

Virginia Tech Myers-Lawson School of Construction

Undergraduate Civil Engineering Sustainability Education Metric (UCESEM)

Benchmarking Civil Engineering Program Performance

Project and Report submitted to the Faculty

In partial fulfillment of the requirements for the degree of
Master of Science in Civil Engineering

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November 30, 2009

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Abstract

Civil engineers design and execute new construction from support infrastructure such as water pipelines, roads, and bridges to suburban housing and metropolitan high-rises. Colleges and universities have the responsibility to prepare new civil engineers with the toolbox they will need in order to succeed in the workforce, yet they continue to provide sporadic education of sustainable design and construction practices. This is due, in part, to the difficult-to-quantify, context-dependent, and non-standardized nature of sustainable engineering instruction, and the missing incentive toward the aggressive pursuit of implementation. The annual *U.S. News and World Report* issue on 'America's Best Colleges' is a recognized metric reporting how colleges 'rack and stack' against each other. While there is some controversy as to the appreciated validity of these rankings, in an effort to maintain their competitiveness for quality students, colleges will alter their programs in relation to ranking criteria. Similarly, the College Sustainability Report Card, also known as the 'Green Report Card', established with its first report on sustainability in 2006, evaluates the quality and comprehensiveness of the campus sustainability practices of 300 institutions. While the resulting 'grades' motivate college administrators to surpass their competitors, no similar metric exists to measure performance of a program with regard to sustainability education. This paper describes the development of such a comparative metric, modeled after the *U.S. News and World Report* system and the *Green Report Card*, for undergraduate civil engineering sustainability education. A review of existing literature, case studies, and attitudinal reports, while considering feasibility of program data collection, are included as factors toward metric criteria identification. Finally, the metric is tested on civil engineer-applicable syllabi included in the Center for Sustainable Engineering's final report, *Benchmarking Sustainable Engineering Education*. Generation of the metric categories, assignment of weightings, and finally testing of the metric on the syllabi identified further areas for research, included in this report.

1.0 Introduction

As world governments continue to recognize the need to operate leaner, with a decreasing impact on the environment; as corporations respond to the 'energy crisis' and desire to be competitive with their challengers; as citizens of the world pursue an intrinsic connection to their environment and products they consume, so is there a need to inform these stakeholders in methods available to minimize negative impacts of their operations while improving the sustainability of the environments within which they operate. Providing information to these stakeholders takes many forms, one of which is a need for the members of these stakeholder organizations to have the necessary tools to operate in such a method as to be considered more sustainable. In response to this growing need, the United Nations decreed the 'United Nations Decade of Education for Sustainable Development', Resolution 57/254, February 2003, which gives Higher Education Institutions further incentive to integrate sustainability into their curricula (Haigh 2005).

Buildings in the U.S. account for 39% of total energy use, 12% of total water consumption, 68% of total electricity consumption, and 38% of carbon dioxide emissions (EPA 2008). Employment in the construction industry is projected to increase from the approximately 6.9 million jobs in 2004 to 7.7 million jobs in 2014, an increase of nearly 800,000 jobs (ETA 2008). This growth reflects both skilled laborers as well as degreed professionals. Additionally, civil engineer employment is expected to grow at a rate of 18% between 2006 and 2016 (BLS 2008). The impacts of civil engineer construction products in conjunction with the growth rate of the profession and the increasing attention on sustainable practices, requires a comprehensive engineering education, coupled with subsequent employer training to ensure engineer professionals are equipped to perform sustainably.

The growing need to produce products with an attention to sustainability calls for students to fill positions in industry or future faculty for research that can perform in that manner. Educational institutions worldwide are in pursuit of methods to educate in sustainable options and decision-making to the growing number of future civil engineer professionals. In order for them to be prepared, current faculty must issue them the knowledge and abilities to incorporate sustainability. However, "many believe that our present educational structures are less appropriately geared to meeting the needs of the future than to reinforcing the destructive characteristics of our current age" (Berry 1999; Sterling 2001 as referenced in Haigh 2005). Harvard's Graduate School of Design recently started offering a concentration in sustainable design, a move that "was driven by interest from students and changes in the field". Additionally, Christoph Reinhart, an associate professor in this school, said "over the past few

years, there has been an increased interest and pressure to provide this knowledge in more depth, whereas before, maybe a class would have been sufficient...now there's an expectation that more of these [sustainability] skills are being learned" (Berman 2009). These educational structures are making change, as will be explained in a later section, but there are no methods to currently assess the starting point or progress of them.

University educational programs, particularly in the applied field of civil engineering, play a crucial role in sustainability education because they educate the future leaders in the construction industry (Ahn et al. 2007). As Haigh argued, despite the growing importance placed on sustainable engineering education:

"it is difficult to imagine higher education making the changes needed to effect ESD [Education for Sustainable Development], even in 'greening' of their own offerings without outside help...in academe, the voices that speak for the future and for green issues are few, often marginal...such ideas are challenged by a powerful mindset that still regards the world as boundless..." (Haigh 2005).

One genesis of this 'outside help' takes the form of metrics that can benchmark and stimulate competition between programs and provide for ultimate baseline standardization of civil engineering sustainability instructional methods.

Such a metric would serve multiple ends. Companies are already familiar with, and in some cases develop, their own internal evaluation system for the quality of their employees from various colleges and universities, and a civil engineering sustainability education metric will help to quantify the anticipated education of new hires (Strategies 2009). Students and parents searching for a comprehensive civil engineering education would be empowered to further delineate the factors important to them in their continued education. Above all, a recognized sustainability metric would encourage institutions to improve their focus on sustainability and sustainable issues, through their desire to achieve top rankings and remain competitive with their peers. The first step towards understanding the concept of sustainability for civil engineers is to have it defined, in order for the drivers and stakeholders to be identified. These drivers, combined with the stakeholders, help to identify the construct for a metric as well as those who could utilize such a product. The following sections further set the stage for metric genesis.

1.1 Sustainability Defined

The concept of sustainability comes in many forms, and has multiple definitions. The often quoted definition of sustainability practices requires that they “meet present needs without compromising the ability of future generations to meet their needs” (WECD 1987). This research utilized the definition of sustainability as “the practice of producing, consuming, and developing in a manner that preserves the environment, economy, and society for future generations” (Riley et al. 2007). The environment, economy, and society are the three well-known pillars of sustainability which were defined following the Earth Summit held in Rio de Janeiro, Brazil, in June 1992 and the subsequent United Nations creation of the Commission for Sustainable Development (Development 1992). Sustainable construction practices require that buildings are “designed, constructed, operated, and demolished in an environmentally and energy efficient manner which can reduce the impact of buildings on the environment, to improve working environments for building occupants, and reduce building operation and maintenance costs” (Bosch and Pearce 2003 as referenced in Ahn et al. 2007). Sustainability often includes ‘sustainable development’, which is sustainability at a local, regional and international development scale. Some of the resources for sustainable development were used in the course of this research, as it identifies key indicators or categories for assessing the level of sustainability for a project, some of which may be implemented to assess sustainability coverage of a program.

In turn, sustainability education is often substituted with ‘greening the curriculum’ or ‘education for sustainable development’ and ‘environmental education’ (McKeown and Hopkins as referenced in Haigh 2005). Established and senior civil engineers become educated about sustainability concepts through employer-administered training and seminars sponsored by professional organizations, among other venues. It remains the responsibility of colleges and universities to prepare new civil engineer professionals. Despite this responsibility, as was illustrated in the *Benchmarking Sustainability Engineering Education Final Report* and through other sources identified in a literature review, institutions continue to provide sporadic offerings of sustainability civil engineering education courses for design and construction practices (Allen et al. 2009; Cotgrave and Alkhaddar 2006). The need for innovation in sustainability may be viewed along the lines as that for leadership. As Chinowsky and Songer discussed, “no longer can industry enterprises be satisfied with continuing long-held family or corporate traditions. Similarly, universities can no longer view the education of future professionals in the same manner” (Chinowsky and Songer 2005). McGraw-Hill predicts that by 2010, the annual expenditure on green building will exceed \$59 billion; this is a growth of \$48.8 billion since 2004

numbers of \$10.2 billion (McGraw-Hill Construction 2005 as referenced in Ahn and Pearce 2007). As new graduates enter the industry, they are expected to be familiar with the most recent developments in the engineering and construction field. A survey performed in 2006 at construction career fairs and recruitment visits at three universities, showed that 65% of industry survey respondents “indicated that they expect graduates to have some knowledge of green building” (Ahn and Pearce 2007). The demand for graduates with knowledge and familiarity in sustainability stems from ‘real world’ drivers such as growing concerns about finite natural resources and environmental impacts. The stakeholders in the education for sustainability include students, faculty and education. These stakeholders and how a metric could facilitate sustainability education are further discussed in the next section.

1.2 Sustainability Metric Drivers

Metrics provide a framework for the establishment of quality programs. The Construction Industry Institute studies the benefits of benchmarking and metrics. Their report showed that effective benchmarking identifies ‘critical success factors’ and in doing so, provides measurable, meaningful, and simple results that are related to the desired outcome and drives further refinement of the measured criteria. An often-quoted mantra of managers, developed by the Total Quality Management movement and ISO 9000 is, ‘that which gets measured, gets improved’. An internet search of this quote shows that it is a widely-applied benchmarking and metrics adage from topics such as fitness, to sales, and in this case, educational programs. To further understand the value of metrics to users, one must only look at the pervasive and referential nature of *Consumer Reports*, an independent magazine that reports on quality indicators for a multitude of categories of consumer products. Or, in the area of education, the value users place on metrics evaluating colleges for them to send their children to, attend, or hire from, can be understood through their magazine sales. In 2005, *U.S. News & World Report* sold 45,000 newsstand copies of the “Best Colleges” edition, which was in addition to a paid subscriber list of 2 million. Additionally, they sold “several hundred thousand” copies of their 280-plus page “America’s Best Colleges” newsstand guide, which included a directory of 1,400 colleges (Su 2006).

The missing piece from the current pursuit of educating civil engineers in the practice of sustainability is depicted in Figure 1.1. This research will propose an introductory framework for the Undergraduate Sustainable Civil Engineering Education Metric (USCEEM), which could be modified and used for other programs.

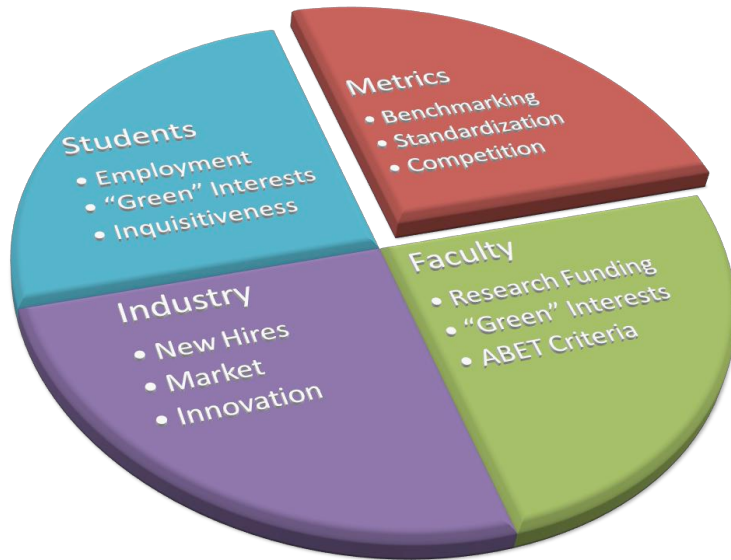


Figure 1.1 The Missing Piece: Metrics

The figure shows the stakeholders in sustainability engineering education, some of their respective motivations in general and specifically in regard to sustainability. As depicted in the figure, metrics are the missing piece for education in sustainability and their inclusion would aid to provide topic and method benchmarking, which could facilitate standardization upon those topics that are considered to be the foundation that every civil engineer should have. Innovation beyond the standard coverage would result from competition between universities. The stakeholders and their expectations are further discussed in the literature analysis section of this report.

Krieger advocated the need for “environmentally friendly construction” professionals by suggesting that “demand is booming...but it’s booming so fast that there aren’t enough skilled professionals to do the work” (Krieger 2008). It is imperative for undergraduate institutions to educate and prepare these new engineering professionals in the burgeoning field of sustainability. However, each institution is in effect, required to reinvent the wheel. The recently completed *Benchmarking Sustainability Engineering Education Final Report* took a significant step toward identifying existing sustainability engineering education, in an effort to provide a stepping stone for course creation and refinement, but the challenge for educators, industry and students is the currently non-standardized nature of these programs. Some would argue that standardization will limit innovation. However, standardization does not necessarily prohibit creativity. Flexibility and creativity are important, but the lack of a benchmarked metric with which to compare and rank programs leaves educators to either sporadically implement sustainability into their programs, or to avoid it altogether. Additionally, a metric would serve as an evaluative tool

for industry headhunters in their application review process, as well as a resource for new civil engineering students evaluating prospective programs.

Sustainability-minded professionals in the United Kingdom studied the challenges for the implementation of sustainability into universities, and suggested that the source of the problem might be research funding. They suggested that the pursuit to achieve cross-discipline, integrated programs is hampered, by the departmental pursuit of specialization. In this regard, departments treat environmental issues as their property and “lock their offerings away behind the barriers of specialization” (Haigh 2005). As engineering programs consider the implementation methods for sustainability, they should consider that educational psychologists note that people retain 80% of what they do and only 10-20% of what they hear or read (Cortese 2001 as referenced in Haigh 2005). Therefore, a civil engineering program should include a mixture of sustainability concepts integrated into core curriculum, while ensuring that opportunities for practice are also included.

What constructs of sustainability engineering education currently exist and what would be an appropriate metric with which to summarily evaluate the programs provided by undergraduate civil engineering programs? It is important for there to be a consolidated resource for sustainability education, an initiative which is currently underway through the Center for Sustainable Engineering and the *Engineering* Pathway. Education in sustainability for civil engineers continues to grow and varies across institutions. The inconsistent methods for sustainable education in civil engineering programs lead to inconsistencies in the acquired skills of graduates.

While the ABET criteria do outline general skills, they do not identify methods for employers to delineate the quality of the education in sustainability that applicants possess. Additionally, applicants to civil engineering programs do not have a tool to assess the quality and importance of sustainability topics in the curriculum of institutions to which they apply. Current educational quality programs evaluate the passing rate of graduates taking the Fundamentals of Engineering exam. While this is an advantage engineering schools have in program evaluation over some other disciplines, it does not capture the sustainability concepts, critical for today’s and the next generation’s civil engineers.

Metrics serve multiple ends. They provide a benchmarked framework along with a comparative and competitive means to evaluate similar programs. Recognition provided by an evaluative metric serves as a catalyst to boost the number of projects that are increasingly environmentally friendly (Siddiqi, Chatman and Cook 2008). This phenomenon is facilitated through the LEED certification process and the

Green Report Card, but a metric to evaluate the quality of sustainable engineering programs does not yet exist. This research captured reported expectations of university faculty, industrial professionals and students, coupled with current methods for sustainability practice instruction, while maximizing utilization of existing data streams for metric capture, in order to develop a metric of benchmarks to facilitate the future comparison of undergraduate civil engineering programs.

1.3 Overview

This research focuses on the development of undergraduate civil engineering education programs for sustainability and a metric with which to provide an evaluative framework for developing and improving educational methods while encouraging healthy competition between civil engineering programs.

This project identifies indicators of quality sustainability integration in civil engineering programs. The key concepts for indicator/category development, as detailed in the World Bank publication, *Indicators of Environment and Sustainable Development*, are data, indicators, indices and information. The data is the basis for indicators and when selecting data it is important to consider its availability. Indicators are derived from data and provide a “basis for assessment by providing information on conditions and trends of sustainable development”. They provide “input to policy formulation processes” and through the roll-up process of combining several pieces of data in one statistic, “they can facilitate communication between different groups, for example between experts and non-experts”. Combining two or more indicators results in an index, this is used at an “aggregated analytical level”. Once indices are created, their goal is for improved decision-making, once that is achieved, as the report suggests, so too has ‘information’ (Segnestam 2009).

The course of this project identified multiple categories and tools for integrating sustainable engineering into civil engineering curricula. Background investigations into sustainability options for civil engineers led to the creation of a preliminary method for evaluating the pursuit and coverage of sustainable engineering in civil engineering programs through the Undergraduate Civil Engineering Sustainability Education Metric (UCESEM). This metric utilized materials and results from the *Benchmarking Sustainable Engineering Education: Final Report*, the structure for the Sustainability in Higher Education Assessment Rubric (SHEAR) developed by members at Pennsylvania State University, the Sustainability Skills Matrix for the Built Environment Functions and the Campus Sustainability Green Report Card. Additionally, characteristics from a case study and attitudinal surveys were compiled to

develop criteria, along with a suggested weighting, to generate a preliminary evaluation matrix for undergraduate civil engineering programs. The preliminary form of the metric presented in the findings section, factors in changes to the Green Report Card ratings for a school from year to year and deducts points for slipping grades.

Not only does this metric have the capability of being implemented in a similar fashion as the U.S. News & World Report and the Campus Sustainability Green Report Card, but once vetted by education and industry professionals may serve as a general framework for sustainability topics for current and future courses. When the education sector is aware of how they compare internally, and fully understands the needs and wants of the industrial sector to which they are providing graduates, they may better understand expectations and produce results that meet or exceed those expectations.

2.0 Project Methodology

In pursuit of developing metric and benchmarking methods for sustainability engineering education, the research will follow the left-hand side of Figure 2.1. This figure illustrates the cyclical and refining nature of benchmarking initiatives. This project largely concentrates on the first two operations within the roadmap, but does go further into developing a method for data collection from syllabi and continues to collect that data to show how the Undergraduate Civil Engineering Sustainability Education Metric (UCESEM) could work.

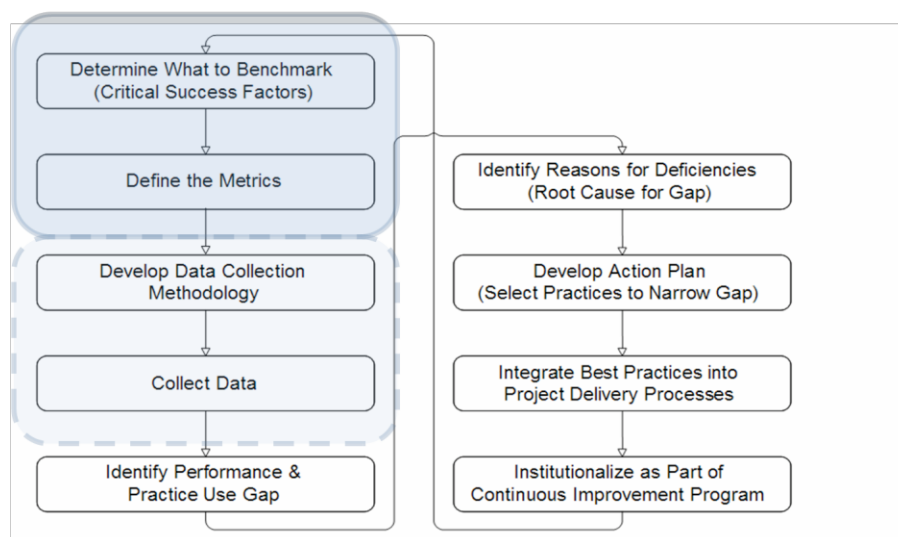


Figure 2.1 Benchmarking roadmap (Adapted from Camp, 1989. (Robert C. Camp)

Specifically considering sustainability, the World Bank suggested methods to implement a similar framework, with suggestions for how each step might be accomplished. The steps as detailed in the World Bank publication, *Indicators of Environment and Sustainable Development*, were as follows:

1. Development and harmonization of a framework to organize the information
 - a. Identify what is to be monitored
 - b. Identify Impacts of monitoring
2. Definition of selection criteria, indicator sets, and analytical methods/tools
3. Establishment of participatory/consultative network
 - a. Workshops to identify goals and needs
 - b. Personal visits
 - c. Identify contact people
 - d. Exchange results
4. Data search and development of databases for the indicator sets and analytical tools
 - a. Availability of data
 - b. Development of Indicators
 - c. Development of capacities and tools to visualize information and analyze cause-effect relationships
 - d. Enable identification of causal links
 - e. Visualize the results
5. Development of test studies for the validation of project results
6. Dissemination of information and tools
7. Design of actions and implementation

(Segnestam 2002)

A challenge for developing indices for sustainability topics, to include coverage of sustainability in education, is that, as shown in Figure 2.2, in theory, the data set should have a “broad base of good quality primary data on which the indicators and indices rest on”. Yet, in actuality, the available data set to quantitatively measure sustainability coverage in education is small and many indices attempt to capture sustainability from the small data set (Segnestam 2002). As will be discussed later in this report, current measurements of sustainability and engineering education include the Green Report Card and ABET degree certification, respectively. This report identifies a construct with which to analyze and include syllabi in this primary data set, as well as recommending in the areas for further research, other data that could be included in future iterations of the metric.

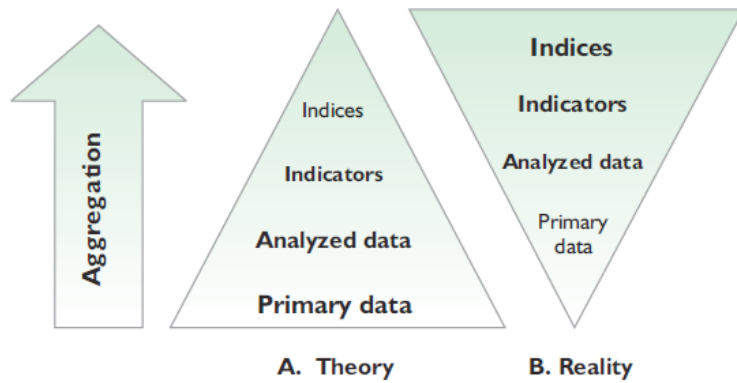


Figure 2.2 The Information Pyramid (Segnestam 2002)

This project reviewed civil and environmental engineering courses from the *Benchmarking Sustainable Engineering Education Final Report* to compile sustainability engineering options within a typical civil engineering department, as illustrated in Figure 2.3. Characteristics and expectations identified from existing research and reports, for sustainability education will be translated into a proposed evaluation metric.

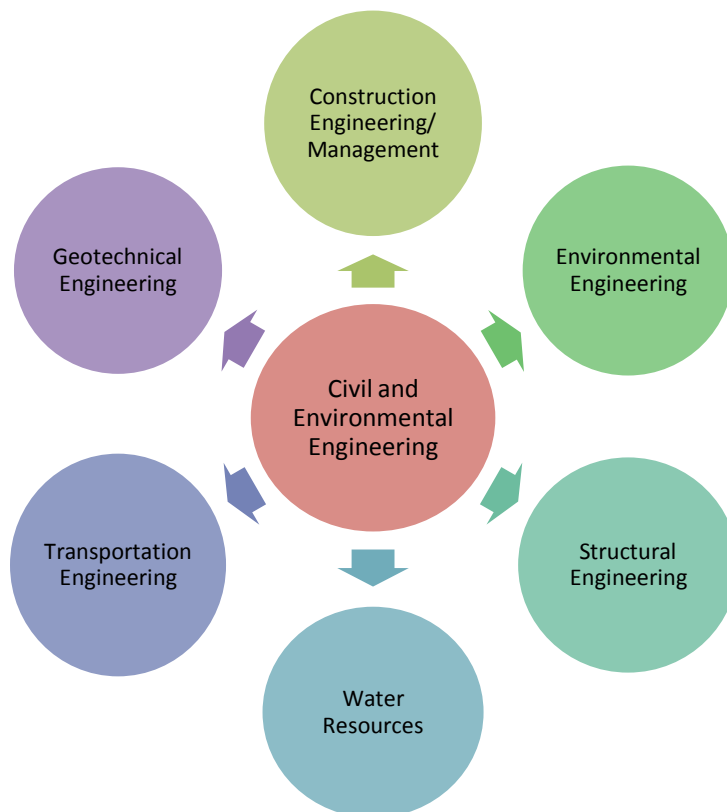


Figure 2.3 Civil and Environmental Engineering Department Structure

The previously discussed frameworks were considered during the creation of this project's methodology. The methodology for this research followed the framework shown in Figure 2.4.

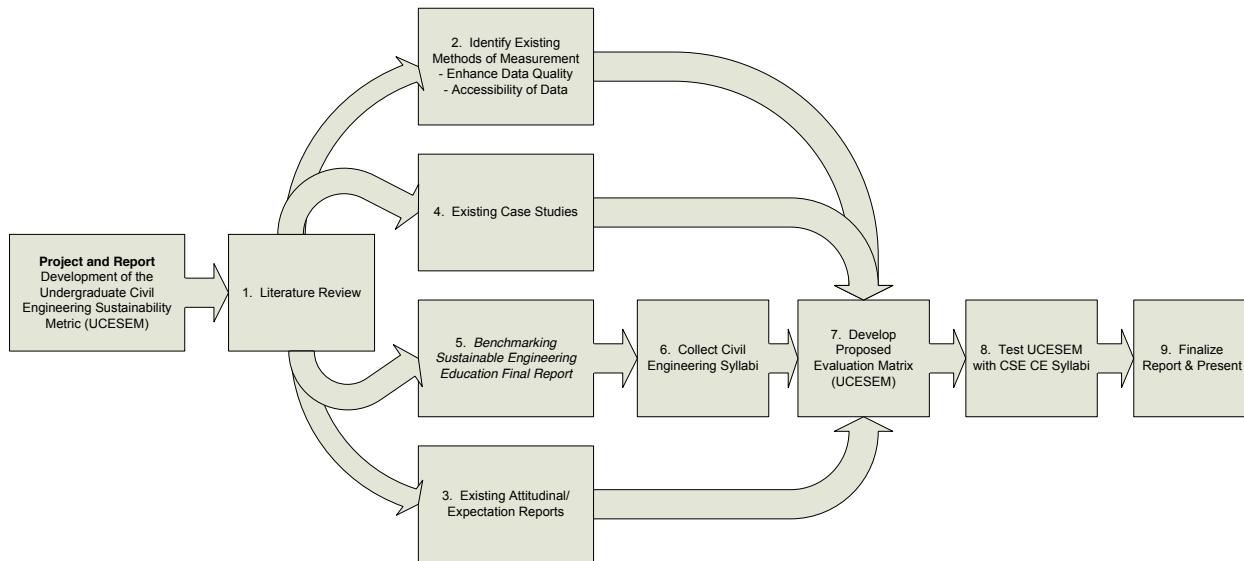


Figure 2.4 UCESEM Development Methodology

The first step towards the UCESEM was the literature review. It provided extensive information contributing to the generation of the metric as expectations and demand for sustainability-infused programs came from previous studies and reports. Additionally, these expectations, in concert with existing frameworks for sustainability instruction were combined to form the categories for the metric. The second step was infused through step seven, to identify categories that could be easily responded to and easily included in the metric. The third step included harvesting existing attitudinal and expectation reports from industry, faculty and students, as well as using ABET certification as an expectation and motivational area for faculty. The fourth step was to use existing case studies of university sustainability infusion and specific course sustainability instruction methods. The fifth step was to review the *Benchmarking Sustainable Engineering Education Final Report* for the utilized methods and harvested information in their benchmarking endeavors. The sixth step included identifying the syllabi from the appendix of this report to utilize for the generation of categories, in addition to the existing constructs and expectations, for the UCESEM, the seventh step, and then test the UCESEM in the eighth step. The third section of this report goes into further detail on steps two through five, while the fourth section, metric development that were taken through the progress of this research. The fourth section details the process in steps six through eight.

3.0 Literature Analysis

The literature analysis was conducted in order to identify the existing work in the areas of sustainability education and metrics. A literature map illustrating the stakeholders of civil engineering education was used to categorize the literature obtained in this project and is depicted in Figure 3.1.

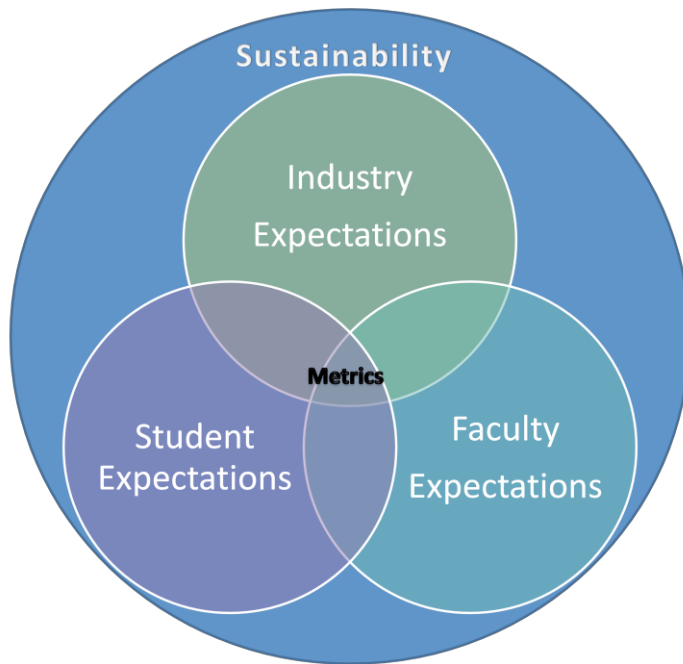


Figure 3.1 Stakeholder Literature Map

Each of the areas within the Venn diagram resulted in at least three references, and in many cases, especially the areas of industry and faculty expectations. The intersection of those users and their expectations in regards to sustainability should be the primary criteria that would coordinate to form the evaluation metric. There are existing reports and organizations involved in the area of characteristic and criteria identification for sustainability in education. These include the Green Report Card, an established assessment of campus sustainability practices, The Center for Sustainable Engineering (CSE) at Carnegie Mellon University, and the Sustainability in Higher Education Assessment Rubric (SHEAR) developed by members at Pennsylvania State University. Information from these sources, in combination with the expectations and demand of the stakeholders, were utilized to form the Undergraduate Civil Engineering Sustainability Metric (UCESM). The second step from Figure 2.4, identifying existing methods of measurement to enhance data quality and accessibility, was considered throughout the literature review of attitudinal and expectation reports, case studies, and the *Benchmarking Sustainable Engineering Education Final Report*.

3.1 Methods of Measurement

The second step from Figure 2.4, the methodology toward metric development, required identification of existing methods and metrics to assess sustainability. The focus for this research net was on measurement methods in civil engineering and construction fields. This step identified categories, beyond those netted from the expectation reports and case studies, discussed in the following sections, for inclusion in the Undergraduate Civil Engineering Sustainability Education Metric (UCESEM). The methods of measurement are divided into overall, individual and project, program and university measurement.

3.1.1 Overall Sustainability Measurement

Overall measurement of sustainability includes many organizations worldwide involved in the initiative to further sustainability. For example, the International Institute for Sustainable Development (IISD), a non-partisan, charitable organization “dedicated to...implementation of policies that are beneficial to the world’s economy, environment, and social well-being”. The IISD recently updated their methods for measurement and assessment of sustainability. The ISSD BellagioSTAMP: SusTainability Assessment and Measurement Principles, published in 2009, replaced the original Bellagio Principles published in 1996, and intends to “guide the totality of the sustainability assessment process” to include the “choice and design of indicators, and how they are interpreted and communicated”. The eight guiding principles for the STAMP, include guiding vision, essential considerations, adequate scope, framework and indicators, transparency, effective communication, broad participation, and continuity and capacity (IISD 2009). These principles should be considered when developing a metric, such as the UCESEM.

3.1.2 Individual and Project Sustainability Measurement

This section on sustainability measurement includes methods used in industry to quantify and capture the sustainability of construction projects, such as provided by the LEED rating system. The LEED system also provides methods to assess metric familiarization by recognizing LEED accredited professionals following successful passing of the accreditation exam. Other methods exist for assessing sustainability in projects, and these are discussed at the end of this subsection, wherein a study identified tools that are used to facilitate green building. Both of these subsections identify potential categories for inclusion in the UCESEM.

3.1.2.1 LEED

Leadership in Energy and Environment Design, more commonly referred to by the acronym LEED, is the most widely recognized method for individual accreditation and facility certification in the United States. The United States Green Building Council (USGBC), the 501 c3 non-profit organization charged with “transform([ing] the way buildings and communities are designed, built and operated, enabling an environmentally and socially responsible, healthy, and prosperous environment that improves the quality of life” owns the LEED system. The LEED website reports over 35,000 projects participating in LEED, in all 50 states and 91 countries. Additionally, involvement of industry and education professionals grew to over 100,000 LEED Accredited Professionals (APs) with more than 20,000 member companies and organizations. These participants make up “an unlikely diverse constituency of builders and environmentalists, corporations and nonprofit organizations, elected officials and concerned citizens, and teachers and students (USGBC 2009).

LEED v3.0, launched on April 27, 2009, entails many procedural changes from the previous version. The previous accreditation requirement included passing a LEED v 2.2 test, with no continuing education or testing requirements. New applicants to LEED must first pass the Green Associate exam and may then take a LEED specialty exam to become a LEED AP. Additionally, LEED v3.0 will require increased maintenance from LEED v2.2, as the new process requires following a Credentialing Maintenance Program (CMP). All credentials, whether they be LEED AP or LEED Green Associate must maintain 30 and 15 Continuing Education (CE) hours biennially, respectively. There is a grace period for current LEED APs, who tested under LEED v2.2, where they have 3 years from their certification date to register under the CMP. The program is self-reported, and therefore the information could be easily copied and tracked by the civil engineering department administration office, once the LEED Green Associate/AP reports their CE hours in the CMP. Another option for continued certification for LEED Professionals, both Green Associate and AP, is to retake the exam between 3 and 12 months from the end of their reporting period. Whichever method the LEED professional takes to maintain their certification, the civil engineering department administration office could be notified of CE credit updates and/or test retakes. This would give the department visibility on the certification of their faculty.

Tracking LEED accredited professionals should be considered for UCESEM implementation. It is a recognized certification method for industry professionals, and it is assumed that a department that encourages certification of its faculty would encourage sustainability education in the program and amongst its students. However, when the administration in Virginia Tech’s Department of Civil

Engineering was asked, due to the accessibility of staff to the researcher, if they tracked the number of faculty LEED APs, they responded that it was not currently tracked. Since it is not required by any existing metric, Virginia Tech is not likely to be the only one with the same response. Instead, until it is required, tracking of this certification will not likely be implemented. Tracking the certification of LEED AP faculty would not be energy intensive, and could provide more useful information for future UCESEM implementation. Initial implementation of this category's inclusion would be challenging, because some departments do not track it, and the data would need to be gathered by metric implementers. However, once it is accepted in a metric such as the UCESEM, following an initial grace period to give departments the chance to start tracking accreditations, it is suggested that those departments that do not report this information, have their lack of participation negatively reflected in the metric.

3.1.2.2 Green Building Data Selection Tools

Many decision support tools exist to facilitate green building, such as the previous subsection discussing LEED. A survey of these identified 275 design-related tools that could be used for different subsets within the design of a facility. It was determined that a small number of these would be applicable to reviewing credit accomplishment within LEED (Keysar and Pearce 2009). The LEED-applicable tools would be ideal to impart upon future building professionals, such as those generated through undergraduate civil engineering programs. The categories of selected tools are provided in Table 3.1.

Table 3.1 Green Building Data Selection Tool Categories

Mechanical/Electrical/Plumbing Systems	Air Flow and Ventilation	Lighting and Daylighting
Web Sites	LEED-Recommend Tools	Sites
Rating Tools	Compliance, Code Checking, and Standards	Case Studies
Education and Professional Development	Materials and Product Specification	Energy Analysis
Life Cycle Analysis	Life Cycle Costing	

(Keysar and Pearce 2009)

These selection tools provide example categories that were considered in the development of the UCESEM. The provide examples of categories that could be covered, and as will be seen in the findings section, were covered, in the syllabi contained in the *Benchmarking Sustainable Engineering Education Final Report*, the source utilized in the development and testing of the proposed UCESEM.

3.1.3 Program Measurement

As discussed earlier, measurement provides a method with which to benchmark and provides competition incentive for educational programs and overall institutions as a whole. The point of departure for existing measurement methods of civil engineering programs includes external and internal evaluation systems. Civil engineering program accreditation is accomplished through ABET, which accredits programs that meet with its requirements. External ranking systems such as U.S. News and World Report provide comparisons between schools and educational programs based on established criteria and weightings. Additionally, university faculties have the option of utilizing internal self-assessment tools such as the Penn State Sustainability in Higher Education Assessment Rubric (SHEAR). Finally, overall school comparative ratings are accomplished through metrics that evaluate the college or university's sustainability of its operations, such as the Green Report Card. These tools differ in their scale of application, the person who applies them and the utility of their outcomes.

3.1.3.1 External Measurement

The following external measurement methods for civil engineering programs are undertaken through collaboration between departments and the organization conducting the assessment. The Undergraduate Civil Engineering Sustainability Education Metric (UCESEM), when implemented, would be an additional external measurement that would be facilitated through participation of the department in tracking and responding to the categories, as discussed in the metric development section of this report.

ABET

The organization originally known as the Accreditation Board for Engineering and Technology, now officially referred to as 'ABET', is the recognized certification body for university and college engineering programs. ABET currently accredits approximately 3,000 programs at over 600 colleges and universities nationwide, including 225 civil engineering programs, four of which are outside of the U.S. with an additional two in Puerto Rico.

Early ABET criteria were criticized as being "overly restrictive and focused upon design and science requirements of an earlier era" (Bowman and Farr 2000). With the inception of Engineering Criteria 2000 (EC2000), ABET changed its focus from input-based criteria, to outcome-centered, from "what is taught" to "what is learned". This gave programs the flexibility to innovate methods and topics for instruction, to include innovations in the area of sustainability (ABET 2009).

The ABET certification process includes a program self-examination, and an on-campus visit with reviews of course materials, student projects, sample assignments and interviews of students, faculty and administrators. The school will receive feedback to include strengths, weaknesses, deficiencies and recommendations, from which the school may make improvements. Programs are granted a maximum of 6-years of accreditation and must be renewed by the institution (ABET 2009).

ABET Criterion 3a-k requires a “multi-disciplinary approach to education that instills ethics, responsibility, and awareness in engineering students in addition to the technical skills traditionally required of them so that students fully understand the impacts of their profession on the built and natural environments” (Riley et al. 2007). These criteria were divided into ‘hard’ and ‘soft’ skills, as shown in Table 3.4. Of note are the parallels between Criterion 3h, “understand the impact of engineering solutions in a global, economic, environmental, and societal context”, and the sustainability pillars of environment, economic and social. “The new ‘soft,’ or intangible, skills mandated by the accrediting board [...] have proven difficult to define, teach, and measure, leaving educators grappling for instructional methods that can be used to instill the new [soft] skills in our students” (Riley et al. 2007).

Table 3.4 ABET Requirements

“Hard” Skills - An ability to apply knowledge of mathematics, science and engineering (3.a) - An ability to design and conduct experiments, as well as to analyze and interpret data (3.b) - An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability (3.c) - An ability to identify, formulate, and solve engineering problems (3.e) - An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice (3.k)
“Soft” Skills - An ability to function on multi-disciplinary teams (3.d) - An understanding of professional and ethical responsibility (3.f) - An ability to communicate effectively (3.g) - The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context (3.h) - Recognition of the need for, and an ability to engage in lifelong learning (3.i) - A knowledge of contemporary issues (3.j)

(ABET 2005 as referenced in Riley et al. 2007)

ABET accredited degree programs must address these sustainability-oriented “hard” and “soft” skills in order to be accredited. As is discussed in the metric development section of this report, these

programs were essentially vetted by ABET and represent a solid point of departure for the UCESEM development.

Degree Ranking Systems

In his article, *What Does College Teach*, Richard Hersh identified some of the other measures available for ranking systems. He listed the four major categories of measures of college quality that were originally listed by Mark Chun: actuarial data, expert ratings, student/alumni surveys, and the direct assessment of student performance. Each of these has pros and cons, but Hersh suggests that ranking systems should be concerned with cumulative assessment programs, but that current barriers to development are the arguments of “intellectual freedom and faculty autonomy” (Hersh 2005).

Students pursue higher education for many reasons. Topping the list is the ultimate pursuit of future employment. When students select programs, they will consider many issues. Among these is the rank that their school has. This is because “students are aware that the rank of their school may affect their employment activities” (Reese 1998 as referenced in Clarke 2007). Research shows that rankings “have been linked to changes in national and cross-national application patterns as achievement-oriented students seek the globally top-ranked program in their area” (Davie 2006 as referenced in Clarke 2007).

Critiques of current ranking systems focus on the validity of the indicators and weights used (Clarke 2004 as referenced in Clarke 2007). Whether current metrics are the ultimate solution for understanding the quality of education provided by a school or university, they are one method for normalizing and comparing programs when it comes to decision making.

Alvin Sanoff, managing editor of the ranking project within *U.S. News and World Report* (USNWR) for many years discussed the evolution of the USNWR rankings in his report. Sanoff pointed out that “developing the methodology for the rankings was really a process of trial and error”. Though the first USNWR ranking dates back to 1983, the annual edition did not start until 1987. 1991 was the first time that USNWR explained the methodology behind their ranking system, to include explaining the weightings used. Since that time, the ratings have continued to be massaged and tweaked due to feedback from college officials and others. The “principle weakness” of the USNWR rankings is that “it is difficult to defend on any grounds other than the *U.S. News* staff’s best judgment on how to combine the measures” (NORC 1997 as referenced in Sanoff 2007).

As stated earlier, in 2005, *U.S. News & World Report* sold 45,000 newsstand copies of the “Best Colleges” edition, which was in addition to a paid subscriber list of 2 million. Additionally, they sold “several hundred thousand” copies of their 280-plus page “America’s Best Colleges” newsstand guide, which included a directory of 1,400 colleges (Su 2006). There exists an interest in tools that assist decision making in selecting colleges, whether it be from the employer side picking where to focus efforts on recruitment, or that be from the student side, in selecting their program to attend. The UCESEM aims to fill the void in advertised metrics to future students in selecting their university to attend in order to study civil engineering rated according to sustainability coverage. Additionally, it would serve to inform the industry in the attention different universities pay towards sustainability and could provide further support for hiring decisions and research funding support in sustainability.

3.1.3.2 Internal Assessment

The Sustainability in Higher Education Assessment Rubric (SHEAR) is a subjective evaluation tool, developed by faculty at Penn State, of coursework in which faculty may assign values based on the relative perceived level of support that their class provides in areas such as knowledge and awareness, skill development, lifelong learning, partnerships, and reflection. The purpose of the rubric, shown in Figure 3.2, is to empower faculty to “shape effective programs and courses of their own to teach concepts of sustainability to their students” (Riley et al. 2007). Faculty members interested in implementing sustainability in their courses may use the tool to self-measure the level of coverage for each of the five areas. Evaluation of the usefulness for the internal tool to faculty was tested in the evaluation of two courses, with a report of the findings provided (ibid). This was the only tool identified in the literature review that faculty may use to objectively assess the sustainability coverage of their course.

	0 – none	1- little	2-moderate	3 – strong
Knowledge and Awareness	Class does not provide an opportunity to develop knowledge and awareness of contemporary issues <i>nor</i> to be aware of different perspectives	Class provides an opportunity to develop awareness of contemporary issues <i>or</i> to make students aware of different perspectives	Class provides an opportunity to develop knowledge of contemporary issues <i>and</i> to make students aware of different perspectives	Class provides an opportunity to develop knowledge of multiple contemporary issues <i>and</i> to make students aware of multiple contemporary issues
Skill Development	Class does not provide an opportunity to develop skills	Class provides an opportunity to develop 1-4 skills	Class provides an opportunity to develop 5+ skills	Class provides an opportunity to develop 9+ skills
Responsibility	Class not ask students to understand how to <i>nor</i> to express an interest in minimizing negative environmental impacts	Class asks students to understand how to <i>or</i> to express an interest in minimizing negative environmental impacts	Class asks students to understand how to <i>and</i> to express an interest in minimizing negative environmental impacts	Class asks students to understand how to and to express an interest in minimizing negative environmental impacts
Lifelong Learning	Class does not promote learning in unconventional situations <i>or</i> provide education opportunity for non-students	Class promotes learning in unconventional situations	Class provides an educational opportunity for non-students	Class promotes learning in unconventional situations <i>and</i> provides an educational opportunity for non-students
Application in Diverse Settings	Class does not provide an opportunity to work outside of the classroom	Class provides 1 of 5: a diverse learning experience; a hands-on project; civic engagement; applied research/community outreach and education; community service	Class provides 2 of 5: a diverse learning experience; a hands-on project; civic engagement; applied research/community outreach and education; community service	Class provides 3+ of 5: a diverse learning experience; a hands-on project; civic engagement; applied research/community outreach and education; community service
Diverse Interactions	Class does not expose students to other disciplines, cultures, generations, or economic backgrounds	Class exposes students to 1 of 4: other disciplines, cultures, generations, economic backgrounds	Class exposes students to 2 of 4: other disciplines, cultures, generations, economic backgrounds	Class exposes students to 3+ of 4: other disciplines, cultures, generations, economic backgrounds
Partnerships	Class does not partner with a community entity	Class has created a new working partnership with a community entity (<2 years)	Class has maintained a 2-4 year working partnership with a community entity and has created mutual goals	Class has maintained a 5+ year working partnership with a community entity and has pursued mutual goals
Reflection	Class does not provide a structured opportunity for reflection	Class provides structured reflection through 1 of 4: class discussions; thought-provoking questions; memory-jogger handouts; writing	Class provides structured reflection through 2 of 4: class discussions; thought-provoking questions; memory-jogger handouts; writing	Class provides structured reflection through 3+ of 4: class discussions; thought-provoking questions; memory-jogger handouts; writing

Figure 3.2 Sustainability in Higher Education Assessment Rubric (SHEAR) (Riley et al. 2007)

During the course of the literature review for the rubric creation, the authors identified the North American Association for Environmental Education (NAAEE) recommendations for “learner-centered instruction, alternative learning techniques, expanded learning environments, interdisciplinary

approaches, and connecting lessons to learners' everyday lives" (NAAEE 1996 as referenced in Riley et al. 2007). Specific suggestions for environmental educators are to:

- "Focus on concepts, rather than focusing on facts and figures, such as environmental issues, values, quality of life, and quality of environment
 - Teach lessons in context and connect lessons to student's everyday lives, locally and globally
 - Expose students to a variety of viewpoints and theories and give them the opportunity to explore alternative perspectives
 - Allow students to be aware of and reflect upon the diversity of cultures, races, social groups, and generations with respect and equity
 - Provide opportunities to identify environmental issues, investigate the problems, analyze the results, and evaluate the outcomes
 - Give students the chance to think critically and creatively about problems and their solutions, to make decisions, and to clarify their positions"
- (NAAEE 1996 as referenced in Riley et al. 2007).

These suggestions were included in the formation of the categories within the SHEAR. Following testing of the SHEAR on two courses at Penn State, they found increased retention in the students enrolled in the courses, as well as an increased desire for students to share what they have learned with fellow students and family members. Feedback from the students included comments such as "I've learned that sustainability is an ideal that interplays between all aspects of life" and "the most noticeable change I have experienced is a greater desire to learn about green sustainable building techniques". In addition to sustainability topics, these students have demonstrated the desire for continued exploration of this topic. This may be correlated with ABET skill 3.I., the need for 'lifelong learning'.

The researchers summarized their findings by saying that the SHEAR "is more than just education for sustainability: it is education for sustainability plus the most successful characteristics of environmental education, service learning, and engineering education, making it a consolidated approach to teaching concepts of sustainability to university students" (Riley et al. 2007). This internal assessment tool is valuable because it empowers users to affect change. However, the nature of it being an internal tool precludes it from becoming a facilitator of competition or a comparative metric between programs. Yet,

as may be seen in later sections of this report, the SHEAR provides some categories that could be modified, and were, for inclusion in the UCESEM.

3.1.4 University Sustainability Measurement

Initiatives such as the Presidents' Climate Commitment and Green Report Card capture the involvement and commitment of the university as a whole, in practices of sustainability. In a poll conducted by the Princeton Review, 68% of 12,715 high school students applying to college said they would like to have information about a college's commitment to the environment (SEI 2009). Some argue that while this is a good measure for the institution's practice of sustainability concepts, and these practices do not go unnoticed by students, "these measures do not change the qualities of the formal education that is delivered" (Haigh 2005). Yet, the exposure of students to sustainability practices will increase their awareness of issues and concerns with relation to sustainability. Students at some universities form action committees to encourage change to school practices. The interests and pursuits of these students will no doubt have an impact on the courses that are offered. This could result from faculty wanting to engage their students and connect with their interests, as well as the administration motivating and encouraging the infusion of their desires for sustainability actions into sustainability instruction from the faculty.

The American College and University Presidents' Climate Action Commitment should also be noted in this section as it is a commitment of member universities to defined goals for sustainability. The commitment is an effort to "neutralize greenhouse gas emissions, and to accelerate the research and educational efforts of higher education to equip society to re-stabilize the earth's climate" (ACUPCC 2009). Presidents that sign the commitment agree to:

- Complete an emissions inventory
- Set a 'climate neutral' target date and milestones within 2 years of signing
- Take immediate steps through short-term actions to reduce greenhouse gas emissions (includes option to purchase green credits)
- Integrate sustainability into the curriculum
- Ensure transparency by making the plan, inventory, and progress reports publicly available (ACUPCC 2009)

As of November 2009, 659 colleges and universities have signed the Presidents' Climate Commitment. One university, Virginia Tech, decided not to sign the commitment as they desired to sign something they believed they could achieve. When asked why President Steger chose not to sign, the response from the sustainability program manager was that "It's always been his [President Steger's] policy to sign something that he is convinced the university can achieve" (Petchen 2009) and that they

did not agree with requirements such as the purchase of green credits which would implement sustainability elsewhere, than at Virginia Tech. Those involved in the recommendation to sign or not believed their investment could make a bigger, local impact, if Virginia Tech devised their own commitment (Coleman 2009). Virginia Tech is not the only school to decide not to sign. The College of William & Mary decided to devise its own sustainability commitment because they wanted the “freedom to build up a sustainability program without having to cater their system to an outside organization” (Zapfel as quoted in Petchen 2009). A proponent of the Presidents’ Climate Commitment states that it is “both effective and flexible” by creating a framework for a school to develop their own plan and “participating in a collective effort makes it easier to attract publicity and share information across universities” (Dyer as quoted in Petchen 2009).

Whether schools decide to sign the Presidents’ Climate Commitment or not, the sustainability of campus operations is captured in the Campus Sustainability Report Card. Also known as the ‘Green Report Card’, and first reported in 2006, it evaluates the quality and comprehensiveness of the campus sustainability practices of 332 institutions. The first and only rating scheme available to measure campus sustainability practice, the report for 2008 resulted in a 97% participation rate from the 300 colleges invited to participate. The methodology for the report card “entailed researching publicly available information, conducting surveys of appropriate school officials, and assessing performance with 120 questions across 48 indicators in the following 9 categories: Administration, Climate Change & Energy, Food & Recycling, Green Building, Transportation, Student Involvement, Endowment Transparency, Shareholder Engagement and Investment Priorities” (SEI 2009). Each of these categories was equally weighted and translated to a 4.0 scale, with the highest score in 2010 being an A- (ibid.).

3.2 Expectations and Demand

The third step within the UCESEM development methodology, as was illustrated in Figure 2.4, was to identify expectations and demand for the key stakeholders of the educational system, for they drive the structure and content for that system. In order to understand the importance of civil engineering sustainability content coverage, the expectations and demands of the users must first be identified. The methods used in this report included results from attitudinal surveys and interviews of industry, faculty and students, as well as results from case studies.

3.2.1 Industry Expectations

The civil engineering industry is one of the three main stakeholders in the education of future civil engineers. The development of a metric assessing sustainability education for civil engineers requires identifying the demand and skills the industry expects of engineers in the area of sustainability.

The construction and design industry is a major source of demand and investment for education. Industry plucks graduates from educational programs and provides investment via donations and research support (Huntzinger et al. 2007). The demand for green construction is growing as was mentioned in the background section of this paper. It has been found that “exceptionally large companies...recognize that a business is no longer judged solely on the economic value added by a company’s activity; it is also judged on the social and environmental value they add (or destroy)” (Myers 2005). Others state that “there is a desperate need for education about sustainable development and construction as well as useful indicators of these. If the “vicious circle of blame” is to be broken, as it must be if sustainable construction is to be delivered, these must be provided” (Keeping 2009).

There are those in the industry who have a “lack of respect for sustainability” (Myers 2005). However the growth projections in ‘green’ construction continue to show a different trend. As regulation of society’s impact, to include that in the building sector grow, so too, must and demand will grow, the needed supply of those companies and individuals who can execute projects with higher expectations.

Further support for the professional civil engineer are that “the civil engineer as a leader must broaden his or her horizon beyond issues centered on the design aspect of civil engineering to encompass considerations of how, where, and under what context civil engineering projects are to be constructed in today’s global environment.” In regards to sustainability, “the civil engineer must undertake these projects with a view to sustainability in order to maintain a balance between the needs of the population and the survival of our planet.” (Galloway 2003).

The literature identified four major frameworks measuring sustainability for industry (Keysar and Pearce 2007; Solutions 2004; USGBC 2009; ConstructionSkills 2009). In particular, Figure 3.3 shows the Sustainability Skills Matrix for the Built Environment Functions. This matrix was developed in the United Kingdom by ConstructionSkills. The website it was gathered from did not describe the genesis of the matrix, but it is an organization licensed and maintained by the UK “government to assist the Construction sector to build a more sustainable future” (ConstructionSkills 2009).

NB¹: Number of stars denotes level of involvement, not relative importance (*** = primary role, ** = involved in, * = aware and take action as necessary, no* = aware)

NB²: Generic skills that are considered essential to the delivery of a sustainable built environment are listed on the attached 'Notes Page'

NB³: No significance should be attached to the order in which 'components'/abilities' are presented nor to their relative importance

COMPONENTS OF SUSTAINABILITY	ABILITIES	Investment Function	Insurance Function	Planning Function	Client Function	Procurement Function	Design Function	Specification/Preliminary Function	Construction Function	Regulatory Function	Supply Function	Operations & Management	Demolition Function
To achieve Sustainability by:	The 'Functions' need to be able to:												
SOCIAL													
Optimising opportunities and social benefits	create useable public and private space to deliver successful communities	**		***	***	*	***	*	*	***	*	*	**
	improve health, wellbeing, accessibility and security of community	**	*	**	***	*	**	*	**	***	*	*	**
	enhance employment and skills development opportunities for the local community	**		**	***	**	**	**	**	*	**	***	*
Promoting sustainable communities through planning and design	meet requirements of local regional and national development and regeneration strategies	**	*	***	***		***	**		***	*	**	
	ensure appropriateness of development to needs of the community including multiple use and adaptability	**		***	***	*	**	*		***		**	
Engaging Stakeholders	consult with the public authorities, general public and other stakeholders, including end users and respond accordingly	**	**	***	***		***	*	***	***		**	**
	involve and manage expectations of stakeholders in development process from concept to commissioning	**	**	***	***	**	***	*	**	**	**	***	*
	consult and manage expectations of stakeholders on changes to ongoing use and operation	*			**	**	***		**	***	***		
Minimising negative impacts	plan for effective public and private transport use		*	***	*	*	**	**	***	***	***	**	***
	control nuisance (noise, dust, light etc)		*	***			**	***	***	***	***	*	***
	ensure a secure site, in construction		*		**	*	**	***	***	***		*	***
	ensure health and safety of site workers and local community	*	*				***	***	***	***	**	*	***
	protect, enhance and maintain appropriate social access to environmentally sensitive areas	**	**	***	**		***	***	***	***	*	**	***
	assess and mitigate flood risk	**	***	**	*	*	***	***	**	***	*	**	*
ENVIRONMENT													
Taking account of natural capacity	assess and mitigate wider environmental impacts (eg water supply, sewerage, transport, waste, etc.)	**	*	***	**		***	*		***	***	*	
	respond to projected impacts of climate change	**	***	***	**	**	***	**	*	**	***	*	
Optimising environmental benefits	minimise energy demand and meet it efficiently aiming to achieve carbon neutrality	**		**	***	**	***	***	***	***	***	***	***
	minimise water demand and aim to maintain water sufficiency from public supply	**		**	***	**	***	***	***	***	***	***	***
	optimise efficiency of materials use	**		**	***	**	***	***	***	***	***	***	***
	maximise range of environmental benefits in the	**	**	**	***	*	***	***		***	***	**	
	maintain and enhance biodiversity	**	**	*	**	**	***	***	***	***	***	**	*
Minimising negative impacts	reduce, reuse, recycle, recover waste	*		*	**	**	***	***	***	***	***	***	***
	reduce emissions to air, land and water	*	*	*	**	*	***	***	***	***	***	***	***
	reduce transport impacts		***	**	**	**	***	***	***	***	***	***	***
	protect ecological resources			***	**	*	**	***	***	***	***	***	***
	minimise take of environmentally valuable land	*		***	**		***		**	***	*	*	
	minimise pollution of air, land and water	*	**	*	**		***	***	***	***	***	***	***
	manage and control in situ contamination of land	**	**	***	**	*	***	***	**	***	**	**	**
	resources	**	**	***	**	*	**	***	**	***	**	**	**
ECONOMIC													
Ensuring economic viability and improving processes	use technologies and materials consistent with sustainability principles	**	**	*	**	***	***	*	***		***	***	***
	keep up-to-date with advances in construction/technology	**	**	***	**	***	***	***	***	**	***	***	***
	establish cost and benefit on the basis of whole life value	**	**	***	**	***	***	***	***	**	***	**	**
	manage the supply chain effectively					***	*	*	***	**	***	***	**
	keep up-to-date with regulatory and planning requirements	*	**	***	**	***	***	*	***	***	***	***	***
	operate effective project management and contingency planning procedures		**	**		***	**	*	***	**	***	**	***
	maximise range of economic benefits including flexibility of use	**	**	***	**	**	***	*		***	**	**	
	achieve cost effective out-performance of statutory requirements	*	**	**	**	***	***	*	***	***	***	***	**
	resources												
Enhancing business opportunities	meet requirements of national, regional and local economic strategy	*	**	***	**		**	***	*	***	*	*	
	capitalise on funding/grant available for more sustainable development	**	*	*	**	***	*	*	**	**	**	*	**

Figure 3.3 Sustainability Skills Matrix for the Built Environment Functions (ConstructionSkills 2009)

The matrix is broken out into the three pillars of sustainability, social, environment and economic, and includes components of sustainability for each of the pillars, which then detail certain ‘functions’ and skills that these functions may require in the construction industry, from investment to design and demolition. Table 3.2 lists the 12 separate functions of the built environment that were identified in the Sustainability Skills Matrix.

Table 3.2 Functions of the Built Environment

Investment	Insurance
Planning	Client
Procurement	Design
Specification/Preliminaries	Construction
Regulatory	Supply
Operations & Management	Demolition

(ConstructionSkills 2009)

Secondly, findings from a survey conducted in 2006 at three major university construction programs garnered responses from 87 different companies who were there recruiting new hires. The report identified contractor experiences, expectations and perceptions of green building. As may be seen in Figure 3.4, among the results was the finding that the top two sources of green building knowledge was through conference attendance and reading trade publications, while a small representation, 9%, come from incoming employees (Ahn and Pearce 2007). However, as education in sustainability becomes more common and potentially, standard, this percentage can be expected to grow.

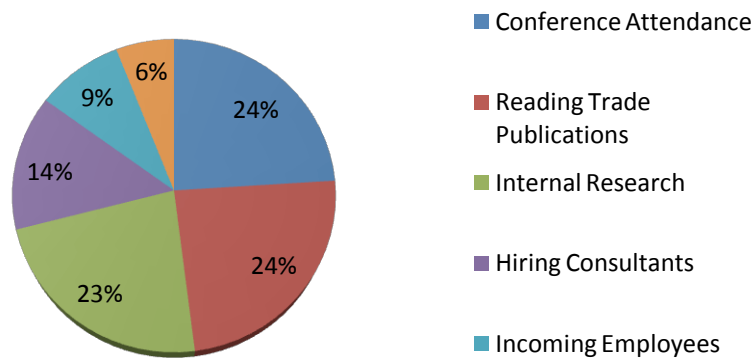


Figure 3.4 Sources of Green Building Knowledge in Responding Companies
(Adapted from Ahn and Pearce 2007)

The report shows that “construction educators need to incorporate sustainability into courses and curricula so that graduates can participate and be valued in the workplace”. The majority of responses, 65% indicated that they expect graduates to have some knowledge of green building, while only 35% answered that they did not expect any knowledge of green building for new graduate hires. The education sector and faculty must recognize and implement the instruction necessary to impart the knowledge and tools that the industry expects of new hires. Additionally, Table 3.3 contains some of the results of a survey, conducted in 2006, of industry professionals (Ahn and Pearce 2007).

Respondents also answered a question as to what specific green building skills and knowledge construction-related programs in schools should impart to students. Thirty-five respondents suggested four main areas of expertise, with the majority of responses being in the area of LEED.

Table 3.3 Requested green building knowledge from respondents

Content of Sustainability in Education	Number of Respondents
<i>Rating system and design of sustainability</i> - LEED requirements - LEED certification course - Economic feasibility for LEED - LEED process and design - Exposure to LEED - Accredited LEED students	19
<i>General knowledge of sustainability in the built environment</i> - Green building familiarity - Basic green knowledge - A general knowledge of the process - In-depth instruction with principles and design application	10
<i>Sustainable construction material and methods</i> - Construction material and sustainable methods of construction alternative energy - Coordination of sustainable efforts with all parties design phase HVAC items - Practical and applicable green building construction techniques and products - Practical system for buildings that save energy study ASHRAE 90.1	5
<i>Others</i> - Environmental philosophy	1

(Ahn and Pearce 2007)

The preceding data identified industry expectations for the infusion of sustainability in civil engineering education. They show that the top two areas for industry are rating systems such as LEED and secondly a general knowledge of sustainability (Ahn and Pearce 2007). Additionally, the references provided categories and rationale for priorities for metric development. The next section discusses the

second stakeholder, faculty, and how ABET accreditation may act to motivate the inclusion of sustainability through certain ABET criterion

3.2.2 Faculty Expectations

The second stakeholder for educating future civil engineers in sustainability topics and methods are those who teach these principles, the faculty. This section discusses a major motivation for faculty and the education sector stakeholders, ABET accreditation, and include results from a study asking faculty to respond on their perceived barriers for sustainability inclusion in construction management programs, and introduces the *Benchmarking Sustainable Engineering Education Final Report*, which provided the syllabi for the metric creation and testing.

ABET accreditation, as discussed previously in the measurement section of this report, is the recognized method for certification of civil engineering degrees. As such, ABET factors strongly into the motivations for faculty expectations as this is an established, renowned, and accepted measure for program accreditation.

A report following a workshop sponsored by the National Science Foundation that included professionals and researchers from the construction and environmental fields recommended that “research must be completed to develop an appropriate pedagogy and curricula that includes accreditation for enabling teaching and learning in sustainable communities, facilities, and civil infrastructure systems within the total education pipeline” (Haselbach and Fiori 2006).

A survey of 56 construction management programs in 2006, resulted in 14 schools responding. Of those that responded, only two schools responded offered sustainability construction courses, while three of the remaining 12 said that they would consider adding one and nine said they would not. The survey concluded by asking what might motivate the inclusion of sustainability in their program. The responses were grouped as listed in Table 3.5.

Table 3.5 Motivation for Sustainability Inclusion in Construction Management Programs

Motivator/Barrier for Sustainability	Number of Responses
Increase Faculty & Funding for the Program	4
Faculty & Advisory Council Consensus on the Need to Teach the Content	3
No Room in the Curriculum	3
Topic Taught with Existing Courses	2
No Comment	2

(Information from Siddiqi et al. 2008)

These results show that faculty and funding for the program were identified as the largest current barrier for sustainability inclusion in construction management programs. Of the greatest importance is the need to ‘sell’ the idea of sustainability inclusion, as this was tied as the second barrier. This idea could be changed through outside motivation of competition that this research proposes to implement.

Kumar and Hsia suggested that “In today’s competitive global market and changing work environment...engineering programs are challenged to come up with innovative ways to teach classes so that the graduates are prepared to take over the challenges facing twenty-first century engineers, and to make these programs consistent with ABET requirements” (Kumar and Hsia 2007). Crucial towards this progress are the educators who will teach the changes necessary for a sustainable future (Cortese 2001 as referenced in Haigh 2005). The following section discusses the expectations of those future engineers, the students.

3.2.3 Student Expectations

The final stakeholder, and the output for education, students represent the future industrial professionals, researchers, and professoriate. While their motivations for study may be diverse, their ultimate goal is to be competitive job and career hunters and builders. In order to capture the individual expectations of students, a survey of sophomores to graduate students was conducted at Virginia Tech. The survey sample size was 254 students and of that sample, 118 responded, a 47% response rate.

The study combined the previously ranked topics, presented in Table 3.2 with the resulted rankings from students. The results are shown in Table 3.6.

Table 3.6. Ranking of Topics for Sustainable Knowledge of Students

Topic	Student Perspective	Industry Perspective
General knowledge of sustainability	1	1 ¹
Sustainable rating system	3	2 ²
Sustainable means and methods	2	3
Environmental philosophy	4	4

(Ahn and Kwon 2008)

Findings from the study showed that construction students recognize that familiarity with sustainability and sustainable construction may help make them more competitive in locating and securing a job following graduation (Ahn and Kwon 2008).

¹ Second in the original Ahn and Pearce 2007 report

² First in the original Ahn and Pearce 2007 report

An article published at the beginning of the 2009 school year discussed the growth trend in the “green sector”. Expectations for “environmental commitment” drove two-thirds of *The Princeton Review* “College Hopes and Worries” survey respondents to respond that it would be a “factor in where they applied” (Berman 2009). David Soto of *The Princeton Review* said, “students are really savvy shoppers these days, so they’re realizing, with a changing economy and green jobs looking to take a leap within the next couple of years, that they want to be armed with those types of skills” (Berman 2009). A recent graduate of the Arizona State University’s School of Sustainability said that he felt his degree would help him secure a job, because of the increased demand in sustainability.

This section identified the desires of students and emphasizes the motivations of students being to find methods that will make them competitive in their career search. The next section introduces some existing case studies in the area of sustainability inclusion as well as the methods as how it may be integrated in existing programs.

3.3 Existing Case Studies

The fourth step in the overall process toward the Undergraduate Civil Engineering Sustainability Education Metric (UCESEM) entailed identifying existing case studies of sustainability integration. Existing case studies provide examples of sustainability integration philosophies, methods, and models for criteria that should be included in the overall framework for a metric. This research resulted in many samples of single course, college of engineering, and overall university methods for implementation. Additionally, assessments of current methods provided a perspective on current efforts for sustainability implementation (Ahn et al. 2007; Pearce and McCoy 2007; Huntzinger et al. 2007; Appledorn and Ankersen 2006).

3.3.1 ‘Bolted-on’ vs. ‘Built-in’ Sustainability

One question when implementing sustainability in curriculums is the philosophy of which method is more effective: “bolted-on” or “built-in” sustainability. Those implementing sustainability often proceed by taking different positions along the continuum of “bolted-on” to “built-in” inclusion. The ideal scenario entails “redesigning engineering education”, as illustrated in Figure 3.5.



Figure 3.5 Degree of Sustainability Integration into Curriculum (Huntzinger et al. 2007)

In a study of 11 engineering programs, nine were considered as having “bolted-on” sustainability coverage, while the remaining two were “built-in” (Huntzinger et al. 2007). The report states that “students need not only the [sustainability] knowledge base to generate effective engineering solutions; they need the intellectual development and awareness to understand the impact of their decisions” (Huntzinger et al. 2007). The delineation between “bolted-on” and “built-in” sustainability was not explicitly integrated into the eventual UCESEM, discussed in later sections of this report. While this philosophy is useful for program development, it is challenging to reliably review and numerically assess how a particular class integrates sustainability. The next case study considered the methods of instruction for innovative topics, to include sustainability.

3.3.2 Educational Ecosystems

Some case studies show that integration and hands-on opportunities can have a positive benefit on all stakeholders in the learning environment. The *Creating an Educational Ecosystem for Construction* report posited and tested the Educational Ecosystems Model, shown in Figure 3.6.

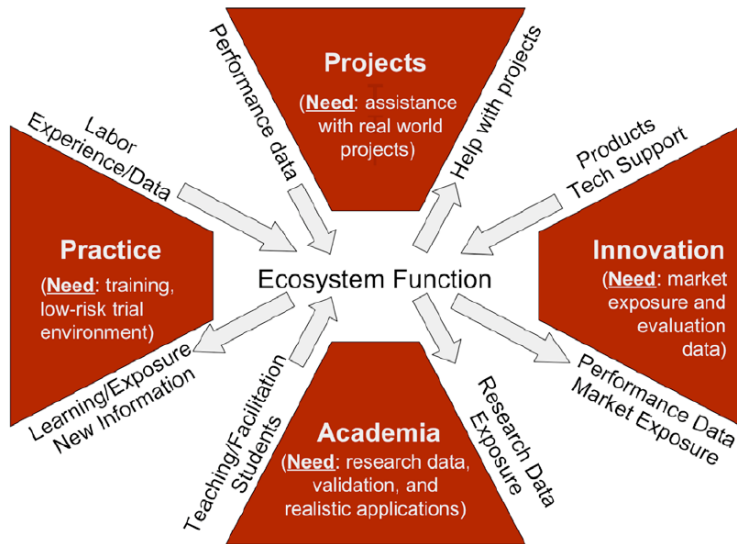


Figure 3.6 Educational Ecosystems Model (Pearce and McCoy 2007)

The model consists of stakeholder sets or holons, “an entity that is simultaneously a whole unto itself while being a part of a larger system (Koestler 1967 as referenced in Pearce and McCoy 2007). This model is a representation of the synergies that could exist in the educational ‘ecosystem’ between research needs, instructional needs, community projects and innovation in industry. The model was tested on a course offered by Virginia Tech’s Building Construction department. The course, entitled ‘Sustainable Facilities’ implemented this model through a study of permeable concrete constructability concerns. All of the holons in the model benefited from this project, as each brought something to the table, and as a result, improved the learning experience and fostered forecasted future benefits through the innovation/industry and research holons.

The Undergraduate Civil Engineering Sustainability Education Metric construct, discussed in later sections of this report, contains categories to address integration with other non-civil engineering topics, class site visits and field trips, and engagement with the community. These categories touch upon each of these holons. The next section discusses how the University of Florida implemented sustainability and completes the discussion on existing case studies.

3.3.3 University of Florida

One school that looked at capturing the inclusion of sustainability throughout the school was the University of Florida. This case study was set up to categorize currently offered courses that were based in theory and practice, related to principles, or implicitly addressed one or more of the principles of sustainability. They were assigned categories of Tier I, Tier II or Tier III, respectively. They identified 17

courses in five colleges in Tier 1, to include eight in the College of Design Construction and Planning and one in the College of Engineering. There were 39 courses in eight colleges in Tier II, and 53 in “almost every college” in Tier III. The study identified 10 “course groupings that lead to a programmatic emphasis based in or related to sustainability (Tier I or Tier II). Of the identified course groupings, the one to note for this research is the environmental studies minor for students in the College of Engineering.

The report included recommendations for integration of sustainability into existing curriculum. The recommendations included emphasizing interdisciplinary sustainability studies, a capstone experience, and faculty support resources such as a small grants initiative, incorporating sustainability in service training for extension and outreach faculty, and settings that emphasize sustainability skills such as studios, labs and clinics (Appledorn and Ankersen 2006).

As this case showed, some programs may choose to pursue sustainability courses through separate certificate or minor programs. This type of program may present challenges for a metric focusing on sustainability within the student’s overall major of civil engineering. While the creation of separate programs to focus on sustainability is one method for sustainability instruction, the separation would not preclude the course’s inclusion in the metric, as it would be available to civil engineering students as a technical elective. A recommendation to refine the capture of this type of program is presented in the areas for further research section of this paper.

3.4 CSE Civil Engineering Syllabi Review

The Center for Sustainable Engineering (CSE), a collaborative research effort between Carnegie Mellon University, the University of Texas at Austin, and Arizona State University, was established in 2005, thanks to support from the National Science Foundation and the Environmental Protection Agency to “enhance education in Sustainable Engineering at colleges and universities around the world” (Center 2009). Their work includes faculty sustainable education workshops, a website with peer-reviewed sustainable engineering education materials, and an assessment of Sustainable Engineering programs and courses currently taught throughout the U.S. They plan to establish “measures of quality”; to assess all 1,500 accredited engineering programs and departments in the U.S., culminating in an award program to recognize “excellence in Sustainable Engineering Education”. The identification of these measures of quality is desired so as to further the journey for standard methods in sustainability engineering education. The center’s website was recently updated in 2009 and refers users to the

Engineering Pathway to access uploaded sustainable engineering materials, containing case studies, tutorials, and other teaching tools (Pathway 2009). The CSE-authored *Benchmarking Sustainable Engineering Education Final Report* benchmarking report provided statistics for the methods, the percentage of the course allotted, the value of research, submitted course syllabi, etc, concerning current practice of sustainable engineering education integration in four-year colleges and universities in the United States (Allen, et al 2009).

The CSE Report syllabi analysis will show that course existing syllabi may be contextually analyzed to capture key sustainability topics and tools that would be covered. Following implementation of the UCESEM, faculty may find that they will score higher if they include more information as to what the course entails, but as the syllabus is a contract between student and faculty for the course administration, format and material, this will only serve to ensure the information is covered as presented.

4.0 Develop Proposed Evaluation Metric

The preceding literature analysis identified the need for sustainability in the education of civil engineers, as well as what that education would entail. This research was accomplished in order to generate a metric to evaluate the coverage of sustainability. Additionally, in an effort to facilitate metric execution, the research identified existing data that could be harvested to round out a metric. The genesis of this project stemmed from the review of existing literature, summarized in the preceding section. In order to develop a metric that could holistically assess civil engineering program attention to, and coverage of, sustainability, it was determined that the metric should include overall university, department and course attention to sustainability. The goals and focus of programs often originate in the upper leadership of the university, which in turn, directs the focus of the departments under its umbrella of influence.

The first step towards the metric was to review the Center for Sustainable Engineering's (CSE) final report on *Benchmarking Sustainable Engineering Education*. This report was selected because it provided a recent and thorough benchmark of sustainable engineering education. Furthermore, Appendix D of the report provided a collection of 65 syllabi spanning 36 schools. This report included the methodology as well as survey questionnaire that was sent to the 1,368 administrative heads of engineering departments at 364 universities and colleges and another 327 additional 'sustainable engineering champions', which were included in this study. The total response rate was 43%. The

report did not mention the names of the schools who were polled nor those that responded. The sole reference to participant universities was in the syllabi that some chose to submit. The CSE received a total of 155 course names for all the engineering disciplines, and received detailed information for about 80% of these, which 64 were for Civil, Architectural, and/or Environmental Engineering (Allen et al. 2009).

The metric development methodology in Figure 4.1 illustrates the steps that were taken in the creation of the proposed Undergraduate Civil Engineering Sustainability Education Metric (UCESEM).

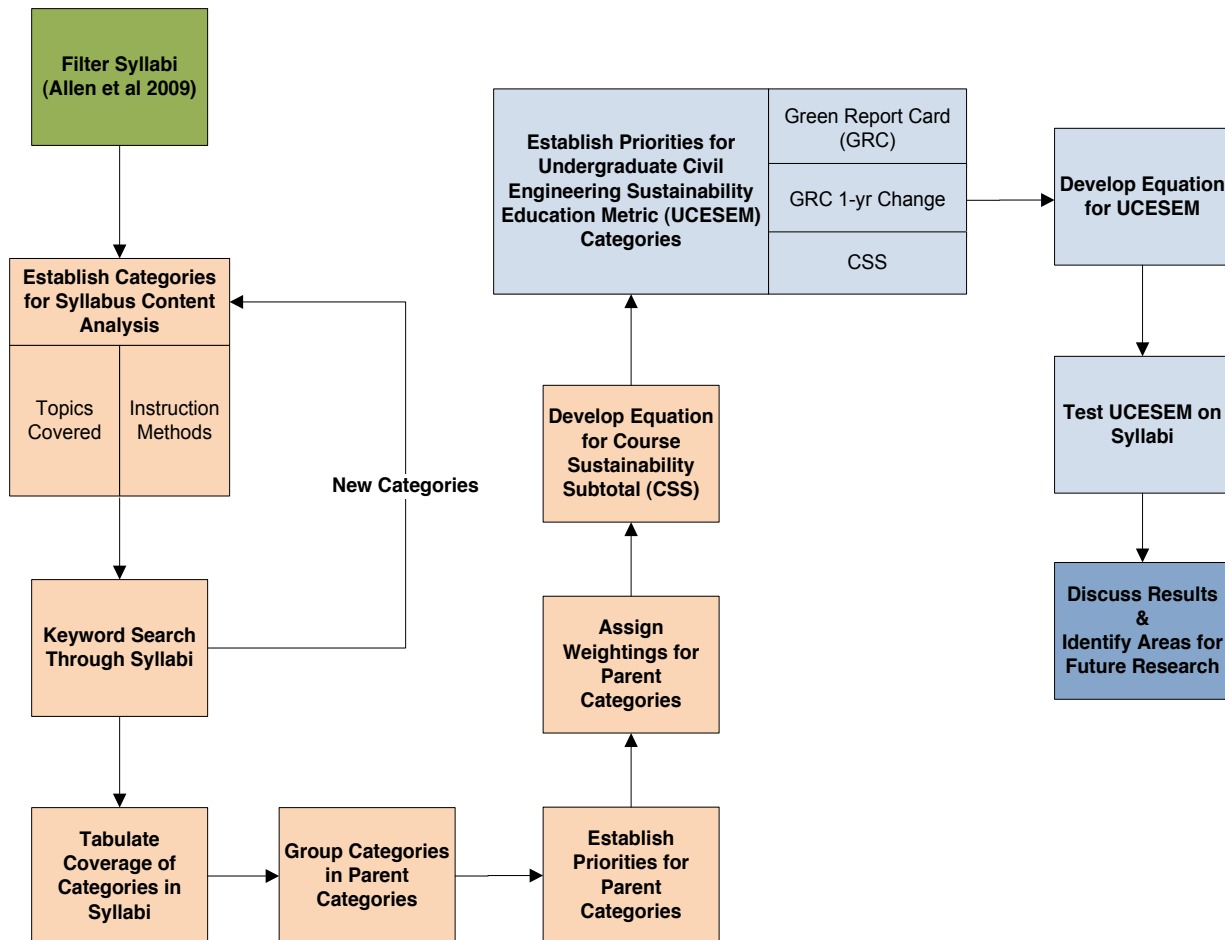


Figure 4.1 Metric Methodology

The first step in metric development was to identify the sample set selection, and this was accomplished by filtering the available syllabi from the *Benchmarking Sustainability Engineering Education Final Report*. The second step was to identify the categories with which to quantify the topics and methods of sustainability instruction from the filtered syllabi. This was a cyclical process, because

once the categories were identified, the third step was to conduct a keyword search of the syllabi; if there were keywords that would not fit in the previously identified categories, a new category was created and the process would start over until all sustainability-oriented categories were established. Once the categories were established, the next step was to record which was covered by each of the 25 syllabi. The categories were grouped into parent categories which were prioritized by the researcher, based off of the literature analysis, these categories were given weights, and then the Course Sustainability Subtotal equation was created. This subtotal was included as a category in the UCESEM, along with the Green Report Card and the change in the Green Report Card from the previous year. These three overarching categories for the UCESEM were assigned weights and then the equation for the UCESEM was created. Finally, these equations were tested with the syllabi from the *Benchmarking Sustainability Engineering Education Final Report* and the results are included in the below sections. The subsequent sections of the report detail the steps that are illustrated in Figure 4.1.

4.1 Sample Set Selection

The focus for this study was to assess the undergraduate civil engineering programs. Without having information as to the core courses and approved technical electives for each program represented in the CSE study, another method was devised to capture classes that an undergraduate civil engineer might take. The process that was taken to establish the sample set from the *Benchmarking Sustainability Engineering Education Final Report* is illustrated in Figure 4.2.

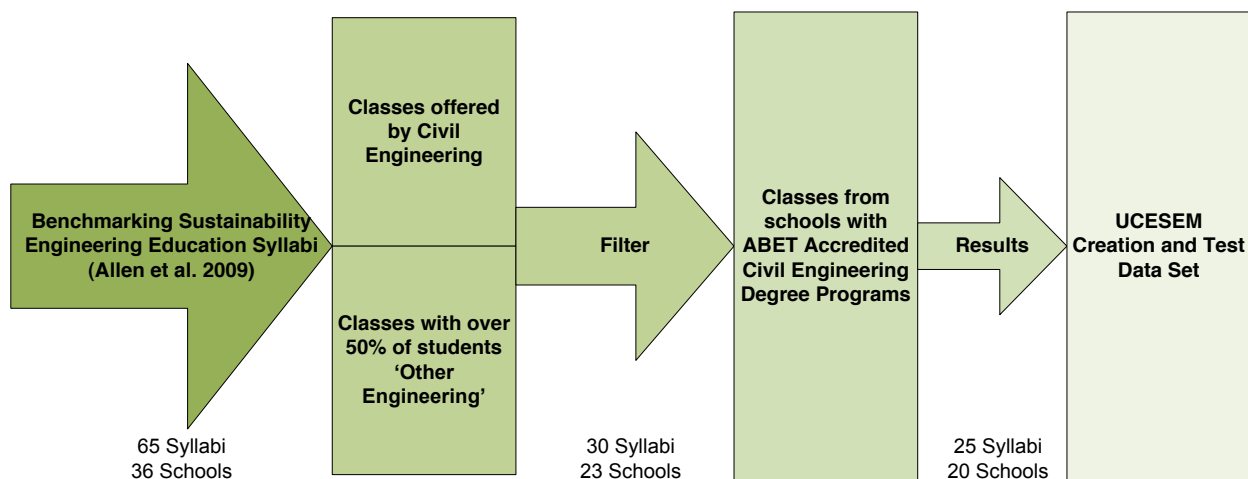


Figure 4.2 Syllabi Filter Process

The first step taken was to identify the syllabi that would be used to generate and test the metric. This was the best method to ensure face validity of the metric construct, as well as demonstrating the

UCESEM results. The *Benchmarking Sustainability Engineering Education Final Report* contained an appendix of 65 syllabi that were submitted from 36 schools (Allen et al. 2009). These syllabi spanned the focuses of engineering education, such as electrical, mechanical and civil. The Benchmarking report asked syllabi submitters to supply standard information for each syllabus such as:

- What departments offered the program (electrical, mechanical, civil, etc.)
- Student Level (undergraduate, lower division, upper division, graduate, and any mix thereof)
- Student's Major (electrical, mechanical, civil, etc.)

The classes offered by civil, architectural and/or environmental engineering departments were selected, as those are classes most likely taken by undergraduate civil engineers and should be included in the metric development. This resulted in 19 classes at 17 universities. However, undergraduate programs do not solely consist of courses offered by the student's major department. Instead, they include courses offered by other departments to fill out core as well as technical electives. A civil engineer might take a course offered by the mechanical engineering or public policy departments. In order to capture this aspect of the learning experience for an undergraduate civil engineer, the syllabi which reported over 50% of their students being 'other engineering' were also included in the project towards developing a metric.

Of the syllabi included in the *Benchmarking Sustainability Engineering Education Final Report*, 11 classes not offered by civil engineering had over 50% of their students classified as 'other engineering'. These classes could conceivably have civil engineers enrolled, taking it as a technical elective, especially due to the high percentage of engineering majors outside of the department that offered the class. Once this filter was complete, 30 syllabi at 25 schools remained.

Though the benchmarking report focused on degrees that were ABET accredited, this did not guarantee that those offered outside of civil engineering departments were at a school with an accredited civil engineering degree. The resulting 30 classes were filtered to highlight only those that had an ABET accredited civil engineering degree. This action removed 5 classes and 3 schools from the metric. These were architectural engineering or general engineering programs. The remaining 25 classes at 20 schools made up the set for metric development and the first test set for the Undergraduate Civil Engineering Sustainability Education Metric (UCESEM).

4.2 Content Analysis

The syllabi from the *Benchmarking Sustainability Engineering Education Final Report* were not in a standard format, as they were from many different institutions, and different programs within those schools. Ideally, there would be a standard information system and format for syllabi, which would help in reviews such as this one. However, as the given products were non-uniform with different methods for outlining the course, addressing topics, methods, and calendar in different combinations, it was determined that content analysis would be the best method to utilize for an understanding of the course content.

Content analysis provides a method to compare differently formatted content from the benchmark report syllabi, by facilitating the creation of a standard framework with which to compare them. “Content analysis procedures create quantitative indicators that assess the degree of attention or concern devoted to cultural units such as themes, categories, or issues” (Weber 1990). A challenge with content analysis is that the content being analyzed does not originate as a numerical value, but instead, as text. The conversion to a numerical value via counting must be taken with care to ensure that the followed process and resulting data is reliable and valid. Reliable content analysis will result in the same quantities for each category while valid content analysis will ensure that the selected categories represent the desired purpose. Key aspects that must be considered when executing content analysis are illustrated in Table 4.1.

Table 4.1 Key Aspects of Content Analysis

Key Aspect	Explanation
Measurement	Assignment of numbers that stand for some aspect of the text
Indication	Inference by the investigator of some unmeasured quality of characteristic of the text from those numbers
Representation	Techniques for describing syntactic, semantic, or pragmatic aspects of texts
Interpretation	Translation of the meaning in text into some other abstract analytical or theoretical language

(Weber 1990)

Different techniques exist for executing content analysis, mainly categorized as computer-based or human-based procedures. This project used human-based review of the syllabi, which was possible due to the manageable sample size of 25 syllabi. Additionally, the human-based review ensured thorough individual review of the syllabi, increased familiarity with sustainability instruction methods, and

refinement of the defined categories, to ensure the sustainability topics would fit into a pre-defined category, or would be captured through a new category. “There is no simple *right way* to do content analysis” (Weber 1990). The best method to achieve the goals of quantity and quality was to use the content analysis method of category counts. The categories were established by using prior categories established by the categories identified in many of the references found in the literature analysis such as the Penn State SHEAR rubric, the CSE survey-suggested categories, and other existing frameworks for sustainability knowledge and tools.

Initially, content analysis of the syllabi focused on the ‘objectives’ and ‘outcomes’ to include awareness and skills that the successful student should garner upon completion of the course. However, this proved impossible, since all syllabi were not formatted the same way. Many did not have a section labeled ‘objectives’ or ‘outcomes’. As stated earlier, in an effort to ensure the reliability of the process, an inconsistently applied method for reviewing the syllabi would not be appropriate. The second attempt was to review objectives, outcomes, course description and course topics sections of the syllabi. Most of the syllabi had at least two of these sections, but once again, a few relied heavily on the course schedule to outline the covered material. Finally, the best way to standardize the review and capture the content of the course, was to analyze each syllabus in its entirety for topics, tools, and methods. Reviewing the syllabi in their entirety was time-intensive, since it was a human-based review, but it did not leave any stone unturned and recognizes the content covered in a course, no matter what heading the faculty might use for the syllabus sections.

4.3 Categories for Syllabus Content Analysis

The first step towards quantifying the syllabi through content analysis was to establish the categories through which their content would be captured. The goal of the UCESEM is to measure the sustainability coverage quantity and quality of a course, while fostering competition and innovation in civil engineering programs. While it is difficult to objectively establish metrics for quality, as it can be viewed as subjective, this project strove to identify categories which could indicate quality, and identified two methods of instruction to capture this aspect of the course. Quantity categories are simpler to establish, as there are many subtopics within sustainability which could be used to indicate coverage within the syllabus. The categories for the UCESEM syllabus assessment included from the Penn State SHEAR rubric, CSE-defined categories, and from other frameworks (Riley et al. 2007; Allen et al. 2009; ConstructionSkills 2009; Segalas et al. 2008).

The Penn State SHEAR rubric was meant to serve as a self-assessment for faculty in building design and engineering. While most of the eight categories could not be implemented consistently across the syllabi, from an outside perspective, three of the categories could: “knowledge and awareness”, “skill development” and “application in diverse settings”. The first two categories were covered through a thorough review and accounting of the sustainability topics and tools addressed in the syllabi. The final category, “application in diverse settings”, was intended to address the coverage of “diverse learning experience; a hands-on project; civic engagement; applied research/community outreach and education; community service”.

For the purpose of the UCESEM and syllabus evaluation, “application in diverse settings” was split into two categories for the instruction methods: site visits/field trips and community engagement. As mentioned in the prior art chapter, the SHEAR was developed following a study of selected courses at Penn State which attempted a holistic method of sustainability instruction to undergraduates. The findings of the report suggested that community engagement and service would further the learning experience of students. Unfortunately, the review of the syllabi from the CSE benchmarking report showed only one class that could be considered to have covered this category. However, the positive results which resulted in this category’s creation and inclusion in the SHEAR rubric, coupled with the stability, reproducibility and accuracy of the criteria, supported it remaining a category for the UCESEM, despite only one program utilizing it.

The first two categories from the SHEAR, “knowledge and awareness” and “skill development”, were set up to assess the depth of awareness of contemporary issues and different perspectives and the quantity of skills the course developed, respectively. The CSE questionnaire suggested the subtopics for sustainability in engineering listed in Table 4.2.

Table 4.2. CSE Sustainability Subtopics

Life Cycle Analysis (LCA)	Natural Resource Management	Climate Change
Design for Environment (DFE)	Policy and Regulations	Renewable Energy
Industrial Ecology	Economics (excluding short-term cost analysis)	Green Design
Material Flow Analysis (MFA)	Pollution Prevention	Reuse and/or Recovery of Products and Materials

(Allen et al. 2009)

As previously mentioned, the Sustainability Skills Matrix for the Built Environment Functions, Figure 2.6, identifies components of sustainability as well as some of the abilities which the different ‘functions’ or players, need to be able to achieve. This matrix was established in accordance with the pillars of sustainability and shows that any one of the abilities is required by at least 8 of the 12 built environment functions listed previously in Table 2.1. The Sustainability Skills Matrix identifies the components of sustainability, and how they should be achieved, and are summarized in Table 4.3.

Table 4.3 Components of Sustainability and Methods for Achievement

Social - Optimizing opportunities and social benefits - Promoting sustainable communities through planning and design - Engaging stakeholders - Minimizing negative impacts
Environment - Taking account of natural capacity - Optimizing environmental benefits - Minimizing negative impacts
Economic - Ensuring economic viability and improving processes - Enhancing business opportunities

(adapted from ConstructionSkills 2009)

The subtopics that the benchmarking report questionnaire listed were covered, in varying combinations, by the ABET civil engineering accredited degree courses. Following review for key terms and methods throughout the syllabi, other categories started to emerge. In an effort to ensure face validity, these categories were cross checked with the reference literature and they were found to be mentioned in different articles, with considerable overlap (Allen et al. 2009; ConstructionSkills 2009; Riley et al. 2007; Segalas et al. 2008; USGBC 2009) . The additional categories present in the syllabi that were covered by at least two of the classes, were included as categories that would capture either knowledge and awareness or skills garnered from the course. The two-class minimum was not required for the methods of instruction parent category, as the creative instruction initiatives of even one class should be included. The inclusion will provide a benchmark for the other classes to consider its implementation.

Finally, in order to ensure a solid foundation in sustainability, the three pillars of sustainability, economic, environmental, and social were included. A class might receive double credit for covering Design for the Environment or Economics, both a pillar and related topics in the topic category, but the

benefits of a solid foundation, represented in coverage of the pillars, were decided to outweigh the small effect that double-counting would have. Complete coverage of the pillars of sustainability represents a solid foundation from which specific skills or general knowledge of sustainability for civil engineers may be built.

These criteria combined to form the metric for the Course Sustainability Subtotal (CSS). Some of the sustainability keywords from the syllabi were not phrased exactly as the category. For instance, the category ‘Technology Assessment Tools’ was identified to capture software tools and familiarization covered in the course, while ‘Global Considerations’ was used to give credit to any mention of ‘global’ concerns. Table 4.4 shows the categories that this process generated as well as clarifications to explain the intent of the category. The categories were grouped into parent categories and color-coded in Table 4.4, which were the category groups used in the Course Sustainability Subtotal.

Table 4.4 Course Sustainability Subtotal Categories and Groups

Category	Keywords/Intent
<i>Three Pillars of Sustainability</i>	
Environmental	Environment; nature; environmental equity; environmental chemistry; ecosystem; natural systems; environmental cost/benefit analysis
Economic	Economic; finance; cost/benefit analysis; net present worth; internal rates of return; return on investment; efficiency; industrial issues; sustainability metrics for industry; environmental management systems
Social	Human communities, social equity, anthropogenic earth, culture; human development; societal importance; human welfare
Knowledge & Skills	
Life Cycle Analysis/Planning	Life cycle analysis; life cycle planning; economic input-output based LCA; life cycle impact analysis
Design for the Environment (DFE)	No clarification
Industrial Ecology	No clarification
Material Flow Analysis (MFA)	Waste audit; hazardous waste management; flow of materials; time to depletion; waste management
Natural Resource Management	Non-renewable resources; finite resources
Policy and Regulations	Regulatory agencies; governing standards, rules and regulations; RCRA, environmental regulations
Economics (excluding short-term cost analysis)	Economic analysis of green buildings; cost of saved energy; valuing ecosystem services; full cost accounting; life cycle economics
Pollution Prevention	Pollutant removal/purification; pollution control; reducing pollution at the source; pollution prevention over compliance; pollutant risk assessment

Category (cont.)	Keywords/Intent (cont.)
Climate Change	Climate change; ozone depletion; degradation; minimize long-term environment damage
Renewable Energy	Sufficient, reliable, and affordable; energy availability; metrics for evaluating energy options; sustainable energy; solar and wind
Green Design/Engineering	Green design; green engineering; green building materials; green technological initiatives; land use; low-impact design
Reuse and/or Recovery of Products and Materials	Recycling; substitute materials; material recovery
Decision Making	Alternative analysis; trade-offs
Systems Engineering/Approach	Systems analysis; spatial & temporal scales
Project Life-cycle cradle to grave	Cradle to grave; managing life-cycle of the infrastructure; integrated end-use design
Environmental/Sustainability Ethic	Environmental ethic; sustainability ethic
Technology Assessment Tools	Analysis/mathematical tools; software; systems modeling
LEED	LEED categories; commissioning
Global Considerations	Global; international; sustainability in the world; global systems; global organizations
Sustainable Development	Sustainable development; sustainable transportation; sustainable engineering; sustainable urban systems
History of Sustainability & Environmental Concerns (not case studies)	History/evolution of environmental concerns; historical factors; Bruntland Report; UNCED
Integration with other (non-CE) topics/studies	Multidisciplinary; integrate research approach across disciplines
Application in Diverse Settings	
Site Visits/Field Trips	No clarification
Community Engagement	Personal diary for one week to identify product consumption (food, water, energy, waste), select one major impact area and analyze, make significant change in this area and identify impact of this change on the economy, social structure, ecology, and environment. This was selected as community engagement because it gets students thinking as to how their decisions impact the greater community. Only one course received credit for this category. Future revisions may include a separate personal behaviors category, if other courses may receive credit with perceived benefit gained from splitting the category.
Offered by Civil Engineering	No clarification
Student Level	No clarification
% of course focused on sustainable engineering	No clarification

Key aspects of content analysis include measurement, indication, representation and interpretation. In order for a content analysis to be successful and complete, each of these aspects should be covered (Weber 1990). Table 4.5 shows how each of these aspects were addressed in the development of the CSS whose results would be injected in the UCESEM. As the table shows, the measurement aspect should include a quantification of categories. The CSS category coverage were denoted as yes-present or blank-absent for each category. The topic categories were subtotaled, as were the methods of instruction categories, and these combine to complete the measurement aspect. Next, the indication aspect strives to assess quality of the measurements. The additional parent category of sustainability pillar coverage was created to capture which topics would count as coverage of one of the three pillars of sustainability: environment, economic and social. These categories address the sustainability foundation coverage. Foundation is important, not always seen, but indicates quality in building structures and education. The representation aspect was covered by detailing the keywords and intent of the category, as previously shown in Table 4.4. Finally, interpretation was accomplished by the creation of an equation to value the category coverage, student level, and offering department. The CSS equation facilitates interpretation and comparison of the scores between syllabi, while the UCESEM equation facilitates comparison between universities.

Table 4.5 Key Aspects of Content Analysis and Synopsis of Use in UCESEM

Key Aspect	Explanation	UCESEM
Measurement	Assignment of numbers that stand for some aspect of the text	Present/Absent for each category
Indication	Inference by the investigator of some unmeasured quality of characteristic of the text from those numbers	Inference that coverage of each of the three sustainability pillars represents comprehensive foundation in regards to preliminary course topic and sustainability
Representation	Techniques for describing syntactic, semantic, or pragmatic aspects of texts	Keyword/phrase review
Interpretation	Translation of the meaning in text into some other abstract analytical or theoretical language	Translated scores into comparable scores between schools

(Weber 1990 combined with UCESEM methodology)

Once all of the syllabi were reviewed, through content analysis, in their entirety, for the topics, skills, and methods, the challenge then became how to capture this data and consolidate the results into one value which could facilitate program comparison. Each of the subcategories would require a weighting, as each should not be taken linearly. A course that covered 5 sustainability topics, with less than 10% of

the course focusing on sustainability, should not be scored higher in sustainability than a course that covered 4 topics with 25-50% of the class focused sustainability. The process to establish the weightings for the parent categories is detailed in the following section.

4.4 Course Sustainability Subtotal

The next step was to create the Course Sustainability Subtotal (CSS), because no previous work could be found that attempted to independently quantify the sustainability coverage of a course in engineering, or more specifically as was the focus of this research, civil engineering. The categories that combined to form the structure for this metric were discussed in the preceding section of this report, in Table 4.5. Had the tally of covered categories and methods been simply added to provide a total number for each score, this would reflect an equal weighting to each category within that metric. This would largely translate into a quantity assessment of sustainability topic coverage and not an inference as to the combination of quantity and quality. Instead of assigning equal weights to every category, this project assigned various weights to the different parent categories.

Each of the parent categories was prioritized by the researcher based on information gathered through the course of this investigation in the order shown and then assigned weights as reflected in Table 4.6. It should be noted that the tally of categories for each of the parent categories represents the total that were identified in the course of this research. As this is the first iteration of the CSS, subsequent validation and research, as identified in the ideas for further research section, may identify or remove some of the categories.

Table 4.6 Course Sustainability Subtotal Metric Weights by Category Group

Priority	Parent Category	Categories	Weight
1	Percent of Course Focused on Sustainability	1	30%
2	Pillars Covered	3	25%
3	Breadth of Topics and Skills	22	25%
4	Student Level	1	10%
5	Offered by Civil Engineering	1	5%
6	Method of Instruction	2	5%

The benchmarking report survey requested that submitters of syllabi address, among other things, the percent of the course that focused on sustainability, as well as the level of the students that took the course. The respondents could choose less than 10%, 10-25%, 25-50% or more than 50% to describe the

portion of the course that focused on sustainable engineering (Allen et al. 2009). These were broken out into 1, 2, 3, or 4, respectively, for the purpose of this metric, in order roll the response up into an equation to quantify the range that was selected for sustainability focus of this course. Additionally, the level of the students, undergraduate, lower division, upper division, or graduate were streamlined into undergraduate, undergraduate and graduate, and graduate categories for the UCESEM. Each was assigned a number, 1, 2, and 3, respectively, in order to roll the category up into an equation for the overall course evaluation.

The percent of the course that focused on sustainability was deemed the most important category because it represents the attention placed on sustainability throughout the course. This was a self-reported percentage range by the CSE respondents, but could be repeated if a metric like this takes hold. Faculty could continue to self-report the focus range for their course; this is the preferred method. Another option that would be more intensive, but could be included, is a review of the course syllabus schedule. If the schedule with topics is provided, the UCESEM metric personnel could tally all topics covered and then separate those that fit within sustainability, to determine an approximate percentage which could fit within one of the four ranges (less than 10%, 10-25%, 25-50%, or more than 50%).

The coverage of the three pillars of sustainability, environmental, economic and social, are the next-highest ranked, as they represent the foundation in sustainability. The depth of each of these pillars is reflected through the overall focus on sustainability from the previous category.

It became necessary to find a balance between importance of breadth of knowledge and skills and the depth which is typically preferred in education. However, the inconsistency of syllabus format and detail made it impossible to measure the depth of sustainability skills or topics. Yet, the topics covered should be captured because “the need for students to exit a course with increased knowledge of contemporary issues, both social and environmental, as well as an awareness of differing world views” (Riley et al. 2007). Therefore, in the absence of an ability to measure the depth, the breadth and coverage of topics were used. The 22 categories of topics allowed credit for familiarization with sustainability knowledge and skills, and although this parent category has the third highest ranking, each category does not considerably affect the course’s overall score.

Student level and offering by civil engineering reflected the probability that undergraduate civil engineers would be required to, or have access to, the course. While these are important categories,

they were given a decreased weighting because they both cover one category. As most undergraduates take core courses early in their degree program, it was inferred that the lower the level of the students taking the class, the higher the probability that the class was a core course. The higher the student level, it became more likely that the class was a technical elective and not taken by all graduates of the program. Additionally, although a course may be a graduate course and/or offered by the public policy department, for instance, undergraduates may still have access to the course and civil engineers may take the course; this was reflected in the CSE response showing that over 50% of the course was 'other engineering'.

The method of instruction category was allotted 2.5% per method that engaged the students outside of the classroom. As mentioned previously, these aspects of the sustainability education experience were highlighted in the SHEAR rubric as being important because "teaching lessons in context and connecting them to students own lives and careers brings about the sense of responsibility desired of students" (Riley et al. 2007).

Once the weights were established, the Course Sustainability Subtotal equation was developed, as is detailed in Figure 4.3.

$$CSS = WT_P * \frac{P}{3} + WT_B * \frac{B}{22} + WT_F * \frac{F}{4} + WT_L * \frac{4-L}{3} + WT_M * \frac{S+C}{2} + WT_{CE}$$

* (1, if offered by CE | 0, if not offered by CE)

WT_P = Weight Factor for Pillar Coverage = 25%

P = Total Number of Pillars Addressed by Course

WT_B = Weight Factor for Breadth of Topics and Skills = 23%

B = Total Number of Topics and Skills Covered by the Course (out of 22)

WT_F = Weight Factor for Percent of course Focused on Sustainability = 30%

F = % of Course Focused on Sustainability (1 = < 10%, 2 = 10 – 25%, 3 = 25 – 50%,
4 = > 50%)

WT_L = Weight Factor for Student Level = 10%

L = Student Level (1 = undergraduate, 2 = undergraduate & graduate, 3 = graduate)

WT_M = Weight Factor for Methods for Instruction = 4%

S = Course utilizes Site Visits/Field Trips

C = Course includes Community Engagement

WT_{CE} = Weight Factor applied if Course Offered by Civil Engineering = 5%

Figure 4.3 Course Sustainability Subtotal Calculation

This calculation quantifies the coverage of sustainability in a class according to the categories. The next step, and section in this report, in UCESEM development is to account for those universities that offer more than one class that incorporates sustainability.

4.5 University Course Sustainability Subtotal

The syllabi that were included in the CSE benchmarking report drew attention to another challenge in this metric. What would be the best way to give credit to schools with more than one course that includes sustainability? An average alone of the scores would not be a fair representation, because it

would only serve to lower high, or increase low scores to an average. In the end, the researcher utilized the following equation in Figure 4.4 to reflect the quantity and quantity of civil engineering sustainability.

$$UC = WT_{CS} * \frac{CS_1 + CS_2 + CS_n}{n} + WT_N * \frac{n}{n_{max}}$$

WT_{CS} = Weight Factor for Course Sustainability Score = 75%

$CS_{1...n}$ = Course Sustainability Score for course 1 thru n for one University

WT_N = Weight Factor for Number of Sust. Courses Available to CE Undergrads = 25%

n = Number of Courses for one University

n_{max} = Maximum Number of Courses available at any one University in the Metric

Figure 4.4 University Course Sustainability Subtotal (UC) Calculation

Quantity and quality were not given the same weighting, as is reflected in the preceding equation. A ratio weighting of 3:1, Course Sustainability Score to number of sustainability courses, was assigned to capture the importance of quality to quantity, respectively. The University Course Sustainability Subtotal is one of the three categories included in this first iteration of the UCESEM.

4.6 UCESEM Calculation

The purpose of the UCESEM is to measure the sustainability coverage in undergraduate civil engineering programs. The preliminary metric for this project includes evaluation of the civil engineering courses with sustainability through the University Course Sustainability Subtotal, the current score from the College Sustainability Report Card, also known as the Green Report Card, as well as the change in the Green Report Card score from the previous year. The chapter of this paper on ideas for further research identifies other categories which might be included in future iterations of metric development, but were not able to be included in this stage of the project.

Once the benchmarking report syllabi were filtered as previously illustrated in Figure 4.2 of this paper, the resulting 25 universities and their corresponding Green Report Card Scores for 2010 and 2009 were as shown in Table 4.7 below.

Table 4.7 UCESEM Universities and their Green Report Card Scores from 2009 and 2010

UCESEM University	Green Report Card	
	2009	2010
Arizona State University	B+	A-
Carnegie Mellon University	B	B
Georgia Institute of Technology	B	B
Michigan Technological University	N/A	N/A
Oregon State University	B	B+
Rice University	B-	B
Santa Clara University	B	B
The University of Toledo	D+	C+
University of California, Berkeley	B	B
University of California, Davis	B+	B+
University of Delaware	C+	C
University of Florida	B+	B
University of Houston	C-	B-
University of Illinois at Urbana-Champaign	B-	B-
University of Michigan	B	B+
University of Nebraska-Lincoln	C+	C+
University of New Hampshire	A-	A-
University of South Florida	C-	C
University of the Pacific	D	C
University of Virginia	B	B-

(Data Compiled from SEI 2009)

A majority, 75%, of the UCESEM comes from the assessment of the sustainability courses offered from the University Course Sustainability Subtotal. The Green Report Card is 20% of the overall UCESEM score because it represents the institution's commitment to sustainability. The remaining 5% of the total score captures the change in Green Report Card score from the previous year. A negative change would subtract from the course score, which is due to a decrease in the overall campus sustainability. The policies of the overarching university set the stage and influence the departments, faculty and

students. Conversely, an active student body, faculty, or departments may affect change, but at a slower, uphill rate. The UCESEM calculation is illustrated in Figure 4.5.

$$UCESEM = WT_{UC} * UC + WT_G * GRC + WT_{GC} * GRC$$

WT_{UC} = Weight Factor for University Course Sustainability Subtotal = 75%

UC = University or College Course Sustainability Subtotal

WT_G = Weight Factor for Green Report Card = 20%

GRC = Green Report Card Score from Current Year

WT_{GC} = Weight Factor for Green Report Card Score Change from Previous Year = 5%

GC = Difference between Current Year G and Previous Year (may be negative)

Figure 4.5 Undergraduate Civil Engineering Sustainability Education Metric (UCESEM) Calculation

The Green Report Card scores were translated to the 4.0 scale, as shown in Table 4.8, so that they might be calculated within the metric.

Table 4.8 Green Report Card Score Translation

Green Report Card Score	Numerical Translation
A	4.0
A-	3.7
B+	3.3
B	3.0
B-	2.7
C+	2.3
C	2.0
C-	1.7
D+	1.3
D	1.0
D-	0.7

(Greene and Greene 2009)

The UCESEM enables an overall comparison between civil engineering sustainability educations at different institutions. Future iterations of the metric creation could include criteria such as LEED Accredited Professional faculty, the value of current research in sustainability, and other criteria.

5.0 Findings

The defined categories and weightings combined to form the proposed metrics to assess the coverage of sustainability within civil engineering programs. As previously defined, the sample set for test implementation of the metric was the syllabi provided in the *Benchmarking Sustainable Engineering Education: Final Report*. Table 5.1 illustrates the results of the Course Sustainability Subtotal and the University Sustainability Subtotals. The course sustainability subtotals were combined in the equation listed in Figure 4.4. It should be repeated that these scores used the included syllabi from the CSE report. The scores for some schools may be higher than depicted in the table, as they may have more courses in sustainability, but for one reason or another, were not submitted in the CSE survey request.

One of the civil engineering-applicable syllabi that were submitted did not respond to the percent of the course that focused on sustainability. This affected the results of the score for this school, the University of Florida. The course received a 0.40 course score with the school garnering a 0.38 score, putting it 11th in the overall UCESEM ranking. A basic sensitivity analysis shows that if assuming the reported percentage was 'under 10%'; the course and school scores would have been 0.47 and 0.44 respectively, and 10th in the overall UCESEM ranking. On the other end of the spectrum, since the course was titled 'Sustainable Engineering', if it had reported 'over 50%' of the course focusing on sustainability, the course and school scores would have been 0.70 and 0.60, moving the University of Florida into the #6 ranking in the UCESEM for the courses of schools included in the CSE civil engineering syllabi. This variance illustrates the impact that the course's focus on sustainability has for the overall Undergraduate Civil Engineering *Sustainability* Education Metric. The course's focus on sustainability was deemed the most important and therefore, absence of data for this category strongly impacted the university's score. Once a metric such as the UCESEM is implemented, the universities would be encouraged to respond to this category for their courses. During the transition to the metric, the category could be answered as was advised in the metric development section of this report. A systematic review of the course schedule with total topics covered should be executed, and those that fit within the sustainability categories from the metric, could be separately identified. Finally, an overall percentage of sustainability focus could be determined and included in the metric.

Table 5.1 Course Sustainability Subtotal

	Arizona State University		University of California, Berkeley		University of California, Davis		Carnegie Mellon University		University of Delaware		University of Florida		Georgia Institute of Technology		University of Houston		University of Illinois at Urbana-Champaign		Michigan Technological University		University of Michigan		University of Nebraska-Lincoln		University of New Hampshire		Oregon State University		University of the Pacific		Rice University		Santa Clara University		University of South Florida		The University of Toledo		University of Virginia		Coverage of Topic
	10	6	29	64	21	35	37	33	55	5	16	34	18	39	57	53	47	38	54	56	12	60	51	19	62																
CSE Syllabus offered by CE or with over 50% other engineering students																																									
Three Pillars of Sustainability																																									
Environmental	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x																92%	
Economic		x	x	x	x				x	x		x				x	x	x	x	x		x	x	x															60%		
Social	x			x	x	x	x		x	x		x				x	x			x																			52%		
Life Cycle Analysis/Planning		x	x	x	x			x				x				x	x	x	x		x		x	x															56%		
Design for the Environment (DFE)		x				x		x														x																	16%		
Industrial Ecology	x	x				x						x											x																20%		
Material Flow Analysis (MFA)			x		x	x	x							x																									24%		
Natural Resource Management	x		x					x	x														x																24%		
Policy and Regulations									x		x										x			x	x	x													24%		
Economics (excluding short-term cost analysis)		x	x							x		x										x																	28%		
Pollution Prevention		x	x					x				x	x	x	x						x	x																	36%		
Climate Change												x	x																										24%		
Renewable Energy												x											x	x															16%		
Green Design/Engineering			x		x				x							x							x	x	x														28%		
Reuse and/or Recovery of Products and Materials															x																									4%	
Decision Making									x	x							x																							20%	
Systems Engineering/Approach	x	x									x							x																						16%	
Project Life-cycle cradle to grave		x	x								x																													16%	
Environmental/Sustainability Ethic	x										x																													8%	
Technology Assessment Tools		x			x	x	x					x						x																						28%	
LEED																																								16%	
Global Considerations	x			x		x	x	x	x			x	x					x																						52%	
Sustainable Development							x											x																						20%	
History of Sustainability/Environmental Concerns (not case studies)							x																																	8%	
Integration with other (non-CE) topics/studies	x											x																												12%	
Site Visits/Field Trips		x		x																			x																	24%	
Community Engagement				x																																					4%
Offered by Civil Engineering	x	x	x	x	x	x	x	x		x				x	x						x	x					x	x												76%	
Student Level	1	2	1	1	3	2	2	2	2	1	1	3	3	1	3	3	2	2	2	1	1	2	1	3	3	1															
% of course focused on sustainable engineering	4	4	4	4	4	4	4	4	4	0	3	4	4	1	2	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	1	
Course Sustainability Subtotal (CSS)	0.67	0.67	0.70	0.72	0.68	0.64	0.65	0.56	0.40	0.68	0.48	0.66	0.33	0.34	0.65	0.65	0.62	0.69	0.72	0.51	0.59	0.77	0.58	0.53	0.23																
University CSS (UC)	0.59	0.59	0.70		0.74		0.50	0.38		0.71			0.33	0.34	0.57	0.57	0.55	0.60	0.62	0.46	0.52	0.66	0.52	0.48	0.25																
Average UC	0.53																																								

Legend	
Student Level	
1	Undergraduate
2	Undergraduate/Graduate
3	Graduate
% of Course Focused on Sustainability	
1	< 10%
2	10-25%
3	25-50%
4	> 50%

The table displays the coverage the coverage of sustainability knowledge and tools varied from course to course and between schools. However, there were some topics that occurred more frequently than others, as may be seen in Table 5.2. The top five categories covered each of the three pillars of sustainability, environmental, economic, and social, were offered by civil engineering, and covered life cycle analysis and/or planning. Since this was a search for civil engineering-applicable courses, the offered by civil engineering parent category should be disregarded in order to identify the following top five sustainability topics:

- 1- Environmental Pillar
- 2- Economic Pillar
- 3- Life Cycle Analysis/Planning
- 4- Social Pillar
- 5- Global Considerations

Table 5.2 Frequency of Categories in CSE Civil Engineering-Applicable Courses

Course Civil Engineering Sustainability Categories	Coverage of Topic
Pillar - Environmental	92%
Offered by Civil Engineering	76%
Pillar - Economic	60%
Life Cycle Analysis/Planning	56%
Pillar - Social	52%
Global Considerations	52%
Pollution Prevention	36%
Economics (excluding short-term cost analysis)	28%
Green Design/Engineering	28%
Technology Assessment Tools	28%
Material Flow Analysis (MFA)	24%
Natural Resource Management	24%
Policy and Regulations	24%
Climate Change	24%
Site Visits/Field Trips	24%
Industrial Ecology	20%
Decision Making	20%
Sustainable Development	20%
Design for the Environment (DFE)	16%
Renewable Energy	16%
Systems Engineering/Approach	16%
Project Life-cycle cradle to grave	16%
LEED	16%
Integration with other (non-CE) topics/studies	12%
Environmental/Sustainability Ethic	8%
History of Sustainability/Environmental Concerns (not case studies)	8%
Reuse and/or Recovery of Products and Materials	4%
Community Engagement	4%

The frequency of these topics, illustrates consensus, and shows that these could be considered a common thread among courses addressing sustainability. A student in a course without one of these topics would be potentially missing the experience that most of their peers may have in sustainability. The final UCESEM scores were calculated using the equation outlined in Figure 4.5, prioritized in order of programs with the largest to smallest overall UCESEM score, and are listed in Table 5.3. As was previously discussed, the Green Report Card started in 2006, and to date covers 332 institutions. Unfortunately, Michigan Technological University is the only school, with an ABET accredited civil engineering program that submitted syllabi applicable to civil engineers, but has not yet participated in the Green Report Card. This resulted in their score not being computed, since the Green Report Card score data represents 25% of the total UCESEM calculation. Participation in the Green Report Card continues to grow annually, and the hope is that the one non-participating school in the development and test of the UCESEM, will soon join the ranks of those universities that have already requested to be included in the annual Green Report Card.

Table 5.3 UCESEM for CSE Civil Engineering Programs

	UCESEM	2010 Green Report Card (GRC)	2009 GRC	GRC One-Year Change	University Course Sustainability Subtotal (UC)
University of New Hampshire	1.19	3.7	3.7	0	0.60
University of California, Davis	1.18	3.3	3.3	0	0.70
Carnegie Mellon University	1.16	3	3	0	0.74
Georgia Institute of Technology	1.13	3	3	0	0.71
Arizona State University	1.12	3.7	3.3	0.4	0.59
Santa Clara University	1.09	3	3	0	0.66
Oregon State University	1.08	3.3	3	0.3	0.62
University of Michigan	1.04	3.3	3	0.3	0.57
University of California, Berkeley	1.04	3	3	0	0.59
Rice University	0.95	3	2.7	0.3	0.52
University of Florida	0.93	3	3.3	-0.3	0.38
University of Nebraska-Lincoln	0.87	2.3	2.3	0	0.55
University of Delaware	0.82	2	2.3	-0.3	0.50
University of Illinois at Urbana-Champaign	0.79	2.7	2.7	0	0.34
University of Virginia	0.77	2.7	3	-0.3	0.25
University of South Florida	0.74	2	1.7	0.3	0.52
The University of Toledo	0.67	2.3	1.3	1	0.48
University of Houston	0.64	2.7	1.7	1	0.33
University of the Pacific	0.6	2	1	1	0.46
Michigan Technological University		N/A	N/A		0.57

6.0 Discussion

Review of current literature identified the need for coverage of sustainability for undergraduate civil engineers. Further research showed the interest in methods for consumers of education products, to assess the exposure of graduates to sustainability skills and topics. This process for this project identified categories that could combine to form a method for assessment. The weightings presented in this report are as of yet, not validated. The currently assigned weights serve the purpose of getting the ball rolling towards a metric, but the first step in further research would be the validation of the categories and weights. Though the former was harvested from existing sustainability frameworks and

attitudinal reports, and the latter came from literature review as to the importance of the sets, a robust metric would require validation.

The *Benchmarking Sustainable Engineering Education Final Report* did not include all schools, or all classes within the schools, that educate civil engineering undergraduates. Additionally, since it was a survey of accredited engineering programs, it only captured courses that were offered by colleges of engineering. However, technical electives for civil engineering undergraduates could be located outside of a college of engineering. For instance, Virginia Tech has many other opportunities for civil engineers, particularly within the Department of Building Construction, under the College of Architecture (Ahn et al. 2008). Further testing and implementation of the metric would capture many of these courses, as long as at least 50% of the students are ‘other engineering’. If the UCESEM gets implemented, as each department is contacted for syllabi submittal and response to the statistics questions, such as class composition and sustainability focus from the benchmarking report, it would be in the best interest of the civil engineering department to identify the technical electives that a high percentage of their students take.

In addition to there being more courses and schools available to study in the current metric, some schools are starting to establish separate programs focused on sustainability. The University of Florida benchmarking case illustrated one school that is doing just that. The report identified 15 colleges or universities with similar sustainability ‘groupings’ (Appledorn and Ankersen 2006).

7.0 Future Research

In order to validate or revise these weightings and/or categories, surveys of industry professionals and educators in sustainability should be executed to capture an average identification and prioritization of these categories. Once the prioritization is completed, validated weightings may be assigned to revise the preliminary weightings. It is recommended that once the metric and weights are validated, there should be limited changes to the weighting system. Changing the weights will make it challenging for consumers (students, industry and faculty) to understand the changes for the programs from one year to the next (Sanoff 2007).

Further research should include surveys to capture the interest of civil engineering students, and possibly all students involved in degree programs that would potentially direct them towards the design, construction, or facility management fields. The survey should identify current topics within these areas

of infrastructure and facilities, to include sustainability, and ask respondents to identify levels of perceived importance to the student. Similar research was conducted for the perceived importance of industry professionals on building topics to include sustainability (Ahn and Pearce 2007). Implementation of this methodology on a survey of students would identify their perceived importance, and would show where the new crop of civil engineers believes sustainability falls in the continuum of topics. The survey should be conducted with upper level undergraduate and graduate students, as these groups are the more informed as to what their career field will entail.

Further enquiry into developing a metric should broaden the subject audience to include the departments involved in the construction trades, such as architectural, civil and environmental engineers, architects, building science, and construction management, among others, to get their support in identifying the quantity of courses that are core to the curriculum, which include sustainability and to the extent that they address it, as well as their identification of the quantity of technical electives (technical because this is the realm that the engineer will mainly be operating in) and the syllabi as well as sustainability focus percentage and the level and program of students typically enrolled. This would solve most of the challenge of identifying the courses that a high percentage of civil engineers take, outside of the civil engineering department. There would remain other courses that qualify as technical electives, and future research should attempt to refine the criteria to identify civil engineer technical electives, beyond those that meet the current filter of 'over 50% other engineering'.

The CSE report asked syllabi submitters to answer some question, one of which was how many times the course was offered. Even though a course might be 'on the books', if it is only offered once every other year, it is not very accessible to students. This will mainly be an issue for non-core/technical electives. Future research should ask the number of times the course was taught in a 4-year period (the typical civil engineer program length) and include that in the calculation, where the ideal scenario is once per year, which would equate to 4 times. If in the unusual case, the course was taught every semester, the school would conceivably get a 'bonus' points. This factor should only be applied if the course is a technical elective, as core courses are required of all graduates, and will be taken by all graduates.

It is hoped that collected research data will support the hypothesis that a department's interest and focus on sustainability will be reflected through its pursuit and attainment of research funding. Industry support for research would be directed towards those programs with innovative ideas in sustainability, an aspect not captured in the currently proposed UCESEM. Future metric development should identify a

method to account for a department's engagement in sustainability research. One possible form this could take would be value ranges, similar to the ranges of sustainability focus in a class, could give increasing credit for higher levels of sustainability research.

A revised version of the metric should include a category in the UCESEM to identify sustainability minors and certificates when completing the final score for the school. While not directly related to civil engineering, the following excerpt from the report shows that one university, for example, Virginia Tech is pursuing sustainable integration into their curriculum. The *Benchmarking Sustainable Engineering Education Final Report* of the College of Engineering's comprehensive approach to sustainability education, provided in the benchmarking report stated:

"An exemplar of an institution with an unusually comprehensive approach to undergraduate education in sustainable engineering is Virginia Tech. At Virginia Tech, students from any undergraduate engineering program can choose a concentration related to sustainable (green) engineering. The students take a total of 18 semester credit hours of courses with sustainable engineering content: six hours within their major, 6 hours of interdisciplinary electives and 6 credit hours that are core to the option. The two core courses provide a general background in environmental science and an introduction to life cycle approaches to engineering problem solving. The consistent approach across all engineering departments and the common core courses, taken by engineers from all departments, make this program noteworthy." (Allen et al. 2009).

This section identified some possible methods to fine tune the UCESEM. As the English idiom goes, "Rome was not built in a day". Similarly, the metric will require further steps to refine. It will likely receive criticism, similar to those who challenge competitive metrics of this sort. However, the benefits brought to educating the stakeholders as to the quality and quantity of education addressing sustainability, an area of great importance and concern today, support its implementation

8.0 Conclusion

This report represents an introduction for the formulation and execution of a metric assessing the attention to and coverage of sustainability in undergraduate civil engineering programs. The steps towards defining a metric to assess sustainability in the coursework for undergraduate civil engineers were taken with care, yet remained organic as the project progressed. The end goal of essentially 'grading' other industry professionals on the quantity and quality of their sustainability offerings and

overall programs may be slightly controversial because of the argued subjectivity of a course-content oriented metric and relative importance of categories metric. Yet, the success and interest in the *U.S. News and World Report's* annual rankings on colleges and universities, shows that these types of metrics are a valued decision-making tool for education. The challenge is to develop a standard method of reviewing coursework and metrics for sustainability, in order to perform the evaluation in a standard manner.

In today's rapidly evolving environment, it is important to note that the provision of the undergraduate civil engineering sustainability metric will help to assess the foundation and specific tools of recent graduates, yet it should not be viewed as a completed mission for these graduates. Professional development and education does not stop at graduation, and in order to remain competitive in today's constantly changing environment, it is necessary for them to build off of their education in sustainability, whether well-ranked or not, to remain competitive and provide valid and up-to-date contributions to their work, whether overtly or minutely connected to sustainability. The education of future civil engineering professionals demands the implementation of a holistic approach in engineering education. This requires the infusion of sustainability knowledge and skills in order to overcome inertia of yesterday's engineering practices.

References

- ABET. (2009). "ABET Leadership and Quality Assurance in Applied Science, Computing, Engineering, and Technology Education." <<http://www.abet.org>>. (Sep. 9 2009).
- Ahn, Y. H., and Kwon, H. (2008). "The Attitude of Construction Students toward Sustainability in the Built Environment." *Journal of Engineering Education Research*, 11(3), 70-77.
- Ahn, Y. H., Kwon, H., and Pearce, A. R. (2008). "Sustainable Education for Construction Students."
- Ahn, Y. H., Kwon, H., Pearce, A. R., and Wells, J. G. (2007). "Integrated Sustainable Construction: A Course in Construction for Students in the U.S.A." Proceedings, American Society for Engineering Education Annual Conference, Pittsburgh, PA.
- Ahn, Y. H., and Pearce, A. R. (2007). "Green construction: Contractor experiences, expectations, and perceptions." *Journal of Green Building*, 2(3), 1-17.
- Allen, D., Allenby, B., Bridges, M., Crittenden, J., Davidson, C., Hendrickson, C., Matthews, S., Murphy, C., and Pijawka, D. (2009). "Benchmarking Sustainable Engineering Education: Final Report." University of Texas at Austin, Carnegie Mellon University, Arizona State University.
- American College & University Presidents' Climate Commitment (ACUPCC). (2009). "American College & University Presidents' Climate Commitment." <<http://www.presidentsclimatecommitment.org>>. (May 7, 2009).
- American Institute of Architects and Associated General Contractors of America. (2004). "Primer on Project Delivery." 1-8.
- Appledorn, B. L., and Ankersen, T. T. (2006). "Fostering Curriculum Development and Cross-Campus Collaboration in Sustainability at the University of Florida: A Report with Conclusions and Recommendations." Center for Governmental Responsibility, University of Florida.
- Berman, J. (2009). "College Students are Flocking to Sustainability Degrees, Careers." USA Today, Gannet Co., Inc.
- Blayse, A. M., and Manley, K. (2004). "Key Influences on Construction Innovation." *Construction Innovation*, 4(3), 1-12.
- Bureau of Labor Statistics (BLS). (2008). "Occupational Outlook Handbook - Engineers." U. S. Department of Labor, ed., Washington, D.C.
- Center for Sustainable Engineering (CSE). (2009). "Center for Sustainable Engineering." <<http://www.csengin.org>>. (Feb. 20, 2009).
- Chan, A., and Chan, E. (2005). "Impact of Perceived Leadership Styles on Work Outcomes: Case of Building Professionals." *Journal of Construction Engineering and Management*, 131(4), 413-422.

- Clarke, M. (2007). "The Impact of Higher Education Rankings on Student Access, Choice, and Opportunity." Institute for Higher Education Policy, Washington, D.C.
- Coleman, M. (2009). "Presidents' Climate Commitment Discussion." K. Augsburger, ed., Blacksburg, VA.
- Commission on Sustainable Development. (1992). "Earth Summit Agenda 21." UN Department of Economic and Social Affairs, ed., United Nations, New York.
- ConstructionSkills. (2009). "Sustainability Skills Matrix for the Built Environment Functions." Sector Skills Council, ed., Norfolk, England.
- Cotgrave, A., and Alkhaddar, R. (2006). "Greening the Curricula within Construction Programmes." *Journal for Education in the Built Environment*, 1(1), 3-29.
- Dainty, A. R. J., Cheng, M.-L., and Moore, D. R. (2005). "Competency-Based Model for Predicting Construction Project Managers' Performance." *Journal of Management in Engineering*, 21(1), 2-9.
- DuBois, A., and Gadde, L. (2002). "The construction industry as a loosely coupled system: implications for productivity and innovation." *Construction Management and Economics*, 20, 621-631.
- EPA. (2004). "Buildings and the Environment: A Statistical Summary." Green Building Workgroup, ed. 5.
- EPA. (2008). "Green Building." <<http://www.epa.gov/greenbuilding/pubs/whybuild.htm>>. (Nov. 12, 2008).
- ETA. (2008). "High Growth Industry Profile - Construction." U. S. Department of Labor, ed., Washington, D.C.
- FMI. (2005). "FMI K-12 Public School Construction Management Survey."
- Galloway, P. (2003). "The Mission of the Civil Engineer in the Movement of Globalization." *Leadership and Management in Engineering*, July.
- Gharehbaghi, K., and McManus, K. (2003). "The Construction Manager as a Leader." *Leadership and Management in Engineering*, 3(1), 56-58.
- Greene, H., and Greene, M. (2009). "How Colleges Look at Your GPA Scale." www.petersons.com.
- Griffis, F. H. B., and Brown, N. "Leadership in the Management of Construction." *Construction Research Congress - Wind of Change: Integration and Innovation*, Honolulu, Hawaii.
- Group, I. S. W. (2009). "Interagency Sustainability Working Group; Past Accomplishments, Current Priorities, and New Opportunities."
- Haigh, M. (2005). "Greening the University Curriculum: Appraising an International Movement." *Journal of Geography in Higher Education*, 29(1), 31-48.

- Haselbach, L. M., and Fiori, C. M. (2006). "Construction and the Environment: Research Foci for a Sustainable Future." *Journal of Green Building*, 1(1), 11.
- Hersh, R. H. (2005). "What Does College Teach?" *The Atlantic Monthly*, 7, November.
- Huntzinger, D., Hutchins, M., Gierke, J., and Sutherland, J. (2007). "Enabling Sustainable Thinking in Undergraduate Engineering Education." *International Journal of Engineering Education*, 23(2), 218-230.
- International Institute for Sustainable Development (IISD). (2009). "BellagioSTAMP: SusTainability Assessment and Measurement Principles." Winnipeg, Canada.
- Keeping, M. (2009). "What About Demand? Do Investors Want Green Buildings?" Oxford Centre for Sustainable Development, Oxford, England.
- Keysar, E., and Pearce, A. R. (2007). "Decision Support Tools for Green Building: Facilitating Selection Among New Adopters on Public Sector Projects." *Journal of Green Building*, 2(3), 153-171.
- Krieger, S. (2008). "Green Gap." *The Wall Street Journal*, New York, New York.
- Lapinski, A. R., Horman, M. J., and Riley, D. R. (2006). "Lean processes for sustainable project delivery." *Journal of Construction Engineering and Management*, 132(10), 1083-109.
- Levenson, E. (2009). "A Clearer Future: Why Sustainability Graduates are in Hot Demand." *The Independent*, Independent News and Media Limited, London, England.
- Manion, M. (2002). "Ethics, Engineering and Sustainable Development." *IEEE Technology and Society*, 39-48.
- Masi, C. G. (1995). "Re-engineering Engineering Education." *Spectrum, IEEE*, 32(9), 44-47.
- Miller, D. M., Fields, R., Kumar, A., and Ortiz, R. (2000). "Leadership and Organizational Vision in Managing a Multiethnic and Multicultural Project Team." *Journal of Management in Engineering*, 16(6), 18-22.
- Morse, R. (2008). "The Birth of the College Rankings-How "Best Colleges" became the top source for information on higher education." *U.S. News & World Report*. May 16, 2008.
- Myers, D. (2005). "A Review of Construction Companies' Attitudes to Sustainability." *Construction Management and Economics*, 23, 781-785.
- Nalewaik, A., and Venters, V. (2009). "Cost Benefits of Building Green." *The AACE International Journal of Cost Estimation, Cost/Schedule Control, and Project Management*, 51(1), 28-34.
- Park, M., Nepal, M. P., and Dulaimi, M. F. (2004). "Dynamic Modeling for Construction Innovation." *Journal of Management in Engineering*, 20(4), 170-177.

- Pathway, E. (2009). "Engineering Pathway." <<http://www.engineeringpathway.com>>. (May 8, 2009).
- Pearce, A. R. (2002). "Resource Allocation and Problem Prioritization for Sustainable Military Facilities, Infrastructure, and Installations." Proceedings, National Defense Industries Association Conference, Charleston, SC, March 25-28.
- Pearce, A. R. (2008). "Influence of Rankings." K. M. Augsburger, ed., Blacksburg, VA.
- Pearce, A. R., and Carpenter, A. (2005). "Sustainable Facilities & Infrastructure Training: Approaches, Findings and Lessons Learned." *2005 Mascaro Sustainability Initiative Sustainable Engineering*, Pittsburgh, PA.
- Pearce, A. R., and Fiori, C. M. (Submitted for Review). "Sustainable Construction Benchmarking: Guidelines and Protocols for Undergraduate Internships." Engineering Pathway, National Engineering Education Delivery System (NEEDS).
- Pearce, A. R., and Maxey, D. E. (2007). "Construction Principles for the Future: A Revised Approach to Teaching the Basics." Proceedings, Construction Research Congress, May 6-8, Grand Bahamas Island.
- Pearce, A. R., and McCoy, A. P. (2007). "Creating an Educational Ecosystem for Construction: A Model for Research, Teaching, and Outreach Integration and Synergy." Proceedings, Construction Research Congress, May 6-8, Grand Bahamas Island.
- Pearce, A. R., and Vanegas, J. A. (2002). "Defining Sustainability for Built Environment Systems: An Operational Framework." *International Journal of Environmental Technology and Management*, 2(1-3), 94-113.
- Pearce, A. R., and Vanegas, J. A. (2003). "A parametric review of the built environment sustainability literature." *International Journal of Environmental Technology and Management*, 2(1-2), 54-93.
- Petchen, R. (2009). "Tech Opts Out of University Climate Coalition." Collegiate Times, Blacksburg, VA, 1, Oct 7, 2009.
- Riley, D. R., Grommes, A. V., and Thatcher, C. E. (2007). "Teaching Sustainability in Building Design and Engineering." *Journal of Green Building*, 2(1), 175-195.
- Rydin, Y., and Vandergert, P. (2006). "Sustainable Construction: the social science research agenda." The LSE SusCon Project.
- Sanoff, A. P. (2007). "The U.S. News College Rankings: A View From the Inside." Institute for Higher Education Policy, Washington, D.C.
- Segalas, J., Ferrer-Balas, D., Svanstrom, M., Lundqvist, U., and Mulder, K. F. (2008). "What has to be Learnt for Sustainability? A Comparison of Bachelor Engineering Education Competences at Three European Universities." *Sustainability Science*, 4(1), 17-27.

- Segnestam, L. (2002). "Indicators of Environment and Sustainable Development: Theories and Practical Experience." The World Bank, Washington, D.C.
- Siddiqi, K. M., Chatman, D., and Cook, G. (2008). "Role of Education and Industry Towards More Sustainable Construction." *International Journal of Environmental Technology and Management*, 8(2/3), 310-321.
- Solutions, M. (2004). "CITB-Construction Skills; Build to Last - Reviewing Sustainable Construction, an executive summary." MRM Solutions.
- Strategies, S. (2009). "Developing an Effective Hiring Process." <<http://www.servicestrategies.com>>. (Oct 3, 2009).
- Su, E. Y. (2006). "How useful are annual college rankings?" The San Diego Union-Tribune, San Diego, Sep 7, 2006.
- Sustainable Endowments Institute (SEI). (2009). "The Sustainability Report Card." <<http://www.greenreportcard.org>>. (May 7, 2009).
- USGBC. (2009). "U.S. Green Building Council." <<http://www.usgbc.org>>. (Sep 9, 2009).
- Vanegas, J. A., Johnson, K. E., and Pearce, A. R. (2004). "Toward a Living Laboratory for Built Environment Sustainability." Proceedings of the International Conference on Engineering Education in Sustainable Development – EESD 2004, Barcelona, Spain, October.
- Vanegas, J. A., and Pearce, A. R. (2004). "An Integrated Undergraduate/Graduate Course Sequence in Sustainable Facilities and Infrastructure." Proceedings of the International Conference on Engineering Education in Sustainable Development – EESD 2004, Barcelona, Spain, October.
- Weber, R. P. (1990). *Basic Content Analysis*, Sage Publications, Inc., Newbury Park, CA.
- Zisk, L. (2007). "Green With Embrey; New Engineering Facility Supports Environmental Learning." SMU Magazine.