Surveying the Evolution of Computing in Architecture, Engineering, and Construction Education

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Abstract

This paper includes the results of an online survey that was conducted by the American Society of Civil Engineers (ASCE) task committee on computing education in order to assess the evolution of computing in Architecture, Engineering, and Construction (AEC) education in 2012. The committee aims to understand and measure the evolution of computing in civil engineering as well as architecture and construction management curricula and evaluate the current state of computing within the AEC curricula. The paper contains an investigation of the levels and concentrations of computer science knowledge versus computer skills in curricula. In addition, the committee seeks to recognize the similarities and differences between architecture, engineering, and construction management programs by comparing the data associated with these disciplines. The paper also includes a discussion of basic aspects of computing education including the prerequisites that are necessary for further learning. The survey results provide useful benchmarks for decision-making regarding research, industry collaboration, and curricula. Findings of the study include: (1) the importance and coverage of computer skills and competence of graduates has increased over the past decade; (2) computing skills are judged to be more important than computer science knowledge in AEC curricula; (3) the links between computer science concepts, and AEC applications of computing are not yet fully recognized; (4) computing education is not sufficient to meet the demands of the AEC industry and that the share of computing courses is less than what educators desire; and (5) scientific concepts of computing are important for preparing architects and engineers for unknown future developments in information technology.

Introduction

The ever-increasing advances in computer software and hardware have equipped engineers and architects with powerful means of processing, storing, retrieving, sharing, and displaying data (Law et al. 1990a,b; Fenves and Rasdorf 2001). These advances have made computing a growing and important part of nearly every architecture, construction and engineering discipline (Abudayyeh et al. 2004). The Architecture, Engineering and Construction (AEC) industry evolves continuously as new trends emerge and many challenges as a result of these new trends evolve, such as issues including sustainability, energy, and technological and institutional transformations. In response to such drivers of change, the AEC industry is redesigning its organizational structures and moving towards integrated enterprises for designing, building, and managing facilities (Albano et al. 1999). To meet the increasing requirements and challenges of the AEC industry, an interdisciplinary and computing focused approach to AEC curricula revision becomes more relevant and prescient (Irizarry et al. 2010).

Computing in AEC education must focus on more aspects than specialized time-limited skills that enable engineers and architects to use commercial tools. The science of computing involves the study of representation and reasoning strategies as well as fundamental topics such as computational complexity. It is important to provide a diversified and collaborative AEC education that embraces the depth of specialization as well as a strong background in fundamentals (Eck 1992). Many architects and engineers believe that computing is only a skill to be acquired on the job, not equally a science to be learnt in an academic setting. Nevertheless, most will agree that there is a growing lack of correlation between what is taught and how architects and engineers use computers in practice (Smith 2003). This discrepancy form a core element of the work reported in this paper. To understand the roots of this discrepancy, the paper reports on findings of an online survey in order to make progress toward addressing two increasingly important questions by creating a benchmark as a first step. These questions are (1) how do we adjust the AEC curricula to make it science-based learning as opposed to skills-based learning, especially when it is related to computing?, and (2) what are the compounding effects of the current trend of AEC integration on curricular decisions?

Advances in technology and the field of computing have a persistent influence on the AEC industry. Many researchers are motivated to advance the use of existing and emerging computing tools and methods. New techniques and tools that result from these research efforts enable architects and engineers to use computing in innovative and imaginative ways. The computing domain is a large field of research that has a great potential for impact on AEC practices. Knowledge of fundamental and multidisciplinary issues in the areas of computing education, research, and professional practice is required for engineers and architects to understand the full potential of these advances (Abudayyeh et al. 2006). Sufficient computing resources, enough credit hours, advanced methods for computing instruction, and appropriate computing topics in the curricula are required to prepare the graduates to deal effectively with the complexity and evolution of their working environment (Abudayyeh et al. 2004). Limiting AEC education only to generalized applications of computer technologies has the disadvantage of limiting the improvements and innovations that could be achieved in the area of computing through a more fundamental education in computer science (Ozkaya et al. 2005). This risk motivated the authors' attempt to understand the perception of computer science knowledge versus computer skills in AEC education. In the context of this paper, possession of computing skills is defined as the ability to use computer-based technologies for AEC tasks, while computer science knowledge is defined as the ability to use mathematical and computational methods and representations for AEC related problem solving. The distinction between computer science knowledge versus computer skills is useful for tracking the evolution of computing in AEC education. Furthermore, there is also an increasing need for multidisciplinary approaches in the AEC industry. Since it seems that AEC computing education often does not cover these areas, this is a timely moment for a reassessment of the computing component within AEC curricula.

This study was initiated to gain insights into current educational environments and to provide a baseline for determining ways forward. The paper includes a review of previous work and continues with a description of the research methodology. A discussion of the data gathered through an online survey follows. Aspects evaluated include defining computing skills that are required for AEC graduates, competence of students, coverage of curricula for skills, computer-science knowledge versus computer-skill educational approaches, and future plans for AEC education. Finally, a discussion of needs for future research and AEC education is provided.

Background and Objectives

Advances in computer technology occasionally leads to evaluations of whether or not graduates are sufficiently prepared to function effectively in new computing environments. The Technical Council on Computing and Information Technology (TCCIT) of the American Society of Civil Engineers (ASCE) conducted a series of computing focused surveys in 1986, 1989, 1995 and 2002 to explore the extent to which computing requirements of the profession are being recognized and met, and whether curriculum modifications should be made (O'Neill et al. 1996a,b).

In 1986, the education committee of the TCCIT conducted a survey (for both academicians and professionals) on the accessibility of computer resources and the approach of faculty and practitioners toward computing in civil engineering education (Godfrey 1987; Fontane 1985). The survey identified that civil engineering students should be exposed to the following areas: the technology of computers, computers as problem solving tools and computers as engineering simulators to assist in design. The results of the survey indicated that most civil engineering programs required at least one computing course in programming concepts conveying the essentials of computer science to future engineers (Rasdorf 1984). To accomplish this goal, different scenarios were described (Law et al. 1990a; Fenves et al. 1988). Many faculty members believed that there should be more emphasis on computing technology as well as the use of computers in their courses and that these courses should be mandatory within a civil engineering degree-granting program even if it would result in increasing the number of credit hours for an undergraduate degree (Abudayyeh et al. 2004).

With the needs identified in the 1986 survey, the TCCIT organized a task committee in 1987 to conduct a second survey. The survey aimed to determine the depth of course offerings in civil engineering departments, to assess the computing education qualifications of educators relative to practitioners' requirements (Law et al. 1990a,b). The survey was sent to both civil engineering educators and practicing engineers. Results indicated that more than half of practicing engineers believed that their computing education was not adequate to give them the ability to use computers effectively in their professional settings. Academicians emphasized the importance of software and hardware knowledge and supported a balanced computing education curriculum that puts equal emphasis on obtaining computing skills with understanding underlying civil-engineering principles. Practicing engineers emphasized the use of personal computer-based software packages that related to civil engineering and the need to teach students how to interpret and evaluate computer-programming results (Law et al. 1990a).

In 1995, the TCCIT education committee conducted another survey, again aimed at both educators and practitioners, to determine their perspectives on the role of computing in civil engineering. This survey indicated that more advanced computing courses were required in addition to the basic programming courses to prepare civil engineering students for future careers (O'Neill et al. 1996a,b). The latest surveys were conducted in 2002 (a practitioners' survey and an educators' survey) by the TCCIT to assess the current computing component of the curriculum in civil engineering. The educators' survey was designed more specifically to investigate what computing skills were considered to be important, what skills were taught, and also to evaluate the competence of the students. (Abudayyeh et al. 2004). The practitioners' survey investigated what industry needed and assessed the competence of the engineers in these skills. It also evaluated the coverage of the curriculum for these skills. The purpose of this survey was to evaluate the computing component of the undergraduate and graduate civil engineering curriculum as perceived by academics and professionals. The findings of the study, which were used as benchmarks in this paper to measure and evaluate changes in computing education, include: (1) the relative importance of the top four skills: spreadsheets, word processors, computer aided-design, electronic communication; (2) the competence of engineers in programming was found insufficient; (3) there was an increase in the importance and use of geographic information systems and specialized engineering software; and (4), there was a decrease in the importance and use of expert systems, equation solvers and databases over that decade. (Abudayyeh et al. 2004).

In addition to the TCCIT surveys, several research studies on aspects of computing in AEC have been undertaken over the last three decades. Studies were conducted to evaluate the status of the fundamentals of computing in AEC curricula such as the studies enumerating the computer skills required of civil engineering graduates (Gerstenfeld et al. 1985); studies evaluating the role of computing within the curricula and discussing a philosophy of integration into the civil engineering curriculum (Baker and Rix 1991; Backer and Rix 1992; Henry 1992); studies investigating the need for teaching computing science knowledge to civil-engineering students (Smith and Raphael, 2000, Smith 2012); studies introducing graduate AEC students to software requirement elicitation and development of process techniques in 2005 (Ozkaya et al. 2005).

Other studies were conducted on the evolution of AEC industry and AEC education regarding the new computing trends, which resulted in technological and institutional transformations and changes. These trends led to the emergence of approaches for new technological innovation and new topics and issues in AEC education such as: information technology in AEC (Menzel et al. 2006; Issa and Anumba 2007; Johnson and Gunderson 2010); design and decision-support tools, educational tools, information modeling and management, simulation modeling, and visualization tools (Becerik-Gerber and Kensek 2010; Becerik-Gerber et al. 2011); and, AEC global issues (Arciszewski et al. 2007). These studies revealed concerns related to the preparation of graduates to operate effectively in the emerging and evolving AEC computing environments. Future architects and engineers need to assimilate advanced, yet fundamental knowledge of computing that is appropriate for their professional careers. Moreover, today's architecture and engineering graduates need strong collaboration and teamwork skills in various disciplines (technical and nontechnical). Graduates student education should include appropriate computing componentsand a more expansive treatment of issues that concern their profession including technical, social, political, environmental, economic and global aspects (Walewski 2011). Finally, they need to know the relevance of fundamental computer science and how to apply computer skills in a range of practical situations now and in the future.

To address these concerns, an online survey was initiated and led by the ASCE's Task Committee on Computing Education of the TCCIT . This paper includes the results of this survey in rder to study the current state of computing within the AEC curricula. The level and concentration of research on computer science knowledge versus computer skills educational approaches is investigated. In addition, the paper seeks to recognize the similarities and differences between architecture, engineering, and construction management programs by analyzing the data within these three disciplines. As there is little empirical data regarding the current status of computing in architecture and construction management education and all the previous surveys focused on civil engineering, there are few benchmarks for further improvements in architecture and construction management fields that can address issues of overlap, redundancy and more importantly collaboration and integration. This survey aims to measure and understand the evolution and changes over time in computing in civil engineering education and provide benchmarks for future evaluation and evolution of computing in architecture and construction management education. It also highlights the issue of where the AEC educational focus should be: computer science skills or computer science knowledge -- an important distinction considering the pace and evolution of technology and computing in the now information technology rich AEC industry.

Survey Methodology

To provide a benchmark to assess the evolution of computing in AEC curricula and for further improvements, a survey methodology was implemented for data collection. The survey was designed in a collaborative and iterative process. The survey underwent several iterations regarding the type, amount and arrangement of questions, between September 2011 and January 2012. The survey was organized into multiple sections designed to investigate the topics of computing evolution within the AEC curricula. The survey included five sections: program information; evaluation of computing courses; evolution of computing in AEC curricula; computing skills vs. computer science knowledge; and program evaluation and future plans. A link to the online survey was administered through a web-based service (Qualtrics). The invitation and subsequent reminder email messages were sent to the participants twice during a four-month period.

Survey Specifics

The survey has been designed to focus on two computing issues in the current AEC curricula: (1) evolution of computing in AEC curricula; and (2), evaluation of computer science knowledge versus computer skills in AEC curricula. None of the survey questions were open ended. Respondents were asked to rank choices. The structure of the survey covers these two areas through the five sections described above.

The survey was open for four months between February and May 2012. A total of 115 valid responses were used for analysis after removing incomplete, duplicate and invalid responses. Table 1 shows the distribution of the programs. The survey targeted and solicited management (deans, department chairs and program directors) (40% of the respondents), and faculty members (60% of the respondents) of architecture, architectural engineering, civil engineering, civil engineering technology, architectural engineering technology, construction engineering, construction engineering technology and construction management programs from North America (53% of the respondents from the United States and 3% of the respondents from Canada), Europe (23% of the respondents), Asia (15% of the respondents), and Australia (6% of the respondents). Demographic information regarding the programs included: program type (i.e., architecture, engineering, and construction management) and educational level (i.e., graduate and undergraduate), 51% of the 115 respondents are from architecture programs, 30% from engineering and 19% from construction programs. About half of the programs are undergraduate programs, totaling 49% of the respondents. Respondents that are from graduate programs account for 51% of the responses. Response rates for each question are provided, where possible.

Table 1- Program distribution (Program type: Architecture (A), Engineering (E) or Construction (C); Education level: Undergraduate (U) or Graduate (G))

The list of programs in the United States 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). The European contributions were obtained through contacting members of the European Group for Intelligent Computing in Engineering (egice.com). The number of recipients receiving the initial email is close to 350. The response rate was thus approximately 33%. This is an acceptable response rate since no population generalization is proposed. The purpose of the study is to provide insight into the activities relative to recent trends in the AEC curricula..

An independent-samples t-test was conducted to compare the distribution of the U.S. based responses vs. non-U.S. based responses. There is no significant difference in both populations for any of the questions, in which the p statistic values were greater than the significance level (α=0.05) for two-tailed t-tests. Therefore, the aggregated responses were used in the following analysis.

Survey Results

The pace of change in the industry and technology has created several challenges and opportunities for AEC educational programs. Integrated computing skills and teaching methods must be developed in the academic curricula to prepare students to deal with new trends. To analyze the survey results, responses to each specific question were examined and counted and percentages were computed. The overall rating for each computing skill or application within a specific question was determined as a weighted average of the percentages. The weights ranged from 1 to 5 as specified in the survey questionnaires -- a higher rating indicates either more important, more competent, more coverage, more sufficient, or more expert. A one-way analysis of variance (ANOVA) was conducted on the participants' responses to different survey questions to find out if there is any significant difference (α=0.05) in responses for different program types.

Evaluation of Computing Courses

The respondents were asked to report the percentage of computing related courses offered in the AEC curricula. The question was answered for 112 different programs. The results indicated that overall computing related courses make up 13% of all programs (9.5% of undergraduate and 15% of graduate programs). At the graduate level, architecture and engineering programs have more computing related courses than construction management programs. At the undergraduate level, engineering and construction management programs have the same level of computing related courses (7-8%) and the level of computing related courses in these two program types is slightly lower than architecture programs (12%).

Figure 1 – Percentage of units/credits containing computing in AEC curricula

An important question for AEC programs is: "when should computing be more emphasized in the curricula?" Each program has different approaches to this question. Excluding simple office and drawing tools, the survey results show that architectural programs apply computing earlier than the other two program types, followed by the engineering and construction management programs.

AEC curricula provide multiple pedagogical methods for teaching computing related courses such as computer labs, lectures, lecture and computer labs as an integrated method, studios, seminars and other pedagogical methods. The survey investigation of predominant pedagogical methods indicate that out of 113 responses, 61% of all the programs identified lecture and computer labs as their predominant pedagogical method for teaching computing related courses: 46% of architectural programs (48% of undergraduate and 45% of architecture graduate programs), 83% of engineering (79% of undergraduate and 88% of engineering graduate programs), and 64% of construction management programs (60% of undergraduate and 67% of construction graduate programs). Less than 5% of all programs (7% of undergraduate and 3.5% of graduate programs) suggested lectures only as pedagogical methods for teaching computer related courses in AEC programs.

Importance and Coverage of Computer Skills and Competence of Graduates

The survey results help to determine the importance of individual computing skills within the program curriculum, the competence of graduates in each skill, and the level to which each computing skill is covered in the academic curricula.

The survey first included questions related to opinions about the importance of various computing abilities in AEC education (Table 2). Out of 84 responses it was signaled that taking advantage of commercial tools in architecture and construction management and programming and algorithms in engineering programs to be important. They believed that the overall importance of search and optimization and data structure skills are neutral in all AEC programs. Most of the computing abilities in engineering programs are rated as neutral or higher. Machine learning, distributed computing, and network science are rated as the least important in architectural and construction management programs.

This is in contrast with industrial needs and current research into these subjects by faculty members at many universities, suggesting a lag in the development of computing in curricula.. The abundance of cloud based collaborative technologies that employ distributed computing in networks, which are already in use in the AEC, is one example.

Table 2 - Survey* of *importance of computing abilities --- educators' opinions (1: Not Important, 2: Somewhat Important, 3: Neutral, 4: Important, 5: Very Important)

There is a key distinction between the responses from Table 2 and Table 3, namely that the first expresses respondents' opinions about the importance of the enumerated computing abilities whereas Table 3 expresses their opinion as it exists in the curricula in their respective institutions, and programs. A total of

83 responses were received for Table 3. The survey results that are shown in this table indicate that respondents rated all of the skills in the three program types as important (3.5 to 4.5) for graduate levels; except for equation solvers and programming in architecture and construction, which are rated as neutral (2.5 to 3.5). Also most of the skills at the undergraduate level are rated as important. Of critical importance is the findings shown in both tables, that irrespective of whether they are the educators' opinions (Table 2) or the status of AEC curricula (Table 3), programming was rated as neutral (2.5 to 3.5) in terms of its importance, except for undergraduate engineering programs where programming is perceived as very important by the respondents.

The survey results also show that generally respondents believed that the undergraduates' competence to be above novice to near expert level for most of the computing skills (7 out of 10 skills received 2 to 2.59, where 3 was an expert and 2 was a novice). Engineering and construction students are considered to have become near experts in the use of word processing, spreadsheets, and presentation packages. Students are considered as novices in the other computing skills.

The extent of academic coverage for computing skills reveals the fact that in general, AEC curricula has covered most of the computing skills for three program types (architecture, engineering and construction management) at the graduate level and most of the skills are at least introduced at the undergraduate level. It is interesting to note that all the computing skills in engineering graduate programs are covered (2.5 to 3.5). The same situation is observed in the construction management graduate programs with the exception of equation solvers, which are only introduced (1.5 to 2.5). The results also indicate that some skills such as presentation packages in undergraduate level and parametric design in graduate level are covered more in the architectural programs than the other two program types, while, skills such as spreadsheets, word processing, equation solvers, and specialized engineering software are just introduced in the architecture graduate and undergraduate programs. It is important to add that there is mounting evidence to suggest more use, interest and integration of specialized engineering software within architectural education. The authors expect this survey to be a benchmark for that trend.

Table 3 - Analysis of importance-competence-coverage of computing skills in AEC curricula (The skill importance within the program curriculum (1: Not Important, 2: Somewhat Important, 3: Neutral, 4: Important, 5: Very Important). The competence of student skill (1: unskilled, 2: novice, 3: expert). The skill coverage within program curriculum (1: not covered, 2: introduced, 3: covered, 4: moderately covered, 5: extensively covered))

A comparison of the importance, competence, and coverage rankings from the survey reveals that there is a consistency between computing skills' importance and students' competence and inconsistency between these two factors and the coverage of computing skills in curricula. Only for electronic communication, collaborative environments, and equation solvers, was there consistency between all three factors, importance, competence, and coverage.

Evolution of Computing in AEC Curricula

One of the goals of this survey (2012) is to provide a basis to evaluate the evolution of computing in AEC curricula going forward. Previous surveys only covered civil engineering programs. The 2012 survey covers AEC educational programs more inclusively in order to begin to track integration and overlap related issues that are believed to be important to the future of AEC curricula. To evaluate the status of computing in AEC curricula, the results of the 2012 survey are compared with the 2002 survey, which was conducted by the TCCIT to assess the computing component of specifically civil engineering education. Since the 2002 survey only considered civil engineering curricula, the civil-engineering responses to the 2012 survey alone are evaluated. The construction management programs that are taught in the civil engineering departments are also included in the responses to the civil engineering program type, totaling 51 responses. To be consistent with the 2012 survey, only the educators' perspectives are used from the 2002 survey to discuss the importance, competence, and coverage of the computing skills for graduates. The weights range from 1 to 5 where a higher rating indicates more importance. The survey is designed so that the extension of the community will serve as a starting point for future tracking of AEC curricular transformation.

Importance

A comparison of the importance ratings and rankings from the 2012 survey and 2002 educators' survey indicates an overall slight increase in the importance of computing skills during the past decade although the difference is not considered to be significant except for collaborative environments, which shows a considerable increase. Table 4 is a comparison of the rating and ranking of the importance for each computing skill of the 2012 survey with their corresponding rating and ranking from the educators' perspectives in the 2002 survey.

Table 4 - Comparison of importance in computing skills in civil engineering curricula (2002-2012)

The top skill in terms of importance, that of spreadsheet use, remains unchanged during the past decade. Also, the comparison of the ratings and rankings shows that the importance of presentation packages, specialized engineering software and collaborative environments has increased. Parametric Design was not measured in the previous 2002 survey but it is a prominent computing skill to continue to track future transformation and it is understood as necessary to support AEC integration.

Competence

Table 5 compares the rating and ranking of the competence for each computing skill of the 2012 survey with their corresponding rating and ranking from the educators' perspectives in the 2002 survey. The comparisons indicate that the competence of the students in each computing skill has increased during the past decade.

Table 5- Comparison of competence of computing skills in civil engineering curricula (2002-2012)

The survey results indicate that the top three computing skills, spreadsheet, word processing, and presentation packages have the highest competence levels during the past decade. Also noteworthy is the considerable increase in the competence of the graduates in specialized engineering software, equation solvers, programming, and collaborative environments. It is interesting to note that although graduates have become more competent in the use of electronic communication, the rank of this skill has decreased during the past ten years. The reason might be the fact that students have become more competent in the use of some other skills such as specialized engineering software at a faster rate.

Coverage

Table 6 compares the rating and ranking of academic curricula coverage according to each computing skill of the 2012 survey with their corresponding rating and ranking from the educators' perspective in the 2002 educators' survey. The comparison indicates the coverage of curricula for these skills has generally increased over the past 10 years (except for spreadsheet use and word processing).

Table 6 - Comparison of the coverage of computing skills in civil engineering curricula (2002-2012)

An examination of the coverage rating and rankings from the 2002 survey and 2012 reveals that while spreadsheet and word-processing skills' rating has increased slightly, their rankings have changed considerably; from 1 down to 4 for spreadsheet use and from 4 down to 8 for word-processing. The reason might be the fact that students learn these skills in high school and that they use word processors and spreadsheets more than before for homework and project reports so they have become experts in these fields or that these entry levels skills have evolved significantly from 2002 to 2012. It is interesting to note that equation solvers is covered more but its rank has declined. One potential explanation might be the fact that many engineering software and applications might already incorporate these components. Considerable changes of note are the increased emphasis on the coverage of specialized engineering software, programming, and collaborative environments. It seems that curricular evolution has provided more coverage for domain specific skills such as specialized engineering software and programming than general skills such as spreadsheet, presentation packages, and word processing during the past decade. This is compatible with the increase in entry-level skills of students.

Comparatives in AEC Curricula from Computer Skills to Computer Science Knowledge

Prerequisites are required for computing courses in AEC educational programs to enhance the learning process. Table 7 shows the prerequisites that are required for AEC programs. A total of 55 responses were received for this question. Results indicate that calculus, geometry, and linear algebra are the top three prerequisites in AEC programs except for architectural graduate programs, in which geometry, graph theory and topology are rated as the three top prerequisites. Also the results show that architectural and engineering programs require more knowledge in graph theory while construction management programs need the students to be more acquainted with areas such as probability and stochastic processes compared to the other program types. The survey did not make a distinction between prerequisite knowledge for completing exercises versus prerequisite knowledge for learning computer concepts.

Table 7 - Prerequisites that are required for computing courses in AEC programs

The survey has also covered the type of programming languages that are taught in AEC curricula. 59 responses (41% from architecture, 46% from engineering, and 13% from construction management programs) were received for this question. Table 8 shows the top ten rankings of programming languages in all the AEC program types. The results indicate that HTML (at the undergraduate level) and python (at the graduate level) are taught more in architectural programs while Matlab and Java in the engineering programs and C++ in the engineering and construction management programs are taught more.

Table 8 - Top 10 languages that are taught in AEC curricula

One of the emerging subjects in education is building information modeling (BIM). In accordance with the perception of how BIM has been integrated into the AEC educational discussion, the survey assessed the BIM computing skills' component in AEC educational programs. Figure 2 shows the program trends and purposes for where BIM is taught versus where BIM is planning to be taught. 78 responses were received for this question.

Figure 2 - The planned and current areas where BIM is/will be taught

When different programs are analyzed, architecture programs teach BIM mostly for modeling (92%) followed by energy analysis (76%), and scripting (63%). This trend is planned to be continued in the future with the exception that BIM based collaboration is planned to be improved in the future. Engineering programs mostly include teaching of BIM for modeling (83%), BIM based collaboration (61%) followed by energy analysis (52%). Trends show that application of model based scheduling is planned to be increased in engineering programs in the future (from 33% to 50%) in the undergraduate programs and from 67% to 100% in the graduate programs). There is also an increasing trend for teaching of BIM for facilities application in the engineering undergraduate programs level (from 19% to 62%) in the future.

It is interesting to note that respondents considered modeling to be taught at 100% of the construction management programs. It is followed by model based scheduling (64%) and model based estimating (64%). Construction management programs are planning to expand BIM's applications to double the concentration on concepts such as BIM based collaboration (from 62% to 100% in undergraduate and from 50% to 100% in graduate programs), and energy analysis (from 0% to 29% in undergraduate programs and from 50% to 83% in graduate programs). BIM integration into the curricula has begun to meet the AEC programs' demands for these skills and the survey suggests these skills are both being taught and planned. Also the results of the survey illustrate an increasing trend for most of the BIM computing skills' applications in the future.

In this survey, in comparison to the previous study that was conducted on the BIM application and its rapid development in AEC curricula (Becerik-Gerber et al. 2011), more coverage of BIM is observed at the graduate level (57%) versus undergraduate level (35%) in all three AEC program types. Noteworthy is the increasing trend in the application of BIM in graduate programs during the past year.

Computing Skills versus Computer Science Knowledge

Computer science knowledge includes both fundamental topics in computing science, such as computational complexity as well as the study of representation and reasoning strategies. Such topics are expected to have an important impact on decisions related to computing during the careers of current engineering students (Smith 2012). Professionals in AEC curricula need to understand, teach, develop and apply more scientific computing methodologies. This will result in engineers and architects who are agile when new technology emerges. It will also lead to development of future computing tools that are easy to use and modify while being able to scale up to full-size AEC applications.

In order to fulfill this need, AEC programs should plan courses that can equip students with comprehensive knowledge of software development and application as a problem solving approach in the AEC (Ozkaya et al. 2005). There is an important distinction regarding computing skills (e.g. programming, commercial tools, etc.) and computer science (e.g. algorithms, database design, search and optimization, machine learning, data structures, network science, etc.).

The respondents were asked about coverage of computer science content within courses in their respective programs. A total of 82 answers were received for this question. The results of the statistical analysis (one-way analysis of variance (ANOVA)) indicate that percentage of computer science related courses in the engineering programs significantly differs from the percentage of computer science courses in the architecture and construction management programs, (p = .000). The survey results illustrate that overall 5% of all programs offer courses that are related to computer science. Engineering programs lead by offering the 8% of their courses in computer science. In general, computer science related courses are offered more at the graduate level.

Figure 3 - Percentage of the courses that are related to computer science

The survey evaluation of the importance of computer science knowledge versus computer skills (Figure 4) reveal that majority of the programs see having computer skills more important than having computer science knowledge to prepare the students for a future within AEC. A total of 83 respondents answered this question. The results of the ANOVA showed that the importance of the computer science knowledge is significantly different in construction management programs compared to the other two program types (p = .002). While the perception of the importance of computer science abilities is variable in different program types (more emphasis on engineering (89%), followed by architecture (78%) and construction management (63%)), in general, there is an agreement about the importance of computer skills. Respondents believe that computing skills are more important at the graduate level (82%) than the undergraduate level (49%). The survey results indicate that computer science knowledge is considered important in engineering programs (59%) compared to the other two program types. The construction management programs see computer science knowledge unimportant (56%), followed by the architecture programs (43%). Overall, there is a disagreement about the importance of computer science knowledge in AEC. The importance of computer science knowledge increases as the level of program level increases (undergraduate 25%; graduate 50%).

Figure 4 – Importance of computer skills vs. computer science knowledge

In the survey, when respondents were asked whether computer scientists should be asked to teach engineering, architecture and construction management students about computing, the response was 50% yes (42 respondents) and 50% no (42 respondents). Some of these results indicate that the respondents do not recognize the links between computer science concepts and architecture and engineering applications of computing. More work is needed to communicate the strategic role that such knowledge may have. Also computer scientists need to have a greater understanding of the unique context of computer science within the AEC industry.

The survey also asked the respondents to prioritize the topics that they believe should be increased in the computer science content of teaching in AEC curricula (Table 9).

Table 9 -Computer science knowledge regarding the respondents' priorities

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These results indicate that respondents do not recognize the implicit links that many topics in computer science currently have to AEC applications. For example, data structures, databases, computer graphics, complexity and geometric modeling are in the lower half of priorities. This indicates that more effort is needed to communicate such links to curricula decision makers. Lack of educator awareness of the importance of computer science principles is one of the most important barriers to increasing the leverage of computing in AEC practice. The following section offers more discussion on this topic.

Program Evaluation and Future Plans

When respondents were asked about the sufficiency of computing education to meet the demands of the AEC industry (answered by 82 responders), The one-way analysis of variance (ANOVA) results indicate that the sufficiency of the computing education to meet the demands of the AEC industry differs significantly for the construction management programs compared to the other two program types (p = .007). There is a dissensus between all three program types: 40% of architectural and just 12% of engineering programs considered computing education as sufficient or somewhat sufficient. It is interesting to note that in construction management programs, no one believed that computing education is sufficient or somewhat sufficient while 73% considered the computing education to be insufficient or somewhat insufficient to meet the demands of AEC industry. Also 47% of architectural and 44% of engineering programs believed that computing education is not sufficient or somewhat insufficient to meet the demands of AEC industry. Graduate levels saw computing education more sufficient (63%) than undergraduate level programs (48%).

The results of the one-way analysis of variance (ANOVA) that was conducted in the respondents' responses indicate that current computing skills of the students for the construction management programs differ significantly from the other two program types (p = .000). In addition, the current computer science abilities of the students is significantly different for engineering programs compared to the other two program types (p = .000) The survey evaluation of current computing abilities of students reveals that 59% of architectural, 44% of engineering and just 19% of construction management programs consider graduates to be above average or expert. While 12% of architectural, only 7% of engineering, and 69% of construction management programs are considered as poor or below average. The other respondents rated the engineering students' abilities as neutral. This finding indicates the fact that curricula should enhance the computing abilities of graduates especially in construction management programs.

The same trend is observed in computer science abilities of graduates. With respect to computer science abilities of graduates: only 5% of architectural; 37% of engineering; and 0% of construction management ranked the graduates to be above average or expert. Also, 73% of architectural, 37% of engineering, and 81% of construction management programs believed that graduates are poor or below average. In general, the respondents rated the computing skills of graduates higher than their computer science knowledge.

In order to characterize the context of decisions related to future plans for AEC curricula, the respondents were asked to indicate the barriers to incorporate computing into AEC program curricula (Table 10). Of the 83 responses that were received for this question, all of the programs at all educational levels indicate that the lack of room in the curricula is the main barrier to further incorporate computing into the AEC program curricula. Respondents in architectural programs believe that insufficient student demand is another significant barrier while the respondents in engineering programs consider the inadequate resources to make the curriculum change as a more important barrier; and respondants in construction management programs believe that lack of expertise to teach is a crucial barrier to further incorporate computing into AEC curricula.

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Barriers one to eight in Table 10 confirm the earlier assertion that a lack of awareness of the importance of computer-science principles prevents AEC educational decision makers from assigning a high enough priority to increase the emphasis on computer science teaching. Higher priorities would encourage educators to make room in the curriculum, find the resources, disregard student demand, push for accreditation acceptance and find the right people to teach the material. The results of the survey also indicate inertial resistance, and lack of teaching assistant support as other barriers to further incorporate computing into the AEC programs curricula.

Table 10 - Barriers to further incorporate computing into the AEC Programs curricula

In the survey, respondents were also asked to list the topics of importance for future AEC curricula. Table 11 shows the respondents' priorities for these topics in all three-program types. A total of 84 responses were received for this question. The results indicate that all programs consider BIM as a very important topic for the future of AEC education. It is notable that parametric design is the most important topic in the architecture programs for the future of AEC education vs. algorithms in the engineering and visualization in construction management programs. Again the 2012 survey will provide an initial basis to monitor this trend and its influence on the evolution and integration of AEC curricula over time.

Table 11- Top 10 important topics for future AEC **education**

A core question for the future of AEC curricula is related to the perception of how important the knowledge of scientific concepts of computing is for preparing architects and engineers for future developments in information technology. A total of 84 respondents answered this question. Sixty-seven percent of respondents see scientific concepts of computing as very important or important while just

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17% believed that it is not important or somewhat important for preparing architects, engineers, and construction managers for future developments in information technology. Therefore, the majority of respondents believe that scientific concepts of computing are important for preparing architects and engineers for unknown future developments in information technology. However, more specific questions related to topics and barriers indicated contradictory opinions. This leads to the conclusion of the lack of awareness that is described above; respondents might be in favor of supporting more fundamental teaching if content and links were better understood.

Discussion and Conclusions

The AEC industry has to improve integration of architecture, engineering, and construction management in order to solve complex problems in the built environment. The goals of most previous studies were to look at the needs of the industry and then motivate modifications of AEC curricula on the basis of these needs, and most specifically they investigated changes required by the civil engineering curricula. This paper not only assesses the evolution of computing in AEC curricula; but it also reveals trends and barriers that are related to AEC curricula decision-making. This research was carried out through obtaining views of educators related to AEC curricula, establishing trends and then linking views related to curricula inclusive of architecture and construction management. Most critically, specific aspects of computing skills and computer science knowledge are studied within an inclusive AEC context.

Assessment of computing components in the civil engineering curricula shows that the importance of individual computing skills has increased over the past decade and students have become more competent in the use of these skills. Explanations of this observation might be: increased entry-level skills, changes in the extent of curricular coverage for these skills, and finally, the opportunities for students to obtain these skills via independent studies and through experience with homework and projects. It is also likely that the students are simply entering universities with more intrinsic computing familiarity given the transformation of pre-university education and access to technologies in recreational settings.

While previous studies concentrated on computing skills, a critical addition to an evolving study of AEC curricula, and a focus of this survey, is a comparison of computer skills with knowledge of relevant aspects of computer science. The authors suggest that fundamental computer science knowledge is necessary for the students to understand representation and reasoning strategies, to gain agility to prepare for inevitable change and rapid transformation within the AEC industry. This survey has been structured to measure opinions related to such basic aspects of computing education including prerequisites and languages that are needed for the fundamental training of the architecture, engineering, and construction management students. Furthermore, the status of new software such as parametric design and programming language emphases is assessed to compare the presence in curricula with previous years.

Assessment of computing skills versus computer science knowledge shows that computing skills are currently judged to be more important than computer science knowledge in AEC curricula and fewer hours need to be dedicated to computer science. Educators are neutral about the importance of computer science knowledge and yet are cognizant that this is an area that AEC curricula need modifications. In 2002, Fenves observed in a preface to a book (Raphael and Smith, 2003) that previous developments of information technologies were all underpinned by fundamental principles in computer science and that understanding these principles was important for the technical agility of future engineers. He went on to say that it would be likely that future developments would also be based on these principles. Since 2002, this prediction has largely held true.

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In addition, respondents indicate that computing education is not sufficient to meet the demands of AEC industry and the share of computing courses is less than what educators desire. In that regard, the study evaluates AEC curricula by reviewing trends and assessing needs and shortcomings. Predominant barriers to further incorporate computing into AEC program curricula are identified as the lack of room in curricula, insufficient student demand, and insufficient numbers of educated faculty. The authors therefore conclude further efforts are needed to increase awareness of the importance of computing science knowledge as fundamental to all AEC future professionals. However, it is recognized that there are limitations in the AEC curricula in terms of time and space. Future surveys could explore if computing related courses should replace other courses and if they should, what courses should be taken out of the curricula to accommodate computer related courses. In any case, replacement of hours for computer skills training with more fundamental computer-science education is increasingly possible as more and more computing skills are acquired at the high-school level.

This analysis cannot be used in isolation to make decisions related to future curricula. An example is the general belief among educators that any use of computing in any course contributes to computing knowledge of students. While this may have been probable in the past, it is not expected to continue to be the case for future students as entry-level skills increase. Finally, results of this survey need to be taken together with aspects of the dynamic nature of the influence of a rapidly changing field (computing) on another field that is evolving due to new challenges.

Computing in the AEC field is a research area with great potential to grow and improve its body of knowledge. In general, curricular development has not followed the results of research. The survey indicates the share of computing in AEC curricula is incomplete and frequently limited only to the skills related to the use of technology. Therefore, conventional teaching and learning scenarios need to be

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revised, organized and extended to fulfill the needs of future engineers, architects, and construction management researchers and practitioners. Also future research should concentrate more on identifying links to computing fundamentals as well as consequences of new advances. The authors conclude with the conjecture that there are two critical topics that must continue to be addressed, disciplinary integration and the role of computer science fundamentals as part of the knowledge necessary to compete, evolve, and innovate in a complex industry that involves difficult challenges.

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Figure Captions List

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Figure 1 – Percentage of units/credits containing computing in AEC curricula

Figure 2 - The planned and current areas where BIM is/will be taught

Figure 3 - Percentage of the courses that are related to computer science

Figure 4 – Importance of computer skills vs. computer science knowledge

Table 1- Program distribution *(Program type: Architecture (A), Engineering (E) or Construction (C); Education level: Undergraduate (U) or Graduate (G))*

Table 2 - Survey **of** ***importance of computing abilities --- educators' opinions*** *(1: Not Important, 2: Somewhat Important, 3: Neutral, 4: Important, 5: Very Important)*

Table 3 - Analysis of importance-competence-coverage of computing skills in AEC *(The skill importance within the program curriculum (1: Not Important, 2: Somewhat Important, 3: Neutral, 4: Important, 5: Very Important). The competence of student skill (1: unskilled, 2: novice, 3: expert). The skill coverage within program curriculum (1: not covered, 2: introduced, 3: covered, 4: moderately covered, 5: extensively covered))*

Table 4 - Comparison of importance in computing skills in civil engineering curricula (2002-2012)

Table 5- Comparison of competence of computing skills in civil engineering curricula (2002-2012)

Table 6 - Comparison of the coverage of computing skills in civil engineering curricula (2002-2012)

Table 7 - Prerequisites that are required for computing courses in AEC programs

Table 8 - Top 10 languages that are taught in AEC curricula

Table 9 -Computer science knowledge regarding the respondents' priorities

Table 10 - Barriers to further incorporate computing into the AEC Programs curricula

Table 11- Top 10 important topics for future AEC education

Figure 1

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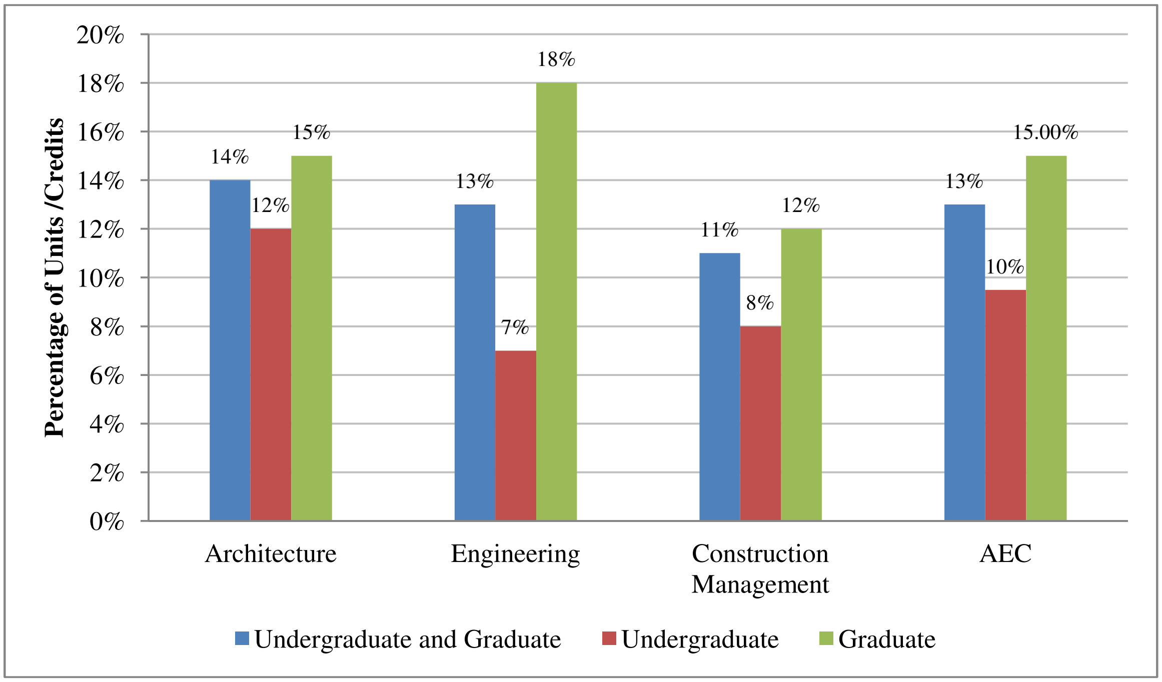

Figure 1 – Percentage of units/credits containing computing in AEC curricula

Figure 2

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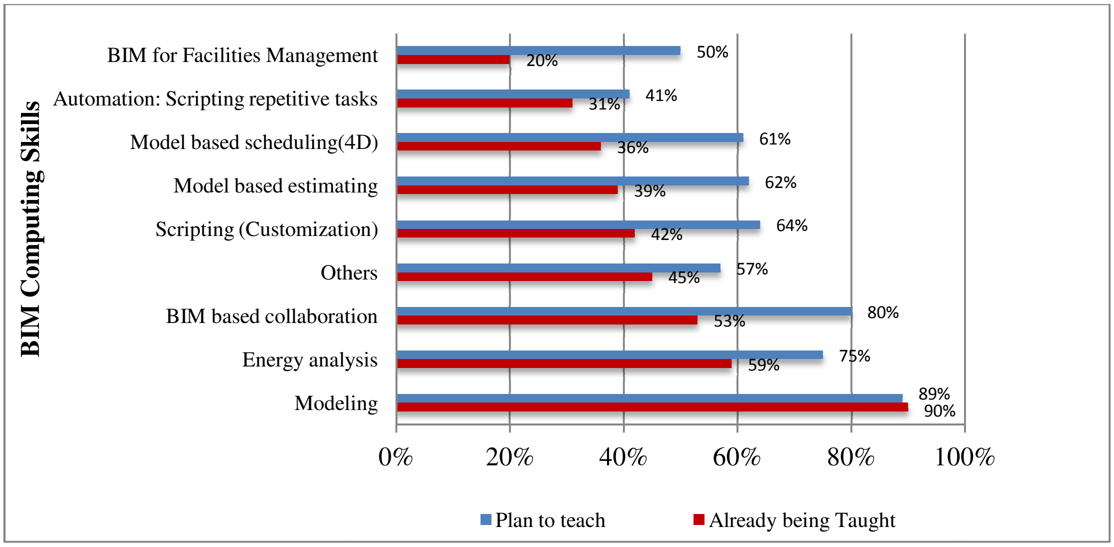

Figure 2 - The planned and current areas where BIM is/will be taught

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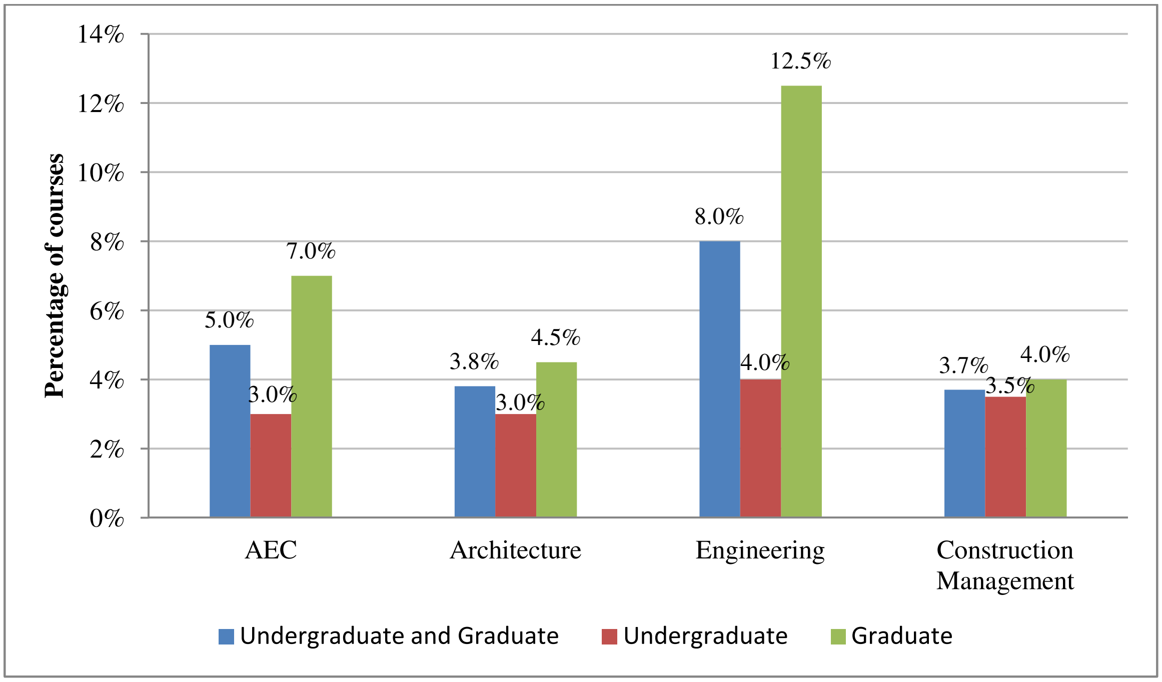

Figure 3 - Percentage of the courses that are related to computer science

Figure 4

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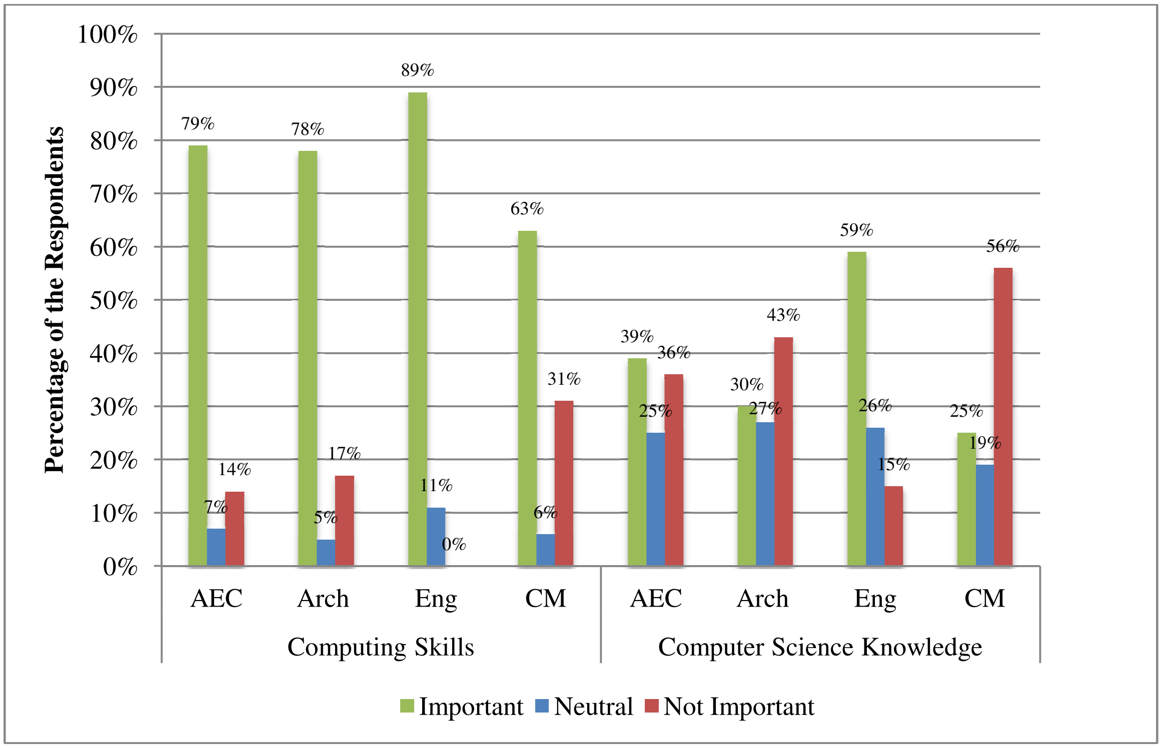

Figure 4 – Importance of computer skills vs. computer science knowledge

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Table 1- Program distribution (Program type: Architecture (A), Engineering (E) or Construction (C); Education level: Undergraduate (U) or Graduate (G))

<table>
<tr><th>GEOGRAPHIC DISTRIBUTION</th><th colspan="3">North America</th><th colspan="3">Europe</th><th colspan="3">Asia</th><th colspan="3">Australia</th></tr>
<tr><td>% of programs per continents</td><td colspan="3">56%</td><td colspan="3">23%</td><td colspan="3">15%</td><td colspan="3">6%</td></tr>
<tr><td>% of program type per continents</td><td colspan="3">(54% A, 18%E, 28%C)</td><td colspan="3">(34% A, 33%E, 33%C)</td><td colspan="3">(56% A, 13%E, 31%C)</td><td colspan="3">(50% A, 17%E, 33%C)</td></tr>
<tr><td>% of education levels per continents</td><td colspan="3">(51% U, 49% G)</td><td colspan="3">(36% U, 64% G)</td><td colspan="3">(62% U, 38% G)</td><td colspan="3">(50% U, 50% G)</td></tr>
<tr><th>EDUCATION LEVEL</th><th colspan="6">Undergraduate Programs</th><th colspan="6">Graduate Programs</th></tr>
<tr><td>% of programs per education levels</td><td colspan="6">49%</td><td colspan="6">51%</td></tr>
<tr><td>% of program type per education levels</td><td colspan="6">(48% A, 34%E, 18%C)</td><td colspan="6">(53% A, 27%E, 20%C)</td></tr>
<tr><th>PROGRAM TYPE</th><th colspan="4">Architecture</th><th colspan="4">Engineering</th><th colspan="4">Construction</th></tr>
<tr><td>% of programs per type</td><td colspan="4">51%</td><td colspan="4">30%</td><td colspan="4">19%</td></tr>
<tr><td>% of education levels per program type</td><td colspan="4">(47% U, 53% G)</td><td colspan="4">(54% U, 46% G)</td><td colspan="4">(45% U, 55% G)</td></tr>
</table>

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Table 2 - Survey* of *importance of computing abilities --- educators' opinions (1: Not Important, 2: Somewhat Important, 3: Neutral, 4: Important, 5: Very Important)

Skills	**AEC**		**Architecture**		**Civil and Environmental Engineering**		**Construction Management**	
	Mean	**Rank**	**Mean**	**Rank**	**Mean**	**Rank**	**Mean**	**Rank**
Commercial Tools	3.85	1	3.98	1	3.5	4	4.13	1
Programming	3.51	2	3.15	2	4.25	1	3.13	2
Algorithms	3.29	3	3.12	3	4.04	2	2.33	8
Search & Optimization	3.04	4	2.63	5	3.63	3	3.07	3
Data Structures	2.98	5	2.78	4	3.39	5	2.73	5
Database Design	2.69	6	2.27	6	3.25	6	2.8	4
Machine Learning	2.35	7	2.1	7	2.7	9	2.4	7
Network Science	2.35	8	2	9	2.75	8	2.53	6
Distributed Computing	2.32	9	2.02	8	2.79	7	2.27	9

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Table 3 - Analysis of importance-competence-coverage of computing skills in AEC curricula (The skill importance within the program curriculum (1: Not Important, 2: Somewhat Important, 3: Neutral, 4: Important, 5: Very Important). The competence of student skill (1: unskilled, 2: novice, 3: expert). The skill coverage within program curriculum (1: not covered, 2: introduced, 3: covered, 4: moderately covered, 5: extensively covered))

Skills	**Importance**			**Competence**			**Coverage**		
	Mean	**Rank**	**Standard Deviation**	**Mean**	**Rank**	**Standard Deviation**	**Mean**	**Rank**	**Standard Deviation**
Presentation Packages	4.21	1	0.77	2.59	1	0.50	3.29	3	1.38
Computed Aided Drafting	4.15	2	1.01	2.42	3	0.52	3.61	1	1.09
Word Processing	4.05	3	1.19	2.49	2	0.55	2.38	9	1.54
Spreadsheet use	3.87	4	1.11	2.27	4	0.63	2.65	8	1.43
Electronic Communications	3.8	5	1.15	2.27	5	0.68	2.78	5	1.31
Parametric Environments	3.76	6	1.25	2.18	6	0.62	3.3	2	1.26
Collaborative Environments	3.71	7	1.12	2.03	7	0.62	2.76	7	1.33
Specialized Engineering Software	3.48	8	1.17	1.95	8	0.73	2.77	6	1.33
Programming	3.41	9	1.20	1.91	9	0.63	2.85	4	1.23
Equation Solvers	2.94	10	1.38	1.86	10	0.79	2.35	10	1.39

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Table 4 - Comparison of importance in computing skills in civil engineering curricula (2002-2012)

Skill	2012 Survey		2002 Survey	
	Rank	Mean	Rank	Mean
Spreadsheet use	1	4.29	1	4.4
Word Processing	2	4.18	2	4.19
Presentation Packages	3	4.06	5	3.72
Computed Aided Drafting	4	3.94	3	3.91
Specialized Engineering Software	5	3.91	6	3.5
Electronic Communications	6	3.88	4	3.65
Collaborative Environments	7	3.88	9	2.95
Programming	8	3.77	8	3.02
Equation Solvers	9	3.69	7	3.31
Parametric Design	10	3.56		

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Table 5- Comparison of competence of computing skills in civil engineering curricula (2002-2012)

Skills	2012 Survey		2002 Survey	
	Rank	Rating	Rank	Rating
Spreadsheet use	1	4.27	2	3.83
Word Processing	2	4.27	1	4.1
Presentation Packages	3	4.05	3	3.71
Specialized Engineering Software	4	3.88	7	2.5
Equation Solvers	5	3.78	6	2.82
Computed Aided Drafting	6	3.77	5	3.15
Electronic Communications	7	3.75	4	3.47
Programming	8	3.53	8	2.15
Collaborative Environments	9	3.48	9	2.14
Parametric Design	10	3.38		

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Table 6 - Comparison of the coverage of computing skills in civil engineering curricula (2002-2012)

Skills	**2012 Survey**		**2002 Survey**	
	Rank	**Rating**	**Rank**	**Rating**
Computed Aided Drafting	1	3.55	2	3.32
Specialized Engineering Software	2	3.44	6	2.7
Programming	3	3.35	7	2.56
Spreadsheet use	4	3.18	1	3.69
Equation Solvers	5	3.09	3	2.92
Parametric Design	6	2.97		
Presentation Packages	7	2.84	5	2.83
Word Processing	8	2.81	4	2.91
Collaborative Environments	9	2.79	10	1.91
Electronic Communications	10	2.64	9	2.49

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Table 7 - Prerequisites that are required for computing courses in AEC programs

AEC		**Architecture**		**Civil and Environmental Engineering**		**Construction Management**	
Prerequisites	Rank	Prerequisites	Rank	Prerequisites	Rank	Prerequisites	Rank
Geometry	1	Geometry	1	Calculus	1	Calculus	1
Calculus	2	Calculus	2	Geometry	2	Geometry	2
Linear algebra	3	Linear algebra	3	Linear algebra	3	Linear algebra	3
Graph theory	4	Graph theory	4	Graph theory	4	Probability and Stochastic Processes	4
Topology	5	Topology	5	Discrete algebra	5	Discrete algebra	5
Discrete algebra	6	Discrete algebra	6	Logic theory	6	Automata theory	6
Probability and Stochastic Processes	7	Probability and Stochastic Processes	7	Automata theory	7	Logic theory	7
Logic theory	8	Logic theory	8	Topology	8	Graph theory	8
Automata theory	9	Automata theory	9	Probability and Stochastic Processes	9	Topology	9

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Table 8 - Top 10 languages that are taught in AEC curricula

AEC		**Architecture**		**Civil and Environmental Engineering**		**Construction Management**	
Program	Rank	Program	Rank	Program	Rank	Program	Rank
C++	1	Python	1	Matlab	1	C++	1
Java	2	HTML	2	C++	2	Java	2
Matlab	3	VB (.NET)	3	Java	3	Matlab	3
Python	4	C++	4	C	4	OpenGL	4
VB(.NET)	5	Java	5	VB (.NET)	5	C	5
C	6	C#	6	Fortran	6	VB(.NET)	6
HTML	7	C	7	Python	7	Python	7
Fortran	8	Lisp,Scheme	8	C#	8	Fortran	8
C#	9	Fortran	9	SAS	9	C#	9
HTML	10	Matlab	10	HTML	10	SPSS	10

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Table 9 -Computer science knowledge regarding the respondents' priorities

1) Machine Learning
2) Distributed Applications and Web
3) Knowledge Systems for Decision Support
4) Constraint Based Reasoning
5) Object Representation and Reasoning
6) Optimization and Search
7) Computational Mechanics
8) Data Structures
9) Data-Base Concepts
10) Complexity
11) Computer Graphics
12) Geometric Modeling

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Table 10 - Barriers to further incorporate computing into the AEC Programs curricula

	Barriers	**Percentage**
1	No room in curriculum	63%
2	Inadequate resources to make the curriculum change	46%
3	Insufficient student demand	41%
4	Not an accreditation criterion	40%
5	Not considered important	37%
6	No one to teach it	33%
7	Inadequate funding	31%
8	Lack of Teaching Assistant support	31%
9	Other, esp. inertial resistance	11%

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Table 11- Top 10 important topics for future AEC education

AEC		Architecture		Civil and Environmental Engineering		Construction Management	
Topic	**% of Respondents**	**Topic**	**% of Respondents**	**Topic**	**% of Respondents**	**Topic**	**% of Respondents**
BIM	86%	Parametric Design	95%	BIM	81%	BIM	88%
Visualization	76%	BIM	88%	Algorithms	63%	Visualization	88%
Parametric Design	74%	Computer Aided Design	85%	Design Decision Support	63%	Simulation (including mechanics)	69%
Computer Aided Design	71%	Visualization	83%	Engineering Calculations	63%	Human-computer interaction	63%
Simulation (including mechanics)	63%	Simulation (including mechanics)	63%	Analysis	59%	Computer Aided Drawing	63%
Algorithms	57%	Automation: scripting repetitive tasks	61%	Visualization	59%	Computer Aided Design	56%
Analysis	56%	Analysis	59%	Simulation (including mechanics)	59%	Data Structures	56%
Human-computer interaction	52%	Algorithms	56%	Computer Aided Design	59%	Sensor Networks	50%
Automation: scripting repetitive tasks	49%	Human-computer interaction	54%	Parametric Design	56%	Web	50%
Sensor Networks	48%	Computer Aided Drawing	51%	Data Interpretation	52%	Computer Supported Infrastructure Management	50%