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Title of Paper: **Sustainability at the Installation Scale: A Comparison of LEED-ND and Systems-Based Sustainability Assessment**

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The United States Department of Defense (DoD) will invest billions of dollars over the next few years in facility and infrastructure systems as part of implementing priorities for Base Realignment and Closure (BRAC) and force transformation at its installations. These investments are anticipated to save significant resources that would otherwise be devoted to the long term operations and maintenance of unnecessary facilities. Part of BRAC planning involves evaluating how investment in sustainability Best Available Technologies and Strategies (BATS) may maintain or increase the ability to deliver mission requirements and readiness while further reducing costs, resource use, and environmental impacts. Specifically, DoD is interested in understanding how current approaches to sustainability assessment can be applied at the scale of military installations to identify and prioritize BATS for investment of limited resources.

Existing techniques such as Leadership in Energy and Environmental Design (LEED)-based planning and design and Life Cycle Costing (LCC) analysis have contributed to the development of more sustainable facility and infrastructure systems on DoD installations, but they do not necessarily result in installations that are truly sustainable. Systems-based sustainability assessment represents an alternative approach based on deviations from "ideal sustainability" that has been successfully applied at the scale of individual facilities to identify and prioritize BATS. This paper describes a recent effort to scale the SBSAT approach to apply to installation-level analysis, including individual facilities and operations, site, and infrastructure systems. The paper compares systems-based analysis to LEED-based analysis and draws conclusions about the utility of each approach in the context of installation sustainability planning.

Introduction

Sustainable construction is becoming more mainstream in the public sector in the United States in response to a variety of policy directives, many of which are being driven by an increased awareness of the vulnerability posed by diminishing resources and significant reliance on foreign sources of energy. These changes are happening for obvious reasons: in the U.S., buildings consume 68% of all electricity and 60% of non-food/fuel raw materials used, and generate 40% of non-industrial solid waste and 35% of carbon dioxide emissions (OFEE 2003, p. 5). Concurrent with these trends, the U.S. Department of Defense (DoD) will be investing billions of dollars over the next few years in facility and infrastructure systems as part of implementing priorities for Base Realignment and Closure (BRAC) and force transformation. These investments are anticipated to save significant resources that would otherwise be devoted to the long-term operations and maintenance of unnecessary facilities at DoD installations, which range from small outposts to military cities that may house up to 100,000 people and provide work facilities, training ranges, housing, and infrastructure systems to support all activities associated with base operations. DoD utilizes the largest variety and quantity of built space of all federal agencies and the Department of the Army leads the DoD in real estate with over half of the square footage, making the Army the largest federal building owner and manager (OFEE 2003). The Army Real Estate Portfolio includes over 150,000 buildings covering 770 million square feet (ACSIM 2006). The Army has adopted a *Strategy for the Environment*[1] based on the principles of sustainability, and the United States Green Building Council's (USGBC) LEED Silver rating is now the standard for all new construction beginning in 2008.[2] Furthermore, the Army must also meet the energy reduction goals of the Energy Policy Act of 2005 (EPAct) and the Energy Independence and Security Act (EISA).[3] These policies have many implications for the procurement, construction and use of facilities, including the attainment of LEED credits for new construction. However, the Army has not yet established a reference standard for sustainability analysis and planning at an installation scale. It is presently evaluating multiple approaches, including LEED for Neighborhood Development, LEED Portfolio, and other non-LEED-based approaches[4].

Research suggests that sustainable design and development concepts will further increase cost savings, improve resource efficiencies, and reduce environmental impacts from facility investments at military installations. Yet with many installations gaining operational units with significant requirements for built and natural infrastructure, it is a challenge to accommodate these new requirements without compromising the long-term sustainability of local installations as well as quality of life for the regional context in which those installations exist. How can facility and infrastructure investment decisions be made that will meet or exceed DoD's requirements while maintaining and enhancing the natural resource bases and ecosystems on which society depends? A larger perspective, including not just individual facility projects but also the natural and man-made infrastructure systems that connect them, is required to meet this goal.

Research Background and Objectives

An entire field of specialized knowledge has developed to implement sustainable design and development, including professional organizations, trade journals, academic courses and research, product branding, and professional certification programs. A substantial pool of decision support tools has emerged, and the challenges associated with finding the right tool for the job are significant (Keysar & Pearce 2007). For instance, DoD seeks to utilize lifecycle cost (LCC) analysis to guide investment decisions for facilities and infrastructure projects in order to reduce total ownership costs, including energy costs and environmental impacts. Additional policy encourages the use of the Leadership in Energy and Environmental Design (LEED) series of green building and neighborhood rating systems as part of the planning and delivery processes for built

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[1] The *Army Strategy for the Environment* is available at: http://www.sustainability.army.mil
[2] January 2006 Memorandum*: Sustainable Design and Development Policy Update – SPiRiT to LEED Transition;* written by Joseph A. Whitaker, Deputy Assistant Secretary of the Army (Installations and Housing) Office of the Assistant Secretary of the Army (Installations and Environment)
[3] 42 USC 15801, Public Law 109-58
[4] Information on all LEED Standards is available online at http://www.usgbc.org.

facilities. LEED is the predominant standard guiding green building in both the public and private sectors in the United States, and has growing acceptance worldwide as a tool to promote the planning and delivery of greener, more sustainable facilities. However, there are acknowledged gaps between a LEED certified building and a truly sustainable building, and existing LEED systems do not always take into account key contextual factors that contribute to a facility's sustainability (e.g., Pearce & Fischer 2001; Scharl 2005; Fowler & Rauch 2006).

The goal of this project was to determine the potential utility of the Systems-Based Sustainability Assessment Technique in identifying effective sustainability improvement opportunities for installation-scale master planning in addition to LEED and LCC-based analysis. This effort (Pearce 2008) was part of a larger initiative reviewing the potential of existing techniques and strategies to evaluate alternative development scenarios and identify BATS to improve the sustainability of installations. The study described in this paper was based on earlier work that demonstrated a process for systems-based sustainability analysis to support the sustainable design and development of built facilities at Army installations (Pearce & Fischer 2001). The method used in this earlier study was developed as a way to systematically identify the impacts of built facilities that influence its sustainability, in three major categories: Stakeholder Satisfaction, Resource Base Impacts, and Ecosystem Impacts (Pearce 1999). Using the method of systems-based sustainability analysis, gaps were identified between three different possible configurations of the facility: the status quo state, the proposed retrofit state developed using LEED for New Construction (USGBC 2001), and the ideal sustainability state. The prior study found that while using LEED-NC as a basis for developing design recommendations helps to identify the majority of BATS that apply to commercial buildings, there was still a gap between the resulting design and a truly sustainable design for a project. The systems-based sustainability analysis provided a method for systematically identifying these gaps and identifying not only what areas can be improved with presently-available technologies and strategies, but also what areas need new technologies and strategies that do not yet exist.

Systems-Based Sustainability Assessment

At a facility scale, systems-based sustainability assessment begins by defining a boundary for the system to be analyzed, which is typically the legal boundary of the site and includes both the building footprint and its associated grounds and parking areas. This boundary and the system it encloses are indicated in the systems models by the shaded circle in the center of the diagrams (Figure 1). The goal of systems modeling is to systematically identify the facility's impacts to resource bases and ecosystems *outside* the system boundary (i.e., extra-system impacts) and *inside* the system boundary (i.e., intra-system impacts) for each system state, so that the system states can be compared in terms of how well they meet sustainability requirements. At the scale of analysis of individual facilities, impacts *within* the system boundary are assumed to be negligible for most facility projects.[5]

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[5] Except for source or sink systems such as landfills or sites from which significant resources are extracted, intra-system impacts can be considered negligible at the facility scale under the assumption that stakeholders intend to maintain site assets at steady state during the facility life cycle and significant ecological assets are not included within the system boundary (or are deliberately isolated if the intention is to preserve them). This is not necessarily the case when conducting analysis at a larger scale. Destruction or degradation of ecological assets as part of facility construction may be omitted under this assumption, and should be considered separately if significant assets are threatened by the project. Flows of matter and energy required to maintain steady state are covered under Extra-

To identify impacts caused by the facility, potential flows of matter and energy are identified for each of the system states. At this phase in the planning and design of project scenarios, flows can be identified only at a conceptual level, and determination of actual quantities and specific sources or sinks is impossible. Therefore, detailed calculation of specific impacts may not be possible due to lack of data. However, the objectives of the process (comparison of system states and identifying opportunities for improving sustainability) can still be accomplished by looking at likely *differences* across system states, and adequate information is typically available to identify these differences. These differences are identified from profiles developed for each system state, which list likely flow types, sources and/or sinks, quantities (expressed in relative terms with respect to the status quo model), and likely impacts caused by the generation or absorption of flow by source or sink systems. Each system state is represented by at least two snapshots in time: net impacts resulting from construction, and one unit of time (typically a year) during steady state operations and maintenance. The ideal sustainability state is portrayed in profile not by specific *quantity* of flow, but rather by noting that all impacts resulting from flows must equal zero, i.e., there must be either: a) no negative impacts to resource bases or ecosystems that are not exactly offset or exceeded by positive impacts, or b) no negative impacts at all associated with each flow.

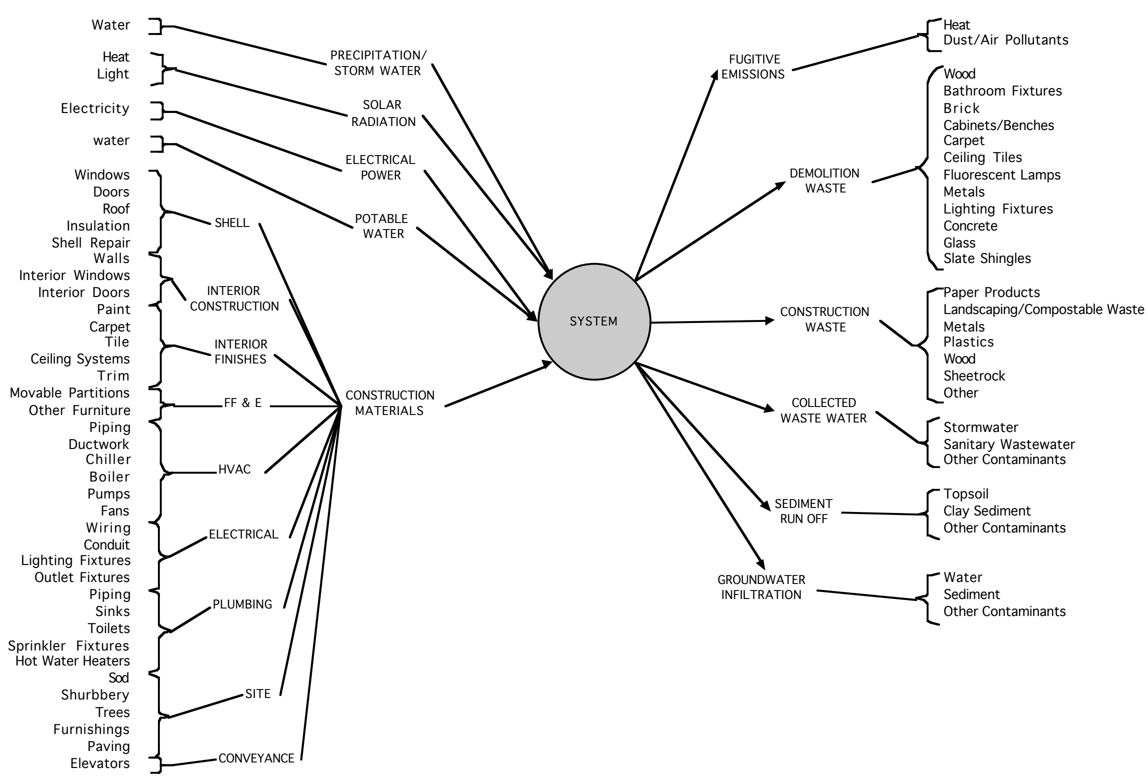

Figure 1: Status Quo Systems Model for Construction (Pearce & Fischer 2001)

Gap analysis involves comparing the likely impacts for each flow type against the corresponding impacts for other system states. For each flow, the impact in the ideal sustainability state is set to

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system Impacts. While synergies among flows are possible on site (e.g., harvesting rainwater for use on-site instead of importing potable water; use of graywater on-site rather than exporting to disposal), they are typically designed in such a way as to remain steady state over the design life of the facility.

zero, and the likely impacts from other states are plotted with respect to that goal. All flows for which the best practice state has less than sustainable, negative impacts represent potential sustainability improvement opportunities. To identify specific ways to bridge these gaps, the analysis must identify what are the *drivers* of negative impacts that prevent the best practice state from meeting the requirements of the ideal sustainability state. This process can result in a complex web of connections linking user functional requirements with the building components that provide them and the affiliate systems that provide the matter and energy needed to construct and operate those building components. These impact chains can be constructed for each of the major groups of unsustainable flows associated with a project to pinpoint where interventions could be made that would reduce, eliminate, or offset any negative impacts of the best practice state.

Having identified specific opportunities to improve sustainability in the form of impact chains explaining the causes of negative impacts, the next step is to seek out ways to reduce, eliminate, or offset negative impacts associated with a project's best practice state. This process involves reviewing the knowledge base of existing BATS for sustainable facilities to search for matches for each opportunity. For each opportunity, potential applicable BATS are identified that might improve the sustainability performance of the resulting facility, i.e., reduce some negative impact caused by the facility as identified in the profiles. Figure 2 illustrates a typology of eight different strategies for minimizing, eliminating, or offsetting negative impacts associated with specific impact chains connected to the facility system.

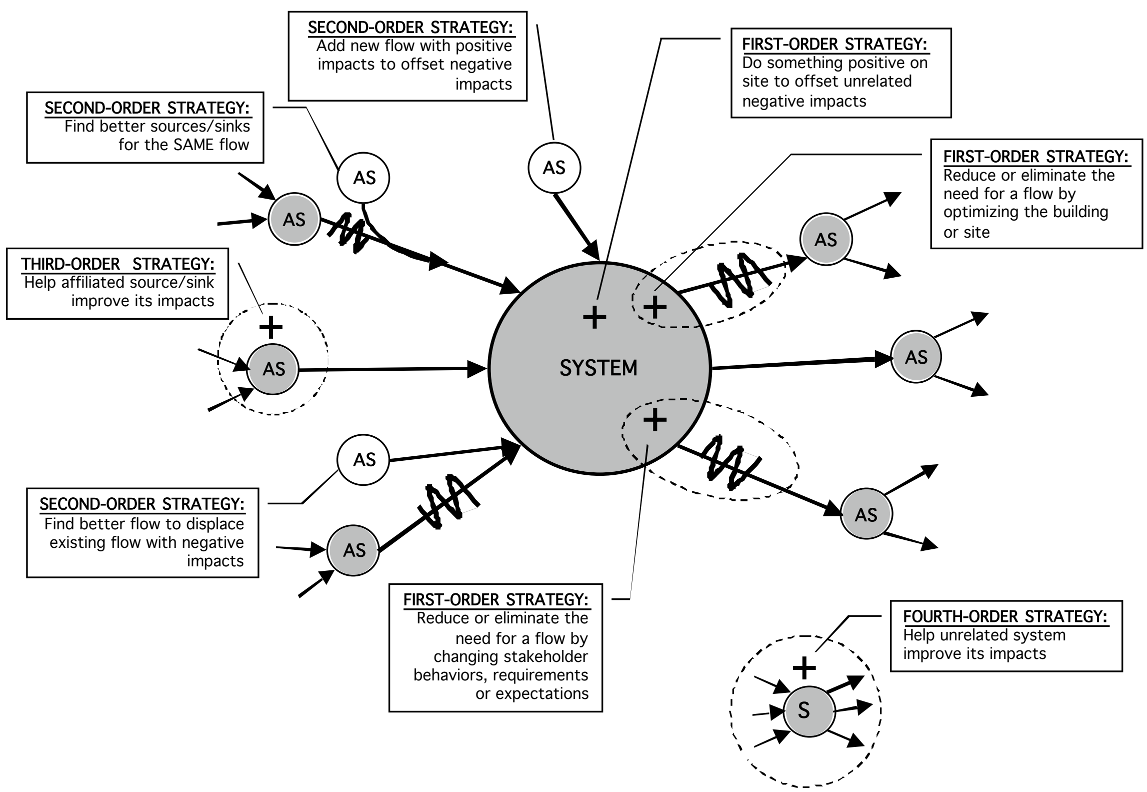

Figure 2: The Spectrum of Strategies for Improving Facility Sustainability (Pearce 2002)

For each impact chain, the search for strategies starts by seeking first-order strategies that would reduce the impacts of the chain to zero. If no BATS are found that are first-order strategies, then the search proceeds on through second-, third-, and fourth-order strategies until a solution is found that can reduce the impacts of the chain to zero. For cases in which no higher-order strategies are available to reduce impacts to zero, the lack of higher-order strategies represents missing or yet-to-be-developed BATS that are noted as items for the research agenda. Each strategy, while having some effect to improve the impact of the target flow, can also have one or more side effects that cause negative impacts with respect to other flows. Consideration of these tradeoffs is ultimately part of the BATS evaluation and prioritization process. BATS can also be further evaluated in terms of feasibility, costs, and benefits to determine implementation priorities.

After reviewing the pool of existing sustainable facility BATS, some sustainability improvement opportunities often exist for which there are no BATS that could reduce negative resource base and ecosystem impacts to zero while maintaining stakeholder satisfaction. For these opportunities, functional descriptions can be developed to describe performance requirements for new technologies and strategies that should be developed to fill these gaps. These performance requirements can be expressed as performance-based specifications for research and development of new technologies and strategies that are needed to achieve true sustainability for built facilities. Together, these performance-based specifications comprise a research and development agenda for new sustainable facilities technologies and strategies that can improve the sustainability of future projects (Pearce & Fischer 2001).

Installation-Scale Sustainability Assessment

While much of the process for systems-based sustainability analysis remains the same between single facility applications and whole installation applications, key changes are necessary to capture essential information that is relevant at this larger scale of planning. From the standpoint of a flow model for an entire installation, one decision/budget cycle (typically one year) is likely to include a variety of different types of projects, including new construction, renovations, infrastructure development, demolition, and remediation, along with all impacts associated with normal operations and maintenance of existing facilities. Accordingly, a flow model for an installation does not require discrete construction and O&M phases as does the individual facility, since the metabolism of the installation incorporates both these phases simultaneously for the multitude of facilities on site that exist at different phases of their own life cycle. Figure 3 shows the revised systems flow model for installation-scale analysis. To facilitate inventory of flows and maximize compatibility with the decision processes used at the installation scale, the system itself is now represented not as a black box which pulls in inputs and pushes out outputs. Instead, the system is represented as a set of generic activities[6] that represent major subsystem types within the scope of master planning analysis (Figure 4).

Intra-system impacts caused by a facility system are felt *within* the bounds of the system or subsystem itself. These impacts are reflected in changes in the quantity and quality of the ecosystems and resource bases on site. From a perspective outside the system, facility systems can add to, maintain as constant, or deplete their initial on-site quantities of resources or ecosystems (Yeang 1995). In terms of the quality of on-site ecosystems and resource bases, facility systems can have intra-system impacts when resources within the boundary of the system are consumed by other entities within the system. In this case, the term *consume* means increasing the entropy of a re-

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[6] The definition of these activities is based on analyst knowledge of typical installation project scopes at a fairly coarse resolution to establish a process and proof of concept. Pending demonstration of the utility of this approach, future research could easily develop activities at a finer resolution to more accurately represent installation-specific projects and activities and incorporate context-specific features as part of subsystem behavior.

source, thus reducing its utility for further use. No matter or energy may actually cross the system boundary in the case of intra-system resource use, but impacts to on-site resource bases and ecosystems can exist nonetheless.

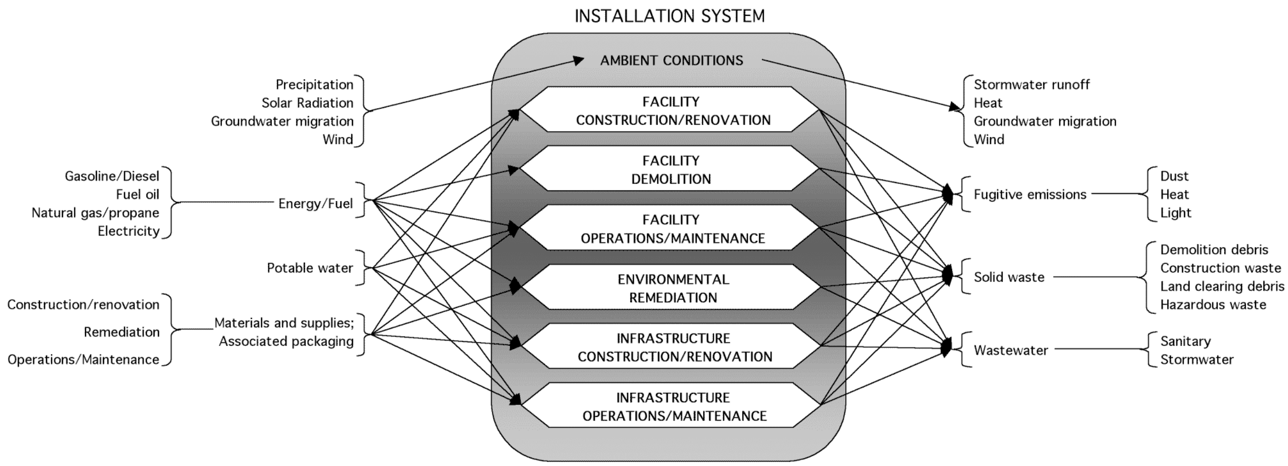

Figure 3: Installation Scale Flow Model (Pearce 2008)

In the case of throughput facilities, the main drivers of negative intra-system impact are the destruction or displacement of on-site ecosystems by the system stakeholders and their structures. For example, an owner may decide to install a paved parking lot in an area currently occupied by an ecosystem, destroying vegetation and displacing fauna during construction, and causing negative impacts to groundwater from stormwater runoff after the lot is installed. This action on the part of the owner will have negative intra-system ecosystem impacts. To offset these impacts, the owner could attempt to restore an ecosystem on another part of the site, or try to mitigate the negative impacts of the paved area by using porous paving material to reduce runoff.

For source facilities, the main driver of negative intra-system impacts is the consumption or excessive export of on-site resource bases. For example, a source system such as a logging facility may impact its intra-system resource base by actively cutting trees and exporting them from the site at a rate faster than they can be restored (Goodland 1992). This loss is reflected in the status of the on-site resource base by the fact that there are fewer remaining trees after logging has taken place. It has implications not only for future availability of trees on the site, but also for the capacity of the site's ecosystems to perform load-bearing services to other systems, such as absorbing rainfall and recycling it into the ground to recharge aquifers (ibid.). Instead of absorbing the rainfall, a more likely possibility is that the rain will run off the site to local streams, carrying with it precious topsoil, clogging the stream courses, and creating a situation of even further degradation—a classic example of a reinforcing feedback situation (Hardin 1993).

Likewise, resource base impacts are often severe for sink systems. For example, performing a mass/energy balance on a landfill facility system shows that significant quantities of matter accumulate within the facility system over time (Tchobanoglous et al. 1993). Since the typical landfill does not have any mechanism for reducing the entropy of the waste deposited within it, continued influxes of high-entropy waste accumulate within the system and eventually overwhelm the capacity of the system to absorb more input (ibid.). If, however, a viable method was developed to reduce the entropy of the waste stored in landfills, such systems might go from being sink systems to source systems, reflecting an increased demand for the matter and potential energy accumulated in the system. This example illustrates a major subvariable of significance: the utility of existing or accumulated resources within the system, which is itself a function of the availability of systems to render matter and energy useful for meeting human needs.

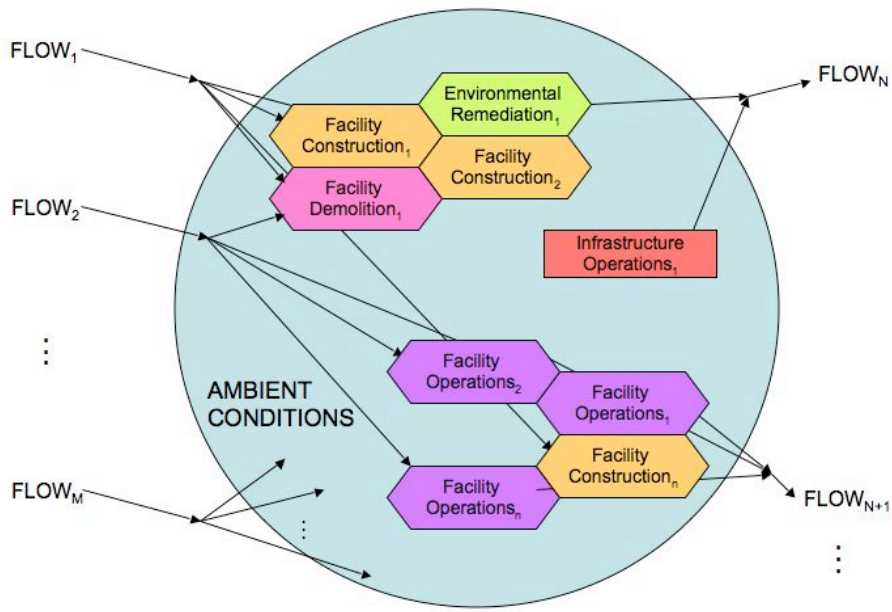

Figure 4: Installation System Model (Pearce 2008)

Intra-system impacts are felt within the facility system as increases or decreases in the capacities of baseline ecosystems and resource bases to generate or absorb flows of matter and energy. By definition, they are most significant for source and sink facility systems, and less significant for throughput systems. In evaluating the impacts of a facility system to on-site ecosystems and resource bases, the objective is to calculate the differences between some baseline and the current or predicted post-action state. Intra-system impacts are a function of two principal variables: 1) change in ecosystems or resource bases within the system; and 2) significance of that change, in the context of the source/sink system.

Each of these variables can be broken down further into measurable factors that will facilitate evaluation of the Resource Base Impact and Ecosystem Impact parameters of sustainability. Using this approach, object-oriented modeling can be used to approximate the systems behavior of the installation, itself a set of subsystems, each of whose behavior is generically defined at an object level. While this object-oriented approach does not capture emergent behavior resulting from interactions among subsystems, it provides a basic analytical framework for inventorying and tracking the impacts the installation is likely to exhibit as a whole[7]. System attributes that are known to exhibit emergence (such as cumulative ecosystem degradation due to halo effects and fragmentation from human activities) can then be modeled separately using large-scale models designed specifically for this purpose.

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[7] This first generation modeling approach could also be used as a foundation for future research using agent-based modeling approaches that are designed specifically to capture emergent properties of systems.

Conclusions

The previous study at a facility scale identified two main types of impacts caused by the built environment that were not addressed by LEED-NC. These impacts were (Pearce & Fischer 2001):

- Unavoidable impacts of any facility project, such as the impacts associated with manufacturing products and transporting them to the project site, or the impacts associated with disposal of waste, even if that disposal involves recycling
- Unconsidered impacts from categories that LEED does not explicitly consider, such as most of the impacts associated with ongoing operations and maintenance of the facility

Within these larger categories, the kinds of impacts not addressed by LEED-NC at the facility scale included impacts due to import of new products to the system, arising from the inevitable manufacture and transport impacts of those products; impacts due to unavoidable export of waste from the site, including transport, recovery, and storage impacts; impacts from fugitive or unintended emissions, i.e., from a "leaky system"; impacts associated with importing potable water that originates outside the system; impacts associated with large-scale wastewater treatment using current best practices; impacts of landscape disturbance; and impacts associated with electrical power generation using current practices.

These unaddressed impacts represented opportunities to improve the sustainability of the project, and the recommendations of BATS generated in the earlier study specifically addressed them. In the current project, expansion of the scale of analysis along with the ongoing evolution of the LEED rating system into new form in the LEED for Neighborhood Development tool has led to credits and LEED-based recommendations that begin to address some of these prior gaps, most especially those associated with infrastructure systems providing critical services for individual facilities. While LEED-ND does not address *all* of the gaps identified in the previous study, it does take significant steps in the right direction to begin to do so. Moreover, in considering the relative effectiveness of LEED-based solution generation vs. SBSAT-based solution generation for application at other installations, this study supported previous findings that use of LEED-based analysis together with systems-based analysis can result in more recommendations than either approach used independently. The complementary aspects of the two techniques may help to identify BATS missed by one or the other.

The LEED standard does not purport to be comprehensive. In fact, the existence of Innovation credits for each of the LEED rating systems explicitly acknowledges that additional opportunities may be presented on projects that go beyond what the standard includes. In contrast, the SBSAT-based analysis, if undertaken with sufficient data reflecting the behavior of the installation or facility, provides a comprehensive and exhaustive way to inventory at least the ways in which the system impacts its context, and to a large extent the way individual projects impact the state of on-site resource bases and ecosystems as well. Incorporating better models of intra-system behavior and emergent properties within the system itself could lead to a modeling approach that at least can comprehensively identify all the aspects of the system that must be improved to achieve true sustainability.

Nevertheless, application of the SBSAT method to any level of detail requires significant data inputs that may or may not be widely available. The approach employed in this study focused instead on identifying major *categories* of likely flows and impacts that would be typical of an Army installation, then systematically generating possible recommendations using the framework established in the systems-based model. This approximated approach did provide sufficient basis to develop a wide variety of recommendations beyond the LEED-based approach. As such, it can be used in this abbreviated form to complement the LEED-based analysis when targeting higher levels of sustainability performance.

Areas for Further Investigation

The generic systems model described in previous parts of this report provides sufficient resolution to identify large-scale principles that could be applied to increase installation sustainability overall. However, it is defined at a coarse granularity that does not provide much assistance in screening best practices that might be relevant for specific installation projects. Several aspects of the model could benefit from further investigation to address this problem.

One approach to address these shortcomings is to specify additional detail for the identified objects based on the context and attributes of the installation being investigated. For instance, if the source of water supplied to the installation is known, then the model can be customized to specify this particular source. Additional contextual heuristics can be derived from local climate, codes, and building practices to further customize both the types and sources/sinks of flows used in the generic models. These heuristics can also be used to screen candidate practices that might be recommended as an outcome of model application. For instance, a climate-specific feasibility heuristic is that evaporative cooling is effective in arid climates, and ineffective in humid climates.

A second approach is to increase the resolution of the generic set of objects to include multiple sub-types for each object based on standard facility prototypes established and commonly used by the services. Prototype designs have been developed and applied for facility types ranging from military family housing[8] to air traffic control towers[9]. Developing a set of sub-types to match the prototypes of the most common facilities could further increase the specificity of the model. Considerable additional detail could also be added by further defining behaviors of subsystem objects with respect to intra-system impacts and cross-boundary flows. These behaviors could be carefully examined for potential synergies if defined at a greater level of specificity for a particular installation. As with all modeling exercises, finding the best balance between model specificity (with increased cost of modeling effort) and applicability of outcomes (with less specific results that may or may not be appropriate for a specific situation) is a challenge.

There is a strong need to identify a larger set of BATS for future efforts. The directed search tactic used in this study to identify candidate BATS for Fort Belvoir resulted in a set of recommendations, which, while certainly not comprehensive, is at least representative of current practices that could be applied to improve installation sustainability. A more thorough investigation of all available BATS should be an ongoing effort to ensure that emerging technologies and practices are captured. Consistent representation of BATS information in a central repository would facilitate consideration and retrieval of applicable BATS for future analysis.

Finally, the proof of concept approach used here relied on separate conceptualizations to capture emergent properties at the installation scale on top of the behavior of individual subsystems. Future efforts can begin to integrate these properties into object-oriented models using agent-based

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[8] See, for example, http://www.hq.usace.army.mil/cepa/pubs/feb02/story15.htm

[9] One such prototype developed by the US Army Corps of Engineers is described in Final Report ADA148840, US Army Construction Engineering & Research Laboratory.

modeling techniques. Agent-based modeling uses simulations of autonomous agents operating on the basis of self-interest to evaluate the effects of the interactions of multiple agents on the performance of the encompassing system as a whole. Computer-based simulation of installation sustainability using this technique could add considerable insight into the overall performance of various scenarios.

References

Fowler, K.M. and Rauch, E.M. (2006). "Sustainable Building Rating Systems Summary," Pacific Northwest National Laboratory, Seattle, WA. Completed for the General Services Administration under Contract DC-AC05-76RL061830.

Goodland, R. (1992). "The Case that the World has Reached Limits," in Goodland, Robert, et al., eds., *Population, Technology, and Lifestyle - The Transition to Sustainability*. Island Press, Washington, DC, 3-22.

Hardin, G. (1993). Living Within Limits: Ecology, Economics, and Population Taboos. Oxford Press, New York, NY.

Keysar, E. and Pearce, A.R. (2007). "Decision Support Tools for Green Building: Facilitating Selection Among New Adopters on Public Sector Projects," *Journal of Green Building*, 2(3), 153-171.

OFEE (Office of the Federal Environmental Executive). (2003). *The Federal Commitment to Green Building: Experiences and Expectations*, Office of the Federal Environmental Executive, Washington, DC. Available online at: http://ofee.gov/sb/fgb.html.

Pearce, A.R. (1999). *Increasing the Sustainability of the Built Environment: A Metric and Process for Prioritizing Improvement Opportunities.* Ph.D. Dissertation, School of Civil & Environmental Engineering, Georgia Institute of Technology, Atlanta, GA.

Pearce, A.R. (2002). " Resource Allocation and Problem Prioritization for Sustainable Military Facilities, Infrastructure, and Installations," *Proceedings, National Defense Industries Association Conference*, Charleston, SC, March 25-28.

Pearce, A.R. (2008). *Systems-Based Sustainability Analysis at the Installation Scale: Proof of Concept and Demonstration at Fort Belvoir.* National Defense Center for Environmental Excellence, Concurrent Technologies Corporation, Inc., Washington, DC.

Pearce, A.R., and Fischer, C.L.J. (2001). *Systems-Based Sustainability Analysis of Building 170, Ft. McPherson, Atlanta, GA.* Summary analysis report to the Army Environmental Policy Institute, Atlanta, GA, May.

Scharl, J.A. (2005). "Sustainable Design and Development," Presentation to the 2006 Installation Management Institute, Office of the Assistant Chief of Staff for Installation Management, January 2005.

Tchobanoglous, G., Theisen, H., and Vigil, S. (1993). *Integrated Solid Waste Management: Engineering Principles and Management Issues*. McGraw-Hill, New York, NY.

USGBC – U.S. Green Building Council. (2001). *Leadership in Energy & Environmental Design – New Construction Reference Guide*. U.S. Green Building Council, Washington, DC.

Yeang, K.P. (1995). *Designing With Nature*. McGraw Hill, New York, NY.