Preparing the Next Generation of Civil Engineering Graduates: Identifying and Combating the Digital Skills Gap

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Introduction

With the rapidly developing role of digital technology, industries have placed significant weight on individuals' level of 'digital literacy', that is, their ability to complete tasks in a digital environment. The construction industry is no exception. It must be viewed as a high-tech industry, necessitating innovation and improvement to remain competitive within today's digital economy. Digital tools offer the construction industry many potentials. However, to realise these benefits, the construction industry needs a different attitude towards the challenges posed not only by the new technology but also by the human component. For the future generation of engineers in the construction industry to be competitive and capable, it is critical in their preparation that they develop skills in the use of digital technologies.

The overarching goal of this study was to determine the required skill set of the future 'digital site engineer'. With this research goal, the study sought to achieve the following objectives: (i) to understand the importance of digital technologies in the future of construction; (ii) to identify deficiencies in the current skills of site engineers; (iii) to identify opportunities to use digital technologies to enhance site operations and productivity; (iv) to determine the benefits of digital technologies in future construction projects; and (v) to determine if universities provide engineering graduates with the necessary digital skills to meet future demands. The study discussed the current deficiencies in digital skills, essential digital skills future site engineers would need, and made recommendations on strategies to provide these new skills in a continuously changing field.

Background

Digital technologies

Digital technology has represented a paradigm shift in the way engineering consultants design buildings and infrastructure. Nevertheless, its implementation in managing and delivering construction projects is still limited. The construction industry is still applying traditional practices and rely on paper-based systems for delivering construction projects. However, digital technologies are making their way into the industry and they present means of streamlining many of the processes and eliminating many of the inefficiencies that have hampered an inherently risky and complex industry over the years. According to the literature, the following digital technologies have been identified to for managing construction projects: big data, Internet of Things (IoT), sensor-based technology, geographic information systems (GIS), building information modelling (BIM), augmented reality (AR) and mobile technology (Alexander et al., 2019; Bilal et al., 2016; Dave et al., 2016; Koretsky and Magana, 2019; Meža, Turk and Dolenc, 2015).

These digital technologies have been integrated to better manage construction processes and staff. The Big Data applications within the construction industry include resource optimisation and waste minimisation, clash detection and resolution, and generative design. In addition, the utility of Big Data is amplified by emerging technologies such as BIM, IoT, and AR which provide methods of storing, computing, processing, analysing, and visualising construction projects data (Bilal et al., 2016). The IoT has the potential to provide many benefits to the construction industry by enabling a higher level of communication and information sharing throughout the project and product lifecycle from initiation, design, construction, handover and through to eventual disposal (Dave et al., 2016). BIM represents a significant advancement in how information is managed and shared in construction projects. applications of BIM include generation of 3D renderings and shop drawings, material quantity and cost estimating, conflict analysis and collision detection, and asset management (Azhar, 2011). Another technology that uses big data is AR which is a state-of-the-art technology that allows users to superimpose information onto the real world (Alexander et al., 2019). Applications of AR include identifying and locating existing building components, supervision of compliance with design and schedule, visualisation of 3D models on-site, and production and understanding of project documentation (Meža, Turk and Dolenc, 2015).

Other digital applications are used for enhancing the productivity on the construction site and monitor the project progress. As construction sites are dynamic and complex systems, sensor-based technologies are a valuable resource for gathering real-time data on the various objects and processes occur on a construction site. The sensors provide the ability to identify, position, track, monitor, and supervise equipment, people, material, actions, and other variables to provide greater situational awareness to site managers (Lu, Huang and Li, 2011). The data from the sensors are coupled and utilised with mobile technologies. This is for improving site monitoring by enabling direct access to databases to view real-time project information, improving task management, and facilitating real-time viewing of CAD drawings by construction participants using different mobile devices (Kim et al, 2013). The GIS are increasingly being used in the construction industry as it can provide an effective visualisation of the construction progress of a project. Applications of GIS include subsurface profiling, quantity take-off and cost estimation, construction site layout, route planning, topography visualisation, and real-time schedule monitoring (Bansal, 2007).

Digital skills

The advent of new digital technologies in engineering has made digital skills an increasingly more essential skill for engineers of all disciplines. The ability of engineers to use digital technologies is recognised as crucial to increased individual and corporate productivity (Koretsky and Magana, 2019). The digital skills are especially essential in the construction industry where the application of digital technology can optimise the construction process and reduce the likelihood of errors. Five digital skills have been identified, namely data management, programming, big data analytics, BIM and GIS.

The ability of engineers to manage data efficiently is a crucial skill in handling the enormous flow of information coming from a variety of sources in a construction project. According to Abudayyeh et al. (2004), databases play a major role in civil engineering digital applications. The programming skills are a valuable asset to engineers and provide them with the means of solving complicated problems with little effort using digital technology. It is important that engineering students learn basic programming skills in early education, followed by more advanced computing courses to get better prepared for the future workforce (Alexander et al., 2019).

The use of big data analytics (BDA) is nothing new within the construction industry. However, the adoption of Big Data technology and related BDA is still in an early phase and lacks the same level of adoption found within other fields (Bilal et al., 2016). BDA requires that users have skills at not only data analytics but also skills in programming and data management.

The value of BIM in addressing many inefficiencies present in the construction industry makes it crucial for a graduate civil engineer to utilise BIM as an essential digital skill necessary for success in the future. The BIM knowledge and skills should be integrated into the engineering curriculum to deliver job ready candidates. It is essential that graduate engineers possess the skill and knowledge not only in BIM technology but, more importantly, in the application of BIM processes in order to realise the potential benefits it may bring (Sacks and Pikas, 2013). In recent years, the potential of GIS has become apparent by many within the construction industry, its use for geospatial analysis has proliferated and is only expected to grow as new applications are realised (Bansal and Pal, 2009). Incorporating GIS into civil engineering education is necessary not only to meet the demand for non-GIS professionals in engineering, but to teach students skills in spatial analysis and data processing, and aid in their problem-solving and critical thinking abilities.

Research Design

The selected mixed-methods research design integrated both quantitative and qualitative research approaches. First, a comprehensive literature review was conducted to gain knowledge on the key digital technologies in the construction industry and the relevant digital skills necessary for engineers to possess. Data was collected through a quantitative-based questionnaire survey distributed among university students followed by a series of semi-structured interviews with industry professionals. Research findings from both qualitative and quantitative research components were then compared in order to identify whether a gap exists between the digital skills of students and that expected of graduates by the industry. Furthermore, this comparison was used to determine whether both parties believe that universities are providing the necessary digital skills to graduates and whether both recognise that more can be done in the form of education. The results of the comparison culminated in the formulation of a digital skill transition strategy along with some recommendations for strengthening the skill sets of the next generation of civil engineering graduates and combating the digital skills gap.

The primary purpose of the quantitative research consisting of questionnaire survey targeting engineering students was to obtain valuable information concerning the digital skill level of graduates and the perceived quality of civil engineering education. The survey was conducted using the data obtained from final year students. All items in the questionnaire were measured using a five-point Likert scale. The data collected from the student survey was analysed by using the IBM SPSS Statistics software package to conduct advanced statistical analysis of data and perform a range of tasks best-suited for research surveys.

In addition to the questionnaire, qualitative survey research was conducted with a selected group of industry professionals from five major construction companies in South East Queensland using one-on-one semi-structured interviews. The purpose of these interviews was to: (i) identify current and future digital technologies in construction; (ii) recognise industry-identified deficits in students' skills; and (iii) define the necessary digital skills for future engineers and how the current university curriculum could be improved in this regard. The selected participants had diverse roles including site engineers, construction managers, project managers who worked for medium-to-large construction contractors across the Gold Coast and Brisbane. All interviews were recorded and transcribed. Throughout the interviews a number of themes have emerged, namely graduate programs, incorporating more real-world software, familiarisation with technology, and greater industry involvement.

Results and Discussion

Student survey

The survey was distributed among civil engineering students in their third and final year of the Bachelor of Engineering as these students would represent the skill level that most graduates would have entered the industry. In all, 59 students participated in the questionnaire survey. All questions were clustered into four categories: (i) familiarity with new and emerging technologies; (ii) experience and confidence in advanced engineering software; (iii) skill level with a number of generic digital skills; and (iv) satisfaction with university education and the importance of digital skills.

Figure 1 shows the level of students' familiarity with five emerging technologies in engineering. Readers should note, that students self-reported their perceptions of their levels of familiarity. As can be seen, the students' familiarity with the use of new digital technology in the construction industry is rather low, with the lowest existing for topics like Big Data and AR, implying that students only have a fundamental knowledge of these technologies. This can be attributed to the general lack of these topics being covered in the current curriculum. Skills in programming using MS Excel VBA and/or other software are reasonable and should be what is expected; most students should be capable of applying these technologies if the circumstance arises. This can be explained by the fact that students are exposed to programs like MATLAB and MS Excel VBA to some extent throughout the degree and are given the ability to develop these skills to at least a basic level.

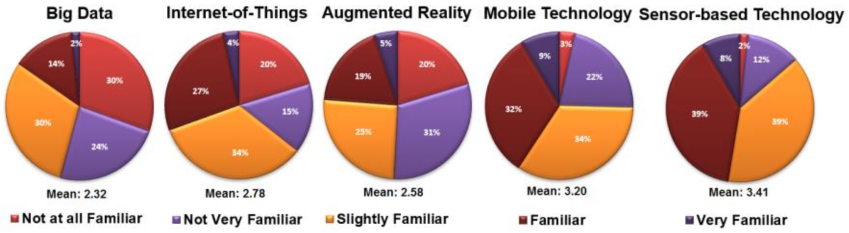

Figure 1: Familiarity of engineering students with a range of emerging technologies

Figure 2 indicates that most students *have 'very little'* experience or less in advanced engineering software. Most alarmingly, the results show that most students have practically no experience in using GIS or construction management (CM) software nor do they feel confident using it within a professional environment. The same is shown for BIM, seeing a slight improvement over the previous two, with most students only having some experience with BIM. This can be largely attributed to the fact that none of these major software programs can be found within the current curriculum, only recently has GIS been introduced. For most students, their only exposure to these programs will be through work experience or internship programs. Therefore, a deficiency in skill can clearly be identified as a result of the extremely low rating provided for these programs.

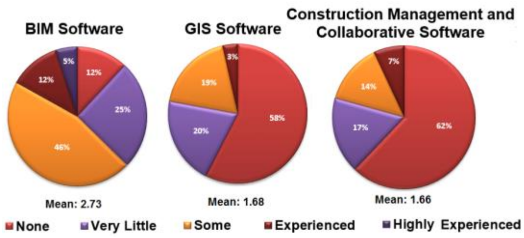

Figure 2: Experience of engineering students in a range of advanced engineering software

Figure 3 shows that students feel that their digital skill level is generally 'neutral' in most cases leaning towards 'fairly low'. Nevertheless, students' skills in data analytics are quite high with most students believing that they possess good abilities in data structuring, algorithms, mathematics and statistics. This can quite easily be explained by the fact that most of these skills are fundamental skills developed as part of the engineering program. This being said, student skill level in database software is considered fairly low and placed lower than that of BIM, owing to the lack of exposure of students to this software throughout their program. This can certainly be identified as a deficiency in skill of students where improvements can be made.

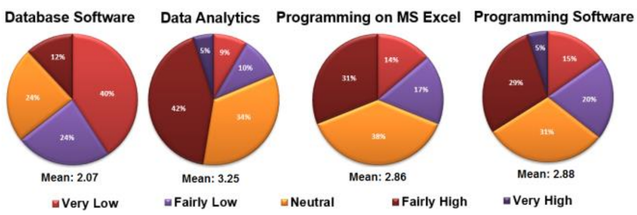

Figure 3: Students' skill level with a number of generic digital skills

In terms of students satisfaction, the survey results showed that most students feel neutral about the amount of digital technology and level of digital skill that integrated in their engineering program. Furthermore, students believe that having digital skills are important when entering the industry as a graduate engineer and that the current engineering curriculum adequately prepare them to be job ready graduates. Overall, students agreed that there could be more to improve their exposure to digital technology used in the industry and develop the associated skills.

Industry interviews

The survey has assisted in identifying the deficiencies in skills and determining whether universities are providing the necessary digital skills to graduates from the perspective of students. In addition to the student survey, a selected group of seven industry professionals were interviewed to determine the industry perspective. The scope of candidates was limited to senior construction/project/site engineers and manager who worked for medium-to-large construction contractors across the Gold Coast and Brisbane.

First of all, from the thematic analysis, it was possible to identify if there is a gap between the digital skills of current graduate civil engineers and the digital skills expected in the industry. The industry representatives' opinions are quite varied. Some of the interviewees believed there is quite a clear digital skill gap, while others mentioned that a gap exists only about specific software. Whereas some participants say they believed that there is currently no gap in digital skills among engineering graduates. Majority of the interviewees noted that for a graduate entering the industry through a cadetship or a graduate program, a skill gap would not exist as students would progressively accumulate the necessary digital skills over time. However, for an engineering graduate who did not have this opportunity, a digital skill gap would be prominent which sophisticates their transition to industry. Also, several participants believe that universities are not teaching students sufficiently about software that is currently being used in the industry such as BIM, Aconex, different kinds of CAD software, and planning and programming software. This issue may not be due to the digital skills students are taught, but the actual platform students are taught it on, i.e. universities are not on the same page with the industry in terms of software being used. What can further be observed from the results is that although some participants believe that a gap currently does not exist, they do not rule out the potential that a skill gap might appear soon. This is because currently many of these new digital technologies are in an incubation phase and are still in the process of being fully implemented across the industry. However, once this has occurred the digital skill gap may become far more prevalent. Overall, it would be fair to say that industry believes that there are some gaps between the skills of graduates and the skills expected in the industry.

Two main themes have been identified that represent the organisations that should be responsible for implementing measures to overcome the skill gap, namely the industry and universities. From the industry side, a method identified for overcoming the skill gap is graduate programs because the software and associated skills vary significantly between companies and therefore the best place to develop the necessary skills are from the company itself. However, the majority believed that the burden of responsibility lay more in the hands of universities that should implement measures to bridge the gap. Some of the measures suggested by interviewees are as follows:

- Universities should identify what is happening in the industry and bring it into the degree. They should be engaging more with the industry and asking them what programs, software and skills they want and expect from graduates and start implementing those in their curriculum so that graduate have the most relevant and appropriate skills when they enter the industry.
- Engineering programs and technology that are used or making their way into the industry should be covered in lectures, especially if universities are unable to provide the specific training in them. It is particularly important as many students do not have

any knowledge of these programs or technologies until quite later in their degrees, or worst case when they are required to use them in the field.

- Universities should employ more lecturers from the industry, bringing in experts with real-world experience in order to provide a different perspective on course content and be invaluable to student development. Furthermore, industry guest speakers should be providing more knowledge on the software and technologies that they use in the industry and outlining to students the competencies and skillsets they would like to see from graduate engineers.

The majority of respondents believe that universities sufficiently prepare their graduates for working in the industry. Overall, universities succeed in providing the base-level skills and theoretical knowledge required for an engineer. Nevertheless, the industry professionals claim that more could be done in some domains:

- Universities are responsible for providing foundation knowledge to students necessary to prepare them for the industry landscape; that is providing the skills to best set them up for their future career in the industry that is continually evolving.
- Universities must provide more real-world experience in order to best facilitate the transition for students from the university to working in the industry and best prepare them for the work they are expected to do.

As mentioned by interviewees, many students are not mentally prepared for the work expected when they get a job as an engineer. Many of the skills they are taught in university do not reflect the roles and responsibilities that they will be given. This can be a very daunting prospect for many graduates. A few respondents identified the importance of work experience to students approaching the end of their degree and recognised the value of supporting the transition, especially in fields like construction that is based heavily onsite experience. Therefore, universities should do more to facilitate work experience for their students.

By observing the responses of industry professionals, it is unquestionable that the industry considers digital skills as indispensable when working in the modern construction industry. Overall, everyone interviewed believed that digital skills were very important without a single conflicting opinion on the matter. However, it can be mentioned that some of those that have been in the industry longer did tend to be more cautious in not overstating its importance. These interviewees acknowledged that other factors come into play when discussing the skill sets of civil engineers.

Three main themes have been identified that represent the key skill areas for civil engineers:

- Reviewing models: graduates need to understand how to use software that allows engineers to review models, run clash detection and make changes to designs.
- Programming: graduates need to have the ability to use software that allows engineers to program various functions and conduct planning for tracking progress.
- Document management: graduates should be able to use software that allows engineers to manage documentation, review and annotate documents such as PDFs and manage the flow of information.

Another theme that was brought up frequently in the interviews was the principles of engineering. Most of the participants believed that one of the most critical things graduates must have is strong knowledge of the basics of engineering principles. They also must be able to understand how to solve problems, how designs are derived and understand precisely what is trying to be done. Furthermore, it is important in understanding exactly how a system works and applying it to different systems to obtain the desired outcomes and then being able to do a sanity check in the end.

Recommendations

Understandably, universities have significant responsibility in providing the necessary knowledge skills for graduate engineers to succeed in the industry. However, from the research conducted, several areas of improvement have been recommended by the industry:

- Follow trends and promptly identify changes in the industry to incorporate those changes within the curriculum.
- Engage more with the industry (e.g. industry reference group meetings) and discuss ways that the curriculum may be improved to identify what programs, software and skills are expected and ways that can be implemented.
- Implement some relevant software to develop a familiarity and a basic understanding of a program so that students can easily transfer that knowledge to other similar programs.
- Invite industry guest speakers to discuss the software and technologies that they use in the industry and outline to students the competencies and skillsets the industry wants to see.

As much as universities are responsible for providing the necessary academic and theoretical foundation for graduate engineers, equally responsible is the industry for providing the necessary practical experience for graduates as well as easing the transition from university to being an engineer dealing with real-world problems. Recommendations are that industry should:

- enable greater communication with universities, suggest ways of how the curriculum may be improved, and provide information for universities to enable the most relevant education to students.
- encourage more professionals from the industry to volunteer for lecturing, either as a guest lecturer mainly to discuss programs they use and the skills they would like to see or to deliver learning modules.
- take part in facilitating more opportunities for work experience and/or internships positions, as per their responsibility to undergraduates and have greater contact with industry such as site visits
- provide graduate or cadet programs to students to best assist the transition from university and build the relevant digital skills they will need to fulfil their job position.

Government has a significant sway when it comes to implementing new digital technologies in the industry. The Government can determine policies and legislation that can have severe impacts on the industry, and furthermore possess the funds and capital to drive new industry-specific initiatives that otherwise would be a significant financial burden for private companies. Some recommendations are that the Australian government should:

- implement strategies that require all private contractors working on government projects to implement digital technologies, such as BIM.
- create ‘soft’ strategies that incentivise the implementation of new digital technologies, such as providing grants and subsidies to universities and industry organisations who are willing to implement new technologies in their projects or curriculum.
- establish a task group that assists the private and public sector in transforming their work practices to facilitate the use of new digital technologies.

Conclusion

This study aimed to investigate the current and future trends in construction management and construction engineering and use the results gathered to determine the required skill sets of future civil engineers. The importance of digital skills to graduate engineers entering the construction industry was validated both from the perspective of the industry and of students. The study offered great insight into and clarity on the digital technologies that the construction industry is beginning to utilise and identified the digital skills necessary to facilitate this transition. The study's findings indicated that: (i) students and the construction industry both considered digital skills to be important for graduate engineers; (ii) a significant digital skills gap was apparent, with most of graduates having insufficient skills in planning and programming software and Building Information Modelling (BIM) software; and (iii) students and the construction both emphasised the necessity of overcoming this skills gap by improving the current engineering curriculum. The following skill sets, viewed as crucial in succeeding as a future 'digital engineer', were identified as needing improvement: construction document management, construction works simulation and construction project planning. Recommendations and conclusions were presented based on the study's findings. Moreover, the study presented a digital skills transition strategy that outlines several methods for overcoming the digital skills gap. The roles of universities, construction industry and its professional associations and government are included in this transition strategy.

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