www.itcon.org - Journal of Information Technology in Construction - ISSN 1874-4753

THE PACE OF TECHNOLOGICAL INNOVATION IN ARCHITECTURE, ENGINEERING, AND CONSTRUCTION EDUCATION: INTEGRATING RECENT TRENDS INTO THE CURRICULA

PUBLISHED: February 2011 at http://itcon.org/2011/24
EDITOR: Turk Z.

Burcin Becerik-Gerber, Assistant Professor
Department of Civil and Environmental Engineering, School of Engineering, University of Southern California, USA
becerik@usc.edu

David J. Gerber, Assistant Professor
School of Architecture, and School of Engineering, University of Southern California, USA
dgerber@usc.edu

Kihong Ku, Assistant Professor
Department of Building Construction, College of Architecture and Urban Studies, Virginia Tech, USA
kku@vt.edu

SUMMARY: *The U.S. AEC industry is faced with the ever-increasing challenge of managing the public and private facilities and infrastructure to support the accomplishment of its economy. The increasing global emphasis on sustainable approaches and the need to increase efficiency and improve cost over the lifecycle of projects, demand new approaches to architecture, engineering, and construction (AEC) education. This study was initiated to look for insight into the current educational environment and to provide a baseline for possible solutions to cope with the complexity of the challenge. This paper examined 101 U.S. AEC programs focusing on emerging subject areas of Building Information Modeling (BIM) and sustainability, and reviewed how educational innovations of distance learning, multidisciplinary collaboration, industry collaborations, are incorporated to develop core competencies in those two subject areas. The researchers reviewed and categorized the AEC disciplines based on the respective accrediting bodies of ABET, NAAB, and ACCE, and surveyed the internal factors (e.g., program resources, expertise, etc.) and external factors (e.g., accreditation requirements, sustainability initiatives, etc.) that affect the pedagogical approaches. This study illustrates the challenges incorporating new knowledge areas into constrained curricula and the various approaches that the university programs are undertaking. A comparative analysis also reveals the similarities and differences and specific advantages and disadvantages of particular approaches across the AEC programs. The findings reinforce the notion that there are disparities in these educational programs, which need realignment to develop the workforce of the future that will lead the AEC industry transformations.*

KEYWORDS: *Building Information Modeling, Integrated Project Delivery, Sustainability, Engineering Education, Architecture Education, and Construction Education*

REFERENCE: *Burcin Becerik-Gerber, David J. Gerber, Kihong Ku (2011) The pace of technological innovation in architecture, engineering, and construction education: integrating recent trends into the curricula, Journal of Information Technology in Construction (ITcon), Vol. 16, pg. 411-432, http://www.itcon.org/2011/24*

1. INTRODUCTION

Currently, the architecture, engineering and construction (AEC) industry is facing enormous technological and institutional transformations with their resultant difficulties and challenges. The industry is embracing new modes of information sharing and adopting emerging and fast growing concepts such as building information modeling (BIM), sustainability, collaboration and related technologies. Almost fifty percent of the AEC industry is now using BIM and twenty percent of non-users are planning to adopt it within two years (McGrawHill, 2009). Lack of adequately BIM trained personnel is a significant constraint hindering the use and adoption of the technology in the industry. Enhancing sustainability through new approaches, methods, and information technology is another vital and emerging trend in the industry (Levitt, 2007). Growing partnerships between the research community and industry through technology in construction, electronic collaboration, and sustainable development are listed as research trends and priorities in the AEC industry (Bakens, 1997). In recent years studies have been conducted (Lang et al. 1999; Johnson and Gunderson, 2010) to determine the technical and personal abilities required of young professionals by today's construction industry. These studies have indicated some key concerns: today's engineering graduates need to have strong collaboration and teamwork skills; they need to have a broader perspective of the issues that concern their profession such as social, environmental and economic; and finally they need to know how to apply fundamental engineering science and computer skills in practice. Today's 21st century architect, engineer and construction manager must be able to deal with a rapid pace of technological change, a highly interconnected world, and complex problems that require multidisciplinary solutions. A mutually beneficial industry and academic collaboration will lead to growth in strategic research and would also address the concerns about computing and information technology research in AEC being self-fulfilling rather than industry transforming (Issa and Anumba, 2007). Historically, the AEC education system did not allow for adequate interplay between disciplines, this is becoming ever more exacerbated due to the increasing adoption of new project delivery systems such as integrated project delivery (IPD) (Kent and Becerik-Gerber, 2010).

While it is obvious that educational environments must maintain some likeness to the real-world practices of the industry, keeping the curriculum in line with the needs of industry is an important challenge given that the AEC industry is poised for rapid transformation. However, AEC education should be setting the pace rather than keeping the pace with the industry. AEC education should be adapting, and structured to evolve to address present and future challenges. What is clear is that the AEC profession can no longer be focused on a single discipline. In concert, the AEC education should acknowledge the collaborative nature of the multidisciplinary AEC design and construction process. In parallel to the industry, AEC educational programs should also promote sustainability (Manoliadis, 2009), embrace technology (Becerik-Gerber and Kensek, 2010), and think cross disciplinarily to keep their momentum in attracting students and resources (Adeli, 2009).

Although the issue of BIM and sustainability in AEC education has attracted much attention in academic literature (Casey, 2008; Chau, 2007; Denzer and Hedges, 2008; Sacks and Barak, 2009; Wang, 2009; Weber and Hedges, 2008), little is known about what the current status of BIM and sustainability is in the AEC curricula. This paper attempts to meet the need for an objective study of the current state of BIM, sustainability, collaboration and virtual learning applications within the AEC education in the U.S. It also investigates the level and integration of research with these recent trends, and level and integration of multidisciplinary approaches to research and teaching. In addition the paper attempts to identify the similarities and differences between architecture, engineering and construction management programs by analyzing the data based on these three categories. The paper aims to provide a fundamental benchmark for institutions to make decisions regarding research, industry collaboration, and curricula, where emphasis on integrations is valued.

2. METHODOLOGY

Since there is little empirical data regarding the current level of integration of recent trends including BIM, sustainability and virtual learning applications into AEC higher education curricula in the U.S. and there are no benchmarks for further improvements, an online survey methodology was implemented. In addition, the survey aimed to measure and understand the status of research in AEC education, and integration of multidisciplinary approaches to the research and teaching.

The survey was designed in a collaborative and iterative process between architecture, engineering, and construction management faculty members. The authors underwent six weeks of iteration regarding the type, amount and configuration of questions, between August 4 and September 12, 2009. The authors structured the survey into multiple sections designed to elucidate the core question, that of the level of recent trends and topics of technology integration within the disparate curriculum of architecture, engineering, and construction management. The survey's design through these six sections (BIM, sustainability, virtual learning applications, research, industry and academia collaboration and multidisciplinary education) was devised to benchmark and quantify trends of current and future integrations of the key topics and technologies for academic programs to parallel and set the pace for the needs of industry.

The survey was open for four weeks between September 29 and October 26, 2009. The survey targeted and solicited the deans, department chairs and program directors of 488 accredited architecture, architectural engineering, civil engineering, civil engineering technology, architectural engineering technology, construction engineering, construction engineering technology and construction management programs throughout the U.S. The list of programs was obtained directly from the Accreditation Board for Engineering and Technology (ABET), the National Architecture Accrediting Board (NAAB), American Council for Construction Education (ACCE), and American Schools of Construction (ASC).

Initially, a total of 140 responses were received. During analysis, in some cases, the authors realized there was more than one person from the same program who responded to the survey. The authors contacted the responders, identified the primary institutional contact for this survey, and reviewed responses with the primary contacts to eliminate duplicates. The following section presents the results from the analysis of a total of 101 programs in the U.S., who responded to the survey, representing a 21% response rate. The purpose of the study is to provide insight into activities relative to the application and integration of the enumerated recent trends in the AEC education rather than providing a generalization of the population (Israel, 2009).

3.1. Survey Specifics

The survey focused on three main areas of innovation in the AEC curricula. These are:

Part I: Level of BIM integration into the current AEC curricula
Part II: Level of sustainability integration into the current AEC curricula
Part III: Level of research and collaboration in support of BIM and sustainability in the AEC curricula

Part I of the survey was structured to determine the level of BIM integration for programs that already offer BIM courses, and to understand the future integration plans for programs that don't currently offer BIM courses but plan to offer them in the future. Level of integration is defined through the number of course offerings, number of years these courses are offered, means of integrating BIM into the curricula, when to start teaching BIM in the curricula, BIM course requirements and the AEC educational areas that BIM is taught for. Future integration plans were investigated through a set of questions that focused on how far into the future, and at which level they will incorporate BIM, how many courses will be offered and the AEC educational areas that BIM will be taught for. In addition, the reasons why the programs haven't incorporated BIM to this date was asked.

Similar to part I, part II of the survey focused on the level of sustainability integration and future integration plans. Level of integration is defined through means of integrating sustainability into the curricula, course requirements and AEC educational areas that sustainability is taught for. In addition, the programs were asked which software platforms are taught in the sustainability courses. If the program indicated that they have future plans to integrate sustainability into the curricula, then the areas that they are planning to teach sustainability were asked.

Collaboration is of particular interest and importance as AEC education needs to not only parallel practice, where collaboration is becoming an ever more necessary skill but also needs to best educate the 21st century architects, engineers and construction managers. The industry also has an expectation that graduates in AEC fields be versed in the latest information technology to assist in technology deployment and integration (Smit et al, 2005). In addition, many of the problems that the AEC industry faces today could be attributed to the lack of research and development within the industry worldwide (Egan, 1998), damaging the industry's ability to keep abreast of innovation in processes and technology. For these reasons, part III of the survey was structured to determine the level of collaboration and graduate level research and how and to what degree virtual collaboration and learning applications are used to support the AEC curricula.

4. PROGRAM PROFILES

Critical to the research approach and survey structure was to be inclusive of disparately accredited educational programs, for the purposes of enumerating differences, similarity and potentials for improved overlaps, and their relationship to the needs of industry changes. Almost half (51%) of the respondent programs were ABET accredited engineering programs, including architectural engineering, architectural engineering technology, civil engineering, civil engineering technology, construction engineering, and construction engineering technology programs. These programs are referred to as 'engineering programs' in the context of this paper. The remaining respondents included ACCE accredited construction management programs (26%) and NAAB accredited architecture programs (23%). The majority of these programs are undergraduate programs totaling 88% of the respondents, including sole undergraduate programs at 62% and programs that have both undergraduate and graduate programs at 26%. Respondents that only had graduate programs account for 12% of the responses.

5. BUILDING INFORMATION MODELING IN AEC EDUCATION

The rapid movement from CAD to BIM by professional architects, engineers and construction managers has created several challenges and opportunities for AEC educational programs. Overall, 56% of all programs offer BIM courses. It is known that BIM has not advanced as quickly in civil engineering as it has in architecture (Casey, 2008). The survey supports this argument. Eighty-one percent of the architecture programs, 60% of the construction management programs and only 44% of the engineering programs offer BIM courses. Of the programs that don't yet offer BIM courses, 57% are planning to integrate BIM courses, approximately 25% of all programs. However, 19% of all programs don't have any plans to offer BIM courses in their programs. When the programs were asked about the importance of BIM to the future of the AEC industry, there is a consensus between all three program types: around 70% of all programs said BIM is very important and around 25% said BIM is important to the future of AEC (Table 1).

TABLE 1: Importance of BIM to the future of AEC

	Very Important	Important	Neutral	Unimportant	Very Unimportant
Arch.	72%	28%	0%	0%	0%
Eng.	67%	29%	5%	0%	0%
CM	70%	22%	4%	4%	0%

Most of the programs started offering BIM courses during the 2006 to 2009 timeframe. Among all three types of programs, architecture programs started offering BIM courses earlier than the engineering and construction management programs (Fig 1). This finding is not surprising considering the visual nature of architectural education and the rapid increase in 3D modeling technology usage since the late 90s. Some of the engineering programs can be considered pioneers in terms of courses that involve BIM, in particular those who implemented BIM earlier than 2000, but they are clearly early adopters and the exceptions. The survey indicates BIM is comparatively new in construction management programs, of the construction management programs that offer BIM courses, 86% started offering BIM courses during the 2006-2009 timeframe, but with a rapid deployment rate. Of the programs that don't yet offer BIM courses, the survey asked a follow up set of questions about their future plans. Almost all programs that plan to offer BIM courses believe that they will be incorporating BIM into their curricula within a year (43%) or two (44%).

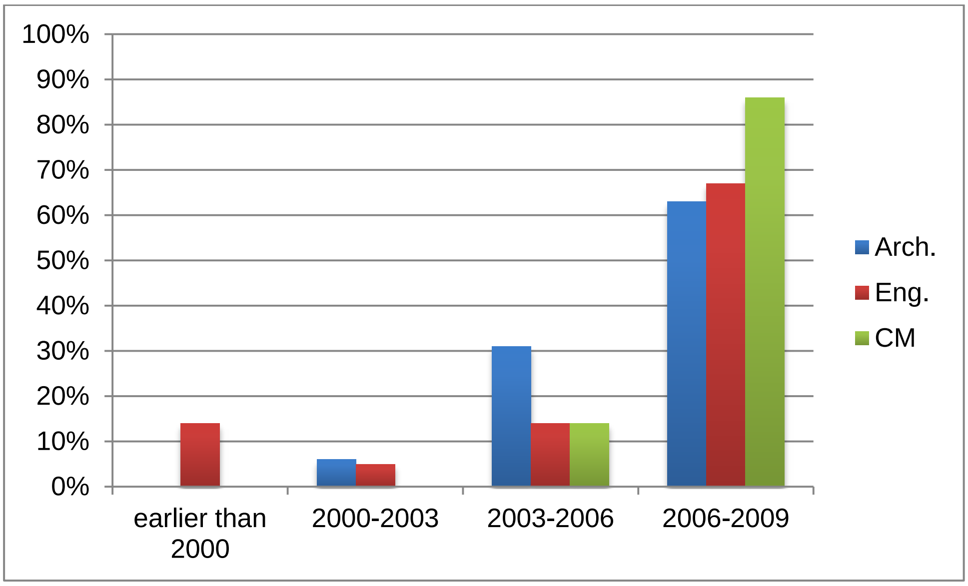

FIG 1: When did BIM become part of the program?

While some of the engineering programs were pioneers in BIM education, BIM become part of the architecture programs earlier than in the other two program types. Moreover, the architecture programs have more courses with BIM components (average 3.8 BIM courses), closely followed by the engineering programs (average 3.6 BIM courses), an important example of a higher level of integration. Construction management programs offer on average 3.1 BIM courses (Fig 2). The survey asked, how many courses will the program integrate into the curricula per the future plan; the majority (67%) said they will have at least one course on BIM, 29% said they will have 2-4 courses and 4% said they will have 4-6 courses.

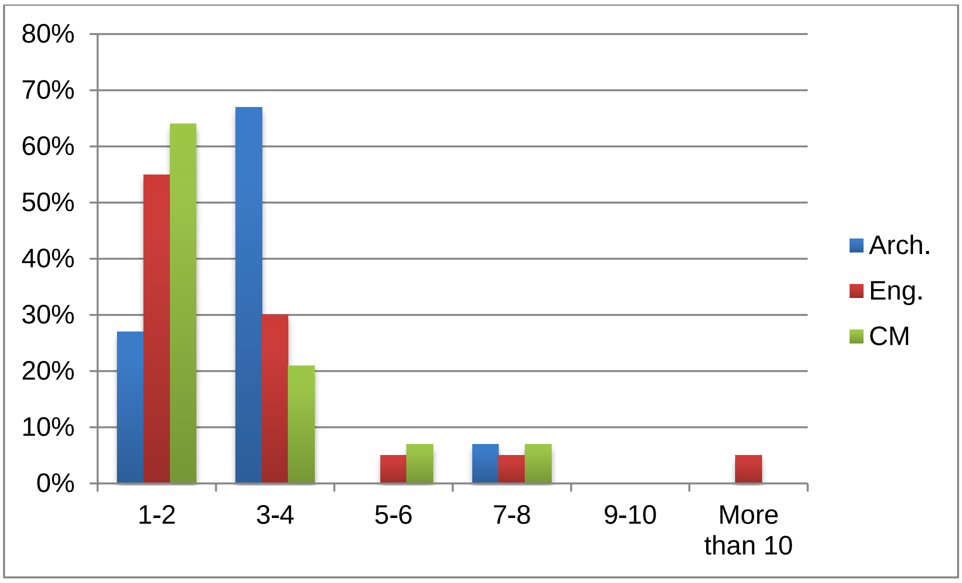

FIG 2: How many courses offered in the program have BIM components?

In order to accurately assess the level of integration of BIM into the AEC curricula, means of integrating BIM into the program is as important as the number of courses with BIM components. A survey of ASC schools reported (Sabongi, 2009) that BIM technology is currently being taught in approximately 10% of undergraduate programs in three ways: part of existing information technology courses (Taylor et al, 2008), part of other construction courses (Woo, 2006) or as a new stand-alone course (Bur, 2009). Architecture programs (69%) have the most number of BIM specific courses, followed closely behind by the construction management programs (67%) (Fig 3). Sixty percent of the construction programs and 56% of the architecture programs also have infused BIM concepts into their traditional courses and design projects, compared to only 38% of the engineering programs. On the other hand, 76% of the engineering programs choose to teach how to use BIM on projects in classes in comparison with 67% of construction management and 63% of architecture programs. Thirty percent of all program types reported having BIM specific research projects. It is interesting to note that architecture programs expect their students to learn BIM skills by themselves (19%) followed by the engineering programs by (10%).

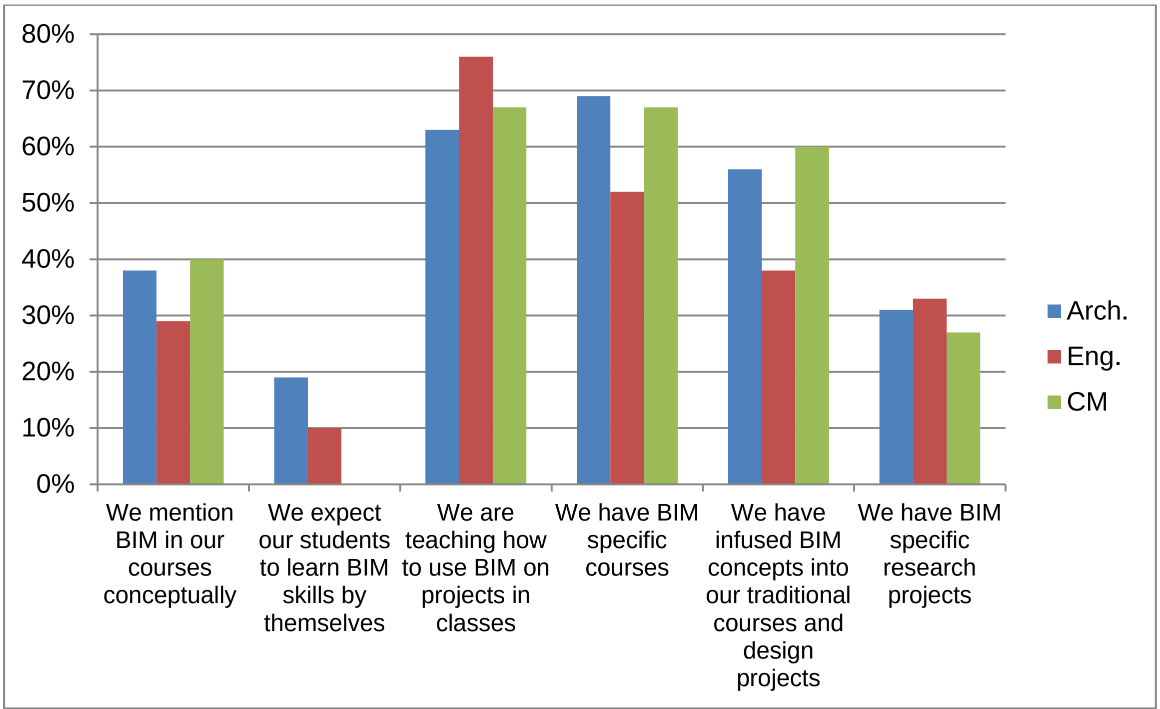

FIG 3: How is BIM taught in the program?

One critical question for AEC programs is when to start teaching BIM. Since ABET doesn't specifically identify any graphic requirements, and BIM is not formally identified in the accreditation criteria from NAAB and ACCE (although, ACCE identifies computer applications as part of certain learning objectives) this leads to several questions regarding when BIM should be introduced into the curriculum (Weber and Hedges, 2008). While at first glance integration of BIM in an institution wide manner may appear to be the most logical choice of adoption, investigating the existing standards of accreditation that establish the performance criteria for accredited degree programs may be a more strategic approach. Different program types have different approaches to this critical question. The survey results show engineering programs introduce BIM earlier than the other two program categories. In engineering, BIM is taught mostly at the sophomore, junior, and senior levels. In architecture programs, BIM courses are offered mostly at the senior and masters levels. In many architectural programs, BIM is seen as a threat to creativity. Discussion around BIM's applicability to the early stages of design is an ongoing one (Penttilä, 2007). However, some disagree and argue that when BIM is defined as a process—as it should be—it begets performative information and simulative environmental conditions into design, placing an emphasis on "the underlying logic of design (Seletsky, 2006)." Perhaps the biggest challenge for design instructors is that BIM demands new teaching methods (Denzer and Hedges, 2008). The same trend is observed in the construction management programs. Although BIM is taught in freshmen, sophomore, and junior years in construction management programs as well as at the master's level, the survey reveals that BIM is mostly taught in senior year. The category 'other' included integrated throughout, and mixed undergraduate and graduate level (Fig 4). When the question about at what level they are planning to incorporate BIM into their curriculum was asked of the programs that don't offer BIM courses yet but are planning to offer BIM courses in the future, most of the programs answered at the undergraduate level, freshman 36%, sophomore 52%, junior 43% and senior 39%. Only 13% of the programs said they are planning to integrate BIM at the master's level. The data suggests curricula are being designed to integrate BIM at the early stages of AEC degree programs.

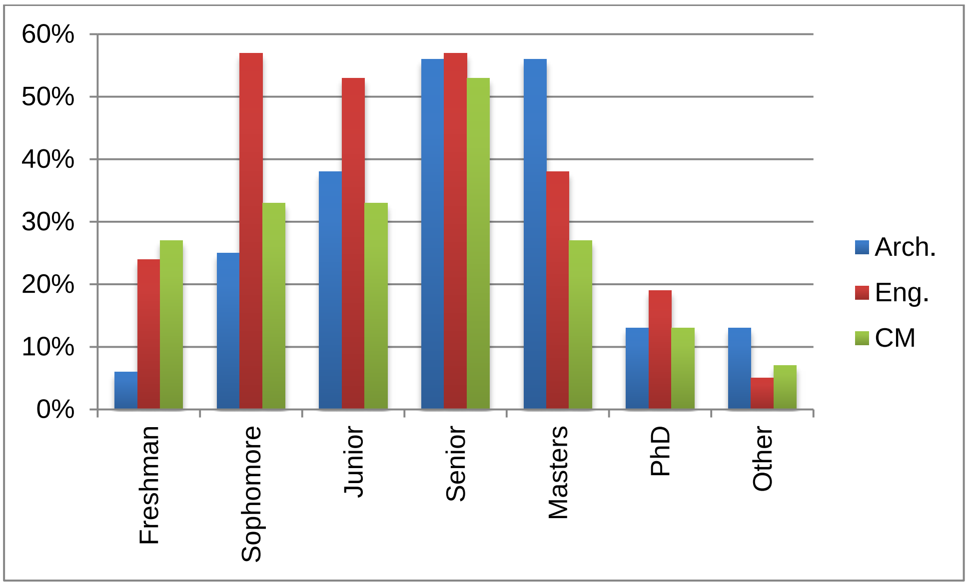

FIG 4: Levels where BIM is taught

The survey reveals more BIM courses are required for undergraduate engineering (57%) and architecture (50%) programs than for the construction management (36%) programs (Fig 5). In terms of quantity the survey data shows engineering programs (62%) and construction management programs (50%) have more elective BIM courses at the undergraduate level than the architecture programs (38%). At the graduate level, BIM courses are mostly elective for architecture programs (69%). Architecture programs also have more required graduate BIM courses (19%). However, when and if students in the programs can get a minor or major in BIM was asked, the overwhelming majority of respondents (96%) said neither is available. This was a trend for all three programs. In fact, only two programs responded to this survey offer a minor in BIM.

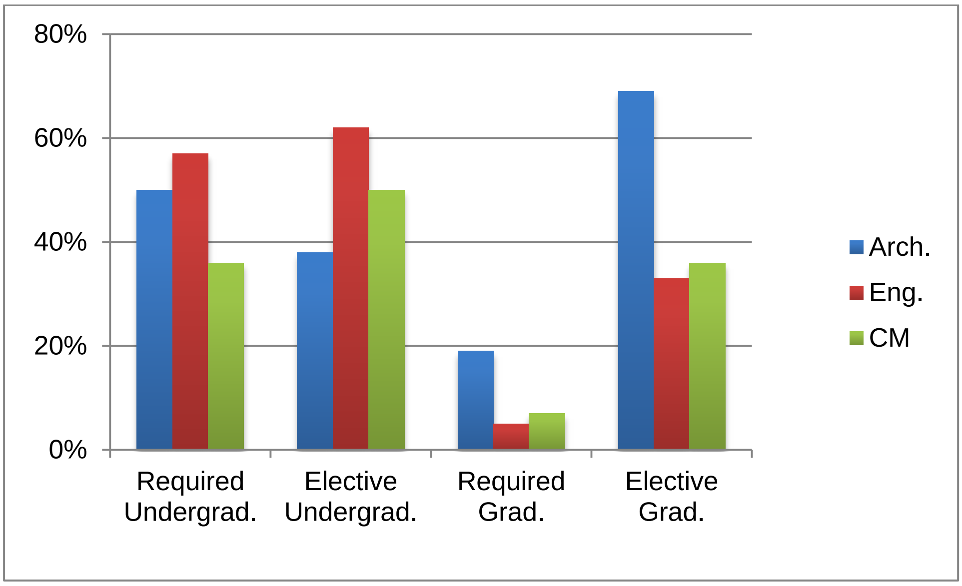

FIG 5: Are these courses with BIM components required or elective?

Figure 6 shows the program trends and purposes for where BIM is taught versus where BIM is planning to be taught in the future. The research shows currently, BIM is mostly used in design visualization and constructability activities. Programs that currently do not offer BIM course but plan to offer courses indicated they would like to expand BIM's applications to teach concepts in sustainability, model based estimating and site planning. Constructability and visualization are among the areas that programs would like to further expand the use of BIM. When different programs are analyzed, architecture programs teach BIM for design and visualization (80%) followed by sustainability, digital fabrication and constructability (approximately 50%). Engineering programs mostly teach BIM for design (90%), followed by visualization and constructability (approximately 60%). Construction management programs teach BIM for constructability, 4D scheduling, and model based estimating (around 60%), followed by design (53%), visualization (47%) and sustainability and cost control (40%). A need exists within construction management education to teach students spatial and visualization skills (Glick, 2010). BIM integration into the curricula has begun to meet this demand and the survey suggests these skills are both being taught and planned.

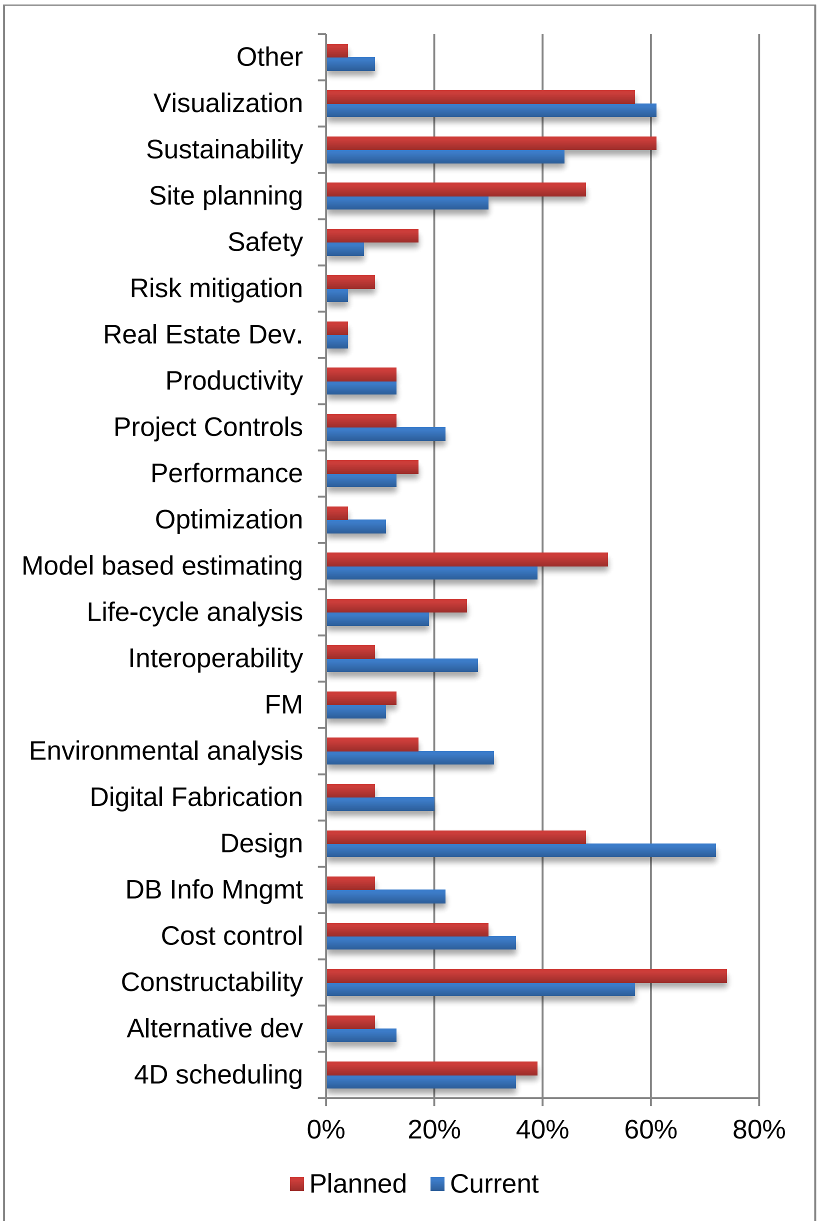

FIG 6: The planned and current areas where BIM is/will be taught

BIM prompts students to ask advanced questions about structures, material assemblies, and detailing that requires the instructors to be relatively more agile in their ability to respond. Fifty-five percent of the programs that don't have BIM courses said the reason is there is no one to teach BIM (Fig 7). Forty-five percent said they don't have adequate resources to make the curriculum change. BIM software packages and concepts are significantly more complex than CAD tools and thus BIM requires space in the curriculum that CAD doesn't (Scheer, 2006). Thirty-six percent of the respondents indicated that they don't have room in their curriculum to integrate BIM courses. ABET doesn't specifically identify any graphics requirements, therefore incorporating BIM is at the instructor's discretion. The architectural design course descriptions don't list any graphics techniques and simply require learning the fundamental principles of design and increasing the project complexity. This lack of accreditation specificity for BIM has been seen as a barrier by 27% of the respondents. The category 'other' could be summarized under lack of focus in curriculum, and time-consuming nature of integrating BIM into curriculum. Only approximately 5% said they didn't consider BIM important or had insufficient student demand. This finding in particular strengthens the argument that BIM is seen as an essential part of AEC curricula in order for academia to set the pace.

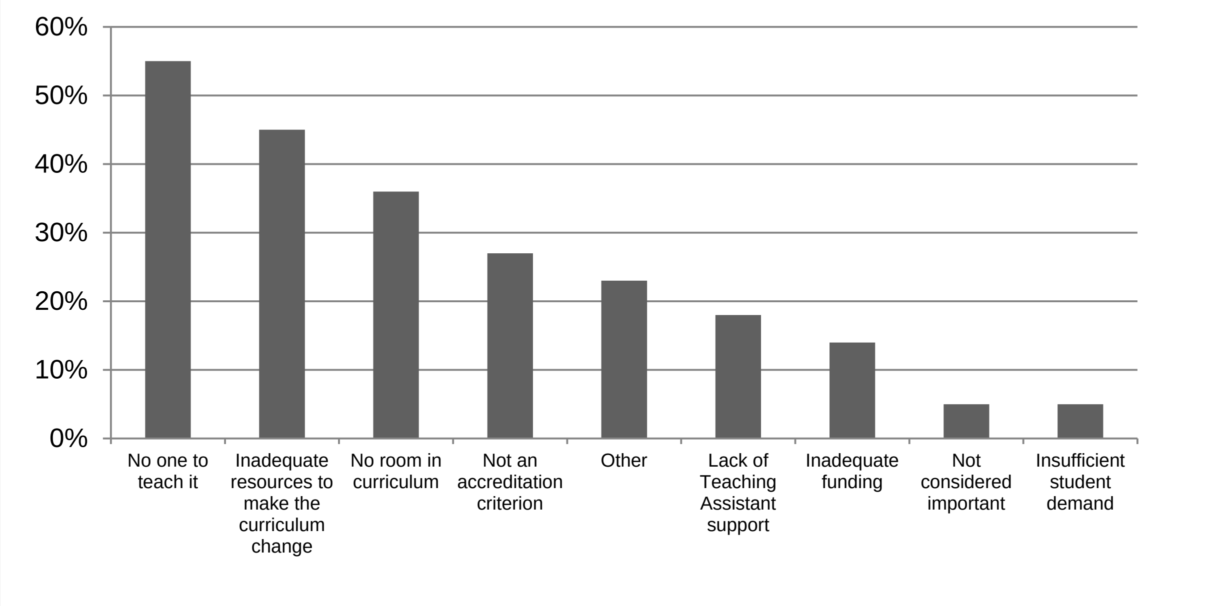

FIG 7: The reasons for not incorporating BIM into curriculum to this date

6. SUSTAINABILITY IN AEC EDUCATION

In this survey, all architecture, engineering, and construction programs saw sustainability as important for the future of the AEC industry. Following the same format of the BIM section, the first question asked if the respondents offered sustainability courses. Seventy-five percent of the respondents offered courses on sustainability. Among those that do not offer courses (25% of all programs), 58% are planning to offer sustainability courses. It is interesting to note that architectural programs (94%) that responded to this survey see sustainability as very important to the future of the AEC industry. Seventy-nine percent of the engineering programs also agree that sustainability is very important to the future of the AEC industry, followed by 19% that think sustainability is important. A smaller number of construction programs indicated sustainability as very important to the future of the AEC industry compared to the architecture and engineering programs (Table 2). The fact that a smaller number of construction programs have incorporated environmentally related construction courses coincides with earlier studies conducted by Tinker and Burt (2004) who surveyed Associated Schools of Construction members.

TABLE 2: Importance of sustainability to the future of AEC

	Very Important	Important	Neutral	Unimportant	Very Unimportant
Arch.	94%	6%	0%	0%	0%
Eng.	79%	19%	2%	0%	0%
CM	57%	43%	0%	0%	0%

In accordance with the perception of how important sustainability is to the respective programs, the survey illustrates that 95% of the architecture programs, 74% of the engineering programs, and 60% of the construction management programs, offer courses in sustainability. Thus, architectural programs lead in curricular efforts while construction program show slower curricular adjustments. Architectural programs also lead in the number of required courses at both the undergraduate level (65%) and graduate level (41%), while construction management programs seem to adapt to the sustainability curriculum needs via elective courses; 64% of construction management programs indicated that undergraduate courses were elective and 50% responded that graduate courses were offered as electives). The engineering programs follow the same trend with 65% of elective undergraduate courses and 32% of elective graduate courses in sustainability (Fig 8).

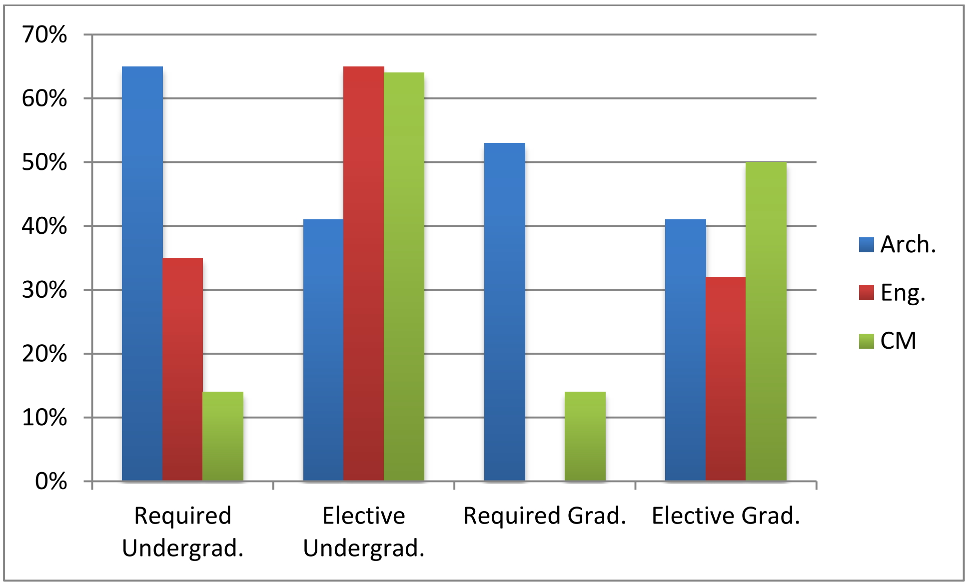

FIG 8: Are the sustainability courses required or electives?

While there is general support for the idea of incorporating sustainability as part of higher education curricula, agreement is lacking as to the best way to achieve this (Jones et al, 2009). Effective integration of sustainability concepts as part of teaching and learning is characterized by full integration of sustainability concepts into the curriculum, student-centered activities and assessments that reward critical thinking and reflective learning, multidisciplinary teaching and learning, teaching that emphasizes that sustainability is an ongoing process without hard and fast answers (Brunton, 2006). In response to the question if the programs offer a minor or major in sustainability, the majority of 81% were not offering a minor or major in sustainability, and only 15% offered a minor, 1% a major, and 3% both minor and major. In relation to this aspect, Figure 9 shows how sustainability is currently addressed in the AEC curriculum. The survey shows that sustainability is evenly accommodated in specific individual courses, or as part of class projects, and other existing courses or projects, which reveals that, sustainability is accepted across the AEC curriculum. Sustainability can be adopted as part of existing courses or as stand-alone courses as technical electives and Ahn et al. (2009b) observed in a study of ten construction education programs that the latter approach had been more prevalent which coincides with the survey results of this study. The findings of this survey indicate that the architectural school respondents in this study have integrated sustainability into their existing courses slightly more than creating stand-alone courses.

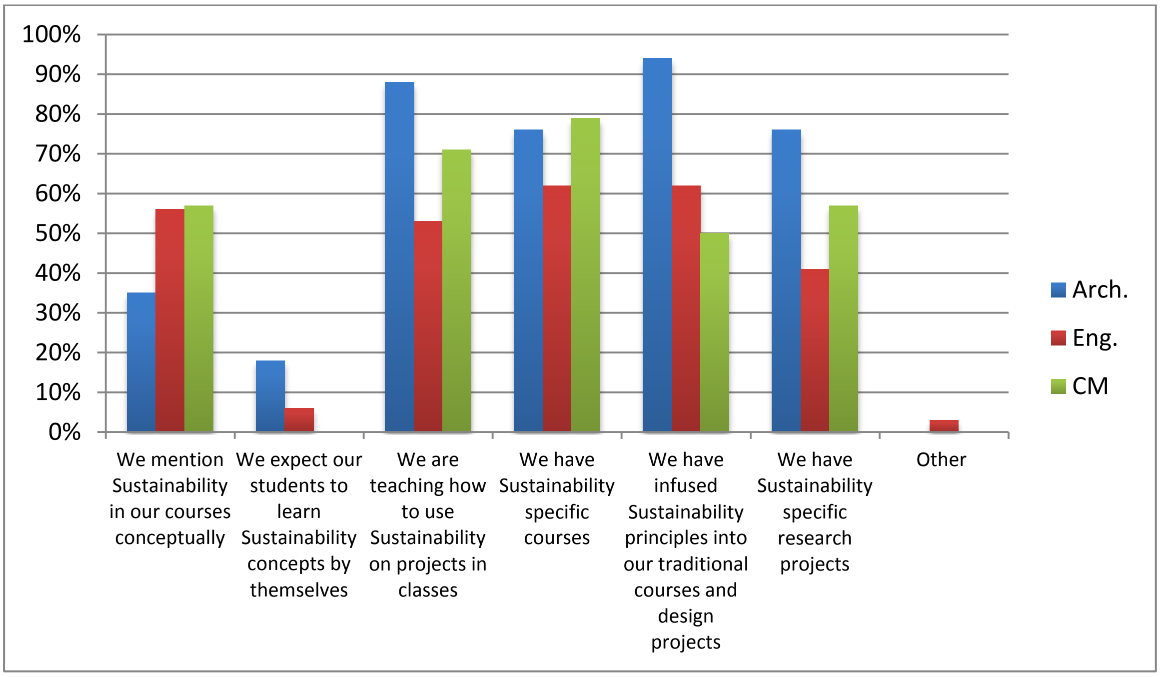

FIG 9: How is sustainability integrated in the current curriculum?

A core question of curriculum and course development efforts relates to understanding the knowledge domain components that should be taught. Literature identifies various competencies that are important for sustainability education such as communication with other disciplines (Ellis & Weekes, 2008), ability to expand the scale of thinking in spatial, temporal, biological, and intellectual terms (ASCE, 2008), ability to evaluate impacts and manage tradeoffs between technological, ecological, human, and economic elements (Pearce & Maxey, 2007). Addressing such competencies, sustainable construction courses should incorporate general knowledge of sustainability, concepts of applied sustainability in construction, understanding and implementation of sustainable construction methods and materials, familiarity with sustainability rating systems, and future directions (Ahn et al., 2009b). Architectural design courses incorporate environmental and energy principles, comfort, climate and energy.

Figure 10 shows that architectural programs put an emphasis on sustainable design and environmental analysis, energy conservation, renewable energy, materials, and LEED. In contrast, for construction programs, LEED is shown as a leading area of interest followed by sustainable construction practice and materials, and energy conservation. Similarly, engineering programs' interest focused on LEED, sustainable construction practice and energy conservation but the overall interest in the various areas of sustainability is lower than the architecture and construction management programs.

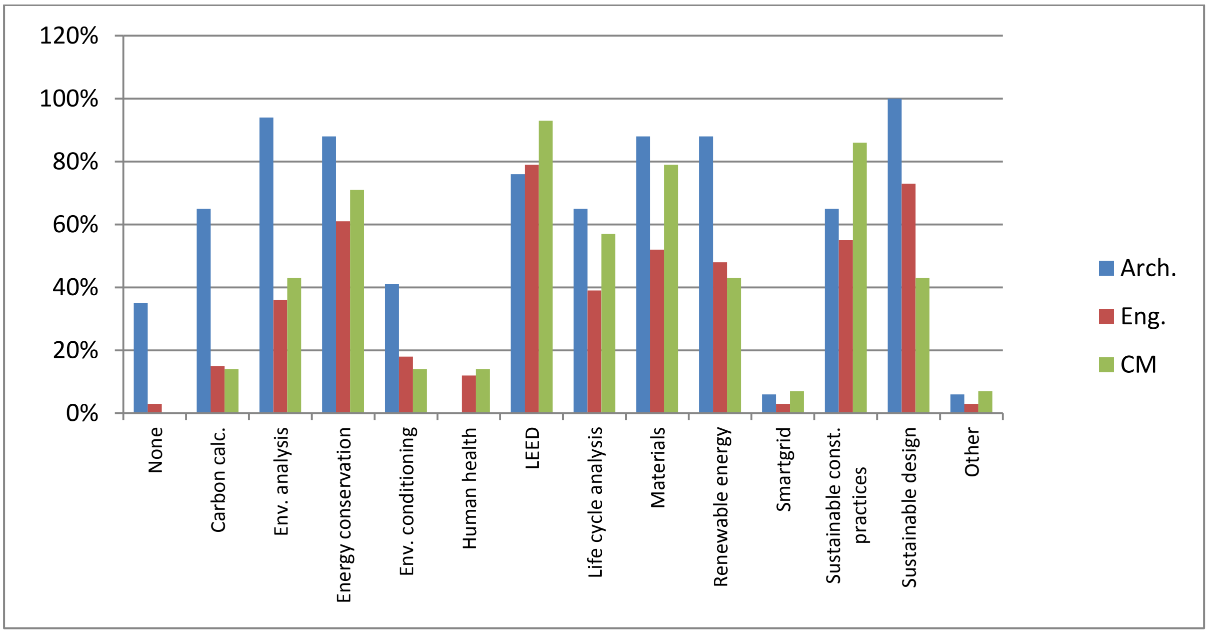

FIG 10: Which of the following areas does the sustainability courses focus on?

A comparison between programs that currently offer sustainability courses and those that plan to offer in the future reveals that sustainable design, sustainable construction practices and renewable energy, materials, life-cycle analysis, and environmental analysis are sought by both groups. However, LEED, energy conservation, and carbon calculations are of lower priority to those who plan to implement sustainability topics (Fig. 11). This may indicate that educators consider focusing on broader sustainability competencies and skills rather than specific professional certification aspects. While this survey only asked about the incorporation of LEED in courses, it may be possible that broader concepts of sustainable rating systems are addressed in the curriculum. Considering that industry considers sustainable rating systems an important competency of graduates (Ahn and Pearce, 2007), this is an area that may need further investigation. The differences between the two groups can also be attributed to the specific domain requirements of architecture, engineering, and construction, as those that are planning to adopt a topic may be representing a specific discipline rather than the perception of the entire group. All three-program types are planning to focus more on sustainable design and construction practices, environmental conditioning, and life cycle analysis in the future.

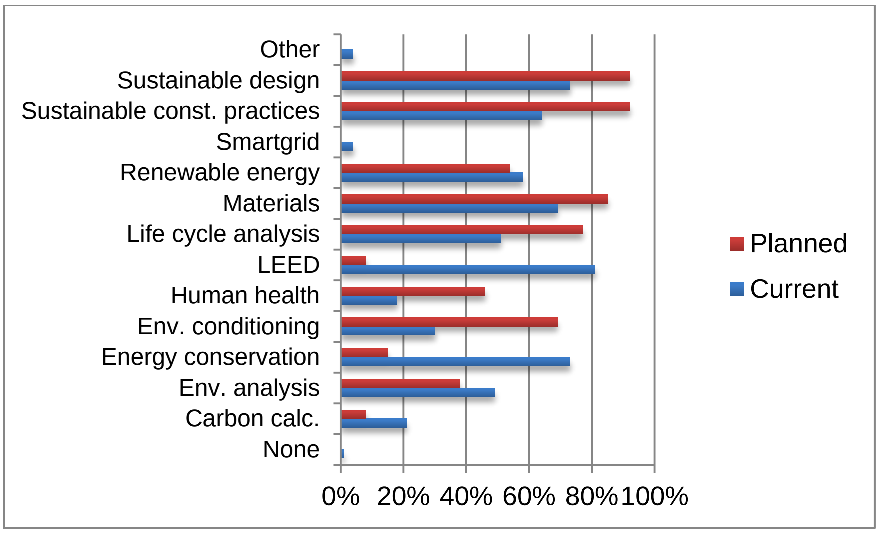

FIG 11: Comparison of sustainability topics of programs that currently offer courses vs. programs that plan to offer courses

The survey also asked what type of relevant software solutions were utilized in teaching sustainability concepts. Figure 12 shows that many construction management (36%) and engineering (44%) programs indicated no software usage while a few additional software packages were suggested such as SAM and BEES by construction management programs, and AutoDesk Revit, Riuska, Bentley Microstation by engineering programs. Architectural programs focused on a variety of energy modeling software including AutoDesk Ecotect, eQuest, EnergyPlus, IES, etc., and also mentioned the use of Revit for modeling purposes. It is interesting to note that a number of construction management programs are teaching energy-modeling software including eQuest, AutoDesk Green Building Studio, and AutoDesk Ecotect, which may be taught at the undergraduate and/or graduate level that may concentrate on research projects.

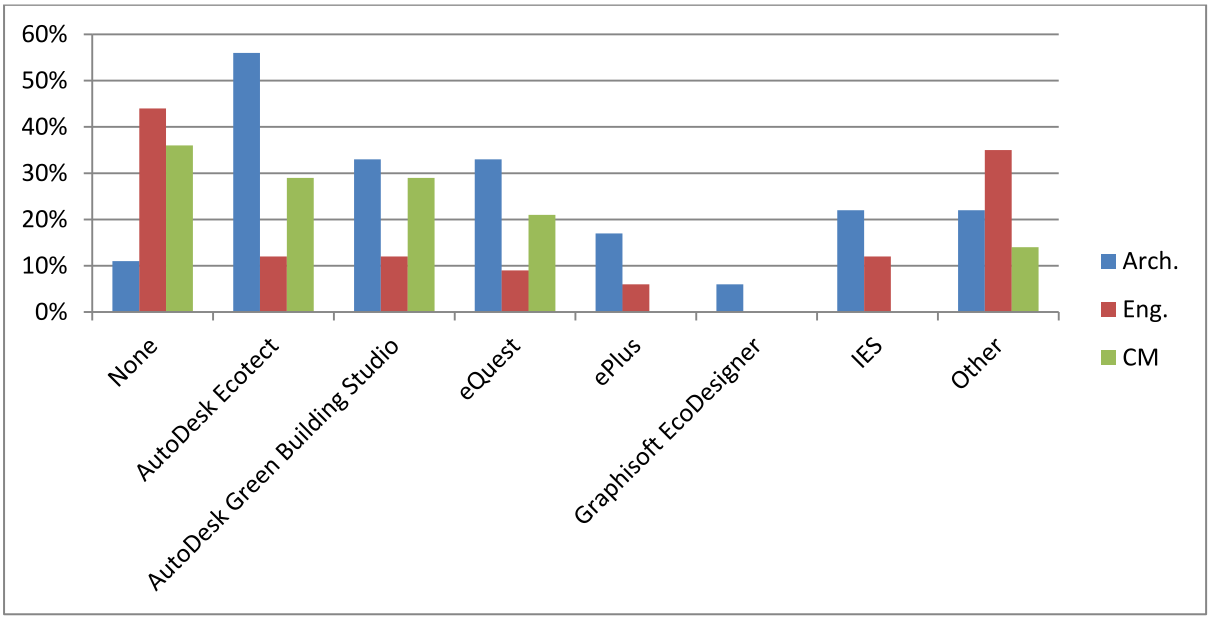

FIG 12. Which of the following software are taught in courses?

7. RESEARCH AND COLLABORATION IN AEC EDUCATION

When the programs were asked if they have PhD level research, overall only 33% of the programs said they do. Construction management programs (46%) have more PhD level research than the engineering (31%) and architecture programs (17%). The low number of PhD level research within architectural programs could be attributed to the level of funding as well as the difference between 'professional' vs. 'research' oriented fields. When the question of which areas of research is conducted was asked; building design (81%), sustainability (75%) and building science (56%) were the top three areas for research conducted in architecture programs. Sustainability (52%), BIM (43%), and project delivery systems (38%) were the top three choices for construction management programs. Engineering programs chose "none" with 38% followed by building design with 33% and sustainability research with 30%. Forty-four percent of architecture, 43% of construction management and 25% of engineering programs reported having research topics on BIM. However, research on sustainability topics is more prevalent: 75% of architecture, 52% of construction management and 30% of engineering programs reported having research on sustainability topics (Fig 13).

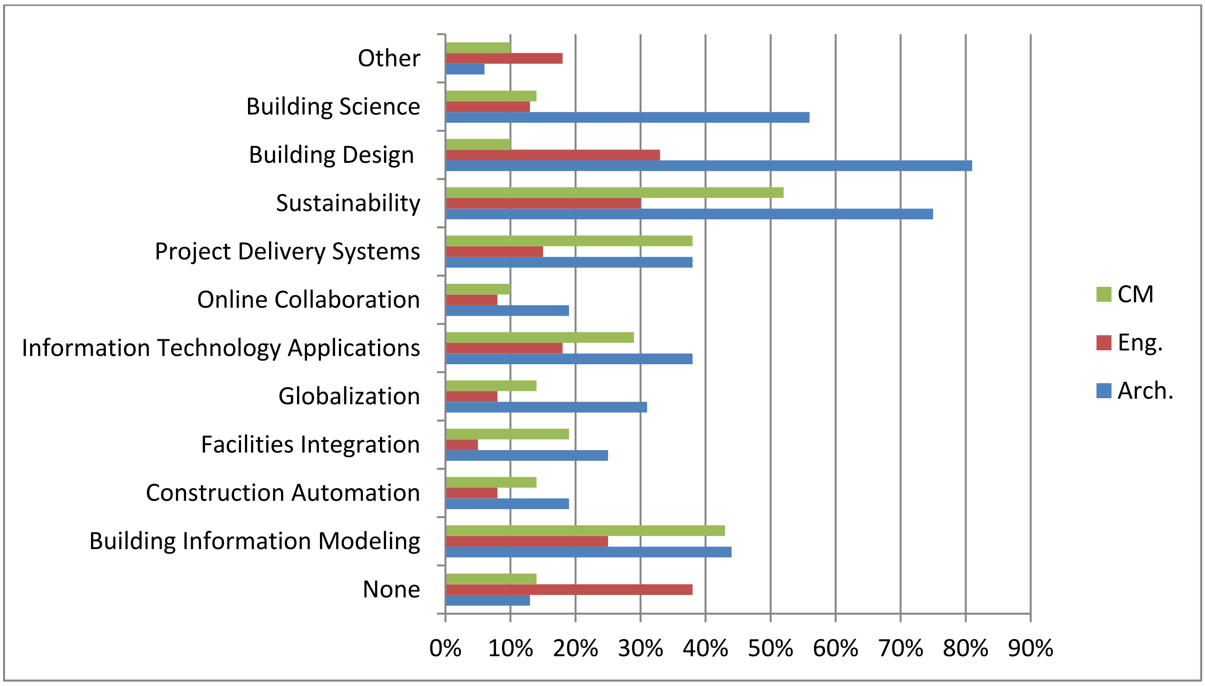

FIG 13: Areas of research the programs focus

Sixty three percent of all programs have research projects that involve industry. Seventy-six percent of architecture programs have research projects that involve the industry, compared to about 60% of the research projects with industry participation in the engineering and construction management programs. Architecture programs (72%) find practice/academia collaboration very valuable to the future of the AEC industry compared to construction (65%) and engineering (50%) programs. However in aggregate, the level of industry participation in AEC research projects is still low, especially when the importance of practice/academia collaboration is considered (Table 3). Overall, 58% of all programs have internship opportunities with companies that have exemplary BIM and sustainability operations. The construction management programs, however, lead in terms of industry internship opportunities by 71%, followed by the engineering programs with 55% and the architecture programs with only 47%. Quantity of internships is considered one indicative factor of academic to industry integration.

TABLE 3: Importance of practice/academia collaboration to the future of AEC

	Very Important	Important	Neutral	Unimportant	Very Unimportant
Arch.	72%	17%	11%	0%	0%
Eng.	50%	36%	14%	0%	0%
CM	65%	30%	4%	0%	0%

Multidisciplinary (or interdisciplinary) research and teaching is defined as a study that relies on the knowledge of more than one traditional discipline. The engineering programs offer courses where the students collaborate with other students from multiple disciplines in a team environment, however mostly at the undergraduate level (Fig 14). The architecture programs have some level of multidisciplinary collaboration approach, however it is still low. The importance of multidisciplinary collaboration to the future of AEC industry was ranked as very important as indicated by the following affirmative responses of 78% of architecture programs and 60% of engineering programs (Table 4). The construction management programs think that multidisciplinary collaboration is less important compared to the other two program types.

TABLE 4: Importance of multidisciplinary collaboration to the future of AEC

	Very Important	Important	Neutral	Unimportant	Very Unimportant
Arch.	78%	22%	0%	0%	0%
Eng.	60%	31%	10%	0%	0%
CM	48%	48%	4%	0%	0%

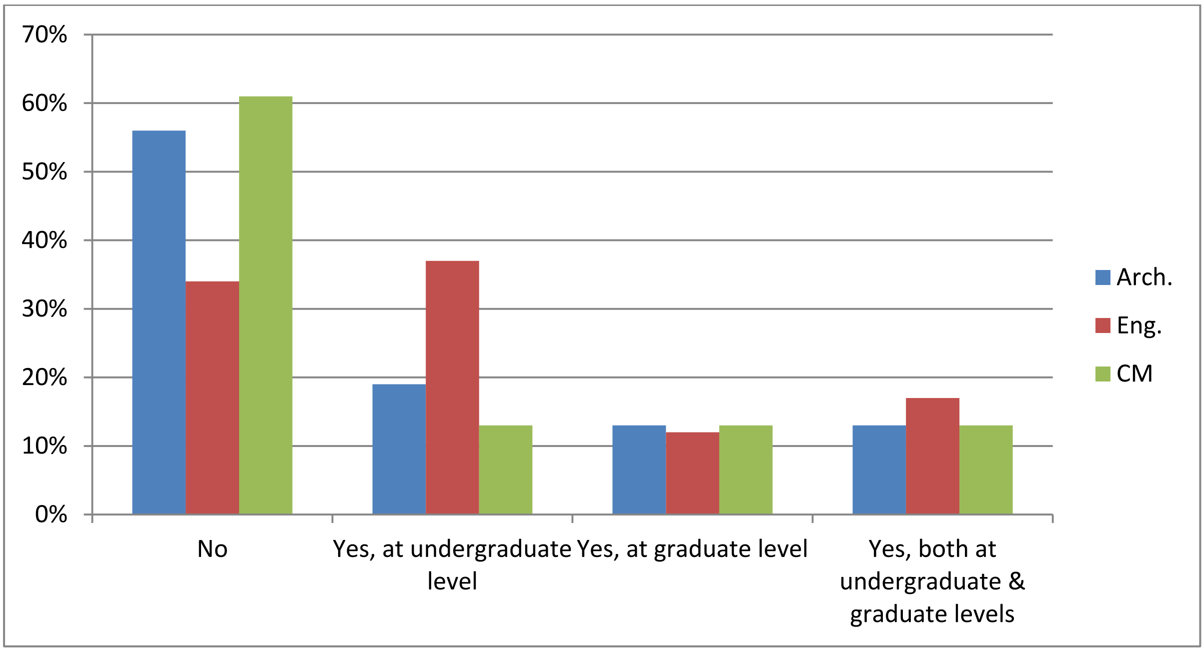

FIG 14: Does the program offer courses where students from multiple disciplines collaborate in a team environment?

56% of all programs said they used BIM to teach how students in these programs interface with other disciplines in a multidisciplinary/collaborative project-learning environment. Engineering programs (57%) use BIM to teach students in their programs how to interface with other disciplines in multidisciplinary and collaborative project-learning environment, slightly more than in the construction management (53%) and architecture programs (50%)

7.1. Virtual Collaboration and Learning Applications in AEC Education

Technology now allows multiple media such as virtual classrooms, course websites, virtual worlds, project models and social networks to be utilized for learning. Overall, only 36% of all programs offer distance education courses, where off campus students can participate in the classroom. Among the three program types, construction management programs (57%) offer more distance education courses than the engineering (37%) and architecture (11%) programs.

A virtual learning environment (VLE) is here defined as an online system designed to support teaching and learning in an educational setting. VLEs support course administration, documentation, tracking and reporting of classroom and online activities and other training content. While originally created for distance education, VLEs are now most often used to supplement traditional face-to-face classroom activities. Overall, 16% of all programs said no virtual learning environment is utilized in their programs. Among the three program types, construction management programs use VLEs more than the others. The majority of the programs use Blackboard as their VLE: 61% of architecture 66% of engineering and 83% of construction management programs. Less than 7% of all programs use Desire2Learn, Moodle, OpenCourseWare, Scholar and Vignette. Thirteen percent of all programs indicated that they use another VLE. The category ‘other’ included Angel, Axio learning services, FirstClass, myCourse and some in-house solutions.

The survey also sought to benchmark and quantify current use of web-based platforms that provide real time communication and collaboration opportunities for virtual learning, collaboration and information exchange. These platforms included instant messaging programs such as Skype, Google chat, AOL, MSN and Yahoo messenger as well as, web conferencing and video conferencing applications such as WebEx, GoToMeeting, Live Meeting, and others. Overall, 58% of all programs said they do not use any of these synchronous communication and collaboration tools: 50% of architecture, 51% of engineering and 68% of construction management programs. This difference could be due to the collaborative nature of design projects. Skype is popular between architecture (29%) and engineering programs (24%) compared to construction management programs (11%). Overall, the rest of the tools received less than 10%. The category 'other' included Elluminate, GoogleDocs, Adobe connect, Wimba, Adobe Breeze meeting and some in-house solutions.

Social network services focus on building and reflecting of social networks among people, who share interests and activities. Overall 60% of the programs indicated that they do not use any of the social network services. Facebook (26%) Youtube (23%), LinkedIn (14%), and Twitter (10%) are among the social network services that the AEC programs use.

A virtual world is an online community that often takes the form of a computer based simulated environment, through which users can interact with one another and use and create objects. Almost all programs (94%) said they do not use virtual world applications for educational purposes. Only 7% of the architecture programs indicated that they have used IMVU and Second Life for architectural education. Similarly, Second Life is implemented by the 11% of construction management programs. This might be due to the argument that traditional classroom curriculum in construction management education may not provide the opportunity for practical experience to allow students to explore the problems they may encounter in the real world (Abourizk and Sawhney, 1994). As discussed by Park (2008), the Second Life CM learning environment provides a highly visual, immersive, interactive and sociable Internet based learning space for students and faculty to explore various teaching/learning opportunities. No clear divide between student-driven and instructor driven use of virtual learning applications has been found.

8. DISCUSSION

Currently, the industry is facing enormous technological and institutional transformations with their resultant difficulties and challenges. One very important instrument for such change is the use of BIM and application of sustainable practices. Although there is a consensus between all three-program types that BIM is important to the future of the AEC industry, only slightly over half of all programs offer BIM courses and almost one fifth of all programs still don't have any plans to offer BIM courses. This is an interesting finding as BIM has gained significant momentum in practice in a relatively short period of time, which suggests the training to prepare current and future practitioners must follow suit. The reason for slow adoption of BIM in the curricula is due to the lack of number of experts to teach BIM courses or resources (teaching, funding, or administrative support) to make curriculum changes or room in the curriculum to make necessary changes. If the AEC educational community is to set the pace rather than trailing industry, necessary recourses need to be allocated to support this change in curricula. However, one promising finding is that the majority of the programs that plan to incorporate BIM into their curricula are planning to offer at least one BIM course within the next two years. While there is general support for the idea of incorporating BIM as part of higher education curricula, agreement is lacking as to the best way to achieve this. When to introduce BIM, and how to introduce BIM are questions programs approach differently. Based on the survey results, among all three-program types, not only have architecture programs started offering BIM courses earlier than the other two program types, the architecture programs also offer more in number of BIM courses. Construction management programs have recently started offering BIM courses with a comparatively rapid deployment rate. Although there are pioneers among the engineering programs, generally, engineering programs lag behind the other two programs in terms of incorporating BIM into their curricula. This could be due to the nature and needs of the programs as well as due to the resources available. The fact that BIM is not formally identified in the accreditation criteria also adds to the difficulty of not having a more unified and comprehensive BIM adoption approach in the AEC curricula.

In comparison to the adoption rate of BIM in the AEC industry, the survey shows that sustainability has been better adopted into the AEC curricula. Seventy-five percent of the respondents said they offer courses on sustainability. There is general support for the idea of incorporating sustainability as part of higher education curricula and considerable attention has been directed toward pedagogical reform and evolution to support sustainability in architecture, engineering and construction related education (Tinker & Burt, 2004; Ahn, 2009a). Accreditation criteria in AEC programs such as the National Architectural Accrediting Board (NAAB), the American Council for Construction Education (ACCE, 2002), and the Accreditation Board for Engineering and Technology (ABET, 2000) emphasize the importance of environmental issues in education. While previous studies have examined that the adoption of sustainability in AEC curriculum, the evidence has been anecdotal as in the following studies. Glyphis (2001) highlighted the need for a broad-based effort to incorporate sustainable design as part of all architectural education. The Royal Melbourne Institute of Technology (RMIT) undergraduate programs addressed the issues of housing sustainability and affordability (Hayles et al., 2006). Cotgrave and Alkhaddar (2006) reviewed the green curriculum in UK construction programs. In comparison to previous studies, this study provides a broader perspective of current implementations of sustainability curricula in AEC programs. Based on the survey results, architectural programs lead in curricular efforts while engineering and construction programs show slower curricular adjustments. In addition, the findings of this survey indicate that the architecture programs in this study have integrated sustainability into their existing courses slightly more than creating stand-alone courses. This might not be a surprising finding as environmental design is part of design disciplines including architecture, landscape design, urban design, and so on. A pleasing finding is that the educators consider focusing on broader sustainability competencies and skills rather than specific professional certification aspects in the future.

Many of the problems that the AEC industry faces today could be attributed to the lack of research and development within the industry worldwide (Egan, 1998), damaging the industry's ability to keep abreast of innovation in processes and technology. The survey findings support this argument; only one third of all programs have the PhD level research. Suprisingly, construction management programs have more PhD level research followed by the engineering programs. Although only 17% of the architecture programs have PhD level research, slighly less than half of these programs have research topics on BIM. However, in general, sustainability related research topics are more more popular than the research topics focused on BIM. Research results in AEC education often face significant barriers to widespread adoption into practice (Issa and Anumba, 2007). While the economic challenge of translating research into innovation is well studied for other fields and the common gap between them has been labeled the "valley of death," (Auerswald and Branscomb, 2003) for AEC education research, there are additional challenges and the "commercialization" process is much more complex. Industry participation in research is important if we are to contribute to crossing the "valley of death" of gap. Although the AEC programs also agree as 63% of all programs have research projects that involve industry, more involved practice/academia collaborations are necessary through research projects, internships and teaching. Although the research volume is lower in the architecture programs compared to the other two programs, the architecture programs have more research projects that involve industry followed by the other two program types.

In addition to practice/academia collaborations, more multidisciplinary research and teaching is a must to assure a versatile, well-trained AEC workforce for the future. People with the same expertise in the same discipline have their limit in developing new ideas and new technologies in their areas. The positive influence from other disciplines can inspire AEC professionals to significantly improve their performance, by providing chances to learn new ways of reasoning and problem solving (Kim et al, 2009). Moreover, architects, engineers and construction managers have to work in a team environment in a collaborative fashion to realize the objectives construction projects. Majority of the architecture and engineering programs don't offer courses where students from multiple disciplines collaborate in a team environment. The engineering programs offer multidisciplinary courses, mostly at the undergraduate level. Fifty-six percent of all programs said they use BIM to teach how students in these programs interface with other disciplines. However, these numbers could be improved as BIM can replace the current norm of a highly fragmented process that the AEC industry practices. BIM implemented into the curricula will facilitate a multidisciplinary approach that consolidates effort and enables more efficient collaboration by responding to the demands for multidisciplinary team activities and by providing a platform for exploring new team structures and collaborations and realizing improved student outcomes.

If AEC programs are to truly motivate students to excel in the classroom, they should look beyond "what" is taught in classroom and consider how the curriculum is delivered and assessed (Farrow et al, 2010). Based on the survey results, there are some AEC programs that don't use any virtual learning environment to facilitate learning and collaboration. The use of synchronous communication and collaboration tools and virtual worlds is also low. As educators wrestle with the issues of how to educate the AEC professionals of the future, there is a need for improving our understanding of what attracts students to the AEC disciplines, and how these students learn the profession. AEC professionals today are used to live the life of "always on-line", and feel more comfortable using tools that they are using in their personal life (Klinc et al, 2009). Overall 60% of the programs indicated that they do not use any of the social network services. These percentages are likely to increase in the near future as some research results have shown that 80% of the workers born after 1980 (millennials) are using social networking, collaboration and web tools daily (Perez, 2008).

9. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

The study attempted to provide an overview of the emerging subject areas of BIM and sustainability as addressed by the AEC educational programs. The survey presents a benchmark for the adoption and planning of these topics into highly constrained curricula. It, furthermore, reveals the similarities and differences across the architecture, engineering, and construction management programs. The research is useful for program administrators and educators to make informed decisions as well as for accreditation bodies to realize where and how they can begin to aid in the implementation of integration with both BIM and sustainability as well as the technologies, research and collaboration to support them.

A disparity in adoption and acceptance of new concepts is found among the three program types, which is expected to some degree given the diverse cultural, academic, research, and economic environments of the studied program types. Future research should focus on the disparity and diversity of methods, objectives, and outcomes to clearly identify which strategies, and methods allow for the best future outcomes for the students to continue developing core knowledge and diverse competencies to support their future careers and continue transforming the industry.

Bridging the gap between the industry and academia requires understanding of both worlds. Some of the challenges that educators face coincide with the challenges that practitioners confront when adopting BIM. This study attempted to understand the academic side of the problem. The next in research would be evaluating the industry viewpoint to understand where industry is ahead of academia and vice versa. Whether the BIM education in the universities will increase the speed of adoption in the industry is still not known. Is the industry ahead of education or visa versa and in which specific categories? What are the skills that the industry requires from students? What are the needs on the industry and academia side as well as the key barriers? Identifying the needs from the AEC practitioner's side would be the next step of this research to close the gap between academia and industry. For AEC education to set the pace for industry, the siloing of curricula must be broken down through integration of the disciplines, similarly to what is seen in the industry. Future studies should address the needs to assess emerging competencies that foster highly multidisciplinary professionals and researchers that can effectively bridge the gaps between practice and academia and lead a transforming industry.

REFERENCES

Abourizk S. and Sawhney A. (1994). Simulation and gaming in construction engineering education. *Proceedings of ASEE/C2E2 /C2EI Conference*, Edmonton, Alberta, Canada, American Society for Engineering Education.

American Council for Construction Education (ACCE) (2002). *Standards and Criteria for Baccalaureate Programs.* Retrieved December 28, 2002: http://www.accehq.org/Accreditation/AccredProc.htm

Adeli H. (2009). Vision for civil and environmental engineering departments in the 21st century. *ASCE Journal of professional issues in engineering education and practice*, Vol. 135, No. 1, 1-3.

Ahn Y. H. and Pearce A. R. (2007). Green construction experiences, expectations, and perceptions. *Journal of Green Building*, Vol. 2. No. 3, 106–122.

Ahn Y.H., Kwon H. and Pearce A.R. (2009a). Sustainable education for construction students. *Proceedings of Associated Schools of Construction Conference*, Gainesville, FL, April 1-4.

Ahn Y.H., Kwon H., Pearce A.R., Wells G. (2009b). The Systematic Course Development Process: Building a Course in Sustainable Construction for Students in the U.S.A., *Journal of Green Building*, Vol. 4(1), 169-182.

American Society of Civil Engineers (ASCE). (2008). *Civil Engineering Body of Knowledge for the 21st Century: Preparing the Civil Engineer for the Future, 2nd ed.* Body of Knowledge Committee, committee on Academic Prerequisites for Professional Practice, American Society of Civil Engineers, Washington, DC.

Auerswald P.E. and Branscomb L. M. (2003). Valleys of Death and Darwinian Seas: Financing the Invention to Innovation Transition in the United States, *Journal of Technology Transfer*, Vo. 28, No. 3-4, 227-239.

Bakens, W. (1997). International trends in building and construction research." *ASCE Journal of construction engineering and management*, Vol. 123, No. 2, 102-104.

Becerik-Gerber B. and Kensek K. (2010). Building information modeling in architecture, engineering and construction: emerging research directions and trends. *ASCE Journal of professional issues in engineering education and practice*, July 2010, Posted ahead of print 4 December 2009.

Brunton K. (2006). Education for sustainable development: principles for curriculum development in business subject areas. *Investigations in University Teaching and Learning*, Vol. 3, No. 2, 36-46.

Bur, K.L. (2009). Creative course design: a study in student-centered course development for a sustainable building/BIM class. *Proceedings of the 45th ASC Annual Conference*, Gainesville, Florida, April 1-4, 2009.

Casey M. J. (2008). "Work in progress: How building informational modeling may unify IT in the civil engineering curriculum." *Proceedings of 38th ASEE/IEEE Frontiers in Education Conference,* IEEE, Saratoga Springs, N.Y., S4J 5–6.

Chau K. W. (2007) Incorporation of sustainability concepts into a civil engineering curriculum. *ASCE Journal of professional issues in engineering education and practice*, Vol. 133, No. 3, 188-191.

Cotgrave, A., and Alkhaddar, R. (2006). "Greening the Curricula with Construction Programs." *Journal of Education in the Built Environment*, 1 (1), 3–29.

Denzer A. S. and Hedges, K. E. (2008). From CAD to BIM: Educational strategies for the coming paradigm shift. In M. M. Ettouney (Ed.) AEI 2008: Building integrated solutions. Reston, VA: ASCE.

Egan J. (1998). *Re-thinking Construction*. Report of the Construction Task Force to the Deputy Prime Minister of the UK. http://www.architecture.com/Files/RIBAHoldings/PolicyAndInternationalRelations/Policy/PublicAffairs/RethinkingConstruction.pdf, accessed on 5/6/2010.

Ellis, G. and Weekes, T. (2008). “Making sustainability ‘real’: using group-enquiry to promote education for sustainable development,” *Environmental Education Research,* 14(4), 482-500.

Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET). (2000). *Criteria for accrediting engineering programs: Effective for evaluations during the 2000–2001 accreditation cycle*, Baltimore, MD. http://www.abet.org

Farrow C.B., Liu J., and Tatum M. (2010). Establishing curriculum delivery preferences of the net generation. *Proceedings of 46th Annual International Conference of the Associated Schools of Construction*, Boston, Massachusetts.

Glick S. (2010). System components visualization: the role of 3D models in construction management education. *Proceedings of 46th Annual International Conference of the Associated Schools of Construction*, Boston, Massachusetts.

Glyphis, J., ed. 2001. How Can the Architect Contribute to a Sustainable World? Proceedings of the Wingspread Conference, 24–26 August, Racine, Wis. www.secondnature.org/pdf/snwritings/proceedings/wingspread.pdf.

Hayles, C. S., and Holdsworth, S. E. (2006) “Curriculum Change for Sustainability.” *Proceedings of the Built Environment Education Annual Conference*, London, United Kingdom.

Isreal, G. D. (2009) Determining sample size, http://edis.ifas.ufl.edu/pd006, accessed on 5/6/2010.

Issa R. and Anumba C. (2007). Computing and information technology (IT) research in civil engineering – self-fulfilling or industry transforming. *ASCE Journal of Computing in Civil Engineering*, Vol. 21, No. 5, 301-302.

Johnson B. T. and Gunderson D. E. (2010) Educating students concerning recent trends in AEC: A survey of ASC member programs, *Associated Schools of Construction Annual International Conference, and CIB Workgroup 89*, April 07-10, 2010 at the Wentworth institute of Technology

Jones P., Trier C.J. and Richards J.P. (2009). Embedding education for sustainable development in higher education: A case study examining common challenges and opportunities for undergraduate programs. *International journal of education research,* Vol. 47, No. 6, 341-350.

Kent C. D. and Becerik-Gerber, B. (2010). Understanding construction industry experience and attitudes toward integrated project delivery. *ASCE Journal of construction engineering and management,* August 2010, Posted ahead of print 16 January 2010.

Kim C., Kim H., Han H.H., Kim C., Kim M. K., and Park S. H., (2009). Developing a Technology Roadmap for Construction R&D through Interdisciplinary Research Efforts", *Automation in Construction*, Vol. 18, No. 3, 330-337.

Klinc R., Dolenc M., and Turk Z. (2009). Engineering collaboration 2.0: requirements and expectations, *Journal of Information Technology in Construction (ITcon),* Vol. 14, Special Issue Next Generation Construction IT: Technology Foresight, Future Studies, Roadmapping, and Scenario Planning, pg. 473-488, http://www.itcon.org/2009/31.

Lang, J.D., Cruise, S., McVey, F.D. and McMasters, J., (1999). Industry expectations of new engineers: A survey to assist curriculum designers. *Journal of Engineering Education*, 88, 1, 43-51.

Levitt, R. (2007). CEM research for the next 50 years: maximizing economic, environmental, societal value of the built environment. *ASCE Journal of construction engineering and management*, Vol. 133, No. 9, 619-628.

Manoliadis O. (2009). Education for sustainability: experiences from Greece. *ASCE Journal of professional issues in engineering education and practice*, Vol. 135, No. 2, 70-74.

McGrawHill (2009). SmartMarket Report, The business value of building information modeling: getting building information modeling to the bottom line.

Park B. (2008). CM education in second life: virtual lab development, implementation, lessons learned and its implications, *Proceedings of the 2008 ADC Region III conference*, Downers Grove, IL.

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.

Penttilä H. (2007). Early architectural design and BIM. *Proceedings of the 12th International CAADFutures Conference*, 291-302 Springer Netherlands.

Perez S. (2008). *Technology Populism: Risks & Rewards,* Read Write Web, http://www.readwriteweb.com/archives/technology_populism_risks_rewards.php, accessed on 5/6/2010.

Sabongi F.J. (2009). The integration of BIM in the undergraduate curriculum: an analysis of undergraduate courses. *Proceedings of the 45th ASC Annual Conference,* Gainesville, Florida, April 1-4, 2009.

Sacks R. and Barak. R. (2009). Teaching building information modeling as an integral part of civil engineering in freshman year. *ASCE Journal of professional issues in engineering education and practice*, Vol. 136, No. 1, 30-38.

Scheer D. R. (2006). From an educational perspective: BIM in the architectural curriculum. Federal Facilities Council, http://sites.nationalacademies.org/DEPS/FFC/DEPS_049447, accessed on 5/6/2010.

Seletsky P. (2006). Questioning the role of BIM in architectural education, a counter-viewpoint: AECbytes Viewpoint #27. http://www.aecbytes.com/viewpoint/2006/issue_27_pr.html, accessed on 5/6/2010.

Smit D. K., Wall J., and Betts M. (2005). ICT and curriculum design to bridge the gap between industry and academia. *Proceedings of the Queensland University of Technology Research Week International Conference*, Queensland University of Technology, Brisbane, Australia.

Taylor J.M., Liu J., and Hein M.F. (2008). Integration of building information modeling into an ACCE accredited construction management curriculum. *Proceedings of the 44th ASC National C*onference, Auburn, AL, April 2-5.

Tinker, A. and Burt, R. (2004). "Greening the Construction Curriculum," *International Journal of Construction Education and Research*, 1(1), 26-33.

Wang Y. (2009) Sustainability in Construction Education. *ASCE Journal of professional issues in engineering education and practice*, Vol. 135, No. 1, 21-30.

Weber, D. and Hedges, K. E. (2008). From CAD to BIM: The engineering student perspectives. In M. M. Ettouney (Ed.) AEI 2008: Building integrated solutions. Reston, VA: ASCE.

Woo J. H. (2006). Building information modeling and pedagogical challenges. *Proceedings of the 43rd ASC National Annual Conference*, Flagstaff, AZ, April 12-14.