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Surveying the Evolution of Computing in Architecture, Engineering, and Construction Education since 2012

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Abstract

This paper presents the results of an online survey that was conducted in 2014 to assess the evolution of computing in Architecture, Engineering, and Construction (AEC) education. A primary goal includes contributing to the understanding of the evolution of computing in architecture, civil engineering, and construction management curricula. The current state of computing within the AEC curricula with respect to changes implemented since 2012 is evaluated. The paper includes a comparison of the 2014 survey with the 2012 survey. Changes in the levels and concentrations of computer science knowledge versus computer skills in the curricula are investigated. Similarities and differences between architecture and engineering (including construction management) programs are studied through comparing the data associated with these disciplines. The survey results are presented as useful benchmarks for decision-making regarding research, industry collaboration, and understanding the speed and needs for change in AEC curricula. Key findings of the study include: (1) the importance of most computing skills and the coverage of curricula for these skills have not changed significantly over these two years, while the competence of the students in these skills have decreased; (2) increasing trends have been seen in the percentages of computer science knowledge related courses in all program types and levels; (3) the percentage of computing skills related courses are more than the percentages of the computer science knowledge related courses in AEC curricula; (4) an increasing trend has been seen in the importance of the knowledge of scientific concepts of computing in respondents' perceptions; and (5) computing education still is not sufficient to meet the demands of the AEC industry.

Introduction

Recent advances in computing play a growing and important role in nearly every architecture, engineering and construction (AEC) discipline. In this regard, future architects and engineers will be expected to contribute to and guide technological transformations for the industry. Integrating computing into the AEC curricula contributes to mastering this change by preparing AEC professionals to meet the emerging industry demands, however, the AEC industry continues to lag and adapt slowly to new opportunities (Stewart and Daet 2002; Bouchlaghem, and El-Hamalawi 2006; Svavarsson et al. 2002). One of the reasons for this noted lag is the time spent on computing, and the content of computing courses within the spectrum of AEC curricula (Danijel and Tibaut 2005). Many architecture and engineering educators believe that computing is only a skill to be acquired on the job, and critically not a science to be learnt in an academic setting. However, most AEC professionals also agree that there is a growing lack of correlation between what is taught and how architects and engineers use computers in practice (Smith 2003). Although computing in the AEC has become an established research area, the results are often not integrated into the curricula (Danijel and Tibaut 2005). Given the complex nexus of forces acting upon the AEC, such as economic changes, global market influences, and information technology that drive changes in industry, the AEC curricula are subject to frequent updates and where this is not the case should be. For our focus, most notably information technology and computing are going to be one of the most powerful catalysts for change (Veeramani and Russell 2000). Therefore, considering the increasing demand within the AEC for computing, an interdisciplinary computing focused approach to AEC curricula revision is relevant and prescient (Irizarry et al. 2010).

It is essential for curricular decision makers to measure and understand what future AEC professionals need to know about computing and what competencies are needed to ensure that AEC educators can prepare these students. To answer these questions, the authors seek the educators' perceptions regarding computing content and trends within the AEC curricula and its particular evolution. The authors solicited the opinions of the educators on the perception of computer science knowledge versus computer skills within AEC educational curricula. In the context of this study, a critical distinction and definition is used throughout, where '*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 appropriately apply the knowledge of, for example, data representations and algorithms to AEC related tasks. Furthermore, there is a growing trend for tool building, automation, and infusion of computer science into AEC practices making this distinction an important contribution and leading indicator (Ceccato 1999; Ceccato and AADipl 2005; Burry 2013; Burry et al. 2001).

The study reported on in this paper was conducted as a follow up to the previous studies conducted in 1986, 1989, 1995, 2002 and 2012 in order to provide insights into current educational environments and to provide greater understanding of the evolution of curricular demands. This paper reviews the previous work and continues with a description of the research approach and methodology previously adopted by the authors in 2012. Then, it discusses the data gathered through an online survey conducted in 2014, from which research directions and trends are discussed. These include: 1) defining the perceived importance of computing skills required for AEC students, competence of the students in these skills, and the coverage of curricula for these skills; 2) defining the perceived importance of computer science knowledge versus computer-skill educational approaches; 3) defining the perceived barriers and issues for better incorporating computing in the AEC curricula; and 4) defining the perceived future plans for the AEC education. Finally, a discussion of limitations and the needs for future research into AEC education is provided.

Background and Objectives

The early use of computer and information sciences in the AEC higher education setting is closely related to the introduction of programming languages (Tibaut et al. 2012a), which resulted in the emergence of an interdisciplinary field that attempted to link computer science and AEC (Turk 2006). It manifested itself in the curricula and emerged as a field which we call "computing in AEC curricula" in this paper. Advances in computer technology often raise concerns regarding the preparation of AEC students to function effectively in new computing environments. To address these concerns, the American Society of Civil Engineers' (ASCE) Task Committee on Computing Education of the Technical Council on Computing and Information Technology (TCCIT) conducted a series of surveys in 1986, 1989, 1995, and 2002 to assess the current computing component of the curriculum in civil engineering. A review of the focus areas of these studies and their findings can be found in the 2012 survey (Gerber et al. 2013). Considering the industry and technological trends enabling or forcing closer ties between the disciplines, the need for the integration of architecture into the discussion and more generally for identifying multidisciplinary approaches in the AEC industry was implemented in follow up survey conducted in 2012. This was performed upon the request of the ASCE TCCIT to assess the evolution of computing in AEC curricula.

The 2012 study recognized the importance of developing a better understanding of the interdependencies, overlaps, similarities and differences between AEC disciplines. In addition, the 2012 study investigated the levels and concentrations of computer science knowledge versus computer skills in the curricula across the disciplines. Again, the authors are highlighting a critical distinction, *computer science knowledge versus computer skills*, as it leads to abilities to not only serve the industry needs in the present but also to affect the AEC industry's ability to adapt and innovate over the long term. The 2012 survey also gathered information related to the prerequisites that are necessary for the fundamental training of students. Key findings of the 2012 study included: 1) the importance and coverage of computer skills and competence of students has increased over the past decade; 2) computing skills are judged to be more important than computer science knowledge in the AEC curricula; 3) several links between computer science concepts and the architecture and engineering applications of computing are not yet 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 perceived as important for preparing architects and engineers for unknown future developments in information technology (Gerber et al. 2013). The results of the 2012 survey are considered as useful benchmarks for our comparison, trend analysis, and policy purposes in this paper and for the planned future work.

In addition to the surveys conducted by the ASCE, there are other studies conducted that have evaluated the computing components of the AEC curricula. These studies have emphasized the importance of integrating computer science and information technology in engineering education and have assessed the academic computing requirements for engineering programs in general. A number of important precedent studies discussed how computer integration can affect the AEC industry and curricula (Heitmann et al. 2003; Smith 2003; Ketz and Hug 1998; Howard et al. 1989). For example, Ketz and Hug (1998) investigated the existing approaches for integration of computer science as a foundation in the engineering curricula. They found that "there is a knowledge transfer gap between computer science and engineering disciplines" and suggested that there should be consistent and adequate level of computer science in engineering education. Howard et al. (1989) suggested that computer technologies can be used as intelligent tools to enhance automation, communication, bookkeeping, problem solving, and decision making in the AEC process. Integration of these technologies into the AEC process will create a new knowledge, which needs to be transmitted into educational programs to prepare engineers and architects for their future roles. Some studies have investigated the need for the issues and shortcomings in the organization and direction of computer usage and the teaching of computing technologies to civil engineering students (Henry 1992; Baker and Rix 1991; Grigg et al. 2004). For example, Grigg et al. (2004) investigated the challenges of integrating computing into the civil engineering curriculum and in conclusion suggested that given that the level of technology and practice of engineering increase in complexity continuously this constant increase is making it difficult for educators to cover the required topics in depth. Therefore, it is hard to find "the right mix of topics and courses for a changing curriculum." Some other studies have examined the share and content of subjects related to computing and information technology in AEC curricula (Smith 2012; Baker and Rix 1992). For example Smith (2012) described a course on the fundamentals of computing taught to second-year civil-engineering undergraduates in Switzerland for ten years. The outcomes suggested that through adopting a strategy of teaching fundamental computer science concepts, relevant in engineering contexts, it is possible to revise the engineering curricula to reflect aspects such as "increasing needs for wide-band competence and agility requirements required for when new technology emerges." Danijel and Tibaut (2005) introduced programs, such as the Erasmus master program, which is an IT focused postgraduate course with the objective of organizing the knowledge in the field of IT (including basic computer science and informatics courses in AEC) for developing an effective learning environment using distant learning technologies. Yu (2013) introduced a new course called "Architectural design" inclusive of digital technology and architecture where structure and teaching content of this course benefit from the basic computer science knowledge and technology. This course covers the computer aided design systems and increases the content of computer graphic principles of new buildings through theory and application. This course was designed to improve the students' skills to employ computing for architecture and design in their projects.

Other AEC researchers also focused on the evolution of the AEC industry and AEC education regarding the new computing trends, which have resulted in technological and institutional transformations and changes. These trends led to the emergence of approaches for integrating new technological innovations, topics, and issues in AEC education; such as design optimization and decision-support tools, educational tools, information modeling and management, simulation, visualization tools (Flager et al. 2009; Abrishami et al. 2013; Hopfe et al. 2006; Issa et al. 2005; Shi 1999),and innovative information technology (IT) and information systems (IS) for construction improvements (Stewart and Daet 2002; Issa and Anumba 2007; Johnson and Gunderson 2009). Building Information Modeling (BIM) is another emerging and now arguably mainstream technology used in the AEC industry. Some studies investigated the level of integration of BIM into the AEC curricula and the level of exposure to BIM technology that AEC curricula should provide to the students (Becerik-Gerber et al. 2011a; Cooksey 2011). The results of studies conducted by Cooksey (2011) showed an increasing need for AEC programs to add BIM into the curricula. In addition, the results suggested that a BIM course should introduce the students to the general principles of BIM as well as the specific capabilities of BIM software packages. In addition, the authors conclude a BIM course should include collaboration techniques in order to share information between disciplines. Other emerging technologies such as intelligent transportation systems (ITS), most common application of IT to infrastructure; intelligent construction systems; applications of IT to the construction process; environmental monitoring and control systems, IT features used in environmental systems, have been adopted in the AEC industry (Grigg et al. 2005). Grigg et al. (2005) investigated how to integrate information technology into the civil engineering curriculum to prepare civil engineers to implement these emerging technologies to plan, build, and operate civil engineering systems and provided some recommendations. The results suggested that engineers need preparation in systems thinking and systems tools such as systems engineering, communication, modeling, network analysis, and problem-solving strategies in order to address the concerns regarding the fast moving changes in technology as they relate to civil infrastructure. Investigating the level of knowledge engineers need to acquire regarding IT-based components, the authors' results illustrated that students need to study a new range of technologies such as integrated control system, including communication, control actuators, data, and decision components. Furthermore, the authors investigated what engineers need to know for their work, the results revealed the need for study of a new further range of IT topics such as "software and personal tools, and IT-based systems used in communications, organization management and design, operation, and maintenance" (Grigg et al. 2005). These new trends revealed and highlighted concerns related to the preparation of students to operate effectively in the emerging and evolving AEC computing environments and how future architects and engineers can best assimilate the advanced, yet fundamental knowledge of computing technologies appropriate for their professional AEC careers.

In order to address these concerns and to continue to address the needs and issues for advancing the AEC education through curricular changes, the authors initiated a follow up survey in 2014. Further motivating the research is to continue the work on a bi or tri-annual basis in order for the results to become a "longitudinal" study for the AEC and its' educators; one that through its frequency will be able to encourage educators to keep pace. This paper reports on findings of this 2014 survey and furthermore identifies trends based on the previous 2012 survey and the aforementioned precursor surveys. Specifically, the authors investigated the evolution of computing in the AEC curricula and the integration and level of *computer science knowledge versus computer skills* in the AEC curricula. In addition, the authors investigated the similarities and differences between architecture, and engineering programs by analyzing the data within and then across these disciplines. Goals include providing support in answering the following questions: 1) what is the appropriate body of knowledge in computing skills and computer science an AEC professional should master?; 2) where do we need to adjust the AEC curricula from skills-based learning to science-based learning with respect to computing?; and 3) where does the current trend of AEC integration have a compounding effect on these curricular decisions?

Survey Methodology

To assess the evolution of computing in the AEC curricula a survey methodology was implemented for data collection. The survey questions were generated by the authors, who teach courses and research actively in the AEC fields. The authors underwent several iterations regarding the type, amount and arrangement of the questions. The authors endeavored to carry forward the critical questions assessed from the 2012 survey and to enhance the survey structure to increase the quality of the data garnered. The authors structured the survey into multiple sections designed to investigate the topics of computing and their evolution within the AEC curricula. The survey included five sections: 1) program information; 2) evaluation of computing courses; 3) evolution of computing in AEC curricula; 4) computing skills vs. computer science knowledge; and 5) program evaluation and future plans. A cover letter and an invitation to participate in the survey were sent via email. A link to the online survey administered through a web-based service (Qualtrics) was included in the cover letter. The invitation and subsequent reminder emails were sent to the participants approximately three times during a four-month period. Our list of recipients was garnered from the North American and European accreditation boards and within our own computing disciplines and scholarly communities.

Survey Specifics

The survey was designed to acquire responses most importantly for two computing issues in the current AEC curricula: (1) evolution of computing in AEC curricula; and (2) evaluation of computer science versus computer skills in AEC curricula. The survey was open for about six months from June to November of 2014.The researchers specifically solicited curricular decision makers such as deans, department chairs and program directors (37% of the respondents), and faculty members (63% of the respondents) from architecture, architectural engineering, civil engineering, civil engineering technology, architectural engineering technology, construction engineering, construction engineering technology, and construction management programs throughout North America, Europe, and Asia. A total of 187 responses were received. After cleaning the data, a total of 170 responses remained.

Half of the respondents were from North America (mostly from the U.S.) and half were from the other continents: Europe (23% of the respondents), Asia (19% of the respondents), South America (5% of the respondents), and Australia (3% of the respondents). The list of programs in the U.S. 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) and through the European architecture and computing communities. The number of recipients receiving the initial email is approximately 680. The response rate was approximately 28%.

Demographic information regarding the programs included: program type (architecture, engineering, and construction) and degrees offered (graduate vs. undergraduate). About the half of the programs were undergraduate programs, totaling 48% of the respondents. Respondents that only had graduate programs accounted for 52% of the responses. Fifty four percent of the respondents were from architecture programs and 46% of the respondents were from civil engineering and construction programs (mentioned as engineering hereafter as the construction programs were offered in the civil engineering departments).

Survey Results

In order to analyze the survey results, the authors examined the responses to each question, counted the number of responses and computed the percentages for all questions. 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 more important, more competent, more coverage, more sufficient, and or more expert. Using t-tests the authors conducted exploratory analyses to investigate 1) the differences in the curricula across the three different AEC disciplines and 2) computing skills vs. computer science knowledge components of the AEC curricula. The statistical results are expressed in terms of a p-value at $\alpha = 0.05$. In addition to reporting the results of the 2014 survey, the authors compared the results from 2014 survey with 2012 survey in order to evaluate the evolution and pace of change in AEC curricula, in the responding educators' opinions.

Evaluation of Computing Components of the AEC Curricula

Computing Skills

The evaluation of the number of computing skills related courses offered in the AEC curricula (Figure 1) indicated that overall computing related courses make up 15% of all programs. Compared to the 2012 survey, results show a 2% increase in the computing content of the curricula in architecture and engineering programs. One hundred and seventy respondents (91 from architecture and 79 from engineering) answered the question seeking the percentage of computing skills related courses in the AEC curricula. Sixteen percent of the architecture and 14% of the engineering curricula were computing courses. The increase is more obvious in the undergraduate programs. The results of t-test analysis indicated that the difference between the percentages of computing skills related courses in the two AEC program types was marginally significant ($\alpha = 0.05$, $p = 0.06$).

Figure 1 - Percentage of computing skills related courses in AEC programs

Survey results indicate the importance of individual computing skills within the program curriculum, the competence of students in each skill, and the level to which each computing skill is covered in the academic curricula. In the 2014 survey like in the 2012 survey, the authors are foregrounding the purposeful distinction between *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.).

Table 1- Analysis of importance-competence-coverage of computing skills in the AEC curricula *(The weights for importance (1: Not Important, 2: Somewhat Important, 3: Neutral, 4: Important, 5: Very Important). For competence (1: somewhat unskilled, 2: unskilled, 3: novice, 4: expert, 5: very expert). For coverage (1: not covered, 2: introduced, 3: covered, 4: moderately covered, 5: extensively covered))*

Table 1 presents the participants' opinions of the importance, competence, and coverage of computing skills in the AEC curricula. Survey results indicate that the respondents rated most of the skills as important (3.5 to 4) in the AEC programs; except programming and equation solvers which are rated as neutral (2.5 to 3.5) in both architecture and engineering programs, and specialized engineering software and spreadsheets which are rated as neutral just in architecture programs. This could be due to the fact that AEC students are expected to gain these computing skills outside the curriculum. In general, most of the computing skills are rated to be more important in engineering programs than architecture programs, except for computer aided drafting, presentation packages and parametric design, which are considered to be more important in architecture programs. It is noteworthy that most of the computing skills are considered to be more important at the graduate level than undergraduate level except for building information modeling (BIM) which is considered to be more important in the undergraduate programs. This is a result that requires further investigation through future data sets which will provide more historical perception of BIM from 2012 onwards.

The survey results also show that in general the respondents rated their students' competence to be at the novice level for most of the computing skills. Students are considered to be experts in computer-aided drafting in architecture programs, as well as spreadsheets in engineering programs. Students in architecture programs are believed to be more competent in most of the computing skills in comparison to the students in engineering programs, except for competency with spreadsheets, specialized engineering software, equation solvers, and programming. In addition, graduate students are believed to be more competent in most of the computing skills in comparison to undergraduate students.

Seeking to measure the perception of academic coverage for computing skills, the results revealed that respondents believed that AEC curriculum has covered most of the computing skills in engineering. Results also indicated that there are some skills that are just introduced in architecture programs, such as specialized engineering software, programming, and equation solvers (1.5 to 2.5). In general, Computing skills are considered to be more important in the engineering programs, however, the percentages of computing related courses in engineering programs is less than the percentages of computing related courses in the architecture programs and students are less competent in the engineering program suggesting that more computing related courses should be integrated to the engineering curriculum.

In the 2012 survey, the authors created a benchmark for assessing the trend of computing adoption in the AEC curricula. Comparisons of the results of the 2012 and 2014 surveys using two sample t-test show that there is no significant difference in the importance of the computing skills and coverage of curricula for these skills between the results of these two surveys. However the competence of the students in these skills has decreased considerably.

Computer Science Knowledge

Computer science knowledge includes fundamental topics in computational complexity and 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 AEC students (Smith 2012). In that regard the expectation is for AEC educators to understand, teach, develop, and apply more scientific computing methodologies in their regular curricular content. This will result in architects, engineers, and construction professionals who are agile when new technology emerges. It will also lead to the development of future computing tools that are easy to use and modify while being able to scale to particular, complex and large AEC applications. The results of this survey can contribute to developing a plan for AEC programs to design courses that equip students with comprehensive knowledge of application of representations and algorithms as a problem solving approach in the AEC. Investigating the respondents' perceptions of the importance of the computer science knowledge in their respective programs, 170 responses were received (91 responses from architecture and 79 responses from engineering). The survey results indicated that overall 6.3% of all AEC programs offer courses that are related to computer science, which shows 1.3% increase compared with the results of the 2012 survey. Engineering programs at the graduate level lead the number of courses (7.9%) followed by architecture graduate programs (7.7%). At the undergraduate level, the architecture programs lead the number courses (5.7%) followed by the engineering programs (3.7%).

Figure 2 - Percentage of the courses that are related to computer science knowledge

In general, the 2014 survey results show an increasing trends in the percentages of computer science knowledge related courses in the different program types and levels when compared with the 2012 survey, especially in architecture programs. However, the results of the t-test indicated that the percentages of computer science related courses (in different program types in the AEC curricula) do not differ significantly ($\alpha = 0.05$, p=.213). In addition, the results of t-test revealed that the percentage of computing skills related courses compared to computer science related knowledge courses are significantly larger at ($\alpha = 0.05$, p =0.000), as expected.

Table 2 shows the participants' opinions about the importance, competence, and coverage of computer science knowledge in the AEC curricula. Investigating the importance of the computer science knowledge shows that, in general, respondents considered the computer science knowledge as more important in engineering programs than in architecture programs. Computer science knowledge is considered as neutral in most of the computer science categories. The importance of computer science knowledge in the architecture programs varies from somewhat important to important, indicating less consensus. The results also indicated that respondents believe that application of the computer science knowledge is more important at the graduate level in comparison with the undergraduate level.

Competence of the students in computer science is variable in different programs and no specific pattern can be observed. Students are judged to be unskilled in most of the computer science areas, except for computer graphics and geometric modeling, and computational mechanics in which the students are novice in engineering programs. The responses indicate that the students are more competent in graduate programs than undergraduate programs. The coverage of computer science varies across different programs and most of the computer science knowledge concepts are perceived as just introduced in the AEC programs, except for the computer graphics and geometric modeling in architecture, and computer graphics and computational mechanics in engineering, which are perceived to be covered.

This correlates with why students are found to be more competent in these topics. Results also indicate that computer science is covered more thoroughly in graduate programs.

In general, respondents rated computer science knowledge as less important than computing skills and students are believed to be less competent in the computer science knowledge than the computing skills. As expected responses also indicate there is less coverage for computer science knowledge compared to computing skills in the AEC curricula. It is important to note that where there is more coverage of computer science knowledge topics, students are more competent in these topics. These results show that respondents have not understood the importance of the scientific concepts of computing in educating students around AEC applications.

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

With respect to understanding which programming languages predominate in the AEC curricula, the authors queried the participants to identify the programming languages that are taught in their programs. A total of 170 participants (91 from architecture and 79 from engineering programs) answered this question. Table 3 presents the ranking of the top ten programming languages in all of the AEC program types. The results show that in general, Matlab and Java are taught more compared to other languages in the AEC curricula. Similar to the 2012 survey, architecture programs still cover HTML more at the undergraduate level whereas Java and python are covered more at the graduate level. Engineering programs cover Matlab, C++ and Java more than the other languages at both graduate and undergraduate levels. These trends are consistent with the trends that are observed in the computing curricula showing a growing trend toward use of "safer" or "more managed languages" (for example, use of Java instead of C), as well as the use of "more dynamic languages", such as Python or JavaScript (Computer Science Curricula 2013; Computing curricula 2001). Monitoring the coverage and shifts in programming languages the authors believe is an important trend to measure as it indicates emphasis on computer science as a fundamental skill but as well allows for discussion of links to industry application development.

Table 3- Top 10 languages that are taught in AEC programs

Computing Skills vs. Computer Science Knowledge

The authors also inquired about the respondents' perceptions about the importance of the knowledge of "scientific" computing concepts for preparing architects, engineers and construction professionals for future developments of information technology for the AEC. A total of 164 responses were received (88 responses from architecture and 76 responses from engineering programs). The survey results indicate that most of the respondents considered computer science as important or very important in both architecture (68%) and engineering and programs (76%). The results of the t-test showed that the respondents' perceptions of the importance of the knowledge in scientific computing concepts for preparing architects and engineers for future developments in information technology do not differ significantly in architecture and engineering programs ($\alpha = 0.05$, $p = 0.389$). Conducting two sample t-test, the results show that there is no significant difference in the importance of the knowledge in scientific computing concepts in respondents' perceptions during the last two years ($\alpha = 0.05$, $p = 0.749$).

In another attempt to evaluate the relevance of computer science versus computer skills, the authors asked the respondents to rate the importance of the computing skills versus computer science knowledge in preparing students for a future within the AEC. One hundred and seventy responses (91 from architecture and 79 from engineering programs) were received. Overall, 89% of all programs said computing skills are very important or important to the future of the AEC educational programs, which shows a 9% increase compared to the results in the 2012 survey (significantly more than the results of the 2012 survey ($\alpha = 0.05$, $p = 0.049$)). Ninety three percent of the respondents in architecture and 85% of the respondents in engineering programs considered computing skills as very important or important to the future of the AEC curricula, which shows an increasing trend in the respondents' perceptions of the importance of the computing skills (Figure 3). It is noteworthy that the increase in architecture programs (15%) is more considerable compared to the engineering programs (6%): this is likely due to a paradigm shift occurring within architectural education, which is moving away from drawing and 2D practices towards 3D modeling as well as analysis and design automation (parametric and algorithmic design) within the core educational components. Computing skills are also perceived to be more important at the graduate level (80% of the respondents considered it as important) than at the undergraduate level (51% of the respondents considered it as important). The results of the t-test indicated that that the perceptions of the respondents in the architecture programs regarding the importance of computing skills in preparing students for a future within the AEC significantly differ from the perceptions of the respondents in the engineering programs ($\alpha = 0.05$, $p = 0.042$). Further analyzing the survey results using t-test showed that the respondents' perceptions of the importance of computer science knowledge in preparing students for a future within AEC in the two program types are not significantly different ($\alpha = 0.05$, $p = 0.883$). The importance of computer science knowledge increases as the level of program increases. In comparison to the 2012 survey, a decreasing trend has been seen in the perceptions of the respondents regarding the importance of the computer science knowledge for preparing students for a future within the AEC (Figure 3) although the differences between the 2012 and 2014 surveys are not significantly important ($\alpha = 0.05$, $p = 0.247$). In general, the respondents rated computer science knowledge as less important than the computing skills. The t-test revealed that there was significant difference between the importance of computing skills and computer science knowledge in the AEC curricula ($\alpha = 0.05$, $p = 0.000$).

Figure 3 – Importance of computer skills vs. computer science knowledge for preparing students for a future within the AEC

Evolution of Computing Skills Since 2002

The results of this survey can be used to develop benchmarks to evaluate the evolution of computing in the AEC curricula going forward. The first surveys covered civil engineering programs solely. Starting with the 2012 survey, the authors covered more inclusively AEC educational programs in order to begin to track integration issues believed to be important to the future of AEC curricula. Here, to evaluate the evolution of computing in the AEC curricula, the authors compare the results of the 2014 survey with the 2012 (Gerber et al. 2013) and 2002 (Abudayyeh 2004) surveys to assess the computing components of specifically civil engineering education. Since the original surveys only considered computing in civil engineering curricula, the focus in this part is on the 2014 and 2012 responses that cover this field. To be consistent with the recent studies, educators' perspectives are used from the 2002 survey to discuss the importance, competence, and coverage of the computing skills for students. The numbers of respondents vary across these three surveys: 44 responses for 2002 survey, 57 responses for 2012, and 79 responses for 2014 survey were received. The weights range from 1 to 5 where a higher rating indicates more importance, competence, and coverage. A comparison of the importance ratings from the 2014 survey and 2002 survey indicates an overall slight increase in the importance of computing skills during the past 12 years although the difference is not significant except for the subject of collaborative environments. The increased emphasis on the importance of design methods and interdisciplinary approaches might be one of the reasons explaining the significant increase in the importance of collaborative environments. It is also noteworthy that the importance of spreadsheet and word processing has decreased slightly. Table 4 illustrates a comparison of the ratings of the importance, competence and coverage for each computing skill of the 2014 and 2012 surveys with their corresponding ratings from the educators' perspectives in the 2002 survey.

Table 4- Comparison of Importance, competence, and coverage of computing skills in the civil engineering curricula (2002-2012-2014) (The knowledge importance within the program curriculum (1: Not Important, 2: Somewhat Important, 3: Neutral, 4: Important, 5: Very Important). The competence of student knowledge (1: somewhat unskilled, 2: unskilled, 3: novice, 4: expert, 5: very expert)). The knowledge coverage within program curriculum (1: not covered, 2: introduced, 3: covered, 4: moderately covered, 5: extensively covered))

Building information modeling (BIM) was not measured in terms of importance, competence and coverage in the previous 2002 and 2012 surveys but it is ranked as the most important topic in the 2014 survey, and is an obviously prominent computing skill to continue to track as it is understood as necessary and now fundamental to the AEC. The comparisons indicate that the importance of most of the computing skills has increased when comparing 2002, 2012 and 2014 surveys except for spreadsheet and word processing (note that the differences in the importance of the computing skills, competence of the students in these skills and coverage of curricula for these skills are not significantly different in 2012 and 2014 surveys). The results also similarly show increase in percieved competence of the students in the computing skills and coverage of the curricula for these skills. Increase in the application of some existing software such as LaTeX might explain why the importance of some traditional skills such as spreadsheet and word processing has decreased and students have become less expert in these skills. In addition the decrease in the level of coverage for these skills might be another reason explaining why students have become less expert in these skills. The coverage results from the 2002, 2012, and 2014 surveys revealed that the rankings of some computing skills in terms of coverage have changed considerably; for example programming ranking has changed from 3 to 8; parametric design has changed from 6 to 10; and electronic communication ranking has changed from 10 to 7. In general, comparison of the results of the 2002, 2012, and 2014 showed an increasing trend in importance, competence, and coverage during 2002 and 2012 but a decreasing trend has been seen since 2012.

Evaluation of Students' Computing Abilities

For the evaluation of current and desired computing abilities of students, 170 responses (91 from architecture and 79 from engineering programs) were received. The survey results illustrate that 66% of architecture and 43% of engineering programs considered students to be currently above average or expert while 9% of architecture and 10% of engineering qualified students' abilities as poor or below average. The rest of the respondents rated the students' abilities as neutral. Comparing to the 2012 survey, we can see that in general respondents believed that computing abilities of the students have increased significantly during the past two years ($\alpha = 0.05$, $p = 0.021$) (Figure 4). The results of the t-test showed, there are marginally significant differences between the current computing skills abilities of the students in the different AEC program types ($\alpha = 0.05$, $p = 0.087$).

In terms of computer science knowledge of students, the results again show consistency. Fifty nine percent of the respondents in all programs rated the students' current abilities to be poor or below average and only 15% of the architecture and 14% of the engineering programs believed the students to be expert or above average. These results contradict the results in the 2012 survey, in which 5% of architecture and 23% of engineering and programs considered the students to be above average or expert. Similar to the computing skills, the result of t-test reveal that there is no significant difference in the current computer science knowledge abilities of the students in the AEC programs ($\alpha = 0.05$, $p = 0.730$).

In general, the respondents rated the current computing skill abilities of students higher than their current computer science knowledge abilities (Figure 4). Students' abilities in computer science knowledge are greater (22% of the respondents rated them as expert or above average) in graduate programs than undergraduate programs (only 5% of the respondents rated them as expert or above average). The results of t-test confirm this observation and show that the respondents' perceptions of current computing skills abilities of students differ significantly with their perceptions of current computer science knowledge and abilities of students ($\alpha = 0.05$, $p = 0.000$).

In general, respondents believe that students in the architecture programs are more expert in the computing skills than the students in the engineering programs. They also believe that students' expertise in computer science knowledge has decreased in the engineering programs and increased in the architecture programs during the last two years. Considering that computing skills and computer science knowledge are perceived to be more important in engineering programs than architecture programs, the results suggest that there is a greater need in engineering programs for increasing the computing content of the curriculum than architecture programs.

Figure 4- Current and desired level of expertise of students in computing skills and computer science

The survey results indicate that respondents believed that the students in architecture programs should be more expert in computing skills than the students in engineering programs (desired abilities). Seventy percent of the respondents in architecture and 51% of the respondents in engineering programs believed that the students should be expert or above average. The results of t-test indicate that respondents' perceptions of the desired level of expertise of students in computing skills differ significantly between architecture and engineering programs (Figure 4) ($\alpha = 0.05$, $p = 0.026$).

With regard to computer science knowledge, 26% of the architecture and 22% of the engineering programs rated the students' abilities as needing to be expert or above average. The t-test results show no significant difference between different program types in terms of their perceptions about the level of expertise students need to have in computer science knowledge. In general, respondents believed that students should be more expert in computing skills than computer science knowledge. Here again, graduate students are rated to be more expert in both computing skills and computer science knowledge than the undergraduate students. The results of t-test indicate that there is significant difference in the respondents' perceptions of the level of expertise that students need to have in computing skills and computer science knowledge ($\alpha = 0.05$, $p = 0.000$).

Program Evaluation and Future Plans

The authors sought the topics of importance for the future of AEC curricula and asked the respondents to prioritize these topics for their program categories. A total of 164 respondents answered this question (88 respondents from architecture programs and 76 respondents from engineering programs).

***Table 5 - Top 10 important topics for future AEC* education**

The results (Table 5) indicate that both programs considered BIM, visualization, computer aided drafting (CAD), and simulation as very important topics for the future of AEC education. The same results were seen in the 2012 survey for the first two topics of BIM and visualization. In looking for causality of these trends the authros have started to look into pure computer science curricula trends and changes. A few of relvance to the AEC include observations such as an increasing emphasis on the use of CAD and visualization tools (Computer Science Curricula 2013; Computing curricula 2001), which might have influenced the AEC curricula. The authors also asked the respondents to prioritize the topics that they believe should be increased in the computer science content of teaching in the AEC curricula. Machine learning and data analytics (Big Data) is rated to be the most important topic. The increase in emphasis of the machine learning in the computing curricula in the past decade (Computer Science Curricula 2013; Computing curricula 2001) is likely another influence upon the priority topics observed by our respondents from the AEC. These results shown in Table 6 indicate that respondents still do not recognize the implicit links that many topics in computer science currently have to AEC applications. For example, databases and computer graphics are in the lower half of the priorities. This indicates that more effort is needed to communicate such links to curricula decision makers.

Table 6 – Ranked priorities by Program of Computer science knowledge topics

In both the 2012 and 2014 surveys, the authors assessed the participants' perceptions of how BIM has been integrated into the AEC educational programs by asking about where BIM is taught versus where BIM is planned to be taught. The 2014 survey results indicate that, architecture programs teach BIM mostly for modeling (91%) followed by energy analysis (63%) whereas engineering programs also mostly teach BIM for modeling (71%) followed by BIM based collaboration (54%). The comparison of the results from 2014 with the 2012 survey shows that in general, the trend of BIM integration into the AEC curricula does not meet what was perceived as planned for in the 2012 survey and the applications of some of the examined computing skills have decreased significantly over the past two years including modeling ($\alpha = 0.05$, $p = 0.000$), energy analysis ($\alpha = 0.05$, $p = 0.043$) and customization ($\alpha = 0.05$, $p = 0.006$).

Figure 5 - The planned and current areas where BIM is/will be taught (2014 compared to 2012)

Using 2012 as an initial benchmark, the authors tracked the evolution of computing in AEC curricula and provide a benchmark for further evaluation of the status of computing education in order to support decision making for the future AEC curricula. The authors asked the respondents to rate the sufficiency of computing education to meet the demands of the AEC industry. A total of 164 respondents answered this question (88 responses from architecture and 76 responses from engineering programs). The t-test results indicate that the sufficiency of the computing education to meet the demands of the AEC industry does not differ significantly for the different program types ($\alpha = 0.05$, $p =0.655$). Thirty-five percent of the architecture and 33% of the engineering programs considered computing education as sufficient or somewhat sufficient whereas, 48% of the architecture and 47% of the engineering programs believed that computing education is not sufficient or somewhat insufficient to meet the demands of AEC industry (Figure 6). Participants believed that computing education is more sufficient in graduate level programs (37%) than undergraduate level programs (34%).

Figure 6- How sufficient is computing education to meet the demands of AEC industry

In order to characterize the context of decisions related to future plans for the AEC curricula, the respondents were asked to list the barriers to incorporate computing into the AEC curricula and provide solutions to address the gaps in the computing education. No room in the curricula, inadequate resources to make the curriculum change, lack of adequate funding, and inadequate criterion were recognized as the main barriers. In addition, increasing the computing skills and computer science knowledge of the curricula, and redesigning traditional AEC courses based on new skills and demands were suggested as solutions to address the gaps in the computing education. The respondents were also asked about their opinions about what can be done to better prepare the students for their future jobs. The main recommendations included: 1) improving computing skills and computer science knowledge of students to meet the demands of the industry; 2) improving communication between the academicians and professionals; 3) adjusting computing content of the AEC curriculum with the needs of the industry; 4) adding courses to curriculum based on industry expert recommendations; and 5) asking professionals to teach computing related courses in academia. These barriers, solutions and recommendations confirm the earlier assertion that the lack of awareness of the importance of computer-science principles prevents AEC educational decision makers from assigning a high enough priority to increase computing teaching emphasis.

Discussion and Conclusions

This paper assesses the evolution of computing in the AEC curricula through seeking educators' views related to the computing components of the AEC curricula, through establishing trends important to measure, and through comparing these trends with the results from the 2012 survey and earlier data sets. In addition, this research provides insight and reveals issues and barriers that are most relevant to and for prioritizing for the AEC curricula decision-making. The research furthermore highlights a gap in the understanding, consensus and integration of *computer science knowledge versus purely computer skills* within the AEC curricula.

Assessment of computing components in the AEC curricula shows increasing trends in the percentages of both computing skills and computer science knowledge related courses in all program types and levels over the past two years. Although the results of the 2012 survey revealed the need for increasing the computing content of the AEC curricula, the results of the 2014 survey indicate the perceived importance of most of the computing skills and coverage of the curricula for these skills have not changed significantly, while competence of the students in these skills, have decreased since 2012.

Another important assessment is that educators are still neutral about the importance of computer science knowledge within their curricula. The results suggest AEC educators believe that students are unskilled in most of the computer science knowledge categories and indicate most of these categories are merely introduced in the AEC curricula. According to Grigg et al. in 2004 the curriculum coverage for important foundational topics such as CAD, graphics, and computational skills was not enough (Grigg et al. 2004). The evidence is consistent in the lineage of survey and precedents that there is a greater need for computing within the AEC as expected but also with a consistent emphasis for computing skills. Furthermore there is consistent lament amongst some AEC educators that there is too much required content for an undergraduate or graduate degree and therefore, it is not to possible to include all topics in a 4-6 year curriculum, whether computer skills or computer science or a balanced combination of both. Furthermore, computing tools are proliferating making it difficult for AEC educators to teach all of them. The data from both 2012 and 2014 highlight this as a key barrier to evolve the AEC curricula in general.

As it has been and remains a primary objective of our research to continue to measure and highlight the distinction and comparison of *computing skills* with that of knowledge of relevant aspects of *computer science* as perceived by AEC educators the data is here too, consistent and suggestive of a neutrality. Assessment of computing skills versus computer science knowledge shows that computing skills are judged to be more important than computer science knowledge in the AEC curricula. While this is expected and reasonable considering the industry is a heavy user of computer applications, it is also clear this will continue to lead to a lagging in innovation when it comes to the development of purpose built methods and technologies specific to the AEC needs and challenges. The survey results clearly support this conclusion and show an increasing trend in the respondents' perceptions of the importance of computing skills for preparing students for a future within the AEC. The results indicate that most of the educators concentrate on the professional criteria that must be met within the programs which we suggest is a reoccurring challenge for the educators who making curricula decisions to evolve their course content adequately to meet the needs of AEC beyond the near term horizon.

Evaluation of current computing abilities of students indicates that students have become less competent in both computing skills and computer science knowledge over the past two years. This result is perhaps most alarming at first glance, although this may be due to the rapid increase in tools and computing capabilities that the industry has access to whereas academic programs have yet to keep pace. Results seem to validate this and show that respondents believe that the computing content in our AEC education is not sufficient to meet the demands of industry and the level of expertise of students should increase in both computing skills and computer science knowledge.

This survey has also been structured to measure the opinions related to fundamental aspects of computing education for the AEC, including the priority of topics, tools and programming languages that are needed for the foundational training of AEC students. These results indicate that respondents still do not recognize the implicit links that many topics in computer science currently have to the AEC applications. Furthermore, the inclusion of measuring the status of new software and skill sets such as those relevant to BIM are assessed in order to compare the current situation in the AEC curricula with previous years and therefore anticipate more appropriately the needs for upcoming years through follow up surveys.

As with the previous survey our last set of questions in the survey was structured to determine the barriers to evolving, the shortcomings, the needs and requirements for the AEC curricula. As expected and consistent with previous work, predominant barriers to further incorporate computing into the AEC curricula are identified as the lack of room in the curricula; inadequate resources to make the curriculum change; inadequate funding; and inadequate criterion for making informed curricular decisions.

Limitations and Future Work

The authors have run the 2014 survey on a two-year reoccurring cycle to establish what the authors anticipate will become a longitudinal study. This paper is the first set of results that the authors present as being benchmarked to that of previous surveys, specifically the 2012 results which also intrinsically reflect the previous work from 2002 and 1998, etc. Although the two-year period might not be the best frequency to evaluate the evolution in the AEC curricula, it is an important benchmark for future work and reflects the speed of change occurring in industry and computer science generally. Important to the work is a criticism that all the previous surveys (except the 2012 survey) focused solely on the civil engineering curriculum and in light of overlaps, new construction delivery models, moves towards tighter integration and coupling of design through to operation models, data and objectives within the entire AEC value chain, our work begins to adjust the focus away from the “silo-ing” that has been historically dominant. Having the results of the 2014 survey in conjunction with the 2012 benchmark, the authors will continue to be able to more critically assess the frequency, structure, and adjustment to the questionnaire more intelligently for future investigations. The results of the survey were reported based on 170 respondents. Although this represents a good sample size and a steady increase in participation, there remain a few challenges including: 1) the disparity between the number of the participants in the architecture and engineering programs (54% architecture and 46% engineering); and 2) difficulty in obtaining identical respondents as educators move and change positions. In the future, the authors will analyze targeting, response rates and consistency of responders more closely. These issues will be addressed by increasing the sample size and by motivating more people to participate in the survey ideally through actively illustrating the value of such data for curricula decision making. In the future, the authors plan to investigate more extensively the causalities and to measure the factors leading the to the changes in perceived value of computing topics and content for the AEC industry.

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Table 1- Analysis of importance-competence-coverage of computing skills in the AEC curricula (The weights for importance (1: Not Important, 2: Somewhat Important, 3: Neutral, 4: Important, 5: Very Important). For competence (1: somewhat unskilled, 2: unskilled, 3: novice, 4: expert, 5: very expert). For coverage (1: not covered, 2: introduced, 3: covered, 4: moderately covered, 5: extensively covered))

Computing Skills	Importance	Rank	Competence	Rank	Coverage	Rank
Building Information Modeling (digital representation of physical and functional characteristics of a space)	4.15	1	3.06	6	3.14	2
Computer Aided Drafting (computer-aided creation, modification, analysis, or optimization of a design)	4.14	2	3.5	3	3.33	1
Presentation Packages (packages used to display information in the form of a slide show)	4.07	3	3.78	2	2.99	4
Word Processing (computer software application used for composition, editing, and formatting of any sort of written material)	4.01	4	3.79	1	2.64	8
Parametric Design (generative, computational, digital, computer aided design)	3.81	5	2.96	8	3.02	3
Electronic Communications (computer mediated communications)	3.73	6	3.45	4	2.68	6
Collaborative Environments (Computer-supported cooperative work environment)	3.72	7	3	7	2.62	9
Spreadsheets (interactive computer application program for organization and analysis of data in tabular form)	3.68	8	3.27	5	2.64	7
Specialized Engineering Software (software that is written for a specific task rather for a broad application)	3.38	9	2.79	9	2.75	5
Programming (computer mediated formulation of a computing problem to executable programs)	3.18	10	2.52	11	2.59	10
Equation Solvers (computer-aided programs used for solution of systems of simultaneous non-linear equations)	3.04	11	2.54	10	2.4	11

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

Computer Science Knowledge	Importance	Rank	Competence	Rank	Coverage	Rank
Computer Graphics (computer aided representation of image data)	2.84	4	2.99	1	2.91	1
Geometric Modeling (computational geometry and applied mathematics used for mathematical description of shapes)	2.9	3	2.56	2	2.47	2
Computational Mechanics (computational methods and devices to study events governed by the principles of mechanics)	3.6	1	2.26	3	2.22	3
Algorithms and computational complexity (mathematical characterization of the difficulty of a problem which describes the resources required by a computing machine to solve the problem)	2.81	5	2.15	4	2.12	4
Data Base Concepts (computer-based databases)	2.72	7	2.14	5	2	5
Object Representation and Reasoning (computer based representations that capture information used to solve complex problems)	2.71	8	2.04	6	1.92	6
Data Structures (computer data storage and organization)	3.14	2	2.04	7	1.9	7
Optimization and Search (meta heuristic method for solving computationally hard optimization problems)	2.74	6	1.99	8	1.86	8
Knowledge Systems for Decision Support (computer-based information system used to support business or organizational decision-making activities.)	2.58	10	1.93	9	1.78	9
Distributed Applications and Web (execution of software on two or more computers in a network)	2.46	11	1.92	10	1.76	10
Constraint Based Reasoning (automated reasoning in artificial intelligence)	2.59	9	1.73	11	1.63	11
Machine learning and data analytics (Big Data) (computational data training and pattern recognition, analyzing and modeling data)	2.31	12	1.7	12	1.56	12

Table 3- Top 10 languages that are taught in AEC programs

#	Architecture		Engineering		AEC	
	2012	2014	2012	2014	2012	2014
1	Python	Python	Matlab	Matlab	C++	Matlab
2	HTML	Java	C++	C++	Java	Java
3	VB (.NET)	HTML	Java	Java	Matlab	C++
4	C++	Others	C	VB (.NET)	Python	Python
5	Java	C++	VB (.NET)	Fortran	VB (.NET)	HTML
6	C#	Matlab	Fortran	C	C	VB (.NET)
7	C	VB (.NET)	Python	Python	HTML	Others
8	Lips, Scheme	C#	OpenGL	`SPSS	Fortran	C
9	Fortran	PHP	SAS	HTML	C#	C#
10	Matlab	OpenGL	SPSS	C#	HTML	SPSS

Table 4- Comparison of Importance, competence, and coverage of computing skills in the civil engineering curricula (2002-2012-2014) (The knowledge importance within the program curriculum (1: Not Important, 2: Somewhat Important, 3: Neutral, 4: Important, 5: Very Important). The competence of student knowledge (1: somewhat unskilled, 2: unskilled, 3: novice, 4: expert, 5: very expert)). The knowledge coverage within program curriculum (1: not covered, 2: introduced, 3: covered, 4: moderately covered, 5: extensively covered))

Skills	**2002 Survey Ratings**			**2012 Survey Ratings**			**2014 Survey Ratings**		
	Importance	**Competence**	**Coverage**	**Importance**	**Competence**	**Coverage**	**Importance**	**Competence**	**Coverage**
Spreadsheet use	4.4	3.83	3.69	4.29	4.27	3.18	4.1	3.59	2.95
Word Processing	4.19	4.1	2.91	4.18	4.27	2.81	4.1	3.77	2.71
Computed Aided Drafting	3.91	3.15	3.32	3.94	3.77	3.55	3.99	3.38	3.38
Electronic Communications	3.65	3.47	2.49	3.88	3.75	2.64	3.81	3.47	2.73
Presentation Packages	3.72	3.71	2.83	4.06	4.05	2.84	4	3.7	2.84
Specialized Engineering Software	3.5	2.5	2.7	3.91	3.88	3.44	3.77	3.04	3.06
Equation Solvers	3.31	2.82	2.92	3.69	3.78	3.09	3.43	2.82	2.81
Programming	3.02	2.15	2.56	3.77	3.53	3.35	3.37	2.57	2.72
Collaborative Environments	2.95	2.14	1.91	3.88	3.48	2.79	3.85	2.89	2.56
Parametric Design				3.56	3.38	2.97	3.58	2.61	2.62
Building Information Modeling							4.28	2.81	3.13

Table 5 - Top 10 important topics for future AEC **education**

AEC	%	Architecture	%	Engineering	%
Building Information Modeling	88%	**Building Information Modeling**	85%	**Building Information Modeling**	92%
Visualization	73%	**Parametric Design**	85%	**Visualization**	68%
Computer Aided Design	69%	**Computer Aided Design**	80%	**Simulation (including mechanics)**	57%
Parametric Design	67%	**Visualization**	76%	**Computer Aided Design**	57%
Simulation (including mechanics)	66%	**Simulation (including mechanics)**	75%	**Optimization**	51%
Analysis	57%	**Analysis**	67%	**Analysis**	46%
Optimization	55%	**Optimization**	59%	**Parametric Design**	46%
Human-computer interaction	46%	**Robotics**	53%	**Data Interpretation**	43%
Algorithms	42%	**Automation: scripting repetitive tasks**	52%	**Human-computer interaction**	42%
Sensor Networks	41%	**Computer Aided Drawing**	52%	**Risk Management and Mitigation**	41%

Table 6 – Ranked priorities by Program of Computer science knowledge topics

#	AEC	Architecture	Engineering
1	Machine learning and data analytics (Big Data)	Machine learning and data analytics (Big Data)	Object Representation and Reasoning
2	Distributed Applications and Web	Distributed Applications and Web	Distributed Applications and Web
3	Optimization and Search	Optimization and Search	Optimization and Search
4	Object Representation and Reasoning	Knowledge Systems for Decision Support	Machine learning and data analytics (Big Data)
5	Knowledge Systems for Decision Support	Object Representation and Reasoning	Constraint Based Reasoning
6	Data Structures	Data Structures	Knowledge Systems for Decision
7	Constraint Based Reasoning	Data Base Concepts	Geometric Modeling
8	Computational Mechanics	Computational Mechanics	Data Structures
9	Data Base Concepts	Constraint Based Reasoning	Computational Mechanics
10	Geometric Modeling	Geometric Modeling	Computer Graphics
11	Computer Graphics	Algorithms and computational complexity	Data Base Concepts
12	Algorithms and computational complexity	Computer Graphics	Algorithms and computational complexity

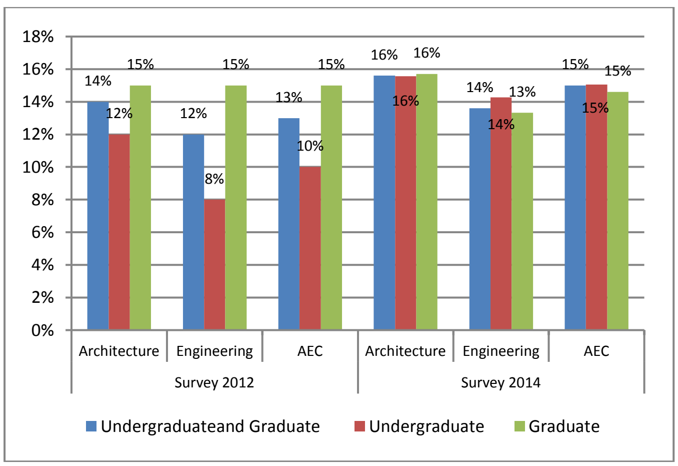

Figure 1 - Percentage of computing skills related courses in AEC programs

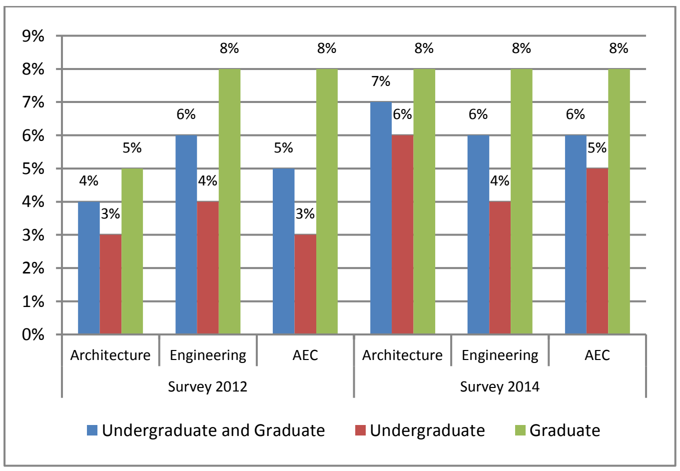

Figure 2 - Percentage of the courses that are related to computer science knowledge

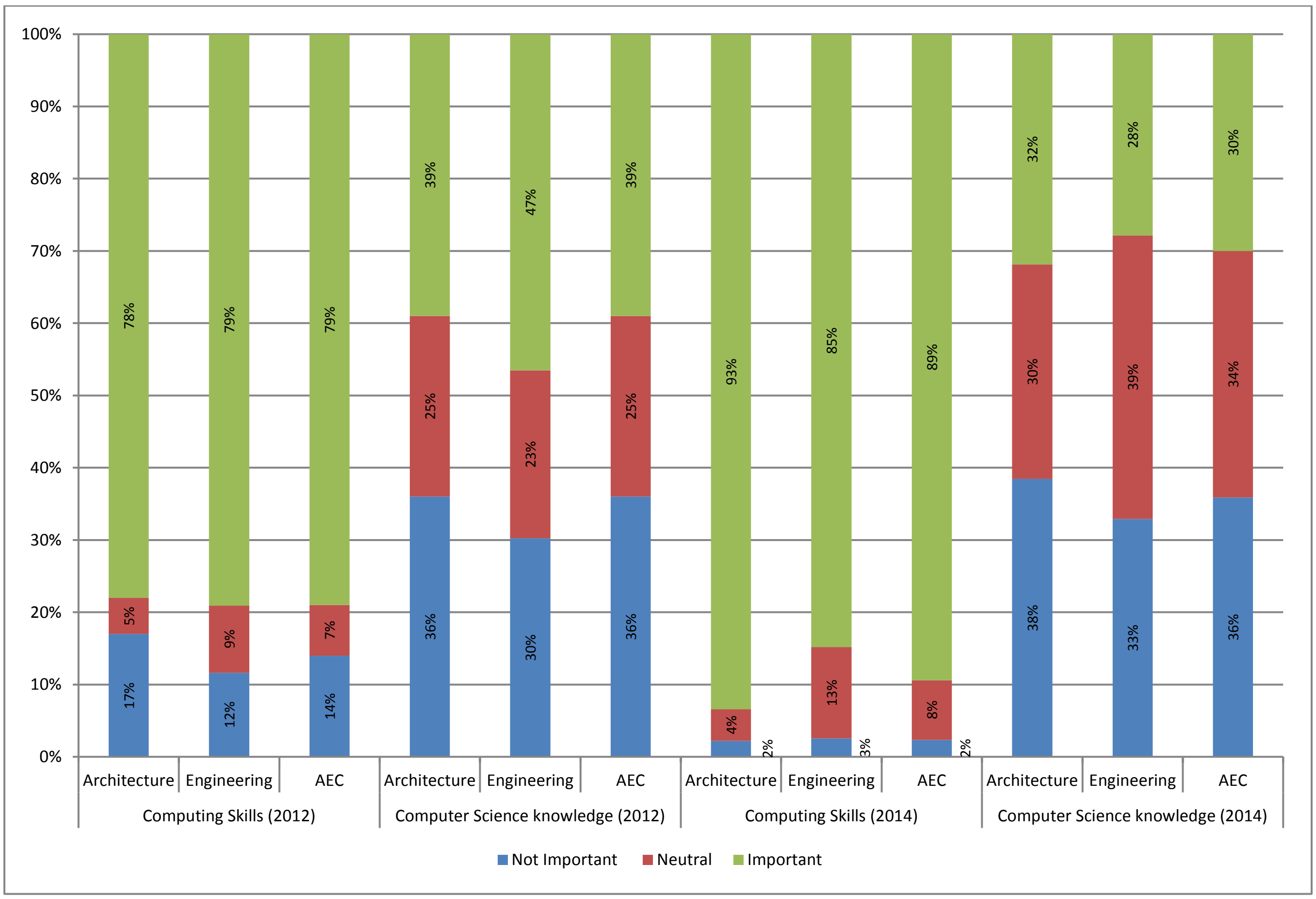

Figure 3 – Importance of computer skills vs. computer science knowledge for preparing students for a future within the AEC

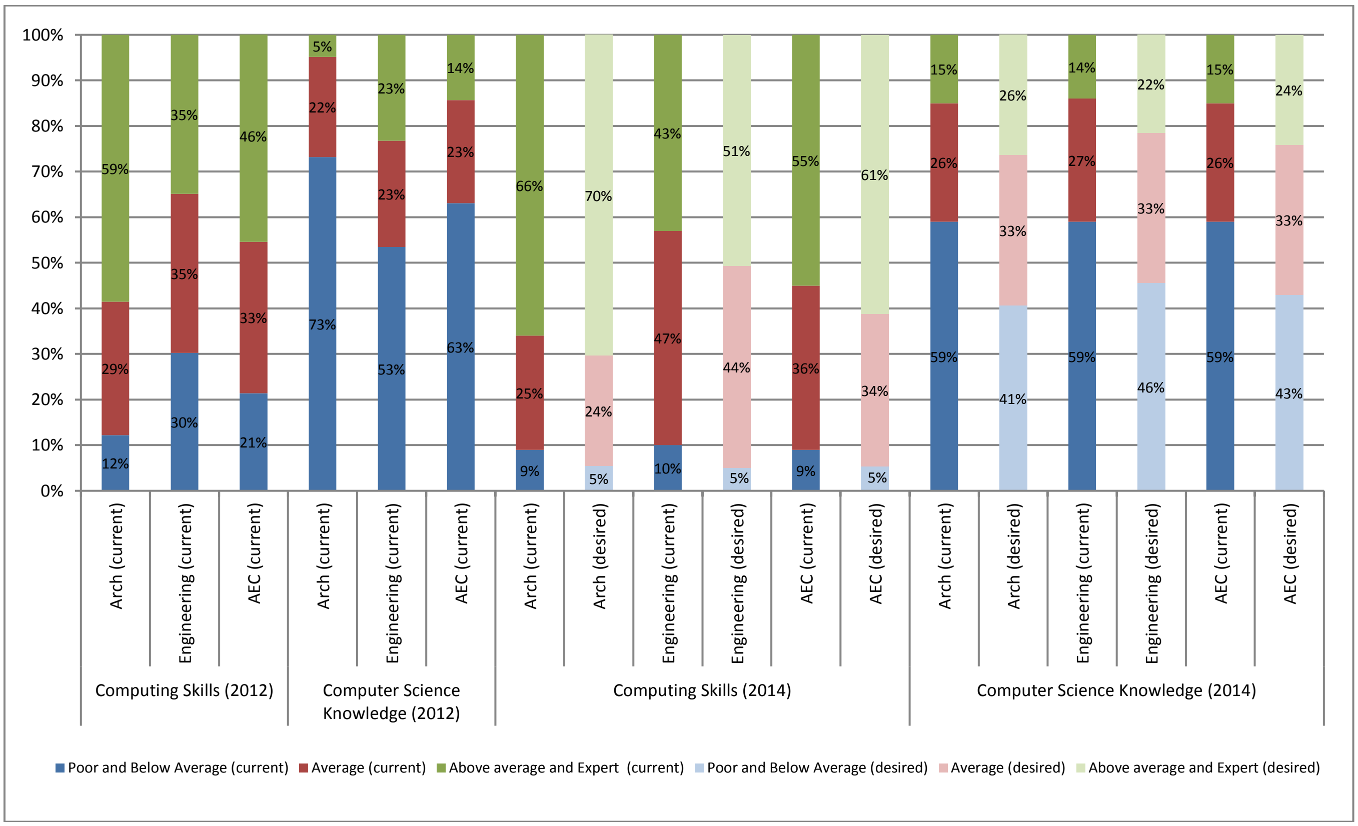

Figure 4- Current and desired level of expertise of students in computing skills and computer science

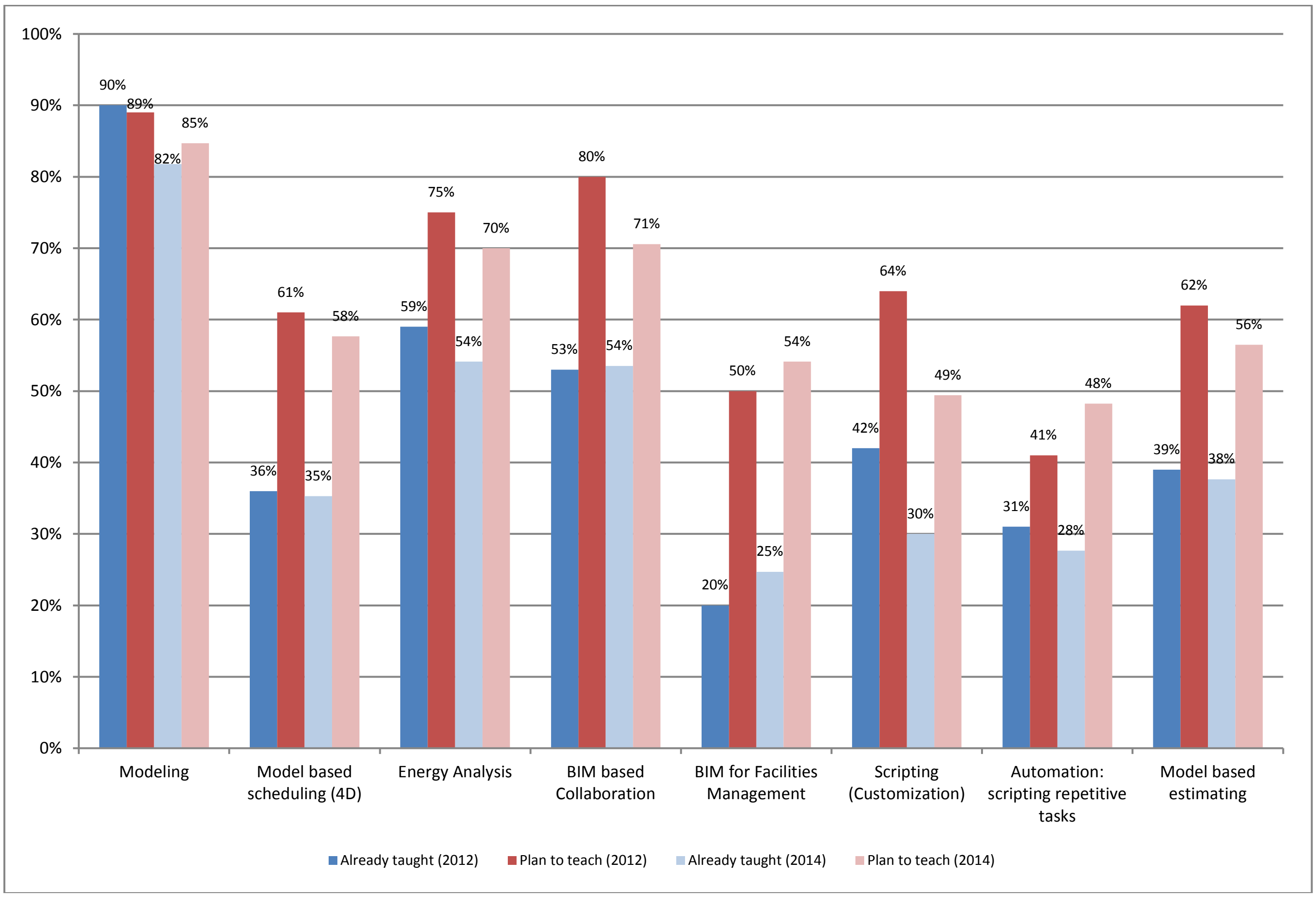

Figure 5- The planned and current areas where BIM is/will be taught (2014 compared to 2012)

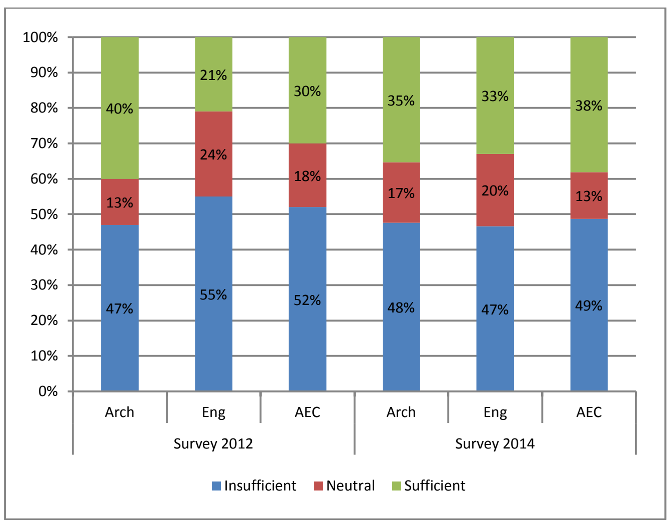

Figure 6- How sufficient are the computing education to meet the demands of AEC industry