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

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## 22 **Abstract**

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

## 39 **Introduction**

40 Recent advances in computing play a growing and important role in nearly every architecture, engineering and  
41 construction (AEC) discipline. In this regard, future architects and engineers will be expected to contribute to and  
42 guide technological transformations for the industry. Integrating computing into the AEC curricula contributes to  
43 mastering this change by preparing AEC professionals to meet the emerging industry demands, however, the AEC  
44 industry continues to lag and adapt slowly to new opportunities (Stewart and Daet 2002; Bouchlaghem, and El-  
45 Hamalawi 2006; Svavarsson et al. 2002). One of the reasons for this noted lag is the time spent on computing, and the  
46 content of computing courses within the spectrum of AEC curricula (Danijel and Tibaut 2005). Many architecture and  
47 engineering educators believe that computing is only a skill to be acquired on the job, and critically not a science to  
48 be learnt in an academic setting. However, most AEC professionals also agree that there is a growing lack of

49 correlation between what is taught and how architects and engineers use computers in practice (Smith 2003). Although  
50 computing in the AEC has become an established research area, the results are often not integrated into the curricula  
51 (Danijel and Tibaut 2005). Given the complex nexus of forces acting upon the AEC, such as economic changes, global  
52 market influences, and information technology that drive changes in industry, the AEC curricula are subject to frequent  
53 updates and where this is not the case should be. For our focus, most notably information technology and computing  
54 are going to be one of the most powerful catalysts for change (Veeramani and Russell 2000). Therefore, considering  
55 the increasing demand within the AEC for computing, an interdisciplinary computing focused approach to AEC  
56 curricula revision is relevant and prescient (Irizarry et al. 2010).

57 It is essential for curricular decision makers to measure and understand what future AEC professionals need to know  
58 about computing and what competencies are needed to ensure that AEC educators can prepare these students. To  
59 answer these questions, the authors seek the educators' perceptions regarding computing content and trends within  
60 the AEC curricula and its particular evolution. The authors solicited the opinions of the educators on the perception  
61 of computer science knowledge versus computer skills within AEC educational curricula. In the context of this study,  
62 a critical distinction and definition is used throughout, where '*computing skills*' is defined as the ability to use  
63 computer-based technologies for AEC tasks, while '*computer science knowledge*' is defined as the ability to  
64 appropriately apply the knowledge of, for example, data representations and algorithms to AEC related tasks.  
65 Furthermore, there is a growing trend for tool building, automation, and infusion of computer science into AEC  
66 practices making this distinction an important contribution and leading indicator (Ceccato 1999; Ceccato and AADipl  
67 2005; Burry 2013; Burry et al. 2001).

68 The study reported on in this paper was conducted as a follow up to the previous studies conducted in 1986, 1989,  
69 1995, 2002 and 2012 in order to provide insights into current educational environments and to provide greater  
70 understanding of the evolution of curricular demands. This paper reviews the previous work and continues with a  
71 description of the research approach and methodology previously adopted by the authors in 2012. Then, it discusses  
72 the data gathered through an online survey conducted in 2014, from which research directions and trends are discussed.  
73 These include: 1) defining the perceived importance of computing skills required for AEC students, competence of  
74 the students in these skills, and the coverage of curricula for these skills; 2) defining the perceived importance of  
75 computer science knowledge versus computer-skill educational approaches; 3) defining the perceived barriers and

76 issues for better incorporating computing in the AEC curricula; and 4) defining the perceived future plans for the AEC  
77 education. Finally, a discussion of limitations and the needs for future research into AEC education is provided.

## 78 **Background and Objectives**

79 The early use of computer and information sciences in the AEC higher education setting is closely related to the  
80 introduction of programming languages (Tibaut et al. 2012a), which resulted in the emergence of an interdisciplinary  
81 field that attempted to link computer science and AEC (Turk 2006). It manifested itself in the curricula and emerged  
82 as a field which we call “computing in AEC curricula” in this paper. Advances in computer technology often raise  
83 concerns regarding the preparation of AEC students to function effectively in new computing environments. To  
84 address these concerns, the American Society of Civil Engineers’ (ASCE) Task Committee on Computing Education  
85 of the Technical Council on Computing and Information Technology (TCCIT) conducted a series of surveys in 1986,  
86 1989, 1995, and 2002 to assess the current computing component of the curriculum in civil engineering. A review of  
87 the focus areas of these studies and their findings can be found in the 2012 survey (Gerber et al. 2013). Considering  
88 the industry and technological trends enabling or forcing closer ties between the disciplines, the need for the  
89 integration of architecture into the discussion and more generally for identifying multidisciplinary approaches in the  
90 AEC industry was implemented in follow up survey conducted in 2012. This was performed upon the request of the  
91 ASCE TCCIT to assess the evolution of computing in AEC curricula.

92 The 2012 study recognized the importance of developing a better understanding of the interdependencies, overlaps,  
93 similarities and differences between AEC disciplines. In addition, the 2012 study investigated the levels and  
94 concentrations of computer science knowledge versus computer skills in the curricula across the disciplines. Again,  
95 the authors are highlighting a critical distinction, *computer science knowledge versus computer skills*, as it leads to  
96 abilities to not only serve the industry needs in the present but also to affect the AEC industry’s ability to adapt and  
97 innovate over the long term. The 2012 survey also gathered information related to the prerequisites that are necessary  
98 for the fundamental training of students. Key findings of the 2012 study included: 1) the importance and coverage of  
99 computer skills and competence of students has increased over the past decade; 2) computing skills are judged to be  
100 more important than computer science knowledge in the AEC curricula; 3) several links between computer science  
101 concepts and the architecture and engineering applications of computing are not yet recognized; 4) computing  
102 education is not sufficient to meet the demands of the AEC industry, and that the share of computing courses is less

103 than what educators desire; and 5) scientific concepts of computing are perceived as important for preparing architects  
104 and engineers for unknown future developments in information technology (Gerber et al. 2013). The results of the  
105 2012 survey are considered as useful benchmarks for our comparison, trend analysis, and policy purposes in this paper  
106 and for the planned future work.

107 In addition to the surveys conducted by the ASCE, there are other studies conducted that have evaluated the computing  
108 components of the AEC curricula. These studies have emphasized the importance of integrating computer science and  
109 information technology in engineering education and have assessed the academic computing requirements for  
110 engineering programs in general. A number of important precedent studies discussed how computer integration can  
111 affect the AEC industry and curricula (Heitmann et al. 2003; Smith 2003; Ketz and Hug 1998; Howard et al. 1989).  
112 For example, Ketz and Hug (1998) investigated the existing approaches for integration of computer science as a  
113 foundation in the engineering curricula. They found that “there is a knowledge transfer gap between computer science  
114 and engineering disciplines” and suggested that there should be consistent and adequate level of computer science in  
115 engineering education. Howard et al. (1989) suggested that computer technologies can be used as intelligent tools to  
116 enhance automation, communication, bookkeeping, problem solving, and decision making in the AEC process.  
117 Integration of these technologies into the AEC process will create a new knowledge, which needs to be transmitted  
118 into educational programs to prepare engineers and architects for their future roles. Some studies have investigated  
119 the need for the issues and shortcomings in the organization and direction of computer usage and the teaching of  
120 computing technologies to civil engineering students (Henry 1992; Baker and Rix 1991; Grigg et al. 2004). For  
121 example, Grigg et al. (2004) investigated the challenges of integrating computing into the civil engineering curriculum  
122 and in conclusion suggested that given that the level of technology and practice of engineering increase in complexity  
123 continuously this constant increase is making it difficult for educators to cover the required topics in depth. Therefore,  
124 it is hard to find “the right mix of topics and courses for a changing curriculum.” Some other studies have examined  
125 the share and content of subjects related to computing and information technology in AEC curricula (Smith 2012;  
126 Baker and Rix 1992). For example Smith (2012) described a course on the fundamentals of computing taught to  
127 second-year civil-engineering undergraduates in Switzerland for ten years. The outcomes suggested that through  
128 adopting a strategy of teaching fundamental computer science concepts, relevant in engineering contexts, it is possible  
129 to revise the engineering curricula to reflect aspects such as “increasing needs for wide-band competence and agility  
130 requirements required for when new technology emerges.” Danijel and Tibaut (2005) introduced programs, such as

131 the Erasmus master program, which is an IT focused postgraduate course with the objective of organizing the  
132 knowledge in the field of IT (including basic computer science and informatics courses in AEC) for developing an  
133 effective learning environment using distant learning technologies. Yu (2013) introduced a new course called  
134 "Architectural design" inclusive of digital technology and architecture where structure and teaching content of this  
135 course benefit from the basic computer science knowledge and technology. This course covers the computer aided  
136 design systems and increases the content of computer graphic principles of new buildings through theory and  
137 application. This course was designed to improve the students' skills to employ computing for architecture and design  
138 in their projects.

139 Other AEC researchers also focused on the evolution of the AEC industry and AEC education regarding the new  
140 computing trends, which have resulted in technological and institutional transformations and changes. These trends  
141 led to the emergence of approaches for integrating new technological innovations, topics, and issues in AEC education;  
142 such as design optimization and decision-support tools, educational tools, information modeling and management,  
143 simulation, visualization tools (Flager et al. 2009; Abrishami et al. 2013; Hopfe et al. 2006; Issa et al. 2005; Shi  
144 1999),and innovative information technology (IT) and information systems (IS) for construction improvements  
145 (Stewart and Daet 2002; Issa and Anumba 2007; Johnson and Gunderson 2009). Building Information Modeling  
146 (BIM) is another emerging and now arguably mainstream technology used in the AEC industry. Some studies  
147 investigated the level of integration of BIM into the AEC curricula and the level of exposure to BIM technology that  
148 AEC curricula should provide to the students (Becerik-Gerber et al. 2011a; Cooksey 2011). The results of studies  
149 conducted by Cooksey (2011) showed an increasing need for AEC programs to add BIM into the curricula. In addition,  
150 the results suggested that a BIM course should introduce the students to the general principles of BIM as well as the  
151 specific capabilities of BIM software packages. In addition, the authors conclude a BIM course should include  
152 collaboration techniques in order to share information between disciplines. Other emerging technologies such as  
153 intelligent transportation systems (ITS), most common application of IT to infrastructure; intelligent construction  
154 systems; applications of IT to the construction process; environmental monitoring and control systems, IT features  
155 used in environmental systems, have been adopted in the AEC industry (Grigg et al. 2005). Grigg et al. (2005)  
156 investigated how to integrate information technology into the civil engineering curriculum to prepare civil engineers  
157 to implement these emerging technologies to plan, build, and operate civil engineering systems and provided some  
158 recommendations. The results suggested that engineers need preparation in systems thinking and systems tools such

159 as systems engineering, communication, modeling, network analysis, and problem-solving strategies in order to  
160 address the concerns regarding the fast moving changes in technology as they relate to civil infrastructure.  
161 Investigating the level of knowledge engineers need to acquire regarding IT-based components, the authors' results  
162 illustrated that students need to study a new range of technologies such as integrated control system, including  
163 communication, control actuators, data, and decision components. Furthermore, the authors investigated what  
164 engineers need to know for their work, the results revealed the need for study of a new further range of IT topics such  
165 as "software and personal tools, and IT-based systems used in communications, organization management and design,  
166 operation, and maintenance" (Grigg et al. 2005). These new trends revealed and highlighted concerns related to the  
167 preparation of students to operate effectively in the emerging and evolving AEC computing environments and how  
168 future architects and engineers can best assimilate the advanced, yet fundamental knowledge of computing  
169 technologies appropriate for their professional AEC careers.

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

### 183 **Survey Methodology**

184 To assess the evolution of computing in the AEC curricula a survey methodology was implemented for data collection.  
185 The survey questions were generated by the authors, who teach courses and research actively in the AEC fields. The

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

### 197 **Survey Specifics**

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

206 Half of the respondents were from North America (mostly from the U.S.) and half were from the other continents:  
207 Europe (23% of the respondents), Asia (19% of the respondents), South America (5% of the respondents), and  
208 Australia (3% of the respondents). The list of programs in the U.S. was obtained directly from the Accreditation Board  
209 for Engineering and Technology (ABET), the National Architecture Accrediting Board (NAAB), American Council  
210 for Construction Education (ACCE), and American Schools of Construction (ASC). The European contributions were  
211 obtained through contacting members of the European Group for Intelligent Computing in Engineering (egice.com)



212 and through the European architecture and computing communities. The number of recipients receiving the initial  
213 email is approximately 680. The response rate was approximately 28%.

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

## 220 **Survey Results**

221 In order to analyze the survey results, the authors examined the responses to each question, counted the number of  
222 responses and computed the percentages for all questions. The overall rating for each computing skill or application  
223 within a specific question was determined as a weighted average of the percentages. The weights ranged from 1 to 5  
224 as specified in the survey questionnaires -- a higher rating indicates more important, more competent, more coverage,  
225 more sufficient, and or more expert. Using t-tests the authors conducted exploratory analyses to investigate 1) the  
226 differences in the curricula across the three different AEC disciplines and 2) computing skills vs. computer science  
227 knowledge components of the AEC curricula. The statistical results are expressed in terms of a p-value at  $\alpha = 0.05$ . In  
228 addition to reporting the results of the 2014 survey, the authors compared the results from 2014 survey with 2012  
229 survey in order to evaluate the evolution and pace of change in AEC curricula, in the responding educators' opinions.

## 230 **Evaluation of Computing Components of the AEC Curricula**

### 231 **Computing Skills**

232 The evaluation of the number of computing skills related courses offered in the AEC curricula (Figure 1) indicated  
233 that overall computing related courses make up 15% of all programs. Compared to the 2012 survey, results show a  
234 2% increase in the computing content of the curricula in architecture and engineering programs. One hundred and  
235 seventy respondents (91 from architecture and 79 from engineering) answered the question seeking the percentage of  
236 computing skills related courses in the AEC curricula. Sixteen percent of the architecture and 14% of the engineering  
237 curricula were computing courses. The increase is more obvious in the undergraduate programs. The results of t-test

238 analysis indicated that the difference between the percentages of computing skills related courses in the two AEC  
239 program types was marginally significant ( $\alpha = 0.05$ ,  $p = 0.06$ ).

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

241 Survey results indicate the importance of individual computing skills within the program curriculum, the competence  
242 of students in each skill, and the level to which each computing skill is covered in the academic curricula. In the 2014  
243 survey like in the 2012 survey, the authors are foregrounding the purposeful distinction between *computing skills* (e.g.  
244 programming, commercial tools, etc.) and *computer science* (e.g. algorithms, database design, search and  
245 optimization, machine learning, data structures, network science, etc.).

246 ***Table 1- Analysis of importance-competence-coverage of computing skills in the AEC curricula*** (The weights for  
247 importance (1: Not Important, 2: Somewhat Important, 3: Neutral, 4: Important, 5: Very Important). For competence  
248 (1: somewhat unskilled, 2: unskilled, 3: novice, 4: expert, 5: very expert). For coverage (1: not covered, 2: introduced,  
249 3: covered, 4: moderately covered, 5: extensively covered))

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

262 The survey results also show that in general the respondents rated their students' competence to be at the novice level  
263 for most of the computing skills. Students are considered to be experts in computer-aided drafting in architecture  
264 programs, as well as spreadsheets in engineering programs. Students in architecture programs are believed to be more

265 competent in most of the computing skills in comparison to the students in engineering programs, except for  
266 competency with spreadsheets, specialized engineering software, equation solvers, and programming. In addition,  
267 graduate students are believed to be more competent in most of the computing skills in comparison to undergraduate  
268 students.

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

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

### 281 **Computer Science Knowledge**

282 Computer science knowledge includes fundamental topics in computational complexity and the study of  
283 representation and reasoning strategies. Such topics are expected to have an important impact on decisions related to  
284 computing during the careers of current AEC students (Smith 2012). In that regard the expectation is for AEC  
285 educators to understand, teach, develop, and apply more scientific computing methodologies in their regular curricular  
286 content. This will result in architects, engineers, and construction professionals who are agile when new technology  
287 emerges. It will also lead to the development of future computing tools that are easy to use and modify while being  
288 able to scale to particular, complex and large AEC applications. The results of this survey can contribute to developing  
289 a plan for AEC programs to design courses that equip students with comprehensive knowledge of application of  
290 representations and algorithms as a problem solving approach in the AEC. Investigating the respondents' perceptions  
291 of the importance of the computer science knowledge in their respective programs, 170 responses were received (91

292 responses from architecture and 79 responses from engineering). The survey results indicated that overall 6.3% of all  
293 AEC programs offer courses that are related to computer science, which shows 1.3% increase compared with the  
294 results of the 2012 survey. Engineering programs at the graduate level lead the number of courses (7.9%) followed by  
295 architecture graduate programs (7.7%). At the undergraduate level, the architecture programs lead the number courses  
296 (5.7%) followed by the engineering programs (3.7%).

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

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

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

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

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

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

327

328 *Table 2 - Analysis of importance-competence-coverage of computer science knowledge in the AEC curricula* (The  
329 knowledge importance within the program curriculum (1: Not Important, 2: Somewhat Important, 3: Neutral, 4:  
330 Important, 5: Very Important). The competence of student knowledge (1: somewhat unskilled, 2: unskilled, 3: novice,  
331 4: expert, 5: very expert)). The knowledge coverage within program curriculum (1: not covered, 2: introduced, 3:  
332 covered, 4: moderately covered, 5: extensively covered))

333 With respect to understanding which programming languages predominate in the AEC curricula, the authors queried  
334 the participants to identify the programming languages that are taught in their programs. A total of 170 participants  
335 (91 from architecture and 79 from engineering programs) answered this question. Table 3 presents the ranking of the  
336 top ten programming languages in all of the AEC program types. The results show that in general, Matlab and Java  
337 are taught more compared to other languages in the AEC curricula. Similar to the 2012 survey, architecture programs  
338 still cover HTML more at the undergraduate level whereas Java and python are covered more at the graduate level.  
339 Engineering programs cover Matlab, C++ and Java more than the other languages at both graduate and undergraduate  
340 levels. These trends are consistent with the trends that are observed in the computing curricula showing a growing  
341 trend toward use of “safer” or “more managed languages” (for example, use of Java instead of C), as well as the use  
342 of “more dynamic languages”, such as Python or JavaScript (Computer Science Curricula 2013; Computing curricula  
343 2001). Monitoring the coverage and shifts in programming languages the authors believe is an important trend to  
344 measure as it indicates emphasis on computer science as a fundamental skill but as well allows for discussion of links  
345 to industry application development.

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

347 **Computing Skills vs. Computer Science Knowledge**

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

358 In another attempt to evaluate the relevance of computer science versus computer skills, the authors asked the  
359 respondents to rate the importance of the computing skills versus computer science knowledge in preparing students  
360 for a future within the AEC. One hundred and seventy responses (91 from architecture and 79 from engineering  
361 programs) were received. Overall, 89% of all programs said computing skills are very important or important to the  
362 future of the AEC educational programs, which shows a 9% increase compared to the results in the 2012 survey  
363 (significantly more than the results of the 2012 survey ( $\alpha = 0.05$ ,  $p = 0.049$ )). Ninety three percent of the respondents  
364 in architecture and 85% of the respondents in engineering programs considered computing skills as very important or  
365 important to the future of the AEC curricula, which shows an increasing trend in the respondents' perceptions of the  
366 importance of the computing skills (Figure 3). It is noteworthy that the increase in architecture programs (15%) is  
367 more considerable compared to the engineering programs (6%): this is likely due to a paradigm shift occurring within  
368 architectural education, which is moving away from drawing and 2D practices towards 3D modeling as well as  
369 analysis and design automation (parametric and algorithmic design) within the core educational components.  
370 Computing skills are also perceived to be more important at the graduate level (80% of the respondents considered it  
371 as important) than at the undergraduate level (51% of the respondents considered it as important). The results of the  
372 t-test indicated that that the perceptions of the respondents in the architecture programs regarding the importance of

373 computing skills in preparing students for a future within the AEC significantly differ from the perceptions of the  
374 respondents in the engineering programs ( $\alpha = 0.05$ ,  $p = 0.042$ ). Further analyzing the survey results using t-test showed  
375 that the respondents' perceptions of the importance of computer science knowledge in preparing students for a future  
376 within AEC in the two program types are not significantly different ( $\alpha = 0.05$ ,  $p = 0.883$ ). The importance of computer  
377 science knowledge increases as the level of program increases. In comparison to the 2012 survey, a decreasing trend  
378 has been seen in the perceptions of the respondents regarding the importance of the computer science knowledge for  
379 preparing students for a future within the AEC (Figure 3) although the differences between the 2012 and 2014 surveys  
380 are not significantly important ( $\alpha = 0.05$ ,  $p = 0.247$ ). In general, the respondents rated computer science knowledge as  
381 less important than the computing skills. The t-test revealed that there was significant difference between the  
382 importance of computing skills and computer science knowledge in the AEC curricula ( $\alpha = 0.05$ ,  $p = 0.000$ ).

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

### 385 **Evolution of Computing Skills Since 2002**

386 The results of this survey can be used to develop benchmarks to evaluate the evolution of computing in the AEC  
387 curricula going forward. The first surveys covered civil engineering programs solely. Starting with the 2012 survey,  
388 the authors covered more inclusively AEC educational programs in order to begin to track integration issues believed  
389 to be important to the future of AEC curricula. Here, to evaluate the evolution of computing in the AEC curricula, the  
390 authors compare the results of the 2014 survey with the 2012 (Gerber et al. 2013) and 2002 (Abudayyeh 2004) surveys  
391 to assess the computing components of specifically civil engineering education. Since the original surveys only  
392 considered computing in civil engineering curricula, the focus in this part is on the 2014 and 2012 responses that cover  
393 this field. To be consistent with the recent studies, educators' perspectives are used from the 2002 survey to discuss  
394 the importance, competence, and coverage of the computing skills for students. The numbers of respondents vary  
395 across these three surveys: 44 responses for 2002 survey, 57 responses for 2012, and 79 responses for 2014 survey  
396 were received. The weights range from 1 to 5 where a higher rating indicates more importance, competence, and  
397 coverage. A comparison of the importance ratings from the 2014 survey and 2002 survey indicates an overall slight  
398 increase in the importance of computing skills during the past 12 years although the difference is not significant except  
399 for the subject of collaborative environments. The increased emphasis on the importance of design methods and

400 interdisciplinary approaches might be one of the reasons explaining the significant increase in the importance of  
401 collaborative environments. It is also noteworthy that the importance of spreadsheet and word processing has  
402 decreased slightly. Table 4 illustrates a comparison of the ratings of the importance, competence and coverage for  
403 each computing skill of the 2014 and 2012 surveys with their corresponding ratings from the educators' perspectives  
404 in the 2002 survey.

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

410  
411 Building information modeling (BIM) was not measured in terms of importance, competence and coverage in the  
412 previous 2002 and 2012 surveys but it is ranked as the most important topic in the 2014 survey, and is an obviously  
413 prominent computing skill to continue to track as it is understood as necessary and now fundamental to the AEC. The  
414 comparisons indicate that the importance of most of the computing skills has increased when comparing 2002, 2012  
415 and 2014 surveys except for spreadsheet and word processing (note that the differences in the importance of the  
416 computing skills, competence of the students in these skills and coverage of curricula for these skills are not  
417 significantly different in 2012 and 2014 surveys). The results also similarly show increase in perceived competence  
418 of the students in the computing skills and coverage of the curricula for these skills. Increase in the application of  
419 some existing software such as LaTeX might explain why the importance of some traditional skills such as spreadsheet  
420 and word processing has decreased and students have become less expert in these skills. In addition the decrease in  
421 the level of coverage for these skills might be another reason explaining why students have become less expert in  
422 these skills. The coverage results from the 2002, 2012, and 2014 surveys revealed that the rankings of some computing  
423 skills in terms of coverage have changed considerably; for example programming ranking has changed from 3 to 8;  
424 parametric design has changed from 6 to 10; and electronic communication ranking has changed from 10 to 7. In  
425 general, comparison of the results of the 2002, 2012, and 2014 showed an increasing trend in importance, competence,  
426 and coverage during 2002 and 2012 but a decreasing trend has been seen since 2012.



## 427 **Evaluation of Students' Computing Abilities**

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

436 In terms of computer science knowledge of students, the results again show consistency. Fifty nine percent of the  
437 respondents in all programs rated the students' current abilities to be poor or below average and only 15% of the  
438 architecture and 14% of the engineering programs believed the students to be expert or above average. These results  
439 contradict the results in the 2012 survey, in which 5% of architecture and 23% of engineering and programs considered  
440 the students to be above average or expert. Similar to the computing skills, the result of t-test reveal that there is no  
441 significant difference in the current computer science knowledge abilities of the students in the AEC programs ( $\alpha =$   
442  $0.05$ ,  $p = 0.730$ ).

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

449 In general, respondents believe that students in the architecture programs are more expert in the computing skills than  
450 the students in the engineering programs. They also believe that students' expertise in computer science knowledge  
451 has decreased in the engineering programs and increased in the architecture programs during the last two years.  
452 Considering that computing skills and computer science knowledge are perceived to be more important in engineering

453 programs than architecture programs, the results suggest that there is a greater need in engineering programs for  
454 increasing the computing content of the curriculum than architecture programs.

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

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

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

469 **Program Evaluation and Future Plans**

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

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

474 The results (Table 5) indicate that both programs considered BIM, visualization, computer aided drafting (CAD), and  
475 simulation as very important topics for the future of AEC education. The same results were seen in the 2012 survey  
476 for the first two topics of BIM and visualization. In looking for causality of these trends the authros have started to  
477 look into pure computer science curricula trends and changes. A few of relvance to the AEC include observations such  
478 as an increasing emphasis on the use of CAD and visualization tools (Computer Science Curricula 2013; Computing

479 curricula 2001), which might have influenced the AEC curricula. The authors also asked the respondents to prioritize  
480 the topics that they believe should be increased in the computer science content of teaching in the AEC curricula.  
481 Machine learning and data analytics (Big Data) is rated to be the most important topic. The increase in emphasis of  
482 the machine learning in the computing curricula in the past decade (Computer Science Curricula 2013; Computing  
483 curricula 2001) is likely another influence upon the priority topics observed by our respondents from the AEC. These  
484 results shown in Table 6 indicate that respondents still do not recognize the implicit links that many topics in computer  
485 science currently have to AEC applications. For example, databases and computer graphics are in the lower half of  
486 the priorities. This indicates that more effort is needed to communicate such links to curricula decision makers.

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

488 In both the 2012 and 2014 surveys, the authors assessed the participants’ perceptions of how BIM has been integrated  
489 into the AEC educational programs by asking about where BIM is taught versus where BIM is planned to be taught.  
490 The 2014 survey results indicate that, architecture programs teach BIM mostly for modeling (91%) followed by energy  
491 analysis (63%) whereas engineering programs also mostly teach BIM for modeling (71%) followed by BIM based  
492 collaboration (54%). The comparison of the results from 2014 with the 2012 survey shows that in general, the trend  
493 of BIM integration into the AEC curricula does not meet what was perceived as planned for in the 2012 survey and  
494 the applications of some of the examined computing skills have decreased significantly over the past two years  
495 including modeling ( $\alpha = 0.05$ ,  $p = 0.000$ ), energy analysis ( $\alpha = 0.05$ ,  $p = 0.043$ ) and customization ( $\alpha = 0.05$ ,  $p =$   
496  $0.006$ ).

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

498 Using 2012 as an initial benchmark, the authors tracked the evolution of computing in AEC curricula and provide a  
499 benchmark for further evaluation of the status of computing education in order to support decision making for the  
500 future AEC curricula. The authors asked the respondents to rate the sufficiency of computing education to meet the  
501 demands of the AEC industry. A total of 164 respondents answered this question (88 responses from architecture and  
502 76 responses from engineering programs). The t-test results indicate that the sufficiency of the computing education  
503 to meet the demands of the AEC industry does not differ significantly for the different program types ( $\alpha = 0.05$ ,  $p$   
504  $=0.655$ ). Thirty-five percent of the architecture and 33% of the engineering programs considered computing education  
505 as sufficient or somewhat sufficient whereas, 48% of the architecture and 47% of the engineering programs believed

506 that computing education is not sufficient or somewhat insufficient to meet the demands of AEC industry (Figure 6).  
507 Participants believed that computing education is more sufficient in graduate level programs (37%) than undergraduate  
508 level programs (34%).

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

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

524 **Discussion and Conclusions**

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

531 Assessment of computing components in the AEC curricula shows increasing trends in the percentages of both  
532 computing skills and computer science knowledge related courses in all program types and levels over the past two

533 years. Although the results of the 2012 survey revealed the need for increasing the computing content of the AEC  
534 curricula, the results of the 2014 survey indicate the perceived importance of most of the computing skills and coverage  
535 of the curricula for these skills have not changed significantly, while competence of the students in these skills, have  
536 decreased since 2012.

537 Another important assessment is that educators are still neutral about the importance of computer science knowledge  
538 within their curricula. The results suggest AEC educators believe that students are unskilled in most of the computer  
539 science knowledge categories and indicate most of these categories are merely introduced in the AEC curricula.  
540 According to Grigg et al. in 2004 the curriculum coverage for important foundational topics such as CAD, graphics,  
541 and computational skills was not enough (Grigg et al. 2004). The evidence is consistent in the lineage of survey and  
542 precedents that there is a greater need for computing within the AEC as expected but also with a consistent emphasis  
543 for computing skills. Furthermore there is consistent lament amongst some AEC educators that there is too much  
544 required content for an undergraduate or graduate degree and therefore, it is not possible to include all topics in a  
545 4-6 year curriculum, whether computer skills or computer science or a balanced combination of both. Furthermore,  
546 computing tools are proliferating making it difficult for AEC educators to teach all of them. The data from both 2012  
547 and 2014 highlight this as a key barrier to evolve the AEC curricula in general.

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

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

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

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

### 578 **Limitations and Future Work**

579 The authors have run the 2014 survey on a two-year reoccurring cycle to establish what the authors anticipate will  
580 become a longitudinal study. This paper is the first set of results that the authors present as being benchmarked to that  
581 of previous surveys, specifically the 2012 results which also intrinsically reflect the previous work from 2002 and  
582 1998, etc. Although the two-year period might not be the best frequency to evaluate the evolution in the AEC curricula,  
583 it is an important benchmark for future work and reflects the speed of change occurring in industry and computer  
584 science generally. Important to the work is a criticism that all the previous surveys (except the 2012 survey) focused  
585 solely on the civil engineering curriculum and in light of overlaps, new construction delivery models, moves towards  
586 tighter integration and coupling of design through to operation models, data and objectives within the entire AEC

587 value chain, our work begins to adjust the focus away from the “silo-ing” that has been historically dominant. Having  
588 the results of the 2014 survey in conjunction with the 2012 benchmark, the authors will continue to be able to more  
589 critically assess the frequency, structure, and adjustment to the questionnaire more intelligently for future  
590 investigations. The results of the survey were reported based on 170 respondents. Although this represents a good  
591 sample size and a steady increase in participation, there remain a few challenges including: 1) the disparity between  
592 the number of the participants in the architecture and engineering programs (54% architecture and 46% engineering);  
593 and 2) difficulty in obtaining identical respondents as educators move and change positions. In the future, the authors  
594 will analyze targeting, response rates and consistency of responders more closely. These issues will be addressed by  
595 increasing the sample size and by motivating more people to participate in the survey ideally through actively  
596 illustrating the value of such data for curricula decision making. In the future, the authors plan to investigate more  
597 extensively the causalities and to measure the factors leading the to the changes in perceived value of computing topics  
598 and content for the AEC industry.

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

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

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696 **Table 2 - Analysis of importance-competence-coverage of computer science knowledge in the AEC**  
 697 **curricula** (The knowledge importance within the program curriculum (1: Not Important, 2: Somewhat  
 698 Important, 3: Neutral, 4: Important, 5: Very Important). The competence of student knowledge (1:  
 699 somewhat unskilled, 2: unskilled, 3: novice, 4: expert, 5: very expert). The knowledge coverage within  
 700 program curriculum (1: not covered, 2: introduced, 3: covered, 4: moderately covered, 5: extensively  
 701 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

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**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

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

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

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

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

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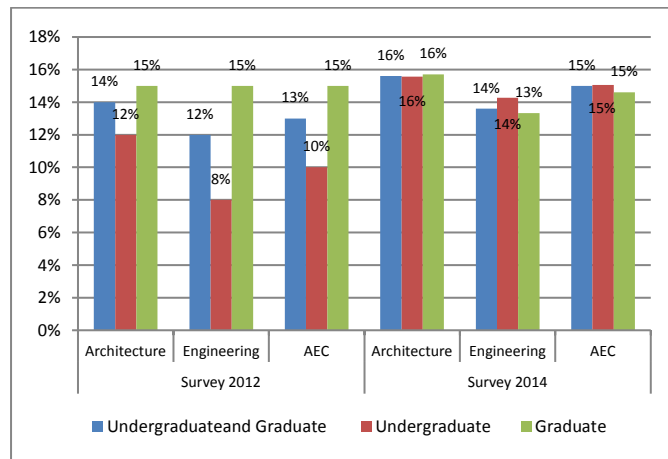
#	AEC	Architecture	Engineering
1	Machine learning and data analytics (Big Data)	Machine learning and data analytics (Big Data)	Object Representation and Reasoning
2	Distributed Applications and Web	Distributed Applications and Web	Distributed Applications and Web
3	Optimization and Search	Optimization 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

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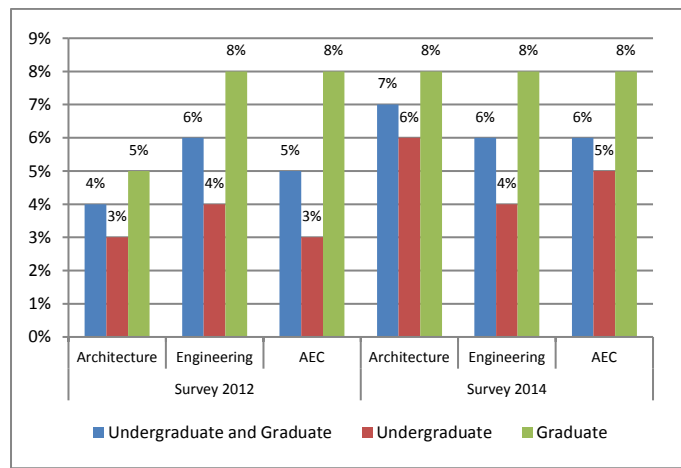
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*Figure 1 - Percentage of computing skills related courses in AEC programs*

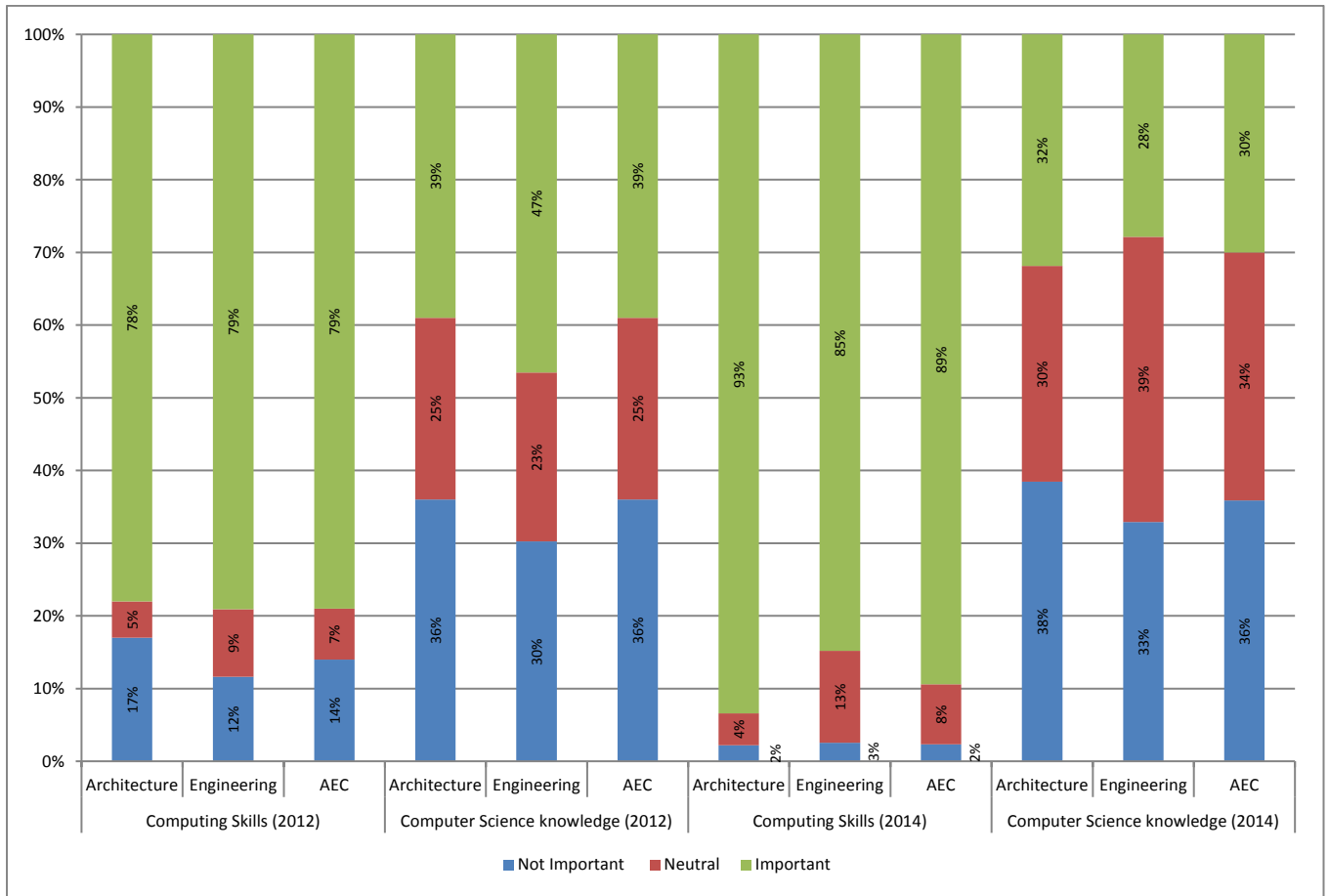
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*Figure 2 - Percentage of the courses that are related to computer science knowledge*

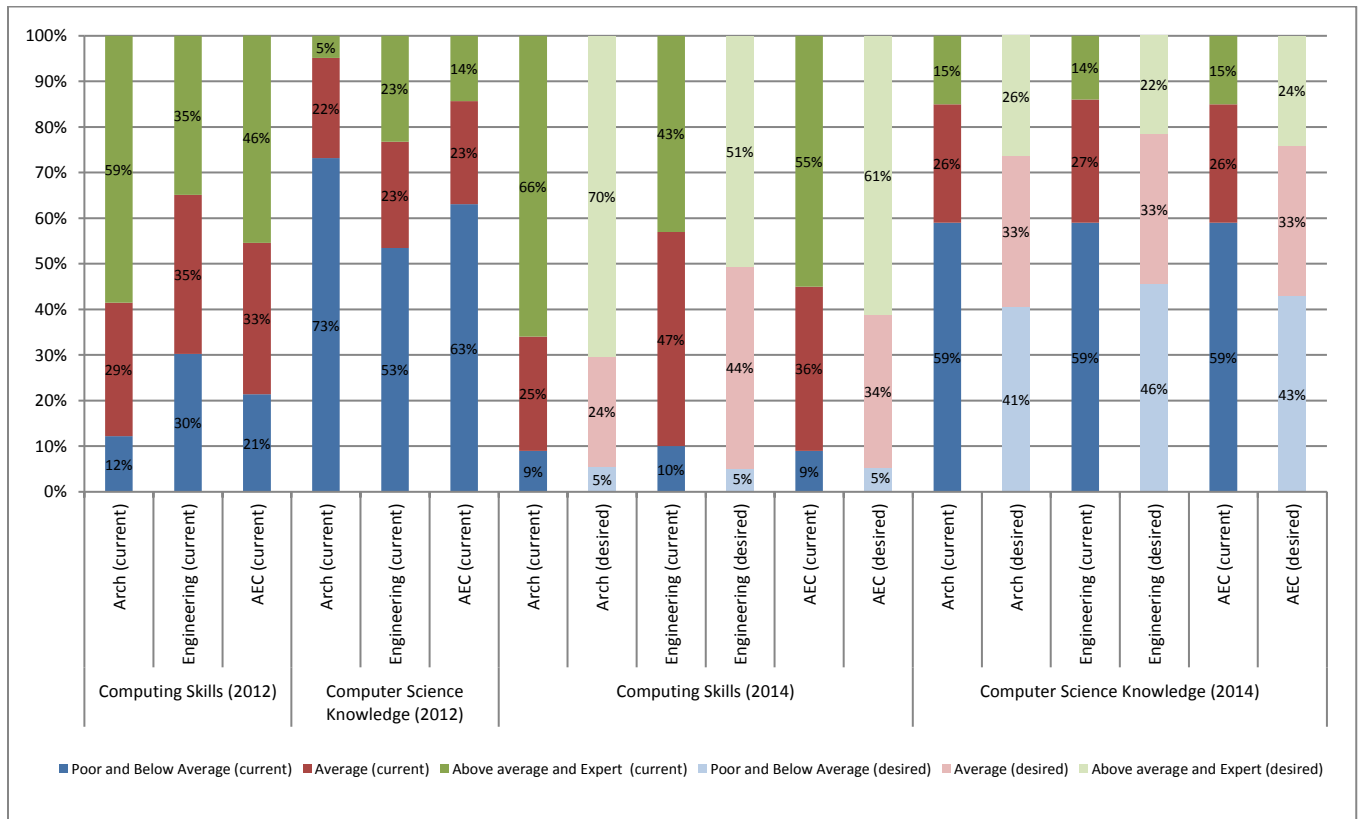
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**Figure 3 – Importance of computer skills vs. computer science knowledge for preparing students for a future within the AEC**

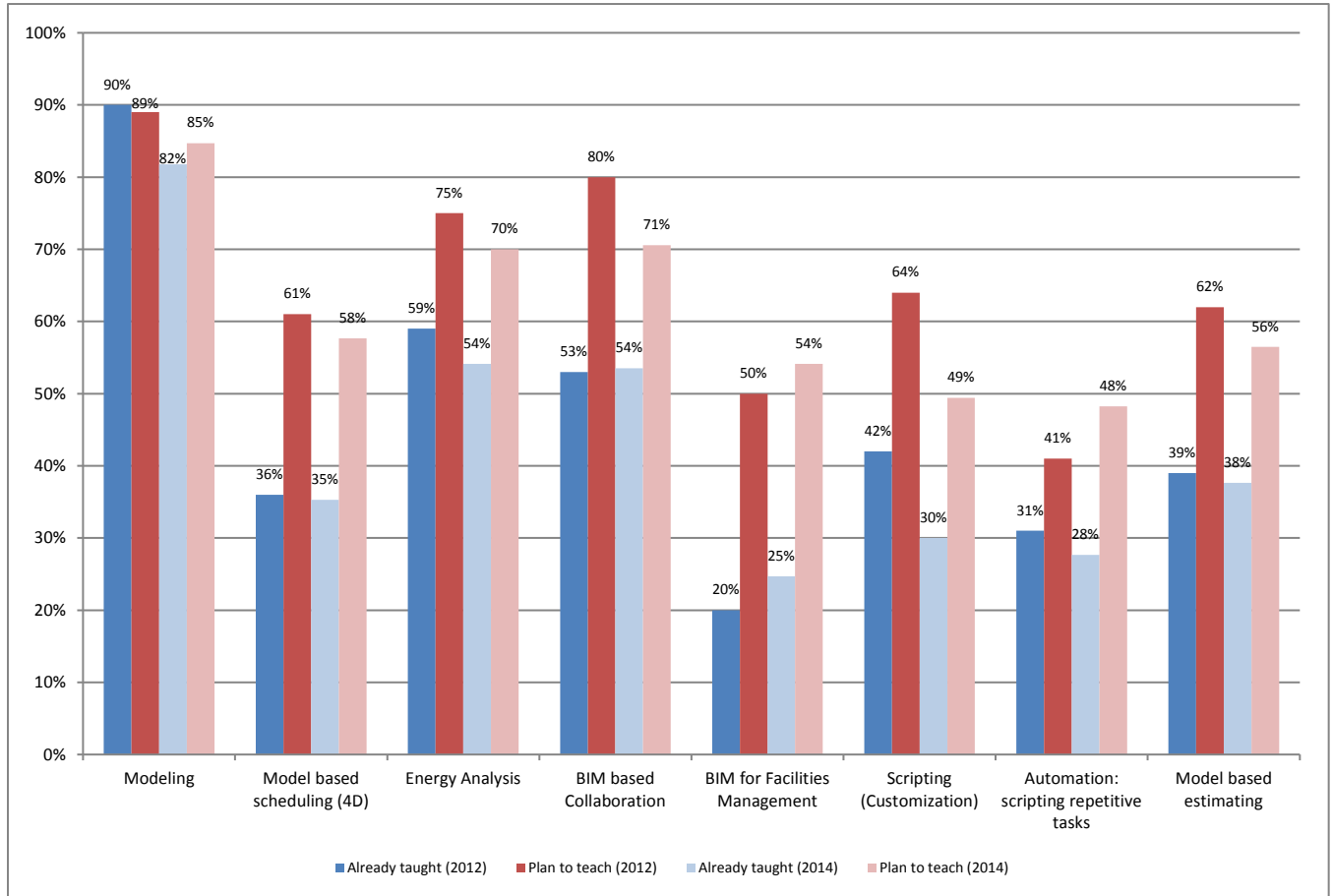
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**Figure 4- Current and desired level of expertise of students in computing skills and computer science**

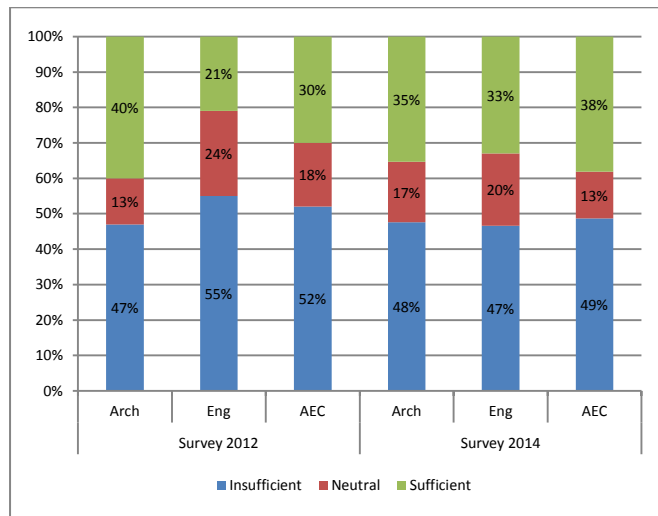
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**Figure 5- The planned and current areas where BIM is/will be taught (2014 compared to 2012)**

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