O. Photo Essay. In *USC Viterbi Engineer*; USC: Los Angeles, CA, USA, 2008. Available online: https://issuu.com/uscedu/docs/58558/24 (accessed on 7 January 2022).
16. Lucena, J.; Schneider, J.; Leydens, J.A. *Engineering and Sustainable Community Development*; Morgan and Claypool Publishers: San Rafael, CA, USA, 2010.
17. Caldwell, R. *Project Design Handbook*; Cooperative Assistance and Relief Everywhere, Inc.: Tucson, AZ, USA, 2002.
18. Tehrani, F.M. Sustainability and Resilience through Project Management. In Proceedings of the 5th International Congress on Civil Engineering, Tehran, Iran, 26–28 December 2017. Available online: https://civilica.com/doc/735200 (accessed on 7 January 2022).
19. Hansen, K.L.; Zenobia, K.E. *Civil Engineering Handbook of Professional Practice*; John Wiley & Sons Inc.: Hoboken, NJ, USA, 2011.
20. Yazdani, M.; Wen, Z.; Liao, H.; Banaitis, A.; Turskis, Z. A grey combined compromise solution (CoCoSo-G) method for supplier selection in construction management. *J. Civ. Eng. Manag.* **2019**, *25*, 858–874. [CrossRef]
21. PMI. *PMBOK: A Guide to the Project Management Body of Knowledge*; Project Management Institute: Newtown Square, PA, USA, 2021.
22. McComb, C.; Cogan, J.; Kotovsky, K. Lifting the Veil: Drawing insights about design teams from a cognitively-inspired computational model. *Des. Stud.* **2015**, *40*, 119–142. [CrossRef]
23. Tehrani, F.M.; Pouramini, M.; Mohammadiyaghini, E. Sustainability Assessment and ENVISION Rating of Light-weight Masonry Walls in Conventional Buildings. In Proceedings of the International Conference on Sustainable Infrastructure 2019: Leading Resilient Communities through the 21st Century, Los Angeles, CA, USA, 6–9 November 2019; pp. 502–507. [CrossRef]

24. Tehrani, F.M.; Dadkhah, M. A Case Study on the Analysis of Energy and Emissions for Sustainability Rating. *Int. J. Clim. Chang. Impacts Responses* **2018**, *1*, 13–23. [CrossRef]
25. Tehrani, F.M.; Farshidpour, R.; Pouramini, M.; Mousavi, M.; Esfahani, A.N. Sustainability Rating of Lightweight Expanded Clay Aggregates using Energy Inputs and Carbon Dioxide Emissions in Life-cycle Analysis. In Proceedings of the Sixth International Symposium on Life Cycle Civil Engineering, Ghent, Belgium, 28–31 October 2018; pp. 2989–2993, ISBN 9781138626331. Available online: www.crcpress.com/Life-Cycle-Analysis-and-Assessment-in-Civil-Engineering-Towards-an-Integrated/Caspeele-Taerwe-Frangopol/p/book/9781138626331 (accessed on 7 January 2022).
26. Tehrani, F.M.; Nazari, M.; Truong, D.; Farshidpour, R. Sustainability of Tire-Derived Aggregate Concrete: A Case Study on Energy, Emissions, Economy, and ENVISION. In Proceedings of the International Conference on Sustainable Infrastructure 2019: Leading Resilient Communities through the 21st Century, Los Angeles, CA, USA, 6–9 November 2019; pp. 399–408. [CrossRef]
27. Nazari, M.; Tehrani, F.M.; Ansari, M. Lightweight Rubberized Concrete Slabs for Sustainable Road Pavements Serving Non-Auto Traffic. *Period. Polytech. Civ. Eng.* **2022**, *66*, 460–470. [CrossRef]
28. Manowong, E. Investigating factors influencing construction waste management efforts in developing countries: An experience from Thailand. *Waste Manag. Resour.* **2012**, *30*, 56–71. [CrossRef] [PubMed]
29. Priyadarshani, K.; Karunasena, G.; Jayasuriya, S. Construction Safety Assessment Framework for Developing Countries: A Case Study of Sri Lanka. *J. Constr. Dev. Ctries.* **2013**, *18*, 33–51.
30. Rondinel-Oviedo, D.R. Construction and demolition waste management in developing countries: A diagnosis from 265 construction sites in the Lima Metropolitan Area. *Int. J. Constr. Manag.* **2021**, 1–12. [CrossRef]
31. Abarca-Guerrero, L.; Maas, G.; Hogland, W. Solid waste management challenges for cities in developing countries. *Waste Manag.* **2013**, *33*, 220–232. [CrossRef]
32. Chinda, T. Investigation of factors affecting a construction waste recycling decision. *Civ. Eng. Environ. Syst.* **2016**, *33*, 214–226. [CrossRef]
33. Carter, R.C. Operation and Maintenance of Rural Water Supplies. Perspectives No 2. Rural Water Supply Network, Sustainable Sanitation and Water Management Toolbox. 2009. Available online: http://www.sswm.info/sites/default/files/reference_attachments/CARTER%202009%20Operation%20and%20Maintenance%20of%20Rural%20Water%20Supplies.pdf (accessed on 7 December 2014).
34. Dillon, L.B. Operation and Maintenance. Sustainable Sanitation and Water Management Toolbox. 1998. Available online: http://www.sswm.info/category/planning-process-tools/ensuring-sustainability/tools-ensure-sustainability/ensure-sustain-4 (accessed on 7 December 2014).
35. Crowther, P. Developing Guidelines for Designing for Deconstruction. In *Deconstruction—Closing the Loop Conference Proceedings*; Building Research Council: Watford, UK, 2000.
36. Fieber, L.M. *Green Demolition and Sustainable Deconstruction*; Burns & McDonnell Engineering: Kansas City, MO, USA, 2009.
37. McComb, C.; Tehrani, F.M. Research and Practice Group Methodology: A Case Study in Student Success. In Proceedings of the 2014 American Society for Engineering Education Zone IV Conference, Long Beach, CA, USA, 24–26 April 2014; pp. 255–267. Available online: http://web.csulb.edu/colleges/coe/2014-asee-zoneiv (accessed on 7 December 2014).
38. Tehrani, F.M.; Regier, J.; Hoffman, K. Modeling Civil Engineering Practice in Student Activities. In Proceedings of the 2014 American Society for Engineering Education Zone IV Conference, Long Beach, CA, USA, 24–26 April 2014; p. 519. Available online: http://web.csulb.edu/colleges/coe/2014-asee-zoneiv (accessed on 7 December 2014).
39. Tehrani, F.M. Implementing Situational Leadership in Engineering Classrooms. In Proceedings of the Pacific Southwest Section of American Society for Engineering Education Conference, Fresno, CA, USA, 1–2 April 2011; pp. 114–124. Available online: http://fresnostate.edu/engineering/asee (accessed on 7 December 2014).
40. Tehrani, F.M.; McComb, C.; Scott, S. A Quantitative Approach to Evaluate the Effectiveness of the Extended Situational Teaching Model in Engineering Education. *Stats* **2021**, *4*, 46–61. [CrossRef]
41. Blackburn, F.; Bluestein, J.; Tehrani, F.M. Engineers without Borders Nicaragua Public Elementary School Project: A Case Study in Enhancing Engineering Education through Project-Based Learning. In Proceedings of the 2016 American Society for Engineering Education Pacific Southwest Conference, Pomona, CA, USA, 21–23 April 2016; pp. 292–301. Available online: https://www.asee.org/documents/papers-and-publications/papers/ZoneIV/2016_ASEE_PSW_Conference_Proceedings.pdf (accessed on 15 July 2021).
42. Tehrani, F.M.; McComb, C.; Papavasiliou, N. Application of Project-based Learning within the Context of Sustainable Development in Education of International Engineer Citizens. In Proceedings of the 5th Iran International Conference on Engineering Education, Tehran, Iran, 21–23 November 2017.