Road Map and Principles for Built Environment Sustainability

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The built environment, defined by the facilities and civil infrastructure systems that people use, is the fundamental foundation upon which a society exists, develops, and survives. As the main provider and the life cycle custodian of the built environment, the Architecture, Engineering, and Construction (AEC) industry plays a critical role in determining the quality, integrity, and longevity of this foundation. In the execution of these two roles, provider and custodian, the AEC industry has had a major direct and indirect impact on the natural environment, contributing both directly and indirectly to natural resource depletion and degradation, waste generation and accumulation, and environmental impact and degradation. These impacts are not unique to the AEC industry. Other industries face similar challenges, and for many years, a wide range of constituencies within them have been attempting the implementation of the concept of sustainability within what these industries do, how they do it, and with what as a possible mechanism to slow, reduce, eliminate these impacts, and even restore conditions to a better state. In the pursuit of sustainability, the AEC industry faces challenges posed by the unique attributes and characteristics nature of facilities and civil infrastructure systems, the complexities of the current processes for their delivery and use, and the diverse set of resources required for both their delivery and their use. This paper offers a road map and an initial set of principles to implement built environment sustainability as a starting point for an ongoing, industry-wide dialogue and debate.

Introduction

A diverse range of people and organizations around the world has been promoting the concept of sustainable development, which according to the Brundtland Commission is a way to ensure "... meeting the needs of the present without compromising the ability of future generations to meet their own needs" (*1*). Liverman et al. go beyond this definition, and define "... sustainability to be the indefinite survival of the human species (with a quality of life beyond mere biological survival) through the maintenance of basic life support systems (air, water, land, biota) and the existence of infrastructure and institutions which distribute and protect the components of these systems" (*2*). Within the international community, examples of organizations addressing sustainable development and sustainability include, among others, the World Business Council for Sustainable Development (WBCSD), the World Federation of Engineering Organizations (WFEO), the World Bank, the United Nations, Lead International, and numerous non-governmental organizations (NGOs). More specifically, examples in the United States include (i) organizations in the private and public sectors, ranging from corporate members of the Business Roundtable, and numerous professional and trade associations, through multiple Federal, State, Local Government Agencies, and the Military Services, to NGOs and civic activist groups; (ii) practitioners from the agricultural, manufacturing, and AEC industries; (iii) researchers and educators in the physical, life, and social sciences and in the many disciplines of engineering, architecture, city planning, and others; and (iv) individuals, families, and communities in urban, suburban, and rural settings. Although the convergence of this diverse set of constituencies around sustainability is very positive, the wide diversity and range of perspectives among them has generated numerous definitions, conceptualizations, and frameworks of sustainability, with some of them compatible and some of them in conflict with each other (*3*). In addition, the magnitude and scope of the existing and evolving body of knowledge on sustainable development and sustainability are daunting. Furthermore, an examination of this body of knowledge also reveals that there is no unified theory of sustainability and that sustainability is addressed in multiple forms such as principles, concepts, heuristics, strategies, guidelines, specifications, standards, processes, tools, best practices, lessons learned, and case studies.

However, within this diversity and complexity, there is one area of consensus: The status quo is not sustainable in the long term, and consequently, to achieve sustainability it must be changed. Individuals, communities, and organizations must invest in the development and the implementation of alternative, innovative, and more sustainable strategies, tactics, and mechanisms because they cannot continue indefinitely as they have in the past, doing (i) what they do (i.e., products, goods, or services); (ii) how they do it (i.e., operations, processes, practices, and procedures followed); and (iii) with what (i.e., the resources required to do what they do, and for how they do it—natural, social, and economic capital). Within the resource base, two inextricably related elements are critical to maintain its integrity. The first element is the industrial base, composed of production systems for goods, products, and services. The second element is the built environment, composed of facilities (e.g., building construction, residential construction, and industrial construction) and of civil infrastructure systems (e.g., transportation, energy, water supply, sewage, and communications systems). For any nation in the world, the quality of life of its citizens and its communities and the effectiveness of its public and private sectors organizations are a function of the quality, performance, and sustainability of these two elements.

The industrial base and the built environment provide the fundamental foundation upon which a society exists, develops, and survives. The AEC industry is the main provider and the life cycle custodian of the built environment, and as such, it plays a critical role in determining the quality, integrity, and longevity of this foundation. Worldwide, the AEC industry continuously (i) develops new and increasingly more technologically complex facilities and civil infrastructure systems, in both greenfields and brownfields; (ii) rehabilitates the ones that are deteriorated; (iii) expands, upgrades, and retrofits some that are operational; (iv) recovers and reconstructs those damaged by natural or human-made disasters; (v) remediates serious externalities associated with their construction and operation; (vi) restores, reconstructs,

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and preserves some that have historical or cultural significance; and (vii) deconstructs, decommissions, and demolishes those that have reached the end of their service lives. These types of AEC industry activities result in a significant yearly volume of economic activity. For example, from 1975 to1995, the value of new construction as a percentage of the gross domestic product (GDP) in the United States averaged about 8% (*4*). In addition, these types of AEC industry activities also lead to major direct and indirect impacts to the environment, such as natural resource consumption, degradation, and depletion; waste generation and accumulation; and environmental impact and degradation. These types of impacts have been extensively documented in the literature (e.g., refs *5*−*7*).

As a result, the AEC industry now faces increasingly restrictive environmental conservation and protection laws and regulations; the emergence of international standards such as ISO 14000 series of environmental management standards of the International Standards Organization (*8*); the emergence of national consensus standards such as the Leadership in Energy and Environmental Design (LEED) green building rating system series for sustainable facilities developed by the U.S. Green Building Council (*9*); and substantial pressures from environmental groups such as the Sierra Club (*10*). These pressures are further complicated by the additional challenges imposed by private and public sector owners on designers, constructors, and suppliers of AEC services and products as a result of increasingly constrained availability of economic resources for capital projects. Thus, owners currently demand the application of best practices, such as the ones promoted by the Construction Industry Institute (*11*), toward achieving higher levels of capital project effectiveness and efficiency; of technical and management performance in the delivery and operation of facilities and civil infrastructure systems over their complete life cycle; and of functional and physical performance of the technologies and materials used in them. In addition, owners are paying more attention in their projects to the optimization of resource use, reduction or elimination of waste, enhancement of environmental compatibility, and satisfaction of intra- and inter-generational needs and aspirations of the principal stakeholders in their projects: from policy-makers, regulators, and the general public, to owners, planners, architectural and engineering designers, vendors/suppliers, constructors, and users/operators.

These demands and expectations are driving the AEC industry (a) to define, plan, and design more sustainable facilities and civil infrastructure systems; (b) to procure, construct, commission, operate, and maintain them in more sustainable ways; and (c) to supply more sustainable building technologies, systems, products and materials used within them. Traditional approaches of environmental regulatory compliance or reactive corrective actions have proven to be consistently costly, inefficient, and many times ineffective. In a sustainable approach to facilities and civil infrastructure systems, all decision-makers integrate sustainability, in any of its multiple manifestations (formally, explicitly, systemically, and systematically) within their decision-making processes at all stages of the life cycle of an AEC project, particularly the early funding allocation, planning, and conceptual design phases.

The literature on built environment sustainability is rich, extensive, and diverse. A parametric review of existing literature in this area (*12*) identified general references (e.g., refs *7*, *13*, *14*); models and frameworks (e.g., refs *15*−*17*); heuristics and guidelines (e.g., refs *18*−*20*); assessment and evaluation tools (e.g., refs *21*−*23*); and resource guides (e.g., refs *24*−*26*). However, the challenges posed by the unique attributes and characteristics of facilities and civil infrastructure systems, the complexities of the current processes for their delivery and use, and the diverse set of resources required for both their delivery and use (e.g., labor, equipment, materials, technologies, money, and energy, among others) make the implementation of built environment sustainability a difficult goal.

This paper offers a road map and an initial set of principles for implementation of built environment sustainability. It is based on the empirical findings and insights gained by the author from the following:

(i) Leadership in the education and research program on built environment sustainability over the last 10 yr in the Construction Engineering and Management Program of the School of Civil and Environmental Engineering at the Georgia Institute of Technology (see refs *27* and *28*).

(ii) Active participation in the activities of the Institute for Sustainable Technology and Development (ISTD) and of the Safety, Health, & Environmental Technology Division (SHETD) of the Electro-Optics, Environment, & Materials Laboratory (EOEML) of the Georgia Tech Research Institute (GTRI), particularly the Sustainable Facilities and Infrastructure (SFI) Branch as a research associate (see refs *29*−*32*).

(iii) A concurrent appointment over the last 3 yr with the Army Environmental Policy Institute (AEPI) of the Department of the U.S. Army as a policy analyst and advisor in the area of Army Installations Sustainability—Facilities, Infrastructure, Ranges, and Ecosystems (FIRE) (see refs *33*−*36*).

Within these activities, several questions keep surfacing regularly: What does sustainability mean to the AEC industry, to AEC enterprises, to AEC projects, and to AEC professionals? What are benefits of sustainability for these constituencies, and why should any of them care about it? If sustainability offers benefits, why is it not already a way-of-life within all these constituencies? How can these constituencies overcome these inhibitors and make sustainability happen? The focus of this paper is on providing an initial answer to the last question as an initial starting point for an on-going, industry-wide dialogue and debate, and a baseline for further investigations of more theoretical and quantitative nature.

Global, Industry, and Project Visions on Built Environment Sustainability

Establishing what sustainability is from an AEC industry point of view provides a point of departure for discussing built environment sustainability. Figure 1 shows the five key elements of built environment sustainability, the systems that define their contextual envelope, and the scales within which these elements and this contextual envelope need to be framed.

First and foremost, built environment sustainability is about people; it is about continuously enabling, maintaining, and enhancing the quality of life of people within families, communities, organizations, and society. To achieve this goal, built environment sustainability requires continuously enabling, maintaining, and enhancing four other elements: (i) the quality, integrity, and performance of the built environment, i.e., facilities and civil infrastructure systems; (ii) the quality, integrity, and performance of the industrial base of production systems for products, goods, and services; (iii) the quality, integrity, and health of the natural environment (i.e., air, water, soil, and biota); and (iv) the quality, integrity, and availability of the resource base (i.e., natural, social, and economic capital) and of the built environment and the industrial base. In addition, sustainability requires managing effectively the influences stemming from social, cultural, political, and regulatory systems, from economic and financial systems, and from environmental and ecological systems. These systems define the contextual envelope, within which people, the built environment, the industrial base, the natural environment, and the resource base coexist,

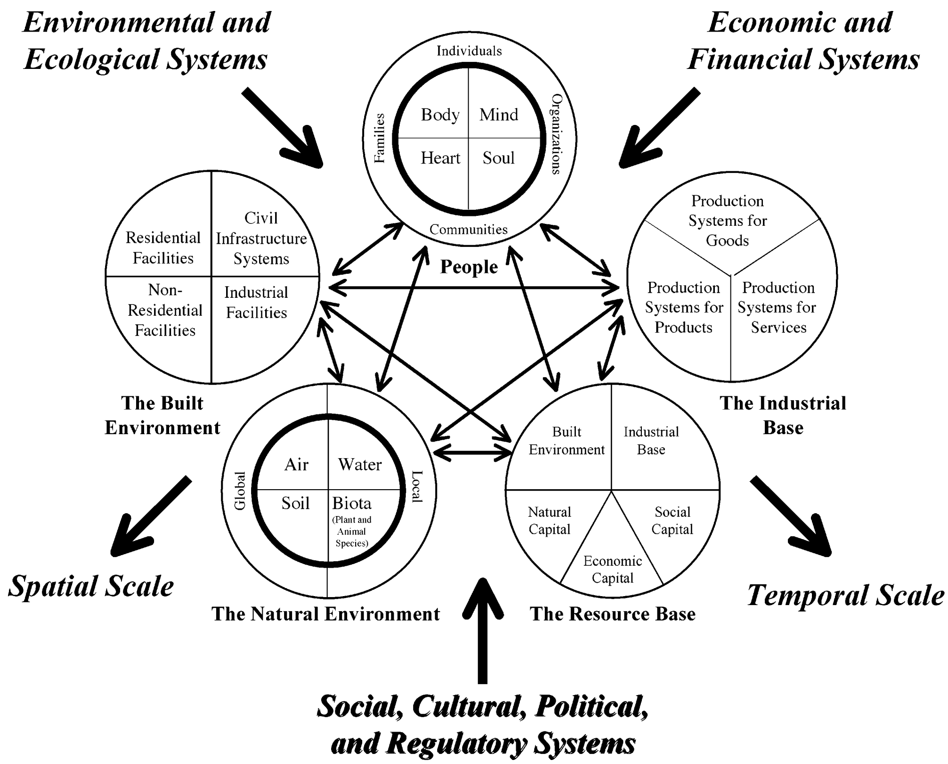

FIGURE 1. Elements, contextual envelope, and spatial and temporal scales of sustainability.

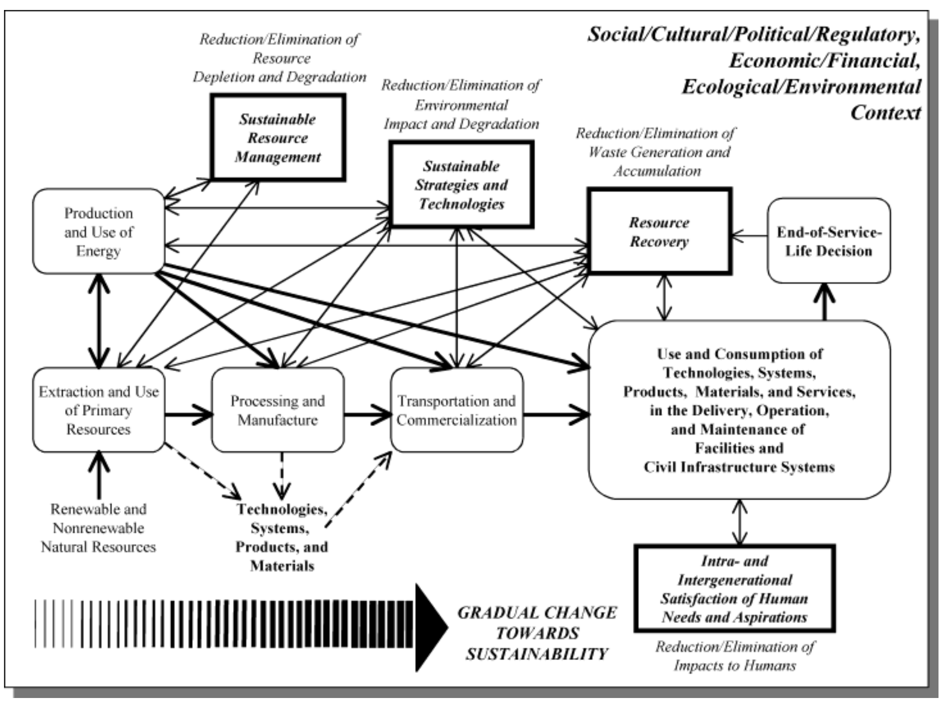

FIGURE 2. Global vision on built environment sustainability.

and they also establish the nature and the complexity of the interrelationships and interdependencies among them. Finally, built environment sustainability requires framing these elements and their contextual envelope within a spatial scale (e.g., from a site, local, state, and regional footprints to a national and global footprints) and a temporal scale, from today (the present) to tomorrow (the future).

The following sections provide an overview of three fundamental visions of built environment sustainability and the requirements for implementation within each one: (a) a global vision; (b) an AEC industry vision; and (c) an AEC project vision. For a more detailed discussion these visions and the requirements they call for, see refs *37* and *38*.

Global Vision of Built Environment Sustainability. A global vision of built environment sustainability calls for the implementation of mechanisms to transform the traditional linear development process followed by the AEC industry into a sustainable closed cyclical system framed within a global context (see Figure 2, which is based on refs *39* and *40*).

The traditional linear development process begins with the extraction and use of primary renewable and nonrenew-

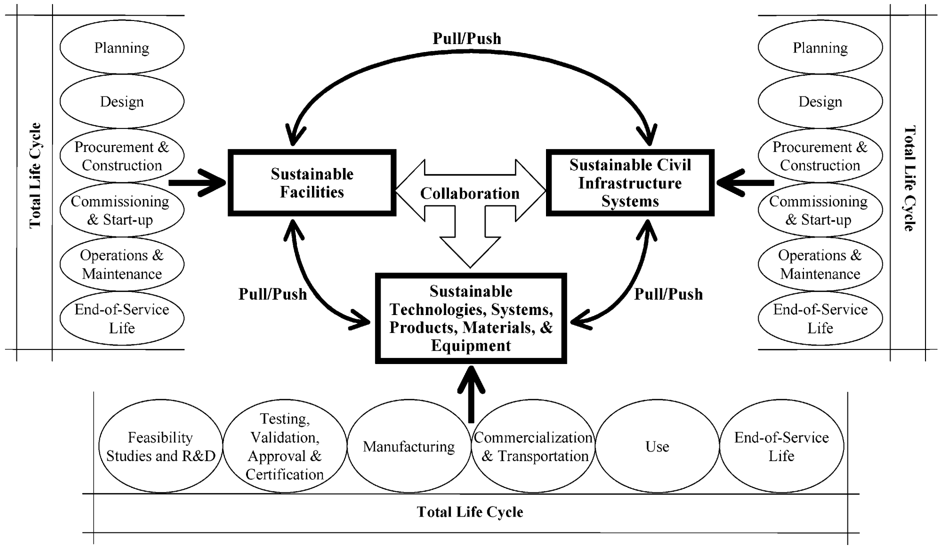

FIGURE 3. AEC industry vision of built environment sustainability.

able natural resources such as air, water, soil, mineral, or biological resources and the production and use of energy. The primary resources and energy become inputs to processing and manufacturing processes with technologies, systems, products, and materials as outputs. These are then commercialized, transported, used, and consumed by the AEC industry in the delivery, operation, and maintenance of facilities and civil infrastructure systems, which, in turn, are rehabilitated, retrofitted, deconstructed, decommissioned, or demolished at the end of their service life. Each stage of this development process uses energy, depletes and degrades the resource base, generates and accumulates waste, and negatively impacts and degrades the environment.

To overcome these negative impacts and achieve built environment sustainability, the AEC industry needs to move toward a sustainable system that operates not as a linear process but rather as a closed cyclical system (*39*, *40*). This system contains several characteristics that are key to achieving sustainability:

(i) The system is framed within a context defined by specific social, cultural, political, and regulatory; the economic and financial; and the ecological and environmental systems.

(ii) Intra- and intergenerational satisfaction of human needs and aspirations are an integral part of the outcomes of the development process.

(iii) Natural resource use is managed proactively through monitoring and control of the extraction of resources from the biosphere in a way that ensures that the supply will always exceed the demand and of the extraction of nonrenewable natural resources from the lithosphere to prevent their total depletion.

(iv) Sustainable strategies and technologies are used proactively within every element of the system to

(a) To promote the development and to enable the use of environmentally conscious alternatives and substitutes to current resources and energy sources used;

(b) To prevent or mitigate environmental impacts before any damage to the environment occurs, such as preservation, pollution prevention, avoidance, monitoring, and technologies for assessment and control; and

(c) To correct environmental impacts when some damage to the environment already has been done, such as remediation or restoration technologies.

(v) Recovery of selected resources and products is actively pursued within every element of the system, through direct reuse of reusable components, remanufacture of reusable elements, reprocessing of recycled materials, and monomer/raw material generation.

(vi) The system is on a gradual and continuous move toward sustainability.

AEC Industry Vision of Built Environment Sustainability. An industry vision of built environment sustainability calls for the implementation of mechanisms to turn the AEC industry into a collaborative pull/push business environment among three distinct groups of stakeholders, as shown in Figure 3.

The traditional business environment within the AEC industry is fragmented, and rarely do the stakeholders within the total life cycle of the delivery and use of facilities, within the total life cycle of the delivery and use of civil infrastructure systems, and within the total life cycle of the delivery and use of technologies, systems, products, materials, and equipment have a collaborative interaction with each other. The tendency is for each one to operate independently of the others.

For built environment sustainability, the converse is required: a collaborative pull/push business environment, within which each of these stakeholders can either pull or push the others toward the development of sustainable facilities, of sustainable civil infrastructure systems, and of sustainable technologies, systems, products, materials, and equipment. An example of the possibilities that this type of collaborative environment offers is the concept that a residence can be a provider of energy rather than a consumer. This concept can pull the development of technologies and materials that can enable this idea to become a reality, while it can push the electric utility providers to capitalize in some way the excess electricity generated by these residences.

General AEC Project Perspective on BES. Finally, achieving the vision of built environment sustainability requires the implementation of mechanisms to expand the scope of what an AEC project encompasses; from the narrow scope of the delivery of the project within a start, a duration, and a finish, in response to a set of project drivers, to a complete life cycle perspective, focused on the evaluation of outcomes of using a delivered facility or civil infrastructure system for the project originator as shown in Figure 4.

In the traditional business environment within the industry, AEC projects are defined and delivered as a linear process that begins with response to a problem, a need, an opportunity, or a desire from an enterprise, an organizational unit, or a functional unit within an enterprise, or from an individual, and ends with the delivery of a completed facility or civil infrastructure system. The focus of this linear

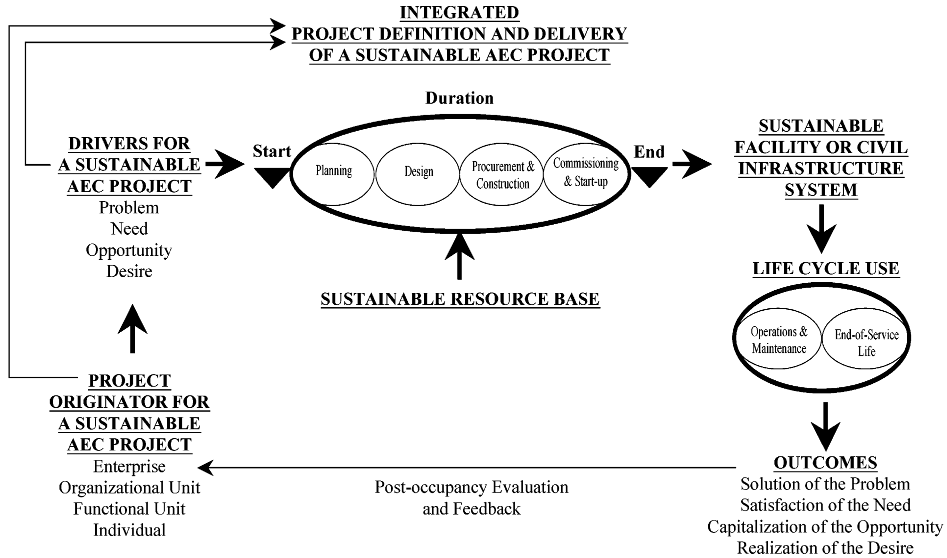

FIGURE 4. AEC project vision of built environment sustainability.

definition and delivery process is on the efficiency and productivity of (i) the management of the planning, the design, the procurement and construction, and the commissioning and start-up processes and (ii) the management and use of the resource base, which can include economic and financial resources; physical resources such as materials, equipment, and tools; human resources such as technical, nontechnical, and administrative personnel; technological resources such as computing, communication, collaboration, and management of information technologies; and miscellaneous other resources such as data/information, knowledge/experience abilities/skills, and technological proficiency.

For built environment sustainability, this scope needs to expand to the following:

(i) Address AEC projects from their complete life cycle perspective, including operations and maintenance, and also the end-of-service life decision;

(ii) Emphasize the use of sustainable resources;

(iii) Monitor and document the outcomes resulting from the use of the facility or civil infrastructure system delivered;

(iv) Provide a post-occupancy evaluation and feedback to the project originator that, depending on what the project driver was, answers the question: Did the project delivered solve the problem? Satisfy the need? Capitalize on the opportunity? Realize the desire?

Road Map for Implementation of Built Environment Sustainability

Although the three visions discussed above provide an initial foundation for implementation of built environment sustainability, they are not enough, and further actions are required at (i) a strategic level; (ii) a tactical level; and (iii) an operational level. Taken as a cohesive whole, these levels provide a road map for implementation of built environment sustainability. For a more detailed discussion of these levels, see refs *41−43*.

Strategic Level Implementation of Built Environment Sustainability. The fundamental approach for enabling and achieving sustainable facilities and civil infrastructure systems at a strategic level is shown in Figure 5. The key to implementation is to frame an AEC project within a contextual envelope which (i) is defined by the requirements and characteristics of the specific facility or civil infrastructure system, the processes followed in its delivery and use, and the resources consumed in its delivery and use and (ii) uses sustainability as a fundamental criterion in making decisions, choosing among various options, or taking actions.

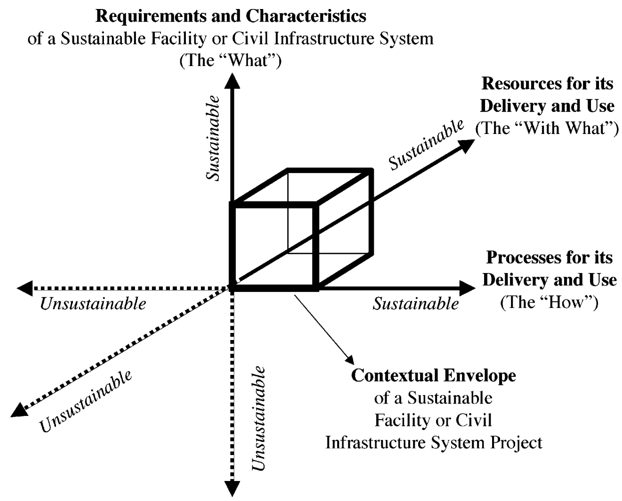

FIGURE 5. Strategic level implementation of built environment sustainability.

The contextual envelope for the project is represented as an (x,y,z) diagram defined by the specific requirements and characteristics of the specific facility or civil infrastructure system "x", its processes "y", and its resources "z", expressed as relative points on an axis, with a scale that spans from what is unsustainable to what is sustainable in each one and with the thresholds that separate the two extremes within each axis as point (0,0,0). The strategy then is to maintain project decisions, choices, and actions within the octant where all three (x,y,z) points are sustainable. While this may be conceptually simple, in reality it is quite complex, and much research is yet to be done to provide clear and absolute definitions of what is sustainable, what is unsustainable, and what is the threshold that separates them. This approach is adapted from research conducted to define an operational framework for sustainability of built environment systems (*38*).

Tactical Level Implementation of Built Environment Sustainability. The fundamental approach for enabling and achieving sustainable facilities and civil infrastructure systems at a tactical level is shown in Figure 6. The key to implementation is to ensure that

(i) The delivery and management systems for an AEC project are sensitive to sustainability and do not inhibit its implementation in any way.

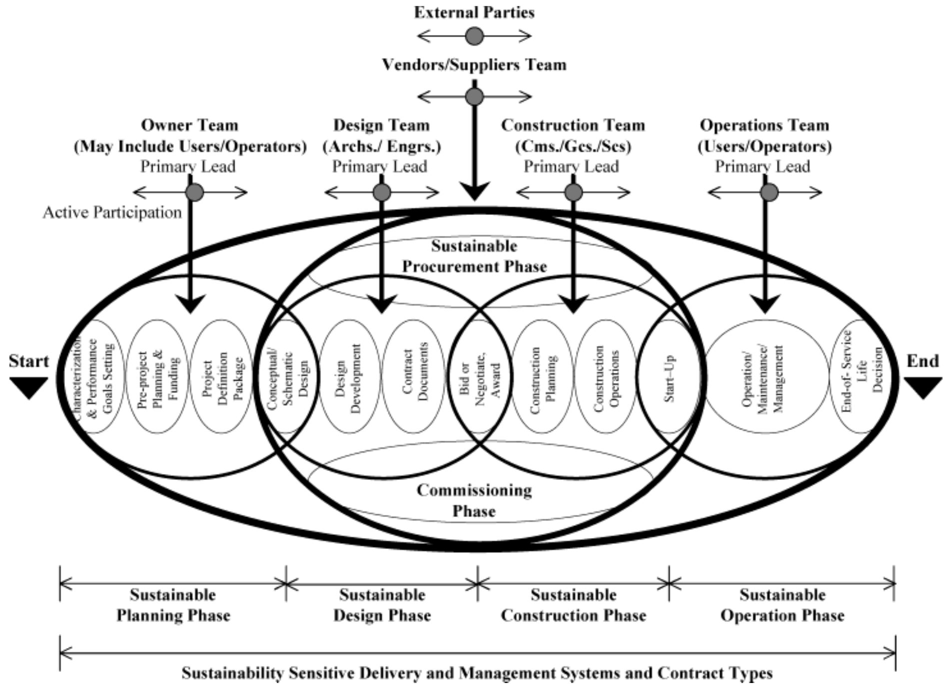

FIGURE 6. Tactical level implementation of built environment sustainability.

(ii) All project stakeholders (i.e., the owner and operations team, the design team, the construction team, vendor and suppliers, and external parties) have a common ground for understanding sustainability principles and concepts; operate as a high-performance team; and use sustainability as a fundamental criterion when making decisions, choosing among various options, or taking actions for the project at each stage of its life cycle.

(iii) Any process, practice, or operating procedure followed within the various phases stage of the project (i.e., the planning phase, the design phase, the construction, procurement, and commissioning phases, and the operations and maintenance phase) provides an entry point for formal and explicit input of sustainability in any of its manifestations.

Each of these phases contributes in different ways to establish the degree, breadth, and depth of sustainability efforts throughout an AEC project. For example, sustainable planning begins with a systemic analysis of the attributes, characteristics, and qualities of a given project from a sustainability perspective in terms of the industry sector represented (real estate development, residential, civil infrastructure, industrial, or building construction) and the type of project (e.g., new construction, rehabilitation, retrofit, etc.) and with a formal and explicit setting of project performance goals. Pre-project planning and funding approval and the development of the project definition package follow, and in some projects, it may also include the conceptual and schematic design for the project. This phase has the greatest potential to influence overall project sustainability at lowest cost. Specific elements considered in this phase include framing of project requirements and characteristics within a sustainability perspective, sustainable site selection, and ensuring the compatibility of project objectives and scope with the constraints of its physical and nonphysical contexts.

Sustainable design begins with the development of the conceptual and schematic design for the project, continuing with detailed design and development of contract documents, and in some cases includes bidding or negotiation and award of the construction contract, which marks the transition into construction. This phase also affords significant opportunities for influencing project sustainability before any construction operations begin on site. Specific elements considered in this phase include sustainable site development, integrated building systems design, energy and water efficiency, sustainable material use, and indoor environmental quality.

Sustainable procurement parallels the design and construction phases and provides the interface with the supply chain that provides all the technologies, systems, products, materials, and equipment specified by designers to physically realize the project. While the nature, levels of performance, and desired attributes of these resources have been fixed by the project design, considerable impact can still result due to the sources of specified materials and how they are brought into the project. Specific elements that should be considered include packaging reduction or elimination, recycled content in materials, waste minimization, and environmental benignness of manufacturer processes.

Sustainable construction includes construction planning, construction operations, and start-up, which marks the transition into the operations phase. Construction is the bridge between concept and reality and offers additional opportunities for increasing sustainability of the project. Specific elements that should be considered include site disturbance, indoor environmental quality, construction recycling and resource reuse, and construction health and safety.

Commissioning is an important phase that ensures that all the building systems and equipment are installed and tested during construction to ensure that their performance is within the parameters desired and specified. Lack of proper commissioning leads to higher operations and maintenance costs as a result of inefficient energy and water use. In addition, poor commissioning has a direct negative impact on the productivity of people working in a facility.

Sustainable operations includes full operation, maintenance, and management of the facility or civil infrastructure system until an end-of-service-life decision is made. Sustainable operations and maintenance involves effective planning and allocation of resources over the operational life of the facility. Specific elements that should be considered include indoor air quality; thermal comfort; light quality; energy, water, and resource conservation; and waste management. Explicit consideration of what happens to the facility

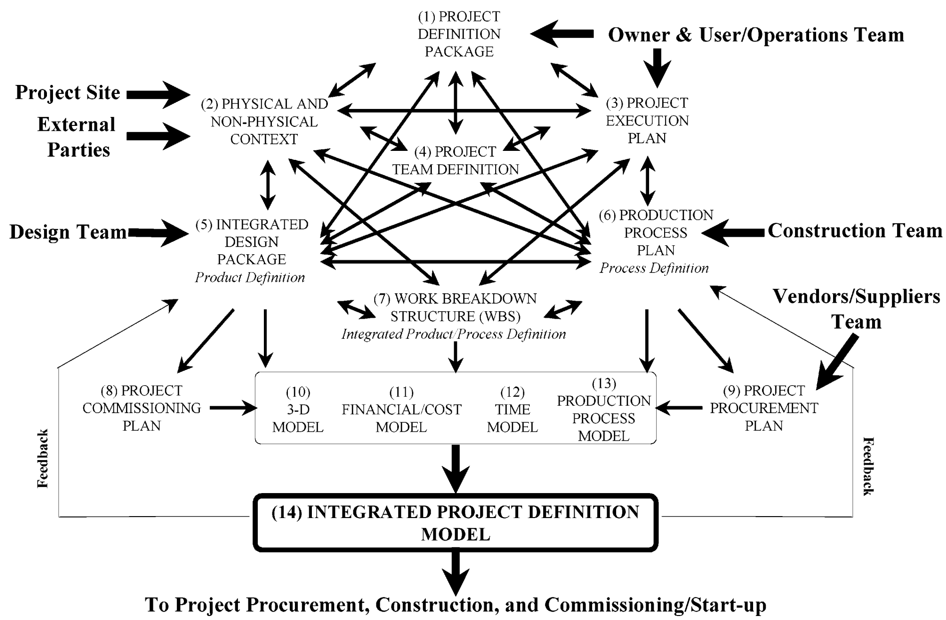

FIGURE 7. Operational level implementation of built environment sustainability: integrated project definition.

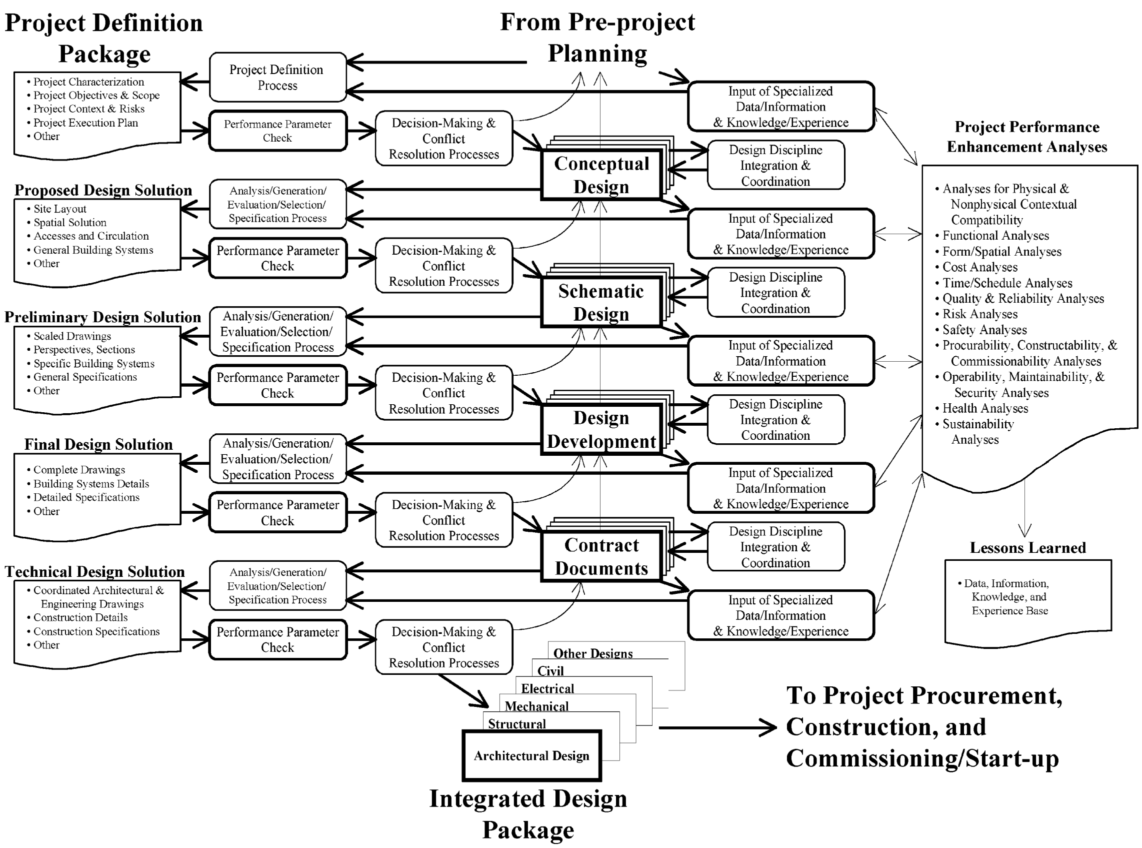

FIGURE 8. Operational level implementation of built environment sustainability: integrated project design.

or civil infrastructure system at the end of its useful life of the facility is important should be considered by all project stakeholders during the project life cycle since decisions, choices, and actions at any project phases can impact actions at this final point of the facility's life. Specific elements that should be considered include disassembly/reuse of components, material recovery/recycling, and site reclamation.

Operational Level Implementation of Built Environment Sustainability. The fundamental approaches for enabling and achieving sustainable facilities and civil infrastructure systems at an operational level are shown in Figures 7 and 8. The key to implementation is to (i) apply an integrated approach to project definition and (ii) apply an integrated approach to project design. Integrated project definition and integrated project design provide multiple entry points for formal and explicit input of sustainability in any of its manifestations within an AEC project.

Integrated Project Definition. As shown in Figure 7, each of the 14 elements that come together as a cohesive whole within an integrated project definition approach contributes in different ways to establish the degree, breadth, and depth of sustainability efforts throughout an AEC project.

The project definition package is the cornerstone of the operational implementation of built environment sustainability. It defines what the project is all about from the owner team and the user-operator team perspectives and includes the following key components:

(i) A project definition process, which includes three phases: formation, in which the aligned owner & user/operator perspective, anchored in the vision, mission, strategic plan, and business plan of the project owner's enterprise, provides a point of departure for the project; communication, which adds the design, construction, procurement, and external parties perspectives; and integration, which develop an integrated and aligned project perspective.

(ii) Seven main project definition steps within the project definition process, which include characterization of the project by industry sector and project type; and identification, definition, and documentation of who the key project stakeholders are, what their principal project goals and objectives are, what the main characteristics of the physical and of the nonphysical contexts of the project are, what the project scope is, what the main project risks are, and what the principal internal and external influences that affect, or can affect, project performance are.

(iii) Formal, explicit, systematic, and systemic identification and documentation of 12 project definition parameters: contextual compatibility and response; functional performance; formal and physical performance; cost performance; time performance; quality and reliability performance; safety performance; risk performance; procurability, constructability, and commissionability performance; operability, maintainability, and security performance; health performance; and sustainability performance.

The physical and nonphysical contexts of the project provide the link between the project and the characteristics of the project site and also, among the project, all external parties and the general business environment. The definition of the physical context includes analyses of geographical location, accessibility, transportation options, surface and subsurface conditions, environmental conditions, existing infrastructure, and surrounding activities or assets. The definition of the nonphysical context includes analyses of policy issues; legal and regulatory issues; applicable codes, standards, and regulations; economic and financial issues; political issues and public relations; community, social, and cultural issues; and industrial and technological issues.

The project execution plan defines in general how a specific AEC project should be executed and provides the link between the project and the construction team. This plan defines the most appropriate delivery system and contract type for the project based on the characterization of unacceptable and prudent reversible risks in the project and on the assessment of their probability, impact, and allocation. It also establishes the overall strategies in the project required (i) to ensure quality of execution, quality of initial conformance, quality of long-term performance, quality of redesign and improvement, and prevention of total or partial failures; (ii) for risk assessment, risk avoidance, risk mitigation, and risk management; and (iii) to ensure the protection of people, property, and the environment from natural and human-caused events and disasters.

Project team definition defines the members of the project team, including all the individuals, functional units, and organizations directly and indirectly involved in the project from the owner team, from the user/operator team, from the design team, from the construction team, from vendors and suppliers, and from any external parties. Furthermore, it also defines a set of common and well-defined goals and objectives for the project; implements partnering development and team building processes; implements project alignment and misalignment elimination processes; establishes a set of acceptable tolerances and team norms within which the team will operate; and implements partnering and team maintenance processes and strong quality leadership on an on-going basis.

The integrated design package defines the design solution for the project from a product definition point of view and provides the link between the project and the design team. The design solution defines how the project responds to each element of the project definition package, specifically:

(i) How the project services and supports the people who will use it, the activities and processes that will take place in it, and the inter-relationships among them;

(ii) How the project addresses the site layout and the spatial solution, and how they perform over time;

(iii) What the technologies, systems, products, materials, and equipment used in the project are, and how they perform over time;

(iv) How the project addresses ease of procurement, construction, and commissioning and start-up;

(v) How the project addresses ease of operations, maintenance, and security;

(vi) How the project ensures the physical health and well-being of the people who will be the project's ultimate users, as a function of indoor air quality, potable water quality, emissions from materials (e.g., paints, carpets, adhesives), lighting, noise pollution, work environment, and comfort;

(vii) How the project eliminates, reduces, or mitigates any type of resource base impacts (i.e., resource consumption and waste generation); eco-system impacts (i.e., environmental impacts to air, water, soil, and biota); and human impacts (i.e., current and future impacts to all project stakeholders).

The production process plan provides the link between the project and the vendors and suppliers in the supply chain. Specifically, this plan defines fabrication and logistics requirements and overall strategies for (i) supply and delivery of all required technologies, systems, products, materials, and equipment; (ii) site installation, testing, and turnover; and (iii) workflow and production unit control.

The work breakdown structure (WBS) defines the various ways in which the work can be broken down in the project from a product and process perspectives. Each type of WBS contains a hierarchy of levels, representing an increasingly detailed description of the project elements. The principal types of WBS include:

(i) General project WBS (i.e., project WBS, contractual WBS, organizational WBS, and resource WBS);

(ii) Specific product-oriented WBS (i.e., functional WBS, building systems/processes WBS, and building components/elements WBS);

(iii) Specific process-oriented WBS (i.e., cost model WBS, time model WBS, and cost control model WBS).

Finally, the project commissioning plan defines how all the building systems and equipment in the project should be commissioned. The project procurement plan defines how all the resources for the project should be procured. The 3D model defines all the three-dimensional spatial data and information of the design solution of the project. The cost/financial model defines the specific parameters required to ensure project performance from a cost point of view, including the financing package; total installed costs (TIC); operations & maintenance (O&M) costs; and life cycle costs (LCC). The time model defines the specific parameters required to ensure project performance from a time point of view, including the cycle times of each of the phases of the life cycle of the project. The production process model defines the parameters of the production process to follow in the field during construction of the project.

Integrated Project Design. Integrated project design contributes in different ways to establish the degree, breadth, and depth of sustainability efforts throughout an AEC project. This process is shown in Figure 8.

The principal elements of integrated project design are

(i) Phased processes for the parallel development, coordination, and integration of design solutions from all the disciplines involved in a given AEC project (e.g., architectural, structural, mechanical, electrical, civil, and others) in increasing levels of detail, from conceptual and schematic design to design development and contract documents;

(ii) Mechanisms to regulate the flow of design data and information from phase to phase and among stakeholder entities as needed, including processes for analysis, generation, evaluation, selection, and specification; decision-making; and conflict resolution;

(iii) Provisions at each phase for a performance parameters check before proceeding to the next design phase;

(iv) Mechanisms for formal, explicit, and systemic input of specialized data, information, knowledge, and experience resulting from project performance enhancement analyses in each of the performance parameter categories;

(v) Capture of lessons learned to contribute to the data, information, knowledge, and experience knowledge base.

Principles of Built Environment Sustainability

Effective implementation and achievement of built environment sustainability begin with visions for sustainability at global, industry, and project levels and continue with a road map for implementation at strategic, tactical, and operational levels. However, to fully achieve built environment sustainability, what is required is the continuous application of specific sustainability principles, concepts, heuristics, strategies, guidelines, specifications, standards, processes, tools, best practices, lessons learned, or case studies within the various processes embedded in the visions and the road map.

There is an extensive body of general knowledge on sustainability. For example, the International Institute for Sustainable Development provides an extensive compilation of sustainable development principles from numerous sources that address three major aspects: environment, economy, and community (*44*). In addition, and as mentioned previously, there is also an extensive body of specific knowledge on built environment sustainability. The key is to adapt and customize this knowledge to the specific reality of an AEC project.

Some selected examples of principles that can be used to implement and achieve built environment sustainability include

(i) The Precautionary Principle, which guides human activities to prevent harm to the environment and to human health (*45*);

(ii) The Earth Charter Principles, which promote respect and care for the community of life, ecological integrity, social and economic justice, and democracy, nonviolence, and peace (*46*);

(iii) The Natural Step System Conditions, which define basic principles for maintaining essential ecological processes and recognizing the importance of meeting human needs worldwide as integral and essential elements of sustainability (*47*);

(iv) The Daly Principles, which address the regenerative and assimilative capacities of natural capital and the rate of depletion of nonrenewable resources (*48*);

(v) The Ceres Principles, which provide a code of environmental conduct for environmental, investor, and advocacy groups working together for a sustainable future (*49*);

(vi) The Bellagio Principles, which serve as guidelines for starting and improving the sustainability assessment process and activities of community groups, nongovernment organizations, corporations, national governments, and international institutions including the choice and design of indicators, their interpretation and communication of the result (*50*);

(vii) The Ahwahnee Principles, which guide the planning and development of urban and suburban communities in a way that they will more successfully serve the needs of those who live and work within them (*51*);

(viii) The Interface Steps to Sustainability, which were created to guide the Interface company in addressing the needs of society and the environment by developing a system of industrial production that decreases their costs and dramatically reduces the burdens placed upon living systems (*52*);

(ix) The Hannover Principles, which assist planners, government officials, designers, and all involved in setting priorities for the built environment and promoting an approach to design that may meet the needs and aspirations of the present without compromising the ability of the planet to sustain an equally supportive future (*53*);

(x) Design through the 12 Principles of Green Engineering, which provide a framework for scientists and engineers to engage in when designing new materials, products, processes, and systems that are benign to human health and the environment (*54*).

Any principle, from any source such as these, can be made operational within any part of the proposed visions and road map for implementation of built environment sustainability by expressing it in terms of (i) specific objectives, (ii) associated measurable goals, and (iii) a detailed execution plan to achieve them. By doing so, each principle provides a metric that can be used for data collection and benchmarking on specific sustainability considerations; a point of reference to assess organizational behavior and practices of AEC organizations; a compass for maintaining an overall vision for built environment sustainability that can be reached incrementally and realistically.

The most important thing to keep in mind is that the journey to built environment sustainability is a long one and that improving the sustainability of facilities and civil infrastructure systems can be achieved one decision, one choice, or one action at a time; one paradigm at a time; one product or one process at a time; phase by phase in the complete life cycle of an AEC project; one AEC program or one AEC project at a time; one AEC enterprise at a time; one AEC industry sector at a time; in a gradual shift to a sustainable future.

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