Toward a Understanding of Sustainability in the Construction Industry Using Diffusion of Innovation Theory

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This paper looks at sustainability in the construction literature using a diffusion of innovation perspective. The authors found that sustainability includes all construction sectors; incorporates both the material and project life cycles; involves all stakeholders (literally) that contribute to the construction industry, either directly or indirectly; and uses quite complex solution processes to make sustainable decisions. The authors also found, consistent with both diffusion and maturation concepts, conflicts inevitably occur between societal and/or governmental interests and private and/or individual interests. This paper also provides a taxonomic model of the sustainability issues using diffusion of innovation theory as a point of discussion for observing some of the major issues of sustainability in the construction industry.

Key Words: sustainability, sustainable technology, diffusion of innovation, green construction, project life cycle, material life cycle.

Introduction

Strasser (1999) provides a sociological basis for the wastefulness of modern society—it seems to have begun with the industrial revolution, largely because industries break the natural, closed-loop cycle of returning waste to its origins, which was present throughout most of history prior to the industrial revolution. Other factors contributing to the glut of waste include: an increasingly larger middle class, consumerism, obsolescence of products, and the use of temporary products. Over 100 years after the industrial revolution, being "green" is reaching a new popularity, more importantly construction's environmental impacts are increasingly circumspect, owing to an increased awareness of the tenuous practices of construction waste management. And industrial ecology, a phrase coined by Frosch & Gallopoulos (1989), proposes closing that broken ecological cycle between industry and nature.

The sustainability problem in construction is quite ubiquitous; it covers all construction sectors (residential, commercial, heavy/highway, industrial, etc.), incorporates the environmental impacts of material and equipment suppliers, includes all individuals, literally, in the construction industry, and involves quite complex, and extremely challenging processes. Solutions are even more complex, since they are conflicted and somewhat antithetical. Consistent with diffusion of innovation concepts [see for example Rogers (1964)], conflicts occur between "macro" (i.e. societal and/or governmental) versus "micro" (i.e. private and/or individual) objectives. Consistent with maturation model concepts [see, for example Tuckman (1965) or Morgan et.al (1994)], conflicts occur between an "internal" (i.e. I make a difference) versus an "external" (i.e. you make a difference) locus of control.

This paper provides a taxonomic literature review of the sustainability body of knowledge by taking both a macro- and a micro-perspective. Our approach is based on an incomplete, limited search of the sustainability literature, so we do not qualify the ability of this taxonomy to prove robust under intense scrutiny. Instead, the authors intend that this taxonomy become a discussion point of the literature presented.

Diffusion of Sustainability

Our taxonomy begins with the scarcity hypothesis dating back to 1798 under the classic and seminal work of Thomas Malthus, called *An Essay on the Principle of Population*. Although many of Malthus' original predictions did not occur, it raised awareness and provided a foundation for what is now called sustainability. Studies during the 1960s through the 1980s continually showed a need for scarcity awareness, but those studies tended to underestimate the ability of human innovation and new technologies to combat scarcity (Krautkraemer, 2005).

In the 1960s, Rogers (1964) printed another theory to explain this phenomenon, called the diffusion of innovation. This theory is presented below, modified for sustainability of construction wastes, scarce resources, and amenities.

Macro-diffusion of Sustainability

The acceptance of sustainability, like any other innovation in our society, generally follows a diffusion of innovation (DOI) model, where innovation is defined as any idea or practice perceived as new by the adopter. DOI theories model the adoption of technologies from both a macro- and a micro-perspective. Figure 1 shows a general model of macro-diffusion (adoption) concepts. The idea is that needs, on one hand, and technology, on the other hand, have a "symbiotic" relationship that drives the process of diffusion; in other words, it is not one or the other working alone, both are needed. Individual decision makers decide to apply a technology to a need in the "individualization" stage of diffusion. For a technology to be useful, it must pass through both a technology and a social gate. The process of "individualization" represents micro-diffusion concepts, covered later in this paper.

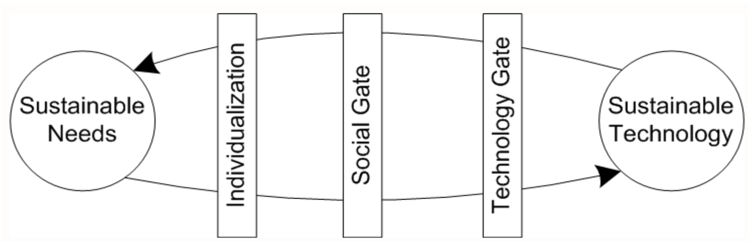

Figure 1. Rogers' (1964) Macro-diffusion Model

The approach of Rogers (1964) aids our understanding of the process of using new technology from the perspective of the adopting organization. This perspective is highly germane here because it helps explain the myriad and complex considerations for the implementation of sustainable technologies, many of which are captured in Figure 2. For example, some sustainable technologies are prohibited from implementation because they cannot pass the Social Gate due to cost prohibitions. Rogers' perspective is that many prevention-type technologies (such as a stop smoking campaign and, for our purpose here, sustainability) are not motivated by making profit, but by other financial benefits related to opposing the technology's adoption. It is the macro-perspective that makes this observation obvious.

The authors now apply this perspective to the diffusion of Sustainable Technology. The following sub-sections of the paper generally follow the layout of both Figure 1 and Figure 2: the discussion begins at the left side of the model in Figure 1, with "Sustainable Needs," which includes air pollution, water pollution, and solid waste pollution; then skipping "Individualization" the sub-sections that follow discuss the "Social Gate," the "Technology Gate," and then "Sustainable Technology." Finally, the paper turns to "Individualization" ("micro-diffusion").

Sustainable Needs.

Our sustainability taxonomy begins with "Sustainable Needs," wherein we attempt to answer the question: What are the needs that push for sustainable solutions? To answer this question, we will use the generally accepted definition of sustainability: leaving the world, i.e. mother earth, in as good or better shape tomorrow as it is today. That is to say, current generations will use earth's resources in a way that will simultaneously sustain both the needs of this current generation and of future generations. The basis of the needs in sustainability, therefore, is minimizing pollution and/or waste that work against the goals of future generations.

El-Haggar (2007) identified six categories of construction wastes: design, procurement, material handling, operational, residual, and others. CIRIA (2005) and Chen and Wong (2000) both established construction waste taxonomies by including: demolition, clearing, debris, dust, odor, air pollution, noise, sediment and erosion, and water pollution. Taking clues from these sources and others, including the U.S. Environmental Protection Agency (EPA) and environmental science literature, among others, this paper uses a somewhat simplistic, but effective, waste taxonomy: solid waste pollution, air pollution (which includes noise), and water pollution.

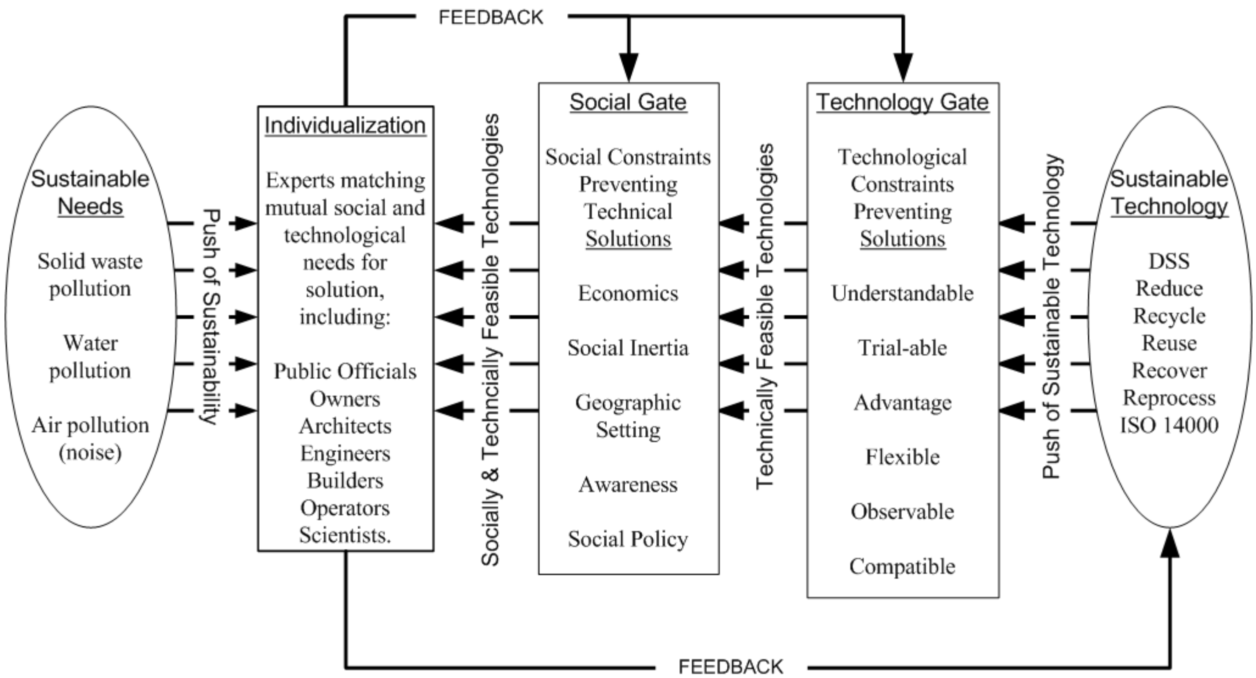

Figure 2. Diffusion of Sustainability in Construction.

Solid Waste Pollution: Construction and Demolition (C&D) Waste. Construction and Demolition (C&D) Waste are solid debris produced in the process of construction, renovation, or demolition of buildings. The components of C&D waste typically include concrete, masonry, asphalt, wood, paper/cardboard, plastic, metals, glass, paint, gypsum wallboard, carpet/padding, insulation, roofing wastes, among others. Other types of waste included in some definitions of C&D are: (1) Land clearing wastes, such as stumps, trees, vegetative materials, rocks, and dirt; and (2) Hazardous wastes, as defined under EPA's Resource Conservation and Recovery Act (RCRA). Most industrialized countries view C&D waste as a significant aspect of waste management given that these wastes are approximately equal to the quantity of municipal solid waste generated each year (Lauritzen & Hahn, 1992). Primarily, the earth is polluted by C&D waste disposal in open dumps, on land, and in landfills. Non-sustainable practices for the disposal of these wastes create environmental problems, and corrective action is likely to be expensive, complex, and time consuming.

Air Pollution: Odor, Dust, and Noise. Historically, C&D waste was considered relatively innocuous. However, odor problems in C&D waste from hydrogen sulfide (H_2S) gas are commonly a major problem, traceable, for the most part, to wet, gypsum drywall within the disposal site. The amount of drywall typically found in C&D waste varies from 5% to 30% (NAHB, 1995). Workers and residents exposed to hydrogen sulfide complain of depression, headache, nausea, vomiting, nosebleeds, breathing abnormalities, and personality changes. At many C&D landfills, H_2S concentrations above 100 ppm are found, exposure to which can quickly paralyze the olfactory senses and is considered immediately hazardous to life and health. The National Institute for Occupational Safety and Health (NIOSH) recommends a 10 ppm H_2S exposure limit for a 10-min exposure period and the Occupational Safety and Health Administration lists a 20 ppm acceptable H_2S ceiling concentration. (CAFO, 2002)

Air pollutants due to the construction industry as a percentage of U.S. totals are 15%, and 9.7% for global warming potential [carbon dioxide (CO_2) equivalent], and total toxic releases, respectively (Hendrickson & Horvath, 2000). A major source of mono-nitrogen oxides (NO_x) and particulate elemental carbon (soot) are from diesel-powered construction activities (Ban-Weiss et al., 2008). As of 2005, diesel equipment accounted for approximately 11% and 14% of NO_x emissions and fine particulate matter ($PM_{2.5}$), respectively, from all mobile sources (CARB, 2009), excluding emissions from equipment and materials delivery.

Other air pollutants from construction sites include dust and noise. Dust can damage the human respiratory system, and can increase cleaning costs, water and air pollution, property damage, fines, and construction delays, etc. For noise, OSHA requires extensive documentation related to the management of worker's exposure, but management of exposure to non-workers seems beyond OSHA's purpose. The risks of construction site noise are hearing damage, annoyance, property damage, fines, and construction delays, chronic physiological disturbances (mental illness), etc.

Water Pollution: Sediment, Erosion and Others. Soil erosion from human activity, especially urban development, contributes significantly beyond natural processes to the sediment load in water ways. Alsharif (2009) established that erosion from construction sites produce impacts over longer time periods than naturally occurring erosion in several ways: (1) fine sediments from construction erosion blanket stream beds, considerably altering stream ecosystems; (2) nutrients carried with eroded soil can contribute to the development of algal blooms and lake eutrophication; (3) higher turbidity levels from construction erosion reduce in-stream photosynthesis; and (4) soil from construction areas leaves behind less fertile subsoil that hinders re-vegetation of disturbed areas.

Estimates from human activities place soil erosion rates at 2–40,000 times preconstruction and agricultural rates (McClintock & Harbor, 1995; Holberger & Truett, 1976). Sediment erosion load from construction sites are 10–20 times those of agricultural lands, and are 1000–2000 times those of forested lands, (USEPA, 2000) and that sediment can potentially contaminate water resources by toxic chemicals attached to sediments (USEPA, 2008).

The construction of new houses, highways, and shopping malls increase the amount of impervious surfaces, thereby increasing the runoff pollutants that could potentially end up in water bodies (EPA, 2002). Even with modern storm water pollution controls, storm water from development is now the leading cause of pollution in receiving waters (Lee, Swamikannu, Radulescu, Kim, & Stenstrom, 2007).

Water pollution concerns also include the chemical contributions of C&D waste fines and the leaching of inorganic ions, specifically sulfate, predominantly from gypsum drywall (Townsend, Jang, & Lee, 1998). When gypsum is present, sulfate may leach into groundwater which may raise sulfate concentrations to as high as 1170 mg/l, compared to "Safe Drinking Water Act" maximum concentration of 250 mg/l.

Social Gate.

The Social Gate in Figure 2 reveals several reasons for sustainable technologies failing to reach implementation:

1. The needs of sustainability are largely pollution-prevention. Since this need is not directly owned by any, including the decision makers, there is little social inertia associated with it. There is certainly little profit incentive for implementing sustainability. Therefore, sustainability may not find adequate representation at the decision making table, taking a "back seat" to other direct financial and economic impacts.
2. The number of people and organizations in the sustainability decision and problem solving process is very large, even massive. Literally, it involves every individual in the construction industry, worldwide. The diffusion of sustainable solutions through this very conservative social network can be daunting.
3. Social Policy must be adequately modified to represent both the actual, direct costs of dispose, recycle, reuse, etc., but also indirect costs of using natural resources. However, the economic value of ecosystem services (from natural resources and amenities) is difficult to quantify (Krautkraemer, 2005).

Technology Gate.

The Technology Gate also helps to understand why many technologies do not diffuse even though they seem to have potential. Many sustainable technologies, such as decision support systems (DSS) tools for building environmental assessment reviewed by Haapio and Viitaniemi (2008), cannot consistently pass this gate due to a failure to be "understandable" to the user, and/or "flexible" in the results provided by the tools. Other technologies, such as ISO 14000 seem to be "un-compatible" with non-European practices (such as the U.S.), even though the advantages and benefits are readily apparent and documented in construction companies (Valdez & Chini, 2002).

Sustainable Technology.

"Sustainable Technology" is any human activity, tool, and/or knowledge that affect how the environment is appropriately used to meet the mission of sustainability. The most commonly known of these is the 3Rs (reduce, reuse, recycle), known as the waste hierarchy, adopted by USEPA and others in educational campaigns. As its name implies, the hierarchy provides an order of preference to sustainable practices (from least to most), namely: recycle, reuse, and reduce, with disposal being the least favorable. Additional R's build the hierarchy up to 4Rs (adding rethink), 6Rs, and 7Rs, adding other strategies, such as recover, reprocess, etc [see for example, El-Haggar (2007)].

A relatively recent technological development is the formalization of corporate sustainability practice in such documents as ISO 14000-Environmental Management Systems. In essence, ISO 14000 formalizes the Plan-Do-Check-Act Cycle (PDCA) decision-support tool attributed to the work of Edwards Deming, the father of modern quality control. Other tools for assisting with sustainability decision making using decision support systems (DSS) can be found in the BEES approach (Lippiatt 1999), in the work of Haapio and Viitaniemi (2008), in NAHB (2008), and in many others contained in the "Works Cited" section of this paper.

Micro-diffusion of Sustainability

At the micro-level, or "Individualization" (as it is called by Rogers in Figure 1), the process for diffusion of sustainable technologies in construction is terribly complex, as well, because both the life of a project and the life of material require consideration. Individualization is a complex, decision-making process where experts match the needs of sustainability with sustainable technological solutions. Figure 3 attempts to captures that complexity by considering sustainability in both the material life cycle (left circle) and the project life cycle (right circle). At each stage in a material's life cycle, its inputs and outputs leave both sustainable and unsustainable "footprints" in the environment. Inputs include the raw material needed to make the product; natural resource amenities such as fresh water, carbon, etc.; and energy. Outputs include carbon, and waste products of production and consumption.

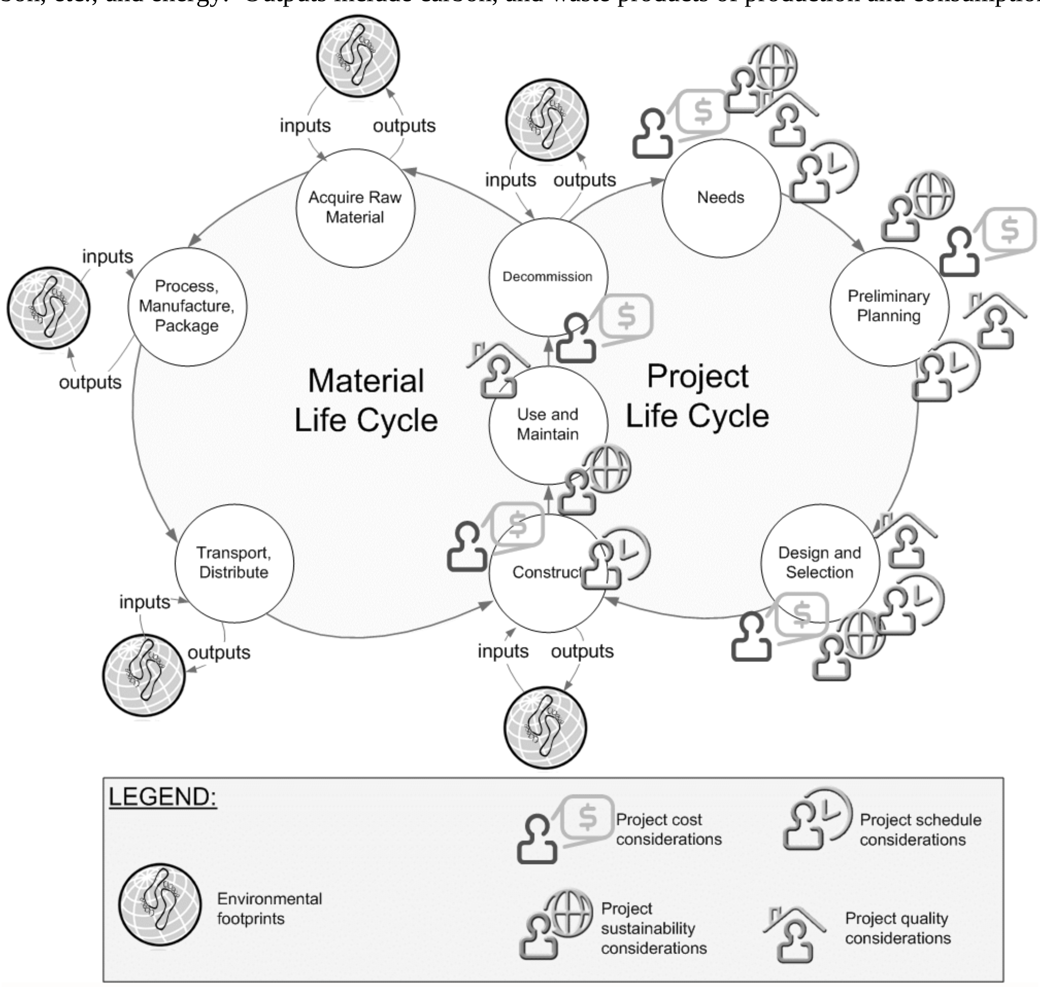

Figure 3. A Micro-Perspective of Sustainable Technology Decision Making.

As shown in Figure 3, many sustainable choices occur in the material life cycle, outside the project life cycle where the major project decisions occur. In other words, many of the sustainable decisions are only indirectly made by project managers. For example, the process of testing and researching recycled material for use in concrete construction, documented by Lin, et. al. (2004), is outside the project life cycle.

This places a great deal of responsibility on the owner and designer of a project. In other words, it requires them to be familiar with the material life cycle at a much deeper level, which, heretofore, has not received sufficient consideration. Surrounding each phase of the project life cycle are project considerations, including the classical trio (time, cost, and money), with the now added consideration for sustainability. Things are changing, for example, consider the tools from the U.S. Green Building Council's "Leadership in Energy and Environmental Design (LEED)", and ISO 14000, among others. These tools are Decision-Support Systems (DSS) that provide new insights for both the economic and environmental impacts in the material life cycle, and how to capture them during design (Lippiatt 1999).

On the other hand, the builder is in a unique place: being on both life cycles (in three phases: construct, use and maintain, and decommission) and therefore contributes to both the material life cycle and the project life cycle. Although the builder does not influence the choice of all materials in a construction project, the builder does choose some of the materials and the methods of installation. These choices give the builder a great deal of latitude in choosing "green" approaches. Many articles, like Valdez & Chini (2002), document the benefits to a builder's implementation of an environmentally-friendly business plan. El-Haggar (2007), USEPA (2008; 2004), and others, document some of the tools and processes available for builders to become more "green" and to implement more sustainable construction techniques.

Observations and Recommendations

Using the models given in Figures 2 and 3, many important and relevant points were made, above, as this paper developed these models. However, many other relevant observations and recommendations are in order here:

First, from the "macro" perspective, we observe that the relatively slow implementation of sustainable technologies, i.e. over a period of over 30 years, are heavily influenced by the "social gate" wherein governmental policies, incentives, and standards do not provide and/or require consistent industrial, ecological, life-cycle practices (Frosch & Gallopoulos, 1989). In fact, proper governmental intervention is crucial to prevent market forces from creating antithetical financial disincentives on private companies (Jaillon, Poon, & Chiang, 2009; Tam V. W., 2008; Shen & Tam, 2002; Tam, Tam, & Zeng, 2000). In the area of environmental sustainability, proper governmental intervention is difficult but critical, because government is the most logical actor for two roles: to provide protection for the environment, and to create a "level playing field" for private company competition. In other words, representing the "needs" of the environment must be properly balanced with the needs of capitalistic enterprises. Government seems to be the most logical arbiter.

Second, again from the "macro" perspective, we observe that implementation of sustainable technologies could be slowed, even prevented, at the "technology gate" due to difficulties in usability, understandability, or market advantage. Additionally, many sustainable technologies do not diffuse because the technologies' advantages are not readily observable, or they appear to be inflexible, and it seems difficult to test their "trial-ability."

Third, from the "micro" and/or "internal" perspective, a major problem with implementation is that currently available sustainable technologies are inadequate to meet the needs of industry. This may point to the need for more innovations, or to the importance of increased training on products and practices, to the need to modify technology to make it more life-cycle friendly, or to the need for more research.

Fourth, again from the "micro" perspective, we observe that the stakeholders in the project life cycle (as opposed to the material life cycle) do not have direct control over the many decisions involved with making a product, and therefore making the project more "green." Indeed, contractors (specifically) often do not have direct control of any of the decisions regarding the materials of construction, since these decisions are made by the material manufacturer, supplier, and/or the designer/owner.

Fifth, one of the issues this research explored was the issue of maturation, especially the maturation of construction companies toward the use of sustainable technologies. What we found is that another body of literature exists that explains group decision making and group dynamics. That body of literature was deemed beyond the scope of this paper. However, even though the maturation literature focuses on small group decision making, there is consistency with the "micro" perspective in the conclusion that group development and group decision making is quite complex and difficult to model (Tuckman 1965). Regardless of this difficulty, contractors should continue to consider the impact of their own construction practices on the sustainability of a construction project, and begin making the difficult changes needed to achieve sustainability.

Summary and Conclusion

The evidence of the impacts of construction activities on the environment is large, and therefore diffusion of sustainable technologies continues, albeit slowly. In all facets of construction, and all elements of nature, the evidence clearly points toward increased diffusion.

However, this paper shows that the diffusion of sustainable technologies through the construction industry is slowed because of the myriad issues, stakeholders, and policies. Equally, at-large societal issues, individual project issues, as well as individual companies, play a role. Making a construction project "green" is not just a matter of having a "green" contractor, that is one element, but it includes the material suppliers, the owner, the A/E, and the governmental actors, among others.

There is a real need for research to continue to support all stakeholders in the construction industry. In almost all areas, macro- and micro-, the need for the development of usable and useful "green" and sustainable technology still exists, as does the need to develop tools that support sustainable decision-making in both the material and the project life cycles. Specifically, further research support is needed on sustainable technology decision making in construction companies.

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