DECISION SUPPORT TOOLS FOR GREEN BUILDING: FACILITATING SELECTION AMONG NEW ADOPTERS ON PUBLIC SECTOR PROJECTS

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ABSTRACT

Green building is becoming more mainstream in the public sector, especially in federal agencies such as the U.S. Department of Defense, in a large part due to federal policies requiring more sustainable outcomes in the design and construction of public sector projects. These policies challenge contracted design professionals by adding new demands to a process already constrained by limited budgets, multiple objectives, and short time frames. The purpose of this research is twofold: (a) to inventory decision support tools available to aid the green design process, and (b) to investigate approaches for organizing these tools to facilitate tool selection and adoption by designers new to green building. The research approach is based on principles of innovation adoption theory, specifically the constructs of relative advantage and trialability of innovations. The 275 design-related tools examined here address the spectrum of green building concepts and represent a range of applicability to different design tasks. The findings of this research indicate that while considerable investment has been made in developing freely available web-based tools to support design, a relatively small number of those tools are immediately applicable to the task of making Leadership in Energy and Environment Design (LEED) credit determinations for specific projects. The two characteristics of innovations explored in this research provide a basis for explaining some of the anecdotal observations of tools employed in practice, suggesting a need for further research to confirm and extend the findings.

INTRODUCTION

Green building concepts have found their way into many federal policy and guidance documents over the past decade, and these concepts are beginning to impact construction projects across multiple federal agencies. Recent policy at the federal level such as the Federal Executive Order (EO) 13423: *Strengthening Federal Environmental, Energy, and Transportation Management*[1] and the *Federal Leadership in High Performance and Sustainable Buildings* Memorandum of Agreement (MOU)[2] are examples. These changes are happening for obvious reasons; in the U.S., buildings consume 68% of all electricity used, 60% of non-food/fuel raw materials used, 40% of non-industrial solid waste generated, and 35% of carbon dioxide emissions (OFEE 2003, p. 5). Policy goals for sustainability must therefore address buildings.

Individual agencies within the federal government are implementing policies based on federal-level requirements as well as internal sustainability efforts. The Department of Defense (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, Appendix B). 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*[3] 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 Fiscal Year 2008.[4] Furthermore, the Army must meet the energy reduction goals of the Energy Policy Act of 2005 (EPAct).[5] These policies have many implications for the procurement, construction and use of facilities, including the attainment of LEED credits during the design/build phase of new construction. Design and construction of Army facilities are primarily conducted by the United States Army Corps of

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Engineers (USACE), which in turn employs private sector Architecture and Engineering (A/E) professionals. This research was initiated specifically to aid these support contractors to USACE as they help Army installations meet sustainability goals related to facilities, although it has broader applicability to other public sector project teams as well.

An entire field of specialized knowledge has developed to implement green building including professional organizations, trade journals, academic courses and research, product branding, and professional certification programs. A substantial pool of green building Decision Support Tools (DSTs) has emerged, and the challenges associated with finding the right tool for the job are significant. The problem is exacerbated by situations in which potential adopters face significant resource constraints and may be resistant to the idea of adoption in the first place. As noted by Vafaie et al. (2006):

> "Ideally, one would test and validate every tool that promises to fulfill some or all of the requirements needed in a specific project, but extensive tool evaluation is a time and resource intensive process. It is often impossible to apply a rigorous level of investigation to all tools that may be applicable to your specific system due to budgetary and scheduling constraints." (p.56)

Accordingly, there is a need to provide guidance for designers new to the concepts of green building to minimize the overhead effort required to find the right tools for achieving project sustainability goals, such as the Army's LEED Silver Rating. A primary driver of this research was to create a user-friendly database to facilitate effective tool selection and adoption. This goal was accomplished by identifying tools through an extensive internet-based search and then investigating approaches to inventorying, characterizing, and mapping the tools that were accumulated.

The search to identify green building tools found 275 readily accessible tools via the internet. A hybrid organizing framework was used to capture the DSTs based on topical areas, purpose and type. This framework was used to enhance user ability to find relevant tools. Tools were further organized based on relevance to obtaining LEED points, and the resulting database is available to USACE practitioners. This paper summarizes what was found in the search process by characterizing and mapping the DSTs using concepts from innovation theory. The results are presented in the following manner: first, a review of green building and the decision context for tool adopters sets the background. A review of organizing frameworks establishes the reasoning behind the framework used to organize the database. Key factors from innovation theory provide a basis for characterizing and mapping the inventoried tools as a foundation for understanding how novice users may approach the population of DSTs, and for identifying possible gaps in the tool base that can be filled to better address the needs of this population.

BACKGROUND

Green building is a term used to refer to new approaches to planning, designing and constructing buildings. Green buildings are designed with environmental impacts and occupant well-being in mind, using engineering and design strategies to reduce the use of non-renewable resources. The Office of the Federal Environmental Executive (OFEE 2003) defines green building as a practice of:

1. increasing the efficiency with which buildings and their sites use energy, water, and materials, and
2. reducing the building impacts in human health and the environment, through better siting, design, construction, operation, maintenance, and removal—the complete building life cycle.

The scope of what is considered "green" with regard to the built environment ranges from energy efficient components and systems, to materials and systems low in toxics or otherwise healthy for indoor environmental quality, to resource-efficient materials incorporating recycled or rapidly renewable content and more. Among the facility-related areas addressed by green building are integrated design, energy performance, water conservation, indoor environmental quality, and environmental impact of building materials. These strategies form the core of the concept of green building.

Green building is defined by the USGBC through its LEED Rating System.[6] This point-based rating system, developed and maintained by the USGBC, is a commonly-referenced metric within many existing policies (OFEE 2003; Pearce et al. 2005), although it is not the only such system offered as a reference standard in all U.S. policies. The LEED system is structured around the categories of Sustainable Sites, Water Efficiency, Energy & Atmosphere, Materials & Resources, and Indoor Environmental Quality (USGBC 2006). The categorization of considerations is consistent across all rating systems under the LEED banner, and represents a broad spectrum of potential actions available on the level of specific projects that can be taken to increase the sustainability of those projects.

Green Building and A/E Professionals Serving the Public Sector

Architectural and engineering design for capital projects was, until recently, undertaken "in-house" within federal agencies responsible for capital projects, but current trends across the federal sector toward privatization of design services mean that these activities are now largely undertaken by private sector A/E firms which are managed by a smaller set of in-house resources (NRC 2000). As such, project goals established at the local and institutional levels are passed through to these A/E firms as part of their Statement of Work (SOW) for the project. Such goals include, at a minimum, budget, schedule, and performance objectives and constraints, as well as federal requirements for anti-terrorism/force protection of facilities, sustainability, and others. Under schedule and budget pressure to deliver more building for less money, A/E firms are faced with the challenge of maximizing scope within a constrained, first cost-driven budget. Unmeasured, unfunded mandates associated with sustainable facilities, coupled with widespread industry perception that green building technologies and practices cost more, lead to a perception that meeting project sustainability goals will be challenging to achieve in practice (OFEE 2003).

From the perspective of the private sector A/E involved in federal projects with sustainability goals, changes in practices necessary to meet the new requirements are often externally driven by SOW requirements. While qualifications-based selection of A/E firms is the norm, explicit documentation of prior green building experience is not yet uniformly required during procurement of design services, nor is it necessarily rewarded during selection—even if it is formally included, it competes against other procurement priorities such as preference for small disadvantaged business enterprises.[7] Firms with a history of past performance on federal projects may represent the most highly qualified applicant whether or not they have sustainability capabilities. It is these firms, whose past performance qualifies them, but whose experience base does not include sustainability, that are the target audience for this research. This stakeholder group can be characterized by the following attributes:

- They have little or no formal project experience with green buildings, but are expected to meet green building goals and requirements as part of new federal initiatives for capital projects, making their motivation for adopting green building tools *externally driven* (Vanegas & Pearce 2000).
- They have little or no experience in using sustainability decision support tools on past projects, and little or no specialized expertise in-house to handle requirements for whole building performance modeling required to comply with LEED-based green building standards.
- They may or may not be formally held accountable for building performance outcomes, depending on governing institutional policy and local interpretations of that policy by federal project and contract managers.

Given the current state of adoption of sustainability throughout the industry, the low or non-existent experience level of these firms with respect to green building means that they represent a segment of the adoption curve beyond the innovators and early adopters. Depending on their individual attributes, they may fall within the early majority, late majority, or even laggard category of adopters (Rogers 2003). Their incorporation of sustainability principles as part of their design of capital projects can be facilitated by the appropriate adoption of tools to support effective decision making during design.

Decision Support Tools

Decision Support Tools (DSTs) can be defined very broadly as any tool used as part of a formal or informal decision process (Kapelan et al. 2005); any tool that "informs the decision-making process by helping actors understand the consequences of different choices" (CMHC 2004. p. 1). While there is no shortage of DSTs created to aid A/E professionals in meeting these new green building requirements, professionals can be overwhelmed when trying to apply these tools to decision making (Carmody et al. 2000). There is a knowledge deficit regarding what tools are available and the potential benefits associated with their use; this deficit is slowing the adoption of environmental performance assessment methods (Mackley et al. 2000). The need to deliver existing knowledge in a manner that facilitates its use has also been recognized as a challenge for the federal government as it moves forward with green building goals (Flanders et al. 2001; OFEE, 2003). The primary problem underscoring the research reported in this paper is the need for ready access to available tools; in many ways this is an educational challenge (Mackley et al. 2000).

DSTs for green building can be categorized in many different ways. The Annex 31 Study (CMHC 2004) describes two broad categories: interactive software and passive tools. The primary distinction among tools in this framework is the extent to which users are required to enter data and manipulate information. The Annex 31 report further divides into the following categories (ibid, p. 2):

Interactive:
Life Cycle Assessment Tools for Buildings and Building Stocks
Energy and Ventilation Modeling Software

Passive:
Environmental Assessment Frameworks and Rating Systems
Environmental Guidelines or Checklists for Design and Management of Buildings
Environmental Products Declarations, Catalogues, Reference Information, Certifications and Labels

The *Green Building Sources* compiled by the Rocky Mountain Institute (RMI 2004) follow a similar logic with categories roughly based on level of user interaction; this list also captures some of the 'professional activities' which were not addressed in this research. The RMI categories are: books; manuals; compact discs (CDs); periodicals; organizations; "web wonders," courses and education; and software tools. The Annex 31 and RMI categories primarily distinguish tools that are highly analytical and technical versus everything else. These categories combine many of information-based tools and thus suffer a similar problem—the categories created contain so many tools it is difficult to identify those applicable to a given topical area. Furthermore, the Annex 31 framework does not capture interactive websites, which are some of the first tools a professional turning to the internet will encounter. The RMI list, in contrast, contained 46 "web wonders," reinforcing the breadth of what is available through the internet.

DSTs can also be organized by the scale of building components they are designed to address. The ATHENA^{TM} Institute (Trusty 2003) proposes a three level organizing framework that distinguishes among: individual product specifications and purchases (Level 1); whole building DSTs (Level 2); and assessment frameworks that incorporate objective and subjective analysis of environmental, economic, and social factors—sustainability (Level 3). This framework includes a "Supporting Tools" category for those DSTs that provide general support to specific topic areas and don't fit into the other three levels. The primary distinction in this framework is the scale, not the topic. The U.S. Department of Energy (DOE), Energy Efficiency and Renewable Energy (EERE), *Building Energy Software Tools Directory*[8] is also organized by building scale with the following categories: whole building analysis; codes and standards; materials, components, equipment and systems; and other applications. The ATHENA and DOE frameworks enable comparison and evaluation between Life Cycle Assessment (LCA) tools and other software tools in that they are grouped according to intended purpose. In particular, LCA tools can be shown as complimentary and not competing. Although these distinctions are useful for comparing certain tools, the categories are insufficient to organize the multitude of tools currently available, given their limitation to just software tools. Also, this type of framework suffers the similar problem in that too many tools would be contained in the given categories. There is also the problem of placing tools that cover more than one of the "Levels" or building scales, such as the websites.

Tools can be organized by stage in the building life cycle (CMHC 2004), such as the Green Matrix website which combines the LEED categories with the phase in the design/build process.[9] One side of the matrix has the stages: pro-forma, master planning, pre-design programming, schematic design, design development, construction documents, and construction/post construction. These categories are cross-referenced with the LEED topical areas. A similar framework is used in the *HOK Guidebook for Sustainable Design* (Mendler et al. 2006), with categories called 'project actions' which include: project definition; team building; education and goal setting; site evaluation; baseline analysis; design concept; design optimization; documents and specifications; bidding and construction; and post-occupancy. These categories are also cross-referenced with the LEED topical areas. Using building life cycle phase is a useful distinction—in particular for assigning tasks to different professionals on the project team—but not relevant to this research as the primary focus is on the design stage. These frameworks have phases even within the 'design stage'—but these distinctions are not critical for the overall purpose of the research, and thus this type of framework was not selected.

It is common to organize green building DSTs by content or topical area, typically corresponding to the categories of the USGBC's LEED Rating Tool. San Francisco's report on green building tools (Global Green USA 2002) utilizes the following categories for tools: general green building; site and landscaping; water conservation; energy; materials selection and waste reduction; indoor air quality: and life cycle costing. References and resources compiled for the Sustainable Project Rating Tool (SPiRiT) are organized by the LEED topical areas: sustainable sites; water efficiency; energy and atmosphere; materials and resources; indoor environmental quality; and delivery process. The SPiRiT references include additional categories for general resources, current mission, and future mission (USACE 2002). There are several advantages of using a topical approach. First, if LEED certification is an objective for the project, topical areas based on this rating tool improve the ability to identify appropriate tools. Second, topical areas correspond to professional specializations, also aiding in the identification of tools. Finally, organizing by topical area also enables various types of tools to be listed together, such as software and websites. One problem with using topical areas is related to evaluation. Comparing tools within a given topical area is often not realistic, since tools may be designed for different purposes. Another concern is limiting the topics to those contained in LEED. This may limit the number of tools captured or pose difficulties in placing a given tool, such as those related to Life Cycle Assessment (LCA) or Life Cycle Costing (LCC).

Tools are designed and built for a variety of tasks, with various user needs and specializations, education and training, time and resource constraints, and building goals and objectives. The diversity of tools also makes evaluation extremely challenging, and helps explain why little evaluation literature is available. The field is dynamic and the assortment of tools is continually expanding, making reviews and evaluations rapidly out-of-date. This complexity is also what challenges the potential user in finding and using tools.

It is possible to narrowly define DSTs for green building as interactive software or computer-based programming developed to aid the design process though manipulating large amounts of information, comparing alternatives and making predictions for building performance. Users enter data and the software generates outputs that can be used to aid in decision-making (Global Green USA 2002). These types of tools serve a predictive function (CMHC 2004), and imply a certain knowledge and acceptance of green building goals. Many of these tools require specialized training (e.g., energy simulation software) and a significant commitment of project resources. The audience (design professionals) this research is intended to address has a wide range of specialized knowledge and skills which may or may not include the ability to effectively employ specialized tools related to sustainability. The types of potential projects also vary widely, as Army installations have facilities ranging from heavy equipment maintenance and repair to barracks, family housing, warehouses, hospitals, schools, and restaurants. Limiting the definition of DSTs to interactive software tools was considered premature based on the intended audience and the broad set of design challenges included in the scope of this project. Additional types of tools considered here included web sites, databases, directories, standards, and other relevant resources to inform the design process.

Decision Support Tool Selection/Adoption Process

Innovation diffusion and adoption provides a relevant knowledge base on which to evaluate DSTs, since the aim of the creating the database was to facilitate effective tool selection and adoption by novices in the field. Given the perspective of designers new to the concept of green or sustainable building, both the concept itself and the tools and techniques used to achieve it represent innovations in that they are either new or perceived to be new and are previously unused by their potential adopters (Rogers 2003). This theory then becomes helpful for enhancing the database. The rate and success of diffusion of innovations across a population of potential adopters is influenced by characteristics of the innovations themselves along with characteristics of adopters.

The characteristics of innovations that have been most widely studied are: 1. relative advantage; 2. compatibility; 3. complexity; 4. trialability; and 5. observability (Rogers 2003). Diffusion of innovation and innovation implementation theory suggests that, all else being equal, the likelihood of adopting an innovation increases with the extent to which perceived benefits exceed costs (e.g., Panzano et al. 2004; Rogers 2003). Key to this notion is the relative importance of perception over hard evidence; in fact, one author states that ". . . scientific evidence in support of the effectiveness of an innovation may be helpful but it is neither necessary nor sufficient for the adoption of innovative practices by organizations" (Panzano et al., 2004, paraphrasing Abrahamson 1991; Denis et al., 2002). Rogers' five attributes of innovations (2003) that affect their successful adoption provide a useful framework for evaluating and comparing candidate tools and predicting their likelihood of success/adoptability with regard to our user base, although other constructs such as technology transparency could also be included. Table 1 provides a definition for each of these constructs along with an interpretation of that construct in the context of DST selection.

The characteristics of adopters also affect adoption decisions (Rogers 2003; Moore 1991; Panzano et al. 2004). Assumptions about the characteristics of the adopter base targeted in this research include the following:

- The adopter base of interest is A/E firms subject to new LEED-based federal green building requirements who have not previously explicitly incorporated green building as a goal for their projects. While some A/E firms on federal projects *do* have prior green building experience, these more experienced firms are not the target of this research.
- The primary metric of success for new adopters is whether or not their design is able to meet LEED requirements, since LEED is the standard that is referenced on most federal projects and for the Army beginning in 2008. Accordingly, the interpretation of innovation attributes used in this research is with respect to the LEED standard.
- Given the market status of green building in the United States (rapidly approaching 10% of the market on new building starts[10]), novices in the field of green building no longer fall into the class of innovators or early adopters; instead, they fall somewhere within the spectrum of early majority, late majority, or laggards (Rogers 2003).

Other key characteristics defining the context of adoption considered here include resource constraints in terms of time and money; rigid organizational requirements such as procurement rules that must be met to achieve a successful solution; significant risk aversion of public sector clients due to public accountability requirements; competing objectives; and low levels of organizational and individual slack among involved stakeholders (OFEE 2003; Pearce & Fischer 2001a, b; Pearce 2001; Pearce 2003). Many of these characteristics serve as inhibitors to innovation adoption (Rogers 2003). Within this context, this research hypothesizes that characteristics of innovations can be operationalized and used as a basis for prioritizing tool recommendations to novice users as well as a means to understand current tool adoption patterns in practice. The next section describes the approach used in this research to evaluate this hypothesis, along with the findings of the research itself.

APPROACH AND FINDINGS

This research was undertaken in three major steps: conducting an inventory of decision support tools to represent the population of tools presently available to designers; mapping the tools within the inventory according to tool type and topical area; and characterizing tools in terms of parameters from diffusion of innovation theory that may affect their adoption as a basis to prioritize recommendations to novice designers. The following subsections describe specific methodology and findings for each of these tasks in greater detail.

TABLE 1. Attributes of innovations that affect their adoption (Rogers 2003).

Attribute	Definition	Interpretation with respect to Green Building DSTs
Relative Advantage	The extent to which an innovation is better than the product/tool it is replacing	Degree to which tool directly provides either (a) necessary ability to calculate a LEED credit; or (b) documentation to support a LEED credit claim
Compatibility	The degree to which the innovation fits within the existing processes and culture of potential adopters	Degree to which tool fits within the established design delivery process of a typical A/E, e.g., no new steps added; no additional time required; no additional supporting innovations required, like new computer systems, to implement tool; no new stakeholder involvement required
Complexity	The degree of difficulty an adopter has in understanding and/or using an innovation	Level of training or prior knowledge required to effectively use tool; degree to which tool requires non-traditional information to achieve results
Trialability	The degree to which a potential adopter can "test drive" an innovation prior to making an adoption commitment	Availability of tool for free via the web; cost associated with using tool is a negative here
Observability	The degree to which the benefits resulting from innovation adoption are apparent as an outcome of adoption	Degree to which tool provides more information than baseline documents that would be helpful in achieving LEED credits

Inventory of Decision Support Tools

The search for DSTs was conducted utilizing the internet. The internet has become an important means of communicating information (e.g., Horrigan 2006) and its ease of use ensures a continued prominence (Mackley et al. 2000). The search portion of the research was based on the assumption that design professionals have access to the internet and will turn to this resource for information on green building DSTs. Text books, manuals, trade journals, periodicals and academic journals are also sources of information and can be considered DSTs according to the definition guiding this work. The search, however, was limited to what was readily accessible via the internet, with a particular focus on government sponsored research, software development and websites. The primary identification method was a web search on the term "green building tools". Other criteria used for including green building DSTs in the inventory included:

1. Mention by a leading green building resource
2. Specific focus on reaching green building objectives
3. Focus on facility design considerations

The primary consideration was that tools were readily accessible for A/E professionals seeking help with green building. In general, tools needed to be related to green building to be included in the database. A focus on 'green' also often means 'high performance' so some general design/build tools within this domain were also included. Some tools were not included if the intent was primarily advocating green building, rather than serving as a resource for A/E professionals. All types of construction were included, although residential tools were limited to a few representative sites and tools, since much of the Army residential design and construction is done by contractors under the Residential Communities Initiative (RCI). The web search was concluded when tools already identified were found to be repeatedly appearing in new sources and the comprehensiveness of the web sites was decreasing. In other words, tools that had comprehensive scope, were related to LEED, or had a specific design role were sought—others that had limited subject matter or were not linked to the design phase were not included. Specific green building resources (item 1 above) for identifying tools included:

1. Published reports and on-line databases of tools such as: the General Green Building Resources (Appendix H) of the *Using LEED NC in Colorado, Tips Resources and Examples* on-line guide;[11] *Green Building Sources* from the Rocky Mountain Institute (RMI 2004); United States Department of Energy Federal Energy Management Program's *Procurement of Architectural and Engineering Services for Sustainable Buildings: A Guide for Federal Project Managers* (2004)[12]
2. USGBC, LEED-NC 2.2 Reference Guide (USGBC 2005);
3. Whole Building Design Guide (WBDG);[13]
4. U.S. Department of Energy (DOE), Energy Efficiency and Renewable Energy (EERE) Building Energy Software Tools Directory;[14]
5. USACE Construction Engineering Research Lab (CERL) *Sustainable Project Rating Tool References and Resources* (USACE 2002);
6. *Tools of the Trade* report for City of San Francisco (Global Green USA 2002)
7. EERE Building Technology Program's *High Performance Buildings Database*.[15]

275 tools were identified and included in the initial inventory, and catalogued as described in the next section.

Mapping of Existing Tool Inventory

An important step in creating the database was establishing a framework to organize the DSTs. A framework was created based on the green building goals, the capital project process, and the specific user base of practitioners new to green building. The primary criterion driving the framework was minimizing search time/investment requirements on the part of constrained (and possibly unmotivated) designers.

The final list of categories used in this research is presented in Table 2 with definitions. These categories were chosen primarily to aid in the retrieval of a tool. With this goal in mind, categories were created by topical area at a level of resolution that balanced the number of tools in each area. Using topical areas, purpose and type of tool as organizing themes also means that some tools will be on more than one page—the final categories are not mutually exclusive.

The entire green building DST database was captured in a Microsoft Excel spreadsheet to allow for easy transmittal through email or posting to shared areas. Creating a relational database in Microsoft Access was considered but discarded in light of the experience required for using this software and challenges associated with electronic transmittal and platform compatibility. Excel was also preferred in that it will be easy to copy, edit and update the database over time. Information collected on DSTs included: the organization that created the tool; a web link to find the tool; a brief description of the tool; cost (if any) for access to the tool; and type of tool (software, checklist/matrix, publication, website, database).

The green building DSTs found during the search portion of the research were captured in a database based on the hybrid organizing framework. Figures 1 and 2 present summary information of the tools identified and captured in the database.[16] It is important to recognize that while this data represents the quantity of tools publicly available to practitioners, it reveals nothing about which tools are used in practice. The database is also not comprehensive; for instance, the international commercial market in software tools is vast, so the software captured within this database was limited to North American developers.[17] Even with this constraint, it is evident that a great deal of effort has been expended by government agencies and for-profit commercial organizations in the development of analytical software, based on the list of tool sources and developers captured in the database.

In the course of this research it became clear that a search for DSTs could be an endless effort in and of itself. Not only are the criteria for inclusion difficult to define, but also internet resources are in a constant state of fluctuation. The work reported in this article represents an initial attempt to search, identify and organize with the objective of assisting A/E professionals within USACE as well as USACE support professionals, and the resulting database is a first step in this direction. After the organizing framework was established and the database populated, the next step was to rate the tools in each category in a manner that reflected how and why new tools are (or are not) adopted. This step was intended to enhance the ability of A/E professionals in identifying and using tools, and is based on theories of innovation diffusion. The next section reviews the applicability of these theories to tool adoption for capital projects.

TABLE 2. Hybrid Organizing Framework by Topical Area, Purpose, and Tool Type.

	Category	Definition
1	Life Cycle Costing	Tools to help clients/building owners understand specific quality differences of sustainable design alternatives so they can move beyond least-first-cost decision-making; to understand the Cost of Ownership and prove to the client that the real cost of doing business is realized over time, not in first construction costs (Loftness et al. 2006).
2	Life Cycle Assessment	Tools for modeling and analyzing building structure, design, and material options and for determining environmental impacts over the life of the building based on various design/build options—to make an environmental assessment of buildings.
3	Energy Analysis	Tools that enable simulation of building energy use; analyze energy and cost savings for different design strategies; and other tools for addressing energy concerns.
4	Product and Material Specification	Tools that describe products or materials for evaluation of alternatives and identification of sustainable products and suppliers.
5	Education and Professional Development	Tools created to inform and educate design professionals on sustainability and green building; to keep informed of trends, opportunities, professional organizations, etc.
6	Case Studies	Databases, websites containing green building projects.
7	Compliance/Code-checking/ Standards	Tools designed to check compliance with building codes and standards. Also includes links to standards relevant to LEED and green building.
8	Rating Tools	Tools for analyzing building structure, design, and material environmental and energy impacts over the life of the building based on various design/build options—to make an environmental assessment of buildings. A rating, or certification, is given to rank the building according to pre-set standards/ categories of achievement.
9	Site Planning/Landscape Design	Tools for identifying and evaluating alternate landscape and site planning options.
10	LEED-Recommended Reference Tools	Tools referenced in the LEED-NC 2.2 Reference Guide, or otherwise specifically addressed to LEED point attainment
11	Websites	Websites designed to assist professionals in meeting green building goals.
12	Lighting/Daylighting	Simulation of design options for lighting and other lighting tools; internal and external lighting.
13	Airflow/Ventilation	Simulation of HVAC systems for air flow with various building design options; other tools for Indoor Air Quality.
14	Mechanical/Electric/ Plumbing Systems	Tools supplying information and/or identifying products for design and specification of M/E/P systems

Characterization of Tools by Innovation Attributes

The organizing framework provides an initial screening basis—founded on the types of tasks to be undertaken in green design—for candidate users to select an initial pool of tools for further consideration. Additional characterization was conducted to rate each tool according to a LEED-based operationalization of two of Rogers' five attributes of innovations. This additional step was motivated by the same consideration driving the entire search effort—to facilitate the selection of effective DSTs by potential users of the database. LEED was used as a point of reference for operationalization since it is the primary metric of

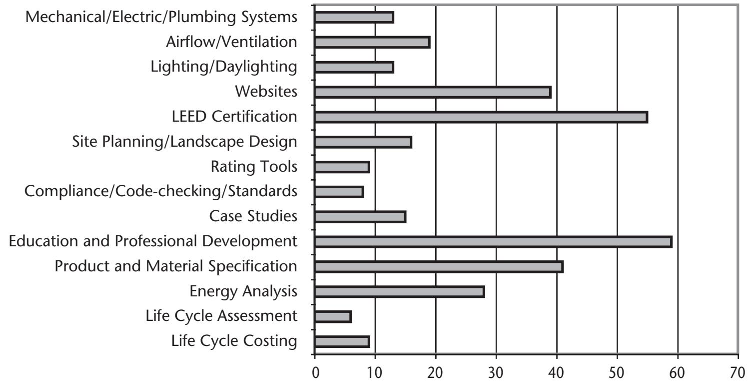


FIGURE 1. Total Occurrences by Tool Category.

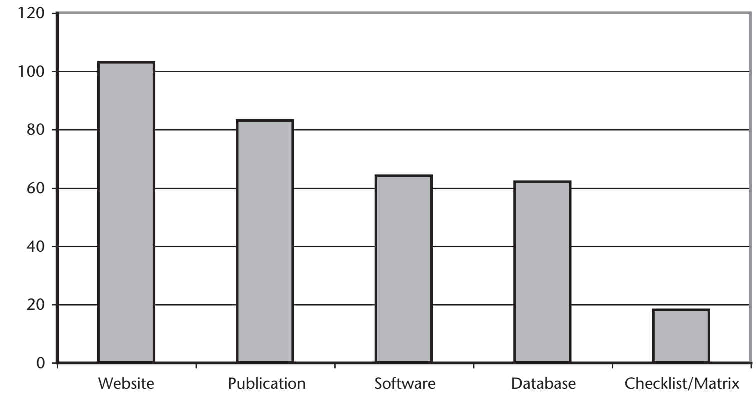


FIGURE 2. Total Occurrences by Tool Type.

success for future Army construction and in most Federal policies.

The use of the LEED rating system can require very different types of DSTs. Some credits under the LEED rating system are easily evaluated using knowledge held by practitioners in general or even laypersons. For instance, evaluating compliance with Indoor Environmental Quality Credit 4.3, low emitting carpet systems, requires only determination whether all carpets meet Green Label Plus requirements as indicated either by the Green Label Plus logo on the spec sheet or existence of that carpet in the Carpet and Rug Institute's database of compliant carpets. Additional components of this credit include determining compliance of carpet padding and adhesives in similar fashion. No specialized knowledge of chemistry or indoor air quality is required.

Other credits such as Credit 1 in Energy and Atmosphere, *Optimizing Energy Performance*, require the ability to construct comprehensive models representing the overall performance of the building. This credit specifically requires an energy model, a task often handled by a specialist within a design firm or outsourced to a third party specializing in energy modeling. Tools supporting this task include a broad range of energy modeling software, much of which requires special training to properly operate. As such, this credit and tools associated with demonstrating compliance thereof represent a high level of complexity. Additionally, such tools may also represent low compatibility with existing processes within the firm, particularly if energy modeling is not typically used as part of design.

These examples illustrate how different LEED credits can lead to the use of different types of tools (a database in the first instance, and a whole building model in the second), each of which has different attributes that correlate both with LEED credit requirements and with the innate properties of each tool. The intent of this phase of the research was to develop a theoretically-based approach for classifying tools independently of specific requirements of their associated LEED credit, but also with respect to the extent to which they support the goal of project LEED certification. Accordingly, two attributes from Rogers' five attributes of innovation (relative advantage and trialability) were selected to classify the existing tool set, based on: 1) the importance of these attributes from the perspective of the adopter base and, 2) the ability of the research team to objectively classify tools.

In this project, relative advantage was operationalized in terms of the tool's (innovation's) ability to yield immediately practicable information to support determination of compliance with LEED credits, or to provide information essential to support documentation of that compliance. As such, tools that contributed directly to a user's ability to move forward directly toward LEED certification were rated higher than tools which provided more general information, or which provided specific information not directly framed in terms of the LEED rating system. This operationalization was selected to reflect the resource constrained, tightly focused decision environment characteristic of our potential adopter base. Other ways to operationalize this attribute could be employed to better reflect the characteristics of other types of users, or users facing different kinds of design situations that are not explicitly LEED-driven.

The additional attribute of trialability was also considered here, since it was comparatively easy to operationalize in terms of cost resources required to "test drive" each tool and since cost often represents a significant barrier to adoption among this user base. Considering trialability and relative advantage together with the other factors of complexity, compatibility, and observability of results would provide a stronger basis to consider the tradeoffs inherent in tool evaluation and selection and offer the possibility of better matches for potential users. Table 3 shows the criteria used for rating each tool in the categories of 'relative advantage' (representing the 'bang' achieved by the tool), and 'trialability' (representing the 'buck'), along with comments on how each attribute pertains to a design firm's ability to reach that goal.

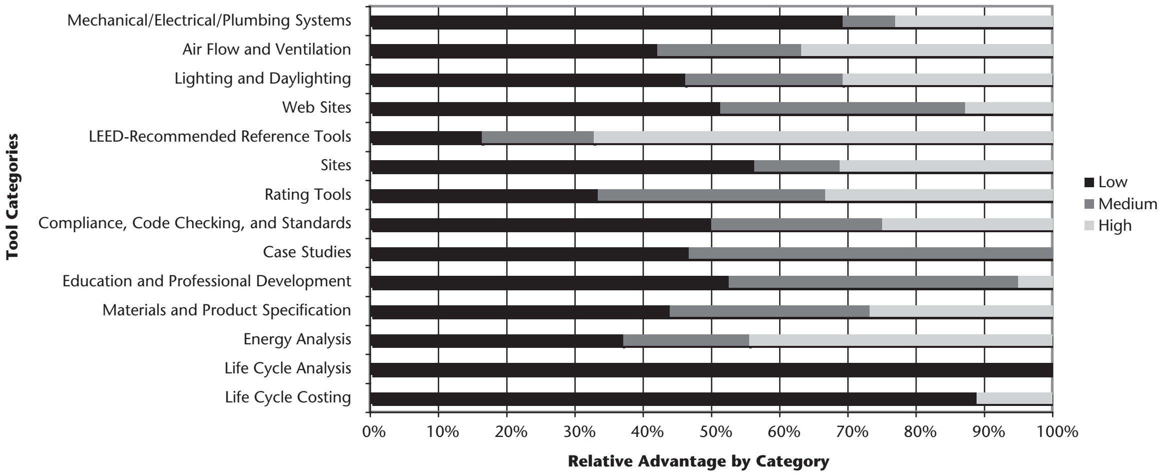
Each tool was classified into one of three levels; High, Medium and Low, where high corresponds to the preferred state of that variable. To determine how to rate a tool in terms of relative advantage, each tool was examined in terms of its relevance for determining compliance with, or documenting achievement of, LEED credits. Some tools, e.g., web sites, were searched using the term "LEED" if the relationship to the rating system was not immediately obvious. If searching the site using the site's search engine resulted in hits on this search term, the site was rated a Medium in terms of relative advantage. Tools without any specific reference to LEED were typically rated Low, unless they consisted of a searchable database with fields corresponding to specific LEED credit requirements or were specified as an actual reference standard by the LEED protocol.

'Trialability' was expressed in terms of the initial cost of the tool to the user. Many tools in the inventory are available free online; these tools received a High rating. If the cost of the tool was greater than zero but less than or equal to $250, the tool received a Medium rating. If the cost was greater than $250, it received a Low trialability rating. The threshold of $250 was selected since it is similar to the cost of a basic office software package for general use. Comparatively few tools were close to this cost threshold; most were either considerably less expensive, or sub-

TABLE 3. Operationalization of Innovation Attributes.

Attribute	High	Medium	Low	Interpretation
Relative Advantage	Directly results in LEED credit knowledge	Indirectly results in LEED knowledge	Completely general information; considerable processing required to get to LEED knowledge	Immediate practicability of information provided relative to objectives
Trialability	Free	$1–$250	> $250	Cost

FIGURE 3. Relative Advantage of Tools for Obtaining LEED Credits.



stantially more expensive. To determine how to rate trialability, the cost of using the tool was determined based on web information about the tool itself. While many tools were completely free, others had license costs, subscription costs, or other associated purchase costs. If a tool with a license cost had a free demonstration version available, it was classified as high trialability even though there would be a cost associated with long term adoption of the tool.

Figure 3 shows the relative proportions of tools within each category according to their relative advantage rating. Since some tools were included in multiple categories, this chart basically shows proportions relevant *within* each category to compare how tools are distributed among the three rating levels.

To see the distribution of relative advantage across *all* tools in the inventory, Figure 4 shows the proportion of tools with duplicates removed, classified according to low, medium, and high relative advantage. About 1/4th of all tools included in the inventory were rated as having high relative advantage in terms of their ability to provide information immediately relevant to achieving LEED certification. Another 1/4th provided at least some reference to the LEED rating system, while nearly half of the tools examined did not reference the LEED rating system at all.

From the standpoint of trialability, Figure 5 shows a breakdown of proportions within categories of tools of what percentage of tools in each category received each rating. A large proportion of tools within each category were rated as having high trialability.

To see the distribution of trialability across *all* tools in the inventory, Figure 6 shows the proportion of tools with duplicates removed, classified according to low, medium, and high trialability. In contrast with the distribution of tools rated for relative advantage, a strong majority of tools (79%) in the inventory received a high trialability rating and are available to be used or at least tested for free. To some extent, this large proportion reflects a deliberate intention of the initial tool survey to locate web-based, easily accessi-

FIGURE 4. Proportions of Tools Rated by Relative Advantage.

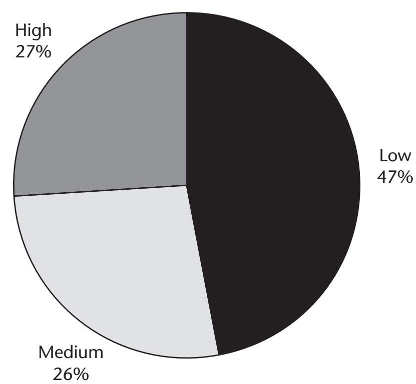
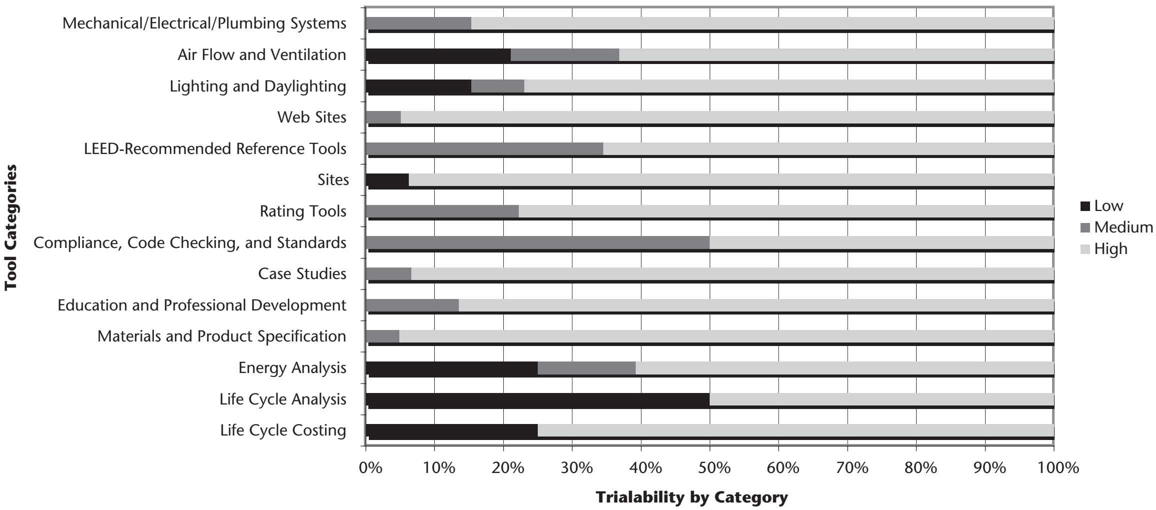


FIGURE 5. Trialability of Tools.



ble tools for inclusion in the inventory. 14% of all tools in the inventory had a comparatively low cost, while a relatively low 7% of tools had a cost higher than $250, some up to $20,000 depending on the user type and license considerations.

To better understand the tradeoffs between these rating factors, Figure 7 shows a distribution of tools in various combinations of high and low relative advantage coupled with high and low trialability. Tools having one or both rated as medium are classified in the "Neither" category in this chart.

As shown in Figure 7, many tools in the inventory (40%) are free but provide no specific links to the tasks associated with LEED certification, supporting the anecdotal observations of some green building novices that there is "too much information" to be able to find what you need to get the job done. Coupled with scarce resources, tight schedules, and little or no organizational slack, plus a general lack of attention to novices in many of the existing social networks serving the green building field, it begins to make sense why novices may have a hard time getting started in this context.

A relatively low 3% of tools were identified as having high relative advantage in terms of immediate LEED relevance, but low trialability due to high initial cost. 17% of all tools in the inventory had both high relative advantage and high trialability, representing a significant body of resources available to new users for no fiscal investment. How many specific LEED credits can be addressed with this tool set is an interesting question that was not addressed in this study, although an examination of Figures 3 and 5 suggests that there are likely to be at least some tools applicable in all of the LEED credit categories.

What is not represented in the graphs and remains for future research is an examination of the other innovation attributes (complexity, compatibility, and

FIGURE 6. Proportions of Tools Rated by Trialability.

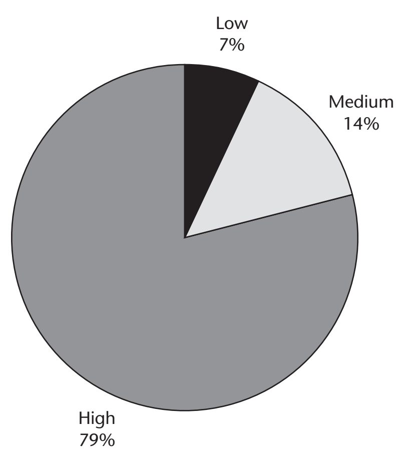
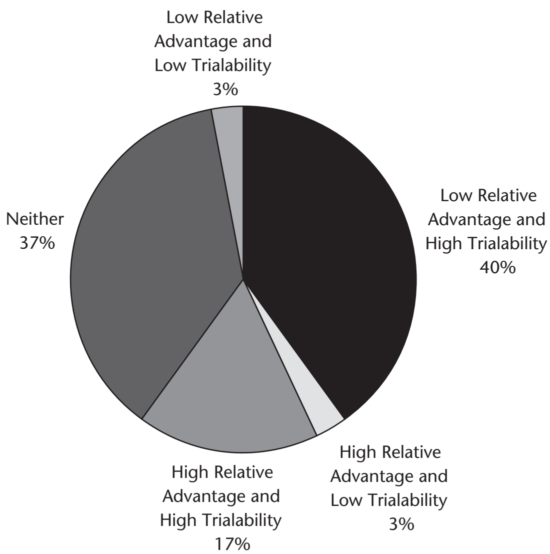


FIGURE 7. Distribution of Tools based on Combined Factors.



observability of results) described by Rogers. A better understanding of how tools rate in terms of these factors would provide additional illumination regarding what tools warrant the strongest recommendation to novice users. Complexity in particular would be a good starting point, since it would reflect how easily non-expert users can effectively use tools without training or additional expertise. This factor is especially important with the majority and laggard adopter categories falling later in the adoption curve, since these categories are less likely than innovators and early adopters to deliberately seek complexity as a desirable attribute of innovations (Moore 1991).

DISCUSSION

The findings of this research lead to several observations about both the status of the current tool inventory to support green building and the overall process of evaluating and selecting decision support tools for capital project design. The following subsections describe these observations in detail.

Status of Current Tool Inventory

The findings of the tool inventory, mapping, and characterization suggest a need to reorganize how technical assistance is provided to green building novices to better address their specific needs from an innovation adoption standpoint. As they proceed to gain more knowledge about LEED goals and implementation, novices may then be willing to invest the costs required to use some of the high relative advantage tools that have lower trialability. They may also then be willing to invest the time and attention necessary to evaluate the relevance and utility of the many excellent tools rated as low relative advantage in this study, thus expanding their tool base to include broader perspectives on green building beyond LEED.

The inventory and evaluation of these tools according to their relative advantage and trialability represents at best a snapshot of the current state of the art. The internet is a dynamic, living knowledge base that changes on a daily basis. In fact, between the time the tool inventory was created and the tools themselves were evaluated (approximately eight weeks), some links were no longer valid as represented in the initial inventory. Within this rapidly evolving environment, ratings assigned for 'relative advantage' based on links or references to LEED are likely to change significantly over time, as will other attributes of the tools.

As fast as the tool base is changing, the user base is changing as well. Different populations of adopters respond differently to the attributes of innovations (Rogers 2003; Moore 1991) based on their individual and organizational characteristics. As such, tools designed for innovators or early adopters may well need to be adapted to be a good fit for later classes of adopters such as early majority, late majority, and laggards (ibid.). Evolving policies in the public sector are driving innovation with regard to green building, and are helping to spur broader adoption of green building tools, practices, and technologies among a wide variety of stakeholders. The tools to support green building implementation must evolve as well to realize ongoing success in achieving sustainability goals across the project portfolio and across the population of all adopters.

Evaluating and Selecting Decision Support Tools for Capital Project Design

The major challenge addressed by this research was how best to make recommendations for potentially useful DSTs to designers of public sector projects new to the concept of green building, or at least to create the best conditions possible for a good match to occur.

The target users of the framework developed in this research are practicing, qualified professionals in the architecture/engineering field, but novices with respect to the technologies, strategies, and practices associated with green building. As previously described, they can also be characterized as functioning within a resource-constrained decision environment in which they are subject to multiple mandates and design objectives which are often unfunded and may be competing or even conflicting. The mechanisms and metrics by which their performance will be evaluated are not always defined, since many agencies rely on self-certification or spot checking to ensure compliance.

These factors combine to create a challenging decision environment, in some cases to the point of reducing motivation due to skepticism that project sustainability goals can actually be achieved. It is in this context, coupled with lack of knowledge about green building plus an overload of available information, in which our pool of potential adopters of green building DSTs undertake their work. Incorporating theories of adoption and diffusion of innovation in this research was based on an understanding that our user base is facing what is in essence an evaluation task coupled with an innovation adoption decision, even as they seek to comprehend the larger construct of sustainability driving overall project objectives.

The ideal tool for our user base, given our understanding of the attributes of innovation that affect their adoption, would exhibit the following characteristics:

- It would yield information directly relevant and immediately practicable for meeting project objectives such as LEED 'Silver' (relative advantage);
- It would yield this information without requiring any changes in existing operational procedures and without requiring additional supporting resources (compatibility);
- It would yield this information to the average user without any specialized expertise or extensive training (complexity);
- It would afford the ability for users to experiment and test drive the tool in real contexts without significant investment or for free (trialability); and
- It would yield rich and complete information sufficient to address the task to which it is being applied (observability).

Many existing tools in the inventory performed well on some of these attributes but not on others. Often, tools with significant relative advantage for making LEED credit determinations (e.g., building energy models or natural ventilation models) fared comparatively poorly with respect to our target user base, which would have to add additional steps and inputs to their design process (poor compatibility), obtain new types of expertise either in-house or on a contract basis (poor complexity), and invest significant cost to purchase licenses (poor trialability). In contrast, tools such as databases of green products that were low cost or free (good trialability) using general practitioner knowledge (good complexity) and requiring comparatively few process changes (good compatibility) often failed to provide enough information to lead to conclusions about LEED credits without significant additional information and process steps (low relative advantage and observability of outcomes). Managing tradeoffs in the evaluation and selection of tools is an additional step that must be undertaken to make effective recommendations to specific user bases about what types of tools may work best for them.

Tasks like product selection/specification, while appearing to be straightforward based on the structure of typical product databases, are really quite complex in the context of public sector facility design, subject as it is to procurement requirements, aversion to risk of product failure by stakeholders, and budgetary and scheduling constraints. In fact, product selection for green building on public projects is not only a task requiring the support of innovative tools to complete, it also is itself an innovation adoption decision where new types of products and materials are being employed to meet project goals. These types of multi-tiered innovation decisions have not been extensively explored in the domain of capital projects and represent an opportunity to explore how diffusion of innovation theory can be applied and adapted to reflect the unique qualities of the industry.

FUTURE RESEARCH/NEXT STEPS

Given the outcomes of this work, several areas for additional research can be considered as next steps, including: usability testing and validation of organizing frameworks to support tool selection; development of new tools and/or adaptation of existing tools to meet both new and presently underserved user requirements; investigation of different delivery and dissemination approaches for tool information; and developing a better understanding of the dynamics of fit among tool, user, problem, and context. The section concludes with a set of recommended next steps for project stakeholders based on the research. The following subsections describe each of these areas in greater detail.

Usability testing of organizing frameworks

The first area for additional research is the need to better understand the different ways in which users interact with organizing frameworks such as the ones reviewed in this article. Empirical validation could be employed to further test the hypotheses posed here that attributes of innovations affect both (a) the adoptability of a tool by a target user base; and (b) the initial and ongoing likelihood of success of the adopter who employs that tool. A better understanding of how selection and adoption processes occur in actual decision environments could lead to insights about how best to organize and provide information about tools to maximize their likelihood of being noticed at the right time and used in the best way possible. One way to approach this task is via empirical usability testing of different ways of representing and organizing information about decision support tools, and observing how different stakeholders interact with different representations. This area of investigation also affords opportunities to empirically validate the innovation-based characterization of tools developed in this research.

Development of new tools/adaptation of existing tools to meet user requirements

The characterization of tools established in this research also highlights opportunities for developing new tools and adapting existing tools to better address the specific needs and attributes of tool adopters new to green building. Increasing the trialability or LEED specificity of existing tools may increase their appeal to novice users subject to LEED as a primary performance metric. Developers of new tools should also consider these attributes when designing tools to appeal to this market niche. While only two of the five attributes of innovations identified by Rogers were explored in detail in this exploratory research, classifying existing tools across all five parameters would likely suggest additional niches that could be filled with additional tools.

Investigation of different delivery/dissemination approaches

From the standpoint of communicating key information about tools to potential users, another important area for research is the investigation not only of *what* information to communicate about the tools, but also *how* best to communicate it. The pilot hybrid framework developed in this research captured information about tools and their attributes in a tabbed spreadsheet format, making it easy to access from a variety of platforms and easy to understand by users already familiar with how spreadsheets work. It was also easy to update—perhaps almost too easy. Given its localized (as opposed to centralized) representation of data, the spreadsheet could easily be modified by individual users without sharing those modifications with other users, thereby missing a key opportunity to capture valuable information from the field and eliminating the ability to impose quality control on the contents of the database. Other delivery/dissemination approaches, most notably web-based approaches, could effectively address some of these weaknesses, but at the cost of ongoing hosting and maintenance requirements. In fact, most of the key sources of tools inventoried in this research were web-based. However, our understanding of how users in the design and construction field perceive and interact with these different types of tools is only beginning to be explored, and additional research could shed considerable light on what approaches may be most effective with different types of users.

Understanding fit between design tools and their context of application

Each of the previously described areas for future research contributes in its own way toward a better understanding of how design tools and other capital project tools are adopted and used with varying levels of success and impact in different contexts, with different users, and to address different problems. Further expanding the application of innovation theory to green building remains a rich area for study—we only explored some of the attributes of innovation here, and did not consider other pieces of the theory that may impact how tools are adopted such as the details of adopter attributes, context attributes, or others. A better understanding of the variations and deviations in practice that occur with respect to our classical understanding and theoretical representation of capital project processes would provide a rich landscape for modeling how tools are actually used in practice, not just how their creators intend or expect them to be used. Better operationalization of the construct of fit between tool, problem, user, and context could lead to recommendations of tools for specific situations that maximize the overall impact of those tools, while reducing the likelihood of negative experiences that could delay adoption of positive innovations.

Next steps for project stakeholders

Project stakeholders seeking to apply this work could immediately benefit from the broad variety of tools identified in this survey about which they may not already know. Novice designers in particular can use the database and filters developed here as a way to prioritize inroads to the vast number of resources already available to support their decisions. Project owners can also benefit by introducing their design teams to these tools and by working with all members of the project team to establish clear, reasonable, and mutually understood project sustainability goals. Active use of the set of existing tools will result in useful feedback to developers of current and future tools which will help them adapt their tools to better fit the needs of future project teams in the constantly evolving public sector project environment. Finally, using tools to result in more effective projects will result in broader diffusion of the benefits of sustainability, and may provide a basis to encourage additional support for research and development in this area.

CONCLUSIONS

The research reported in this article represents an ongoing effort to link green building DSTs to potential users with the goal of improving the sustainability of capital projects. By inventorying a broad spectrum of decision support tools and characterizing their adoptability by a specific user base, this research explored a new way to structure information about available tools that can apply not only to Army capital project teams but also other novice project teams pursuing LEED certification. The database created as a result of this work has the potential to create better matches between designers new to the field of green building and tools that can help them achieve specific project goals related to LEED. While the research was limited to a subset of all variables that could be considered within the rubric of innovation theory, it demonstrates the potential for using this theory as a basis to make tool selection recommendations and help prioritize the search for effective tools.

In the short term, the inventory created in this research is already being used in the public sector as a catalogue of tools to support green building. In the longer term, the database is an initial step toward constructing an effective resource for A/E professionals in the public and private sectors. While the findings of this research focused specifically on a subset of designers involved with public sector projects, specifically designers of Army facilities who are novices to green building concepts, the overall approach used here could be tested in other contexts to determine its generalizability and applicability.

Sustainability is growing as an important consideration across the construction industry. In project environments with multiple constraints and competing objectives, effective tools to support decision making are a welcome resource for designers and other project stakeholders. Finding the right tool for a given problem has been and will always be a challenge in this environment. The principles of innovation theory can help to facilitate this process, thereby forwarding the larger goals of sustainability within the built environment.

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Engineering Research Laboratory (CERL) researchers Dr. Chris Rewerts and Ms. Annette Stumpf. The entire Microsoft Excel database of decision support tools is available at the Engineering Knowledge Online (EKO) Sustainable Design and Development web site: https://eko.usace.army.mil/fa/sdd/.

NOTES

1. EO 13423 can be found in the *Federal Register*, Volume 72, Number. 17, pp 3919–3923
2. *Federal Leadership in High Performance and Sustainable Buildings MOU* is available at: http://www.fedcenter.gov/_kd/Items/actions.cfm?action=Show&item_id=4713&destination=ShowItem
3. The *Army Strategy for the Environment* is available at: http://www.sustainability.army.mil
4. 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)
5. 42 USC 15801, Public Law 109-58
6. See http://www.usgbc.org or http://www.leedbuilding.org for more information on the LEED rating system.
7. See Defense Federal Acquisition Regulation Supplement, Part 236: Construction and Architect-Engineer Contracts, Subpart 236.6: Architect-Engineer Services—Selection Criteria (PGI 236.602-1(a))—available online at http://www.acq.osd.mil/dpap/dars/pgi/pgi_htm/PGI236_6.htm#602_1.
8. Database of Software Tools available at: http://www.eere.energy.gov/buildings/tools_directory/
9. Green Matrix by Ratcliff can be found at: http://www.greenmatrix.net/index.html
10. This statistic is tracked annually and reported on the USGBC web site at http://www.usgbc.org.
11. Guide is available at: http://www.colorado.gov/rebuildco/services/highperformance/leed_co/index.htm
12. Guide is available at: http://www1.eere.energy.gov/femp/pdfs/034413_resguidefedconsmgr.pdf
13. WBDG is available at: http://www.wbdg.org/
14. Database of Software Tools available at: http://www.eere.energy.gov/buildings/tools_directory/
15. Database of High Performance Building Case Studies is available at: http://www.eere.energy.gov/buildings/database/
16. A total of 330 tool 'occurrences' are captured in the database, but this number represents overlap and repetition of tools placed in more than one category.
17. There are a few exceptions for software that was commonly referenced in the sources searched. Furthermore, the EERE database of software tools http://www.eere.energy.gov/buildings/tools_directory/ presents exceptional detail on tools including advantages and disadvantages. This work did not attempt to recreate this resource, only to identify it for potential users.

REFERENCES

Abrahamson, E. (1991). "Managerial fads and fashions: The diffusion and rejection of innovations," *Academy of Management Review,* 16(3), 586-612.

ACSIM (Assistant Chief of Staff for Installation Management). (2006). *Real Property Summary and Site Statistics for Fiscal Year 2006 Quarter 2*. Department of the Army, Assistant Chief of Staff for Installation Management, Washington, DC. Available online at: http://www.hqda.army.mil/acsimweb/doc/06q2_greenbk_final_06-apr17.pdf.

Carmody, J., Guzowski, M. & Wise, J. (2000). "The Minnesota Sustainable Design Guide: A web-based design decision support system," *Proceedings of the International Conference on Sustainable Building 2000*, Maastricht, NL. 418-420.

CMHC (Canada Mortgage and Housing Corporation). (2004). *Types of Tools, Annex 31 Energy-Related Environmental Impact of Building*, Energy Conservation in Buildings and Community Systems, Birmingham, UK. Available online at: http://www.annex31.org.

Denis, J., Hebert, Y., Langley, A., Lozeau, D., & Trottier, L. (2002). "Explaining diffusion patterns for complex health care innovations," *Health Care Management Review,* 27(3), 60-73.

Flanders, S.N., Schneider, R.L., Fournier, D., Deal, B. & Stumpf, A.L. (2001). *Planning, Engineering, and Design of Sustainable Facilities and Infrastructure: An Assessment of the State of Practice*, ERDC TR-01-03. United States Army Corps of Engineers, Engineer Research and Development Center, Champaign, IL.

Global Green USA. (2002). *San Francisco's Tools of the Trade: Practical Tools for Green Building Design and Analysis*. Department of the Environment, City and County of San Francisco, San Francisco, CA.

Horrigan, J.B. (2006). *The Internet as a Resource for News and Information about Science*. Pew Internet & American Life Project, Pew Charitable Trust Foundation, Washington DC. Available online at http://www.pewinternet.org/PPF/r/191/report_display.asp.

Kapelan, Z., Savic, D.A., & Walters, G.A. (2005) Decision-support tools for sustainable urban development, *Proceedings of the Institution of Civil Engineers, Engineering Sustainability* 158(ES3): 135-142

Loftness, V., Hartkopf, V., Gurtekin, B., Hua, Y., Qu, M., Snyder, M., Gu, Y., and Yang, X. (2006). *Building Investment Decision Support (BIDS™): Cost-Benefit Tool to Promote High Performance Components, Flexible Infrastructures and Systems Integration for Sustainable Commercial Buildings and Productive Organizations*. Carnegie Mellon University Center for Building Performance and Diagnostics, Pittsburgh, PA. Portions of this report are available online at http://www.aia.org/SiteObjects/files/BIDS_color.pdf.

Mackley, C., MacLennan, P., Miller, A., and Curwell, S. (2000). "Environmental education for the building industry: An internet resource," *Proceedings of the International Conference on Sustainable Building 2000*, Maastricht, NL, 174-176.

Mendler, S., Odell, W., and Lazarus, M.A. (2006). *The HOK Guidebook to Sustainable Design, 2nd Edition*, John Wiley & Sons, Hoboken, NJ.

Moore, G.A. (1991). *Crossing the Chasm: Marketing and Selling High Tech Products to Mainstream Customers.* Harper Collins, New York, NY.

NRC (National Research Council). (2000). *Outsourcing Management Functions for the Acquisition of Federal Facilities.* Committee on Outsourcing Design and Construction-Related Management Services for Federal Facilities, Board on Infrastructure and the Constructed Environment, National Research Council, Washington, DC.

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.

Panzano, P.C., Roth, D., Crane-Ross, D., Massatti, R., and Carstens, C. (2004). "The innovation diffusion and adoption research project (IDARP): Moving from the diffusion of research results to promoting the adoption of evidence-based innovations in the Ohio Mental Health System," *New Research in Mental Health, Vol. 15.,* Roth, D., ed. Ohio Department of Mental Health, Columbus, OH, 149-156.

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

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

Pearce, A.R. (2001). "Sustainable vs. Traditional Facility Projects: A Holistic Cost Management Approach to Decision Making," White paper prepared for U.S. Army Forces Command, Fort McPherson, GA.

Pearce, A.R. (2003). *An Online Knowledge Base for Sustainable Military Facilities & Infrastructure.* Final Project Report to Region IV Department of Defense Pollution Prevention Partnership, University of South Carolina.

Pearce, A.R., DuBose, J.R., Bosch, S.J., and Carpenter, A.M. (2005). *Greening Georgia Facilities: An Analysis of LEED Requirement Impacts.* Final Project Report to the Georgia Environmental Facilities Authority, Atlanta, GA, September 30.

RMI (Rocky Mountain Institute). (2004). *Green Building Sources.* Rocky Mountain Institute, Snowmass, CO. Available online at: http://www.rmi.org/sitepages/pid174.php#GrnBldgSources.

Rogers, E.M. (2003). *Diffusion of Innovations, 5th ed.* Free Press, New York, NY.

Trusty, W.B. (2003). "Understanding the green building toolkit: Picking the right tool for the job," *Proceedings of the USGBC Greenbuild Conference & Expo*, Pittsburgh, PA. Available online at: http://www.athenasmi.ca/publications/publications.html.

USACE (United States Army Corps of Engineers). (2002). *Sustainable Project Rating Tool References and Resource.* USACE, Engineering Research and Development Center (ERDC), Champaign, IL. Available online at: http://www.cecer.army.mil/SustDesign/SpiritReferencesV1_4.xls.

US DOE FEMP (United States Department of Energy Federal Energy Management Program). (2004). *Procurement of Architectural and Engineering Services for Sustainable Buildings: A Guide for Federal Project Managers*, DOE/GO-102004-1770. United States Department of Energy, Washington, DC. Available online at: http://www1.eere.energy.gov/femp/pdfs/034413_resguidefedconsmgr.pdf.

USGBC (United States Green Building Council). (2005). *LEED-NC for New Construction, Reference Guide Version 2.2*, United States Green Building Council, Washington, DC.

USGBC (United States Green Building Council). (2006). *Leadership in Energy and Environmental Design Green Building Rating System—New Construction, Version 2.2.* U.S. Green Building Council, Washington, DC.

Vafaie, H., Brown, N.F., and Truong, L. (2006). "Methodology for the Selection of Intelligence Analysis Tools," *Proceedings, 18th IEEE International Conference on Tools with Artificial Intelligence.* 55-62.

Vanegas, J.A. and Pearce, A.R. (2000). "Drivers for Change: An Organizational Perspective on Sustainable Construction." *Proceedings, Construction Congress VI*, February 20-22, Orlando, FL, 406-415.