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EMERGING FACULTY ROLE IN OPEN DIGITAL LEARNING

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ABSTRACT

As online learning gains popularity in higher education, the traditional brick-and-mortar based classroom learning environment is migrating to a more sophisticated, technology-facilitated digital learning environment. Faculty-student interaction for online student learning and engagement can be enhanced by technology affordance. Since students' online learning behaviors differ due to self-perceived social presence online and the drastically expanded access to subject matter resources, faculty's interaction with students online often goes beyond what was typically experienced in traditional classroom, to include learning materials curation, subject-specific mentoring, and learning community constructing and moderating. Online learning, both formal and informal, can be an enabler and driving force toward student-centered competency-based education. In the global digital learning era, higher education and its faculty, therefore, need to transition to become curators, evaluators, connectors and analysts for student learning and engagement. This research explores past literature to help identify the pedagogical opportunity and challenges associated with transitioning faculty to become leaders of the necessary partnerships with industry and third-party subject matter experts (SMEs) to create relevant skills and competencies.

Keywords: Digital learning, online learning, competency-based education, faculty role

1. INTRODUCTION

The construction industry is facing a severe shortage of skilled workforce (McGraw-Hill Construction 2012). Contributing factors include the retirement of baby boomers, a rapidly changing technology landscape and the transformed business practices driven by emerging industry trends including sustainability, building information modeling (BIM) and lean construction. To keep up with these trends and stay competitive in business, companies are urged to recruit for positions that demand brand new knowledge and skillsets, which are not readily addressed in existing construction management (CM) or construction engineering management (CEM) curricula (McGraw-Hill Construction 2012; Sacks and Pikas 2013; Wu and Issa 2014). Traditionally, higher education is slow in adapting to societal and technological changes. Incapability of higher education to keep up with the changing competency expectation from industry partners has incentivized rapid development in global access to open online courses, competency-based digital training and independent certification programs, which seem to provide promising alternative education solutions outside of formal academe (McGraw-Hill Construction 2012; Wolfe and Andrews 2014). In the CM/CEM field, for example, courses from edEx, the Autodesk Building Performance Analysis Certificate (BPAC) program, and the ProCore certification series are exemplary open digital learning/training resources that may supplement conventional college curricula to help students develop relevant competency in these critical areas, and improve their preparedness for new performance expectations in workplace.

Considerable uncertainties, however, exist with regard to the relationship between higher education and emerging open digital learning solutions. The fundamental question is: will open digital learning necessarily compete or even completely replace formal higher education? If not, should there be a more inclusive and synergistic perspective to look at their coexistence? These uncertainties and the lack of best practices in leveraging these potentially valuable open digital learning resources are likely impeding the agility of higher education in attracting and retaining students, and preparing them to meet industry partners' demands for a competent workforce.

Amid the transition driven by emerging open digital learning, higher education faculty may be the most appropriate and best qualified people to lead the efforts in investigating and evaluating the challenges and opportunities associated with open digital learning, and to develop strategies and best practices of selecting and adopting open digital resources to foster student learning and success. The rationale behind this premise can be elaborated from three different perspectives. First and foremost, a key feature of effective teaching is the selection of instructional materials that meet the needs of students and fit the constraints of the teaching and learning environment (Committee on Undergraduate Science Education 1997). The scarcity of suitable instructional materials within the faculty community to address such emerging trends in the CM/CEM industry has been documented (Sacks and Pikas 2013; Wu and Issa 2014). It is thus imperative for faculty to either develop new contents from scratch or look for alternative reliable open resources to fulfill their instructional obligations. In the meantime, enhanced partnership between industry and academia in the CM/CEM disciplines has increasingly been regarded as the key factor to mitigate the classic gaps between workplace competency expectations and higher education student learning outcomes (SLOs). Faculty are often consulted by industry employers in terms of hiring and recruiting, with the expectation that faculty can convey clear messages of workplace performance requirements to the students, and help them develop corresponding competency. Last but not least, CM/CEM accreditation requirements such as the American Council for Construction Education (ACCE) accreditation have been transforming from topic-based to performance-based standards. This change significantly removes traditional constraints on faculty's choice on textbook and learning contents, and explicitly encourages enhanced communication between faculty and subject matter experts to achieve better alignment of student learning outcomes with industry-oriented, career-specific competency.

To date, increases in the number of online programs and course offerings are changing the role of the teachers and the nature of teaching, with more and more faculty and support staff required for online teaching (Bennett and Lockyer 2004). Teachers, who are at the center of this increasing demand and pressure to teach online, are being challenged to rethink their underlying assumptions about teaching and learning, and the roles they take as educators (Wiesenberg and Stacey 2008). However, while previous research has explored the definition of online teacher roles and competencies (Bennett and Lockyer 2004; Lee and Tsai 2010; Major 2010; Natriello 2005), less is known about how the role transition of faculty may impact student learning engagement, and what factors may influence such impacts.

2. LITERATURE REVIEW

2.1 Student Engagement and Learning Outcome

Recently, there is an increased emphasis on promoting student engagement and success in STEM education (Carey 2015). Student engagement pertains to the time and physical energy that students expand on activities in their academic experience (Jacobi et al. 1987; Kuh 2003), and it represents the efforts of the student to study a subject, practice, obtain feedback, analyze, and solve problems (Kuh 2003). Student engagement has emerged as a desirable target for intervention efforts due to perceptions of its direct linkage with learning outcomes, critical contributions to authentic and continued learning, and malleability (Clevenger et al. 2015; Fredricks et al. 2004). A plethora of empirical evidence has been garnered to endorse the importance of engagement for fostering student learning (Carini et al. 2006; Handelsman et al. 2005; Zhao and Kuh 2004), promoting student retention (Braxton 2008; Kushman et al. 2000; Woods 1995), enhancing educational quality assurance (Banta et al. 2009; Coates 2005), and impacting student persistence

(Milem and Berger 1997). Higher level of student engagement is thus frequently cited as an indicator of best practices in quality undergraduate STEM education (Fairweather 2008). The findings from 20 years of research on undergraduate education have been unequivocal: the more actively engaged students are – with college faculty and staff, with other students, and with the subject matter they study – the more likely they are to learn, to stick with their studies, and to attain their academic goals (Carini et al. 2006; McClenney and Marti 2006). Similar conclusions were also drawn in research investigating online engagement and student learning (Hew 2016; Wong 2013).

With the advent of the Internet and Web, the amalgamation of knowledge and technology permits higher education to provide learning anytime, anyplace, and to anyone (Aggarwal and Bento 2000; Maeroff 2003). As online learning gains popularity, however, stakeholders continue to demand greater accountability and evidence of effectiveness in teaching (Wilbur 1998). Research in this area tends to focus on whether online learning is as effective as face-to-face learning in achieving learning outcomes. However, the evaluation of online learning needs to go beyond these measures and consider the quality of the learning experience as a whole. Measures of student engagement offer such an evaluation (Robinson and Hullinger 2008). A number of reasons distinguish the significance of understanding online and general student engagement, and engagement research needs to be sensitive to such a possibility in order to remain abreast of the changing dynamics of university education (Coates 2007). Accordingly, the National Survey of Student Engagement (NSSE) was created for on-campus education which includes Seven Principles of Good Practice in Undergraduate Education and have been widely applied to online learning (Robinson and Hullinger 2008).

Student engagement is driven by a broad spectrum of factors, which creates challenges and opportunities to assess and formulate intervention strategies in the absence of a unified definition that captures the scope, intent and parameters of engagement (Mandernach 2015). Literature on student engagement research leads to the convergence of a definition that emphasizes three interrelated dimensions: cognitive, behavioral, and affective, while highlighting the reciprocal responsibility of both the students and the institution to foster engagement (Chapman 2003; Clevenger et al. 2019; Handelsman et al. 2005; Kuh 2003).

2.2 Assessing Student Engagement and Learning

Research into student engagement assessment assumes that it is possible to identify activities and conditions linked with effective learning. Engagement is seen to comprise active and collaborative learning, participation in challenging academic activities, formative communication with academic staff, involvement in enriching educational experiences, and feeling legitimated and supported by university learning communities. Open digital learning resources such as massive open online courses (MOOCs) have arisen as a new form of educational provision occupying a space between formal online courses and informal learning (Walji et al. 2016). The challenge of engaging students in classes that incorporate open digital learning resources is currently challenging due to the intrinsic design factors and varied contexts of adoption. Researchers have considered how learner engagement in courses incorporating open digital learning resources might be designed by looking at three pedagogical aspects: teacher presence, social learning, and peer learning (Walji et al. 2016).

Several studies focused on measuring and evaluating student engagement in on-campus course using online learning systems and in digital learning environments. Coates (2007) evaluated the use of online systems to enhance campus-based student engagement. The study found that student engagement can be characterized as either intense, collaborative, independent, or passive based on the academic and social levels of the students. Findings showed that students can be more engaged using online systems specifically in independent style of engagement. Another study focused on analyzing the impact of web-based learning technologies on student engagement in face-to-face and online learning environments (Chen et al. 2010). The study showed a general positive relationship between web-based learning technology use and student engagement and desired learning outcomes (Chen et al. 2010).

On the other hand, a study was conducted to analyze the use of the four dimensions of student interaction in online learning environment, including three dimensions originally introduced by Moore's editorial in 1989: (1) interaction with the content, (2) interaction with the instructor, and (3) interaction with the students; in addition to interaction with the online system. The study showed that student interaction is a key element and instructors must overcome psychological and communication gaps that may result from the transactional distance associated with online learning to achieve successful online learning environment (Bouhnik and Marcus 2006; Moore 1989). Robinson and Hullinger (2008) conducted a study to measure student engagement in online courses using key engagement factors defined in the National Survey of Student Engagement (NSSE). The study showed that online students reported higher level of engagement as compared to on-campus freshman and senior students in the benchmark of NSSE in the four areas of active and collaborative learning, enriching educational experience, level of academic challenge, and student-faculty interaction

Similarly and more recent studies were conducted on student engagement in online environment. Kahu (2013) discussed the four dimensions of research perspectives on student engagement, including behavioral perspective that centers student behavior and institutional practice, psychological perspective that defines engagement as an individual psycho-social process, socio-cultural perspective that highlights the critical role of the socio-political context, and holistic perspective that takes a broader view of student engagement. McKnight et al. (2016) analyzed the use of technology in the current digital era to improve student learning with five key functions, including *improving access*, *enhancing communication and feedback*, *restructuring of teacher time*, *extending purpose and audience for student work,* and *shifting teacher and student roles*. Additionally, the study also showed that teachers use technology to connect students with each other on new information, ideas, and perspectives.

2.3 Faculty's Role in Student Learning and Engagement

Contact between faculty and students was ranked top of the Seven Principles of Good Practice in Undergraduate Education, which is the foundation to the NSSE framework, and considered to be the most significant factor in and indicator of student motivation and learning engagement (Chickering and Gamson 1987; Komarraju et al. 2010). As the institutional agents who are most proximal to the student experience, faculty are a dominant force in shaping, developing, facilitating and sustaining high levels of student learning engagement and outcomes (Chen et al. 2008; Klem and Connell 2004). Situated in the NSSE framework, much of the energy surrounding the undergraduate experience and student learning was placed on the two major responsibilities of faculty: teaching and research. Thus, faculty's role constitutes a part of the institutional environment and a key variable in research that studies the paradigm shift to improve the quality of undergraduate education, i.e. creating learning-centered institution and maximize students' learning through active and collaborative learning practices (Umbach and Wawrzynski 2005).

As online learning gains popularity in higher education, the traditional brick-and-mortar based classroom learning environment is migrating to a more sophisticated, technology-facilitated digital learning environment. The faculty-student interaction for online student learning and engagement can be enhanced by technology affordance (Robinson and Hullinger 2008). Since students' online learning behaviors may differ due to self-perceived social presence online and the drastically expanded access to subject matter resources, faculty's interaction with students online often goes beyond what was typically experienced in traditional classroom, to include learning materials curation, subject-specific mentoring, and learning community constructing and moderating (Wallace 2003). Online learning, both formal and informal, is considered an enabler and driving force toward student-centered competency-based education. As a result, competency development and career advice add up to the faculty's social presence along with their academic presence in online learning. In the global digital learning era, higher education and its faculty are in transition to become curators, evaluators, connectors and analysts for student learning and engagement (Wolfe and Andrews 2014).

3. PROPOSED NEW ROLE OF FACULTY

Uncertainties in the role of digital learning in student-centered competency-based construction education, and the lack of best practices in leveraging these otherwise readily available and valuable open digital learning resources are potentially impeding the agility of higher education in attracting and retaining students, and preparing them to meet industry expectations of a competent workforce. We propose that, higher education, and individual faculty members in construction and STEM education, should work to investigate and evaluate such uncertainties, and provide students with clear guidance on selecting and adopting open digital learning resources. In particular, we propose a shift from the faculty-dictated traditional brick-mortar classroom, to more proactive educators and pioneers in digital learning research frontiers who consciously create an organic technology-mediated learning community with enhanced faculty-student interaction, interfacing with a broader spectrum of stakeholders (Figure 1).

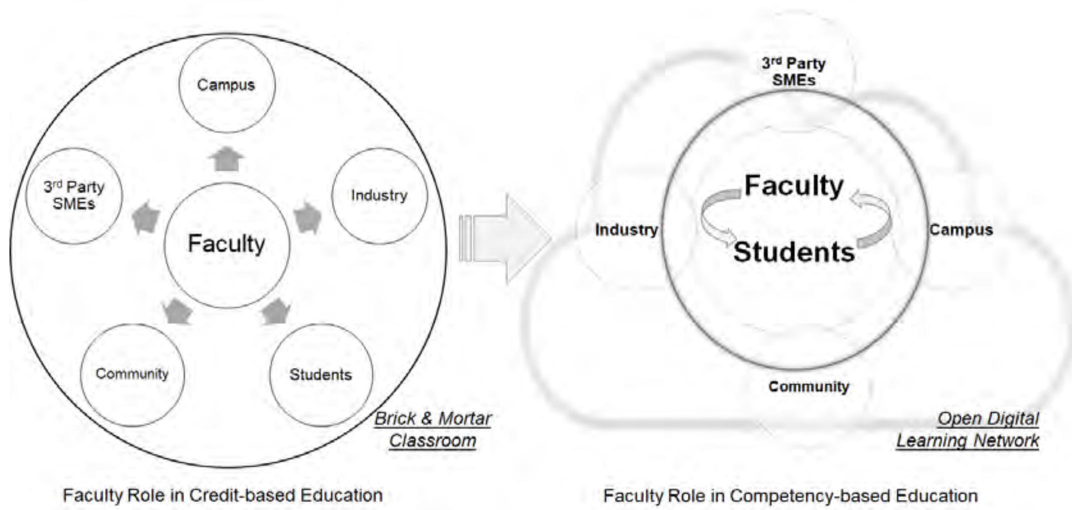

Figure 1. Conceptual transition of faculty's role from credit-based to competency-based education (Clevenger et al. 2019)

To fully address such opportunity, faculty roles must evolve and expand. In particular, there is need for faculty to transition to become curators, evaluators, connectors and analysts for student learning and engagement. To best do this, faculty should form synergistic partnerships among the project investigators, industry employers and subject matter experts (SMEs) to stay current and fully leverage available and external resources. Table 1 is a framework adapted from the one developed by Wolfe and Andrews (2014) and defines multiple roles that faculty may play in open digital learning.

Table 1**.** Multifaceted faculty roles in open digital learning, adapted from Wolfe and Andrews (2014).

Faculty's Roles	Description
Curator	Gather and curate open digital learning/training contents
Connector	Define learning outcomes and align workforce competencies via work meeting with industry employers and subject matter experts (SMEs)
Creator	Create learning modules and design learning activities
Assessor	Conduct meaningful assessments on student engagement and learning outcomes
Certifier	Certify student career-specific competency development with endorsement by industry employers and SMEs

Engagement with a broader spectrum of stakeholders and digital users and experts will also assist open digital learning/training programs gain more acceptance in the marketplace and professional communities. Through their new, emerging and multi-dimensional roles, faculty will develop deeper ties and engage more readily with industry. The intended outcome is not only to improve student learning outcomes, but also to generate and sustain more efficient, industry-relevant education, which better serves the ever evolving construction industry.

A Theory of Change (TOC) is also proposed to provide peer educators in CM/CEM with theoretic and practical guidance on creating intervention strategies to transform their own curriculum by focusing on transitioning faculty roles in using open digital learning contents. A TOC is a theory of how and why an initiative works (Weiss 1995). The proposed TOC will address both desired long-term impact and intermediate outcomes pursued in this project, facilitate backward mapping, identify preconditions and articulate intervention strategies to create these preconditions. Also, it will establish performance metrics and help evaluate factors that may enhance or limit the project success. This research envisions the long-term impact as a competency-based and student-centered STEM education experience for undergraduate students, which will prepare them with essential knowledge and job-specific skills when joining the STEM workforce. Various preconditions (intermediate outcomes) at different levels will need to be present to reach the long-term impact. The expected outcome of this proposed project is specific to CM/CEM disciplines, and aims to cultivate a more competent construction and engineering workforce. Figure 2 illustrates the programmatic representation of the proposed TOC. From left to right, it clearly identifies the necessary *input* and *activity* in order to produce the target *output and outcome*, and eventually lead to the desired long-term impact. While in application, the TOC should be started with the end in mind: working from the right to the left and performing cyclic implementation and consistent evaluation to ensure success.

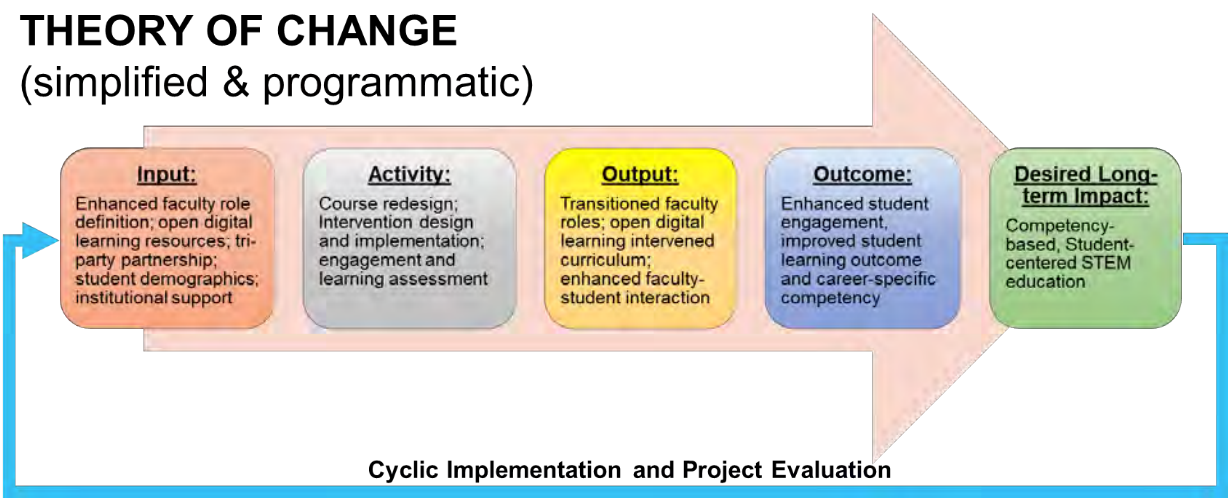

Figure 2. A simple programmatic representation of the proposed TOC

CONCLUSIONS AND FUTURE WORK

The construction industry in the US contributed with approximately $1.35 trillion (4.3%) to the national Gross Domestic Product (GDP) in 2015. Such scale highlights the importance of advancing the existing construction and engineering education by addressing the imperatives. A top priority for college construction management and construction engineering and management programs is to increase the undergraduate and graduate student pipeline by engaging them in the field of study, helping them attain essential knowledge, skills, and develop career-specific competencies driven by emerging trends. The contribution of this research is to encourage greater integration of open digital learning resources into construction education to enhance existing curricula and benefit programs across the nation to align student learning outcomes with industry expectations on job-specific competencies, and to motivate construction faculty to partner with industry and further integrate digital learning resources to advance the existing learning environmental and maximize student learning outcomes. Further research is recommended to evaluate the impact of such recommendations on construction education, student academic success and on the construction workforce, in general.

REFERENCES

Aggarwal, A. K., and Bento, R. (2000). "Web-based education." *Web-based learning and teaching technologies: Opportunities and challenges*, A. Aggarwal, ed., Idea Group, Hershey, PA.

Banta, T. W., Pike, G. R., and Hansen, M. J. (2009). "The use of engagement data in accreditation, planning, and assessment." *New Directions for Institutional Research*, 2009(141), 21-34.

Bennett, S., and Lockyer, L. (2004). "Becoming an Online Teacher: Adapting to a Changed Environment for Teaching and Learning in Higher Education." *Educational Media International*, 41(3), 231-248.

Bouhnik, D., and Marcus, T. (2006). "Interaction in distance-learning courses." *Journal of the American Society for Information Science and Technology*, 57(3), 299-305.

Braxton, J. M. (2008). "Toward a scholarship of practice centered on college student retention." *New Directions for Teaching and Learning*, 2008(115), 101-112.

Carey, S. J. (2015). "Navigating Institutional Change for Student Success in STEM: From the Editor." *Peer Review*, 17(2), 1-1.

Carini, R. M., Kuh, G. D., and Klein, S. P. (2006). "Student engagement and student learning: Testing the linkages." *Research in Higher Education*, 47(1), 1-32.

Chapman, E. (2003). "Alternative approaches to assessing student engagement rates." *Practical Assessment, Research & Evaluation*, 8(13), 1-7.

Chen, H. L., Lattuca, L. R., and Hamilton, E. R. (2008). "Conceptualizing Engagement: Contributions of Faculty to Student Engagement in Engineering." *Journal of Engineering Education*, 97(3), 339-353.

Chen, P.-S. D., Lambert, A. D., and Guidry, K. R. (2010). "Engaging online learners: The impact of Web-based learning technology on college student engagement." *Computers & Education*, 54(4), 1222-1232.

Chickering, A. W., and Gamson, Z. F. (1987). "Seven Principles for Good Practic in Undergraduate Education." *AAHE Bulletin*, Mar, 3-7.

Clevenger, C. M., Abdallah, M., Wu, W., and Barrows, M. (2019). "Assessing an Online Tool to Promote Sustainability Competencies in Construction Engineering Education." *J Prof Iss Eng Ed Pr*, 145(1).

Clevenger, C. M., Ozbek, M. E., Fanning, B., and Vonfeldt, S. (2015). "Case Study of Work-based Learning Involving BIM for Infrastructure in Support of Graduate Construction Research." *International Journal of Construction Education and Research*, 11(3), 163-178.

Coates, H. (2005). "The value of student engagement for higher education quality assurance." *Quality in Higher Education*, 11(1), 25-36.

Coates, H. (2007). "A model of online and general campus-based student engagement." *Assessment & Evaluation in Higher Education*, 32(2), 121-141.

Committee on Undergraduate Science Education (1997). *Science Teaching Reconsidered: A Handbook*, National Academy Press, Washington, D.C.

Fairweather, J. (2008). "Linking Evidence and Promising Practices in Science, Technology, Engineering, and Mathematics (STEM) Undergraduate Education."

Fredricks, J. A., Blumenfeld, P. C., and Paris, A. H. (2004). "School engagement: Potential of the concept, state of the evidence." *Rev Educ Res*, 74(1), 59-109.

Handelsman, M. M., Briggs, W. L., and Sullivan, N. T., A. (2005). "A measure of college student course engagement." *Journal of Educational Research*, 98, 184-191.

Hew, K. F. (2016). "Promoting engagement in online courses: What strategies can we learn from three highly rated MOOCS." *British Journal of Educational Technology*, 47(2), 320-341.

Jacobi, M., Astin, A., and Ayala, F., Jr. (1987). *College Student Outcomes Assessment: A Talent Development Perspective*, Clearinghouse on Higher Education, Washington, DC.

Kahu, E. R. (2013). "Framing student engagement in higher education." *Studies in Higher Education*, 38(5), 758-773.

Klem, A. M., and Connell, J. P. (2004). "Relationships Matter: Linking Teacher Support to Student Engagement and Achievement." *Journal of School Health*, 74(7), 262-273.

Komarraju, M., Musulkin, S., and Bhattacharya, G. (2010). "Role of Student–Faculty Interactions in Developing College Students' Academic Self-Concept, Motivation, and Achievement." *J Coll Student Dev*, 51(3), 332-342.

Kuh, G. D. (2003). "What We're Learning About Student Engagement From NSSE: Benchmarks for Effective Educational Practices." *Change*, 35(2), 24-32.

Kushman, J. W., Sieber, C., and Heariold-Kinney, P. (2000). "This isn't the place for me: School dropout." *Youth at risk: A prevention resource for counselors, teachers, and parents*, D. Capuzzi, and R. G. Douglas, eds., American Counseling Association, Alexandria, VA, 471-507.

Lee, M.-H., and Tsai, C.-C. (2010). "Exploring teachers' perceived self efficacy and technological pedagogical content knowledge with respect to educational use of the World Wide Web." *Instructional Science*, 38(1), 1-21.

Maeroff, G. I. (2003). *A classroom of one: How online learning is changing our schools and colleges*, Pagrave MacMillan, New York.

Major, C. H. (2010). "Do Virtual Professors Dream of Electric Students? University Faculty Experiences with Online Distance Education." *Teachers College Record*, 112(8), 2154-2208.

Mandernach, B. J. (2015). "Assessment of Student Engagement in Higher Education: A Synthesis of Literature and Assessment Tools." *International Journal of Learning, Teaching and Educational Research*, 12(2), 1-14.

McClenney, K. M., and Marti, C. N. (2006). "Exploring Relationships between Student Engagement and Student Outcomes in Community Colleges: Report on Validation Research." The University of Taxas at Austin.

McGraw-Hill Construction (2012). "Construction Industry Workforce Shortages: Role of Certification, Training and Green Jobs in Filling the Gaps." McGraw-Hill Construction, Bedford, MA.

McKnight, K., O'Malley, K., Ruzic, R., Horsley, M. K., Franey, J. J., and Bassett, K. (2016). "Teaching in a Digital Age: How Educators Use Technology to Improve Student Learning." *Journal of Research on Technology in Education*, 48(3), 194-211.

Milem, J. F., and Berger, J. B. (1997). "A modified model of college student persistence: Exploring the relationship between Astin's theory of involvement and Tinto's theory of student departure." *J Coll Student Dev*, 38(4), 387-400.

Moore, M. G. (1989). "Editorial: Three types of interaction." *American Journal of Distance Education*, 3(2), 1-7.

Natriello, G. (2005). "Modest Changes, Revolutionary Possibilities: Distance Learning and the Future of Education." *Teachers College Record*, 107(8), 1885-1904.

Robinson, C. C., and Hullinger, H. (2008). "New Benchmarks in Higher Education: Student Engagement in Online Learning." *Journal of Education for Business*, 84(2), 101-109.

Sacks, R., and Pikas, E. (2013). "Building Information Modeling Education for Construction Engineering and Management. I: Industry Requirements, State of the Art, and Gap Analysis." *Journal of Construction Engineering and Management*, 139(11), 04013016.

Umbach, P. D., and Wawrzynski, M. R. (2005). "Faculty do Matter: The Role of College Faculty in Student Learning and Engagement." *Research in Higher Education*, 46(2), 153-184.

Walji, S., Deacon, A., Small, J., and Czerniewicz, L. (2016). "Learning through engagement: MOOCs as an emergent form of provision." *Distance Education*, 37(2), 208-223.

Wallace, R. M. (2003). "Online Learning in Higher Education: a review of research on interactions among teachers and students." *Education, Communication & Information*, 3(2), 241-280.

Weiss, C. H. (1995). "Nothing as Practical as Good Theory: Exploring Theory-based Evaluation for Comprehensive Community Initiatives for Children and Families." *New Approaches to Evaluating*

Community Initiatives: Concepts, Methods, and Contexts, J. P. Connell, A. C. Kubisch, L. B. Schorr, and C. H. Weiss, eds., Aspen Institute, Washington, DC.
Wiesenberg, F. P., and Stacey, E. (2008). "Teaching Philosophy: Moving from Face-to-Face to Online Classrooms." *Canadian Journal of University Continuing Education*, 34(1), 63-79.
Wilbur, S. (1998). "Creating a community of learning using web-based tools." *The digital university: Reinventing the academy*, R. Hazemi, S. Hailes, and S. Wilbur, eds., Springer-Verlag, London, 73-83.
Wolfe, J. K., and Andrews, D. W. (2014). "The changing roles of higher education: curator, evaluator, connector and analyst." *On the Horizon*, 22(3), 210-217.
Wong, L. (2013). "Student Engagement with Online Resources and Its Impact on Learning Outcomes." *Proceedings of the Informing Science and Information Technology Education Conference 2013*, E. Cohen, and E. Boyd, eds., Informing Science Institute, 129-146.
Woods, E. G. (1995). "Reducing the dropout rate." *School Improvement Research Series (SIRS): Research you can use*Portland, OR.
Wu, W., and Issa, R. R. A. (2014). "BIM Education and Recruiting: Survey-Based Comparative Analysis of Issues, Perceptions, and Collaboration Opportunities." *J Prof Iss Eng Ed Pr*, 140(2), 04013014.
Zhao, C. M., and Kuh, G. D. (2004). "Adding value: Learning communities and student engagement." *Research in Higher Education*, 45(2), 115-138.

SCAN-BIM-FEA STRUCTURAL INTEGRITY INVESTIGATION IN CURTAIN WALL

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ABSTRACT

Evaluating the structural integrity of curtain walls during the life cycle of a building project can assist architects in developing better designs, inform manufacturers on the needs to produce stronger building elements, help contractors establish better installation methods, and allow facilities managers make informed maintenance decisions. Data obtained and recorded from manual inspections is inaccurate, insufficient and unreliable. A case study included in this paper presents the effort to identify a seamless association between three different technologies used to evaluate structural integrity, specifically deformities as the focus of this study, in building elements. A curtain wall component of an existing building was investigated in this study. As more buildings incorporate daylighting, storefront and curtain wall construction has become a much larger portion of the building envelope. Although Finite Element Analysis (FEA) for structural analysis has been studied with regards to its use in conjunction with BIM, curtain wall analysis has been limited. The study included the steps as follows: a LiDAR scan was obtained and then a 3D as-built model was created from a set of point clouds, and further analysis was completed using FEA to potentially identify any structural issues. The combination of scan-to-BIM to FEA was used to showcase the potential of software packages already in use in the design and construction industry. To obtain exact geometry of the wall, 3D laser scanning, using a Faro Focus3D Lidar scanner was used to accelerate the data collection process. Scene software was then used to automatically register the multiple scans to develop an as-built model of the curtain wall. Lastly, FEA on the BIM model of the curtain wall was completed. When conducting FEA, the model is split into minute elements which act as a prototype on which the forces are applied, and stresses are developed accordingly. These stresses are developed on one singular element which represents the stresses developed on the entire wall system. SolidWorks structural analysis software was used for FEA. The results from FEA informs of deformities in the structure and shows the amount of load the structure can support before there is risk of structural damage. This harmonious three-step technique quickens the entire process of identifying the risks to a building element and the more prevalent use for these commonly used software packages would be beneficial to all the stakeholders involved in the life cycle of the building, including professionals in design, construction, and facilities management (FM). The process was transcribed into a "how-to" manual to share and enable teaching FEA in the classroom using these technologies.

Keywords: Laser scanning, Finite Element Analysis, LiDAR, BIM.

1. INTRODUCTION

In the early 2000s, the architectural, engineering and construction industry recognized that quick, precise and automated project progress tracking was needed (Bosche et al., 2014). The construction industry can save money and time by automating the process of planning for challenges like errors, risks, and costs of construction in the project. Similarly, laser scanning, BIM and FEA have automated processes offering a great advantage in reducing discrepancies between the as-planned and as-built models that either go unnoticed due to human error or are not reflected in the design documents. Knowing the inconsistencies beforehand will assist in taking remedial actions on time, and saving money specially allocated for contingencies. Since terrestrial laser scanning is revolutionizing surveying works making dimensional control results more reliable, it is understandably also an applicable tool to develop as-built 3D model (while BIM is valuable in acquiring planned models) (Bosche and Guenet., 2014). With a precise BIM model, facility managers can integrate building operation and maintenance schedules, which would allow them to locate the repairs and update them accordingly (Bosche et al.,2014). Laser scanning during the construction process can help locate structural deformities and BIM can act as a database and documentation for the constructed structure, and in BIM it is interoperable to different stakeholders for various formats (Ghaffarianhoseini et al., 2016). By performing FEA on the recorded data, an analysis highlights the structural deformities due to various loads on that building element. This paper assists to test the integration of these three techniques through a case study, and to graphically show where the deformities might occur in the building. This case study involves a curtain wall as the structural element from one of the buildings on the University of North Carolina at Charlotte (UNC Charlotte) campus. The main objective of this study was to perform finite element analysis on the curtain wall model to investigate the structural integrity, specifically deformities, of the curtain wall. A 3D as-built model of the curtain wall was created by automated recording of the dimensions and geometry through laser scanning. This model is stored in the BIM database to add required material properties and make changes as required for performing FEA. The significance of the study is an initial investigation of steps to investigate structural integrity and additionally, to obtain an as-built model and the interoperable BIM format.

2. LITERATURE REVIEW

2.1 Integration of 3D laser scanning and Building Information Modelling (BIM)

3D laser scanning. The creation of the as-built 3D model needs the acquirement of geometric data, traditionally measured by hand (e.g. measuring tapes) or by progressive techniques such as total stations, photogrammetry and laser scanning (Barazzetti et al., 2015). A laser scanner sweeps its entire surrounding space with laser light to acquire 3D data point with high accuracy, high density and great speed (Bosche & Guenet, 2014). A laser scanner captures distance measurements of surfaces which are perceptible from the vantage point of the sensor, and these dimensions can be transformed into 3D points called a point cloud (Xiong et al., 2013). Some advantages offered by 3D laser scanner as assessed with respect to other contact-type sensors used in the AEC industry include: 1) It can quickly measure a large structure or a huge surface profile. 2) The point cloud data obtained from a scanned surface has a millimeter-level accuracy and spatial resolution. 3) It can offer long-range measurement up to 6,000 m depending on the type of scanner. Due to these benefits, the 3D laser scanning technique is executed in the construction industry for 3D modelling of structures, topographical surveys and monitoring the construction progress and also, safety through detecting deflection and deformation (Kim et al., 2014). For this case study, laser scanning is used as a stepping stone in creating the as-is BIM model which can be further analyzed by FEA, to determine the structural risks of the curtain wall or storefront building elements.

Building information modelling and its benefits. The drawbacks and chores of previous 2D formats propelled the experts to move to better 3D technologies benefiting them in saving huge volumes of spatial and geometric data for designing and effectively condense the cost and resources (Alizadehsalehi et al., 2015). Azhar et al. (2008), mentions Building information modelling as a data-rich, object-oriented and intelligent parametric digital depiction of the proficiency from which the appropriate data and views for respective users can not only be obtained but evaluated to generate decision making significant information. Information stored in BIM software can be input into databases so that it can be queried, reused and manipulated as needed (McGuire et el., 2016). The ability of BIM in adding textural information (properties, materials, geometry, lifecycle, spatial relationships, geographic information, quantities, fire ratings for building product materials, finishes, costs, carbon content) to designed objects keeps BIM at the forefront of exploring future capabilities. The availability of all these features in one software also allows the project stakeholders to keep track of the relationships between the building elements and their respective maintenance details (Ghaffarianhoseini et al., 2016).

Integrating these two technologies (scanning and BIM) has proven to be a boon to the construction industry. Point clouds can be used for some applications such as clash detection, but another useful feature is creating a 3D structural model which is transported to BIM and a more accurate BIM 3D model is developed. This as-is BIM model from point clouds, converted to a Revit model, allows assessment and manipulation of the model at the component level i.e. doors or windows etc., rather than at the point level. This process is more natural, efficient, compact and seamless. This two-step technique of converting point cloud data into an as-is BIM model is referred to as 'Scan-to-BIM'(Xiong et al., 2013). This article describes in the case study work, how the point cloud data was transformed into a BIM model from an as-is BIM model for use in FEA analysis.

2.2 Integration of Building Information Modelling (BIM) and Finite Element Analysis (FEA)

The finite element method is popularly used, and its application in the field of construction for structural analysis is a very effective numerical method which is globally recognized.

What is FEA? Finite element analysis is a numerical technique for solving problems which are described by partial differential equations or can be formulated as functional minimization (Nikishkov, 2004). For a computer to decipher these equations, numerical techniques have been developed over the last few decades and one of the most prominent today is the finite element method (Simscale, 2016). In FEA a large problem is partitioned into simple finite elements and generates equations modelling these elements. These finite elements when assembled together gives calculations/numerical values for larger systems, modelling the entire problem. A continuous physical problem is transformed into a discretized finite element problem with unknown nodal values (Nikishkov, 2004). In other words, rather than attempting to solve larger problems directly in FEA, components are divided into smaller and more easily solvable problems, providing unique results for the system as a whole. Nikishkov (2004) summarized the important features of FEA in two areas: 1) Approximating the physical problem piece-wise into finite elements provides good accuracy even with simple approximating functions (Precision/accuracy is directly proportional to the number of elements in FEM) and 2) Locality of approximation leads to sparse equation systems for a discretized problem, assisting to solve problems with very large number of nodal unknowns.

From BIM to Finite Elements. For the structural analysis, a BIM model must be converted into a simplified format to perform specific and advanced simulations. Hence the seamless integration of the techniques BIM to FEA is a significant need for analysis. The traditional FEM tactics preferred in structural analysis depend on the simplifications of the structural elements into 1D (beams, trusses) or 2D (plates, shells) elements, which can be easily divided into simpler 2D finite elements (Barazzetti et al., 2015). BIM to FEA transference requires further research for the uses in complex vaulted historical structures, as their geometry is difficult to develop and discretize. But the integration of 3D FEA and BIM technology is readily achievable for simple regular shaped building elements with basic geometry which is easily isolatable (Barazzetti et al., 2015). This is possible through a variety of software options. For instance the structural analysis tool, Solidworks is fully integrated with Revit. A variety of plugins are available to ensure interoperability with other structural analysis software like Midas FEA or Ansys. Other software tools currently used in industry include Risa and RAM Elements. These tools allow the transferr of the model contents from Revit to obtain a simplified version for finite element analysis (Barazzetti et al., 2015). However there are disadvantages to these plugins currently in that they are applicable only if the geometry of the structure is not too complex. For this reason, this case study utilizes a building with an uncomplicated geometric structure. Input parameters for performing FEA include boundary conditions, material properties and loading conditions which are partially available from the BIM model and also partially manually entered, whereas the irregular stress information or deformation patterns can be easily recognized under self-weight (Barazzetti et al., 2015). The interoperability feature (export files for other uses) of BIM is immensely helpful in FEA, as the model and structure information developed in BIM is transferred directly into the simpler export model of FEA to perform simulations and examine the structure for deformities from excessive loading.

3. METHODOLOGY

The planned case study included a proposed five-step technique (Figure 1) for scanning and analysis of a curtain wall in an existing building located on the UNC Charlotte campus. Once scanning was complete, files were converted from the point cloud into an as-is BIM model which could then be used to perform finite element analysis. The goal of the analysis was to determine where and how much the wall would deform due to planned dead and wind loads.

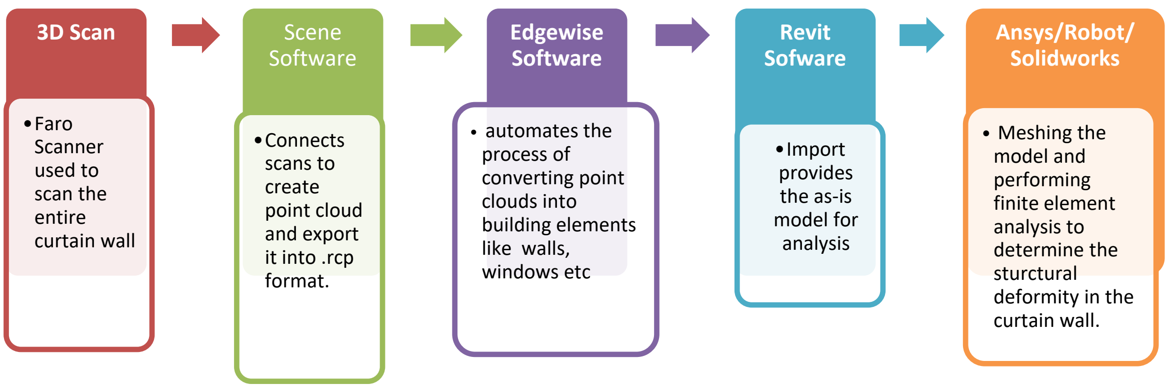

Figure 1: Sequence of Software Uses (and file types)

Step 1. Collection of Point Cloud Data. The equipment used in this process was a Faro Focus3D Lidar scanner with the capability to scan up to a maximum distance of 130 meters (approximately 427 feet). The scanner was relocated for each scan to attempt to obtain sufficient coverage of the curtain wall as suggested by Xiong et al. (2013). It took 5 scans to document the entire wall with each scan taking approximately 8 minutes. The scanner was also used to obtain photos and the camera function of the scanner can capture photos at a resolution of 70 megapixels.

Step 2. Data Registration. The point clouds collected from the different locations were combined by the process known as registration (Xiong et al., 2013). Scene software was used to complete the registration of point clouds and it involves several tasks: all the scans are import into Scene; remove all the unnecessary noise from the point cloud; all the scans are combined or registered together to form a single 3D volumetric image; explore this 3D image and edit if when necessary; export the final 3D image into a file that can be used for further analyses. This entire process can take up to several hours to accomplish.

Step 3. Development of the BIM Model. To transition the point cloud into the Revit software, the researchers used Scene to export the file into an rcp file. This rcp file is then imported into Revit to create and begin a BIM model. Edgewise software was used to create elements such as walls, doors and windows automatically from the point cloud, by grouping all the points on one plane as one component. Once the scans were processed in Edgewise, the levels were assigned manually, so that when this model is transferred to a BIM software package, they automatically detect actual levels and heights. From the scanned point clouds, all the points are grouped into walls and components such as doors and windows. At this point, the goal is not to form an as-is BIM model, but a very rough head start for the 3D model for analysis. However, the benefits of Revit as a software is that it is supported by a parametric change engine so additional data included in the model to later provide information for facilities is best supported during this step (Demchak et al., 2009).

One benefit of the Scene software is its heatmapping feature which can determine the existing deformities of the surface by detecting the distance of the points from the standard selected plane. Figure 2 shows the results from this step in the process. In this figure, structural components that have larger than normal deformities are highlighted in red. This feature enables facilities managers have a quick understanding of the existing conditions of curtain walls, and can make prompt maintenance decisions even before a FEA is performed.

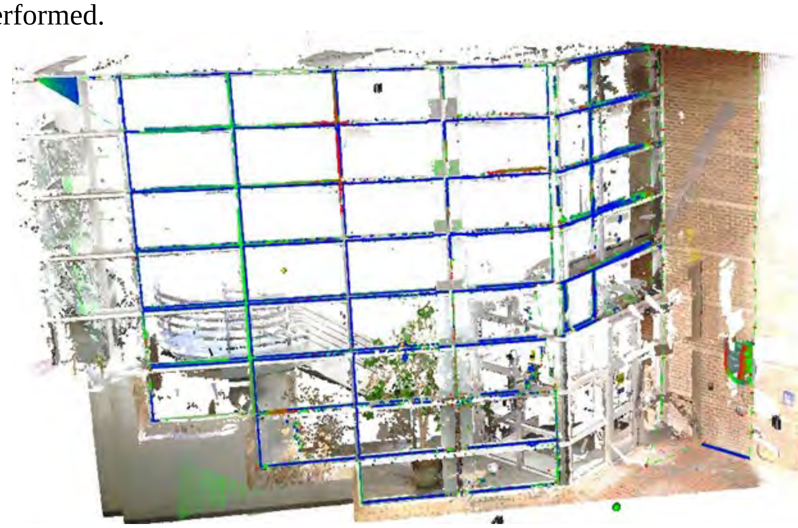

Figure 2: Heat Mapping of the Cameron Building Curtain Wall

Revit is one of the most widespread and broadly used BIM software packages because along with this interoperable features it also offers custom families and user defined parameters. For this reason, using Revit for this study assisted with the goal to create and compare two models, one directly from the point cloud (using the heatmap visualization) while the other one included the additional Edgewise model and a full FEA analysis. Detailing the rough Edgewise model in Revit provided the as-is BIM model of the curtain wall and showcased a potential benefit for facility managers after the structure exists. The heat mapping and the recognition of the deformities by comparing the two BIM models and the existing deformation to the curtain wall.

Step 4. FEA Analysis. The main objective of this research was to utilize a case study using various software packages to assess curtain wall structures – and with the use of a structural software which would assist in performing FEA on the model. Robot Structural analysis software from Autodesk was initially chosen to perform FEA on the model, but due to limitations in accessibility of that software and certain challenges in learning Robot, it became necessary to use Ansys, another structural software. To transfer the model information from Revit to Ansys, the Revit file needs to be imported and then converted into .iges file which is the preferred format for Ansys software. But the educational version of Ansys available has its limitations and could create only 20,000 entities after meshing. These entities formed a really course mesh for the curtain wall and the resulting deformities are not accurate. Eventually SolidWorks was chosen as the FEA software because of its availability and satisfactory functionalities. SolidWorks allows the import of the Revit file directly into SolidWorks in a format standard called ACIS format or .sat format, which was straightforward.

4. RESULTS

After the performing FEA on the curtain wall, SolidWorks helped graphically represent the deformation on the curtain wall. After updating the SolidWorks model with material properties of the curtain wall, loading it with dead load and wind load and adding the boundary conditions of the wall, it is meshed into smaller components. The software calculated the dead load of the wall after a gravitational force was applied to it while the wind load had to be manually calculated for each glass panel of the wall. The wind load, that was calculated with a help of a wind load calculator, and applied was maximum 7.89 lbf as an equivalent point load for every glass panel. The wind load gradually decreased towards the bottom of the curtain wall. These two loads together created certain deformities in the curtain wall which was graphically represented in SolidWorks, Figure 3.

By comparing Figure 2 and Figure 3, it is evident that maximum deformation which is not more than 0.15mm is at the top center of the wall. The heat map (Figure 2) shows the deformation that exists currently, while the results from SolidWorks shows the computer generated deformation due to wind load and dead load. The similarity between Figure 2 and Figure 3 may assist in post-construction applications to evaluate actual deformities as compared to the design analysis.

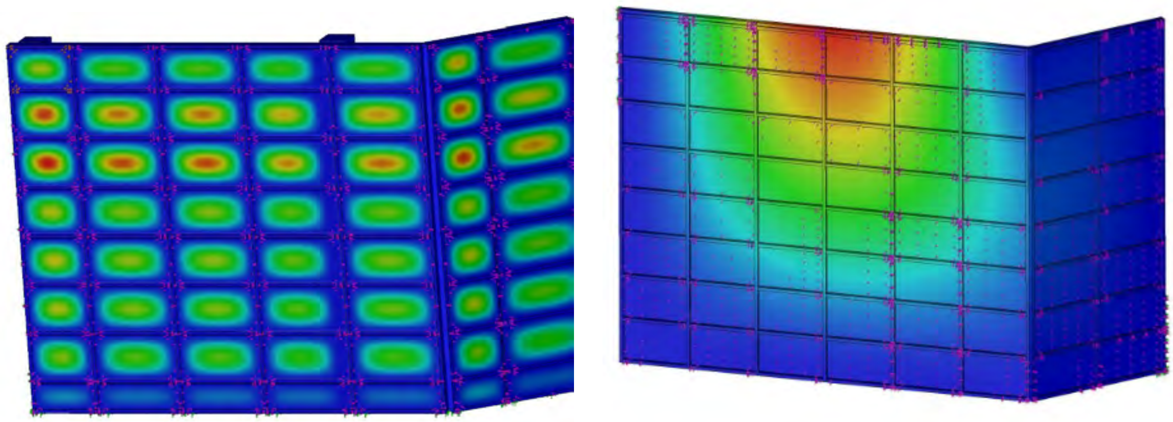

Figure 3: Deformation for Design Model (L) and As-Built (R)

These results aid in identifying the structural risks to a building element and furthermore, may can assist architects in developing better designs, inform manufacturers on the needs to produce stronger building elements, help contractors establish better installation methods, and allow facilities managers make informed maintenance decisions.

5. CONCLUSION AND FUTURE WORK

The main goal of this study was to investigate structural integrity of curtain walls using a Scan-BIM-FEA process. This was achieved by developing a framework that allows the integration of multiple software packages to provide an accurate BIM model generated from point clouds, meshed to perform structural analysis by using FEA as a medium. Similar to Barazzetti et al., this work is more laser scanning and BIM focused where FEA is just an additional step in workflow. This study not only depends on generation of the new model for structural analysis but emphases more on the transition between the three different technologies utilized together to save money and time in the construction industry. As a result, the demand for more research on 3D laser scanning, BIM and FEA, and an integration of these technologies is needed. This three-step technique is very advantageous, especially where simple geometric shapes can be analyzed efficiently. The technique appears to be seamless, but is not completely hassle free. The work carried out to perform automated point cloud-BIM-FEM conversion as a starting point as manual corrections are still required because of the absence of 'intelligent' algorithms (Barazzetti et al., 2015). Autodesk Robot Structural analysis software was the first preference for structural analysis of this wall, but due to issues related to usability, a switch to SolidWorks was made. The transference from one format to another to import into different software, is not challenging but is not completely harmonious either. Revit doesn't allow exporting data into .iges format, which is the preferred import format for several software packages. As a result the help of AutoCAD is required. This study is only applicable to regular shaped curtain wall, as circular walls are not easily identifiable in the Edgewise software. Apart from the limitations in the programming of the software, recognition of the discrepancies between the as-is BIM model geometry and the as-planned BIM model geometry is not completely automated, but involves manual corrections. Future work is needed specially on the programming of the Laser scanning and BIM software, to accommodate smooth transition between different formats, and also recognition of variety of shapes and geometry. Some manual methods to identify the deformations between as-is and as-planned dimensions can be automated in the future. User interface, error recognition and help availability, can make Robot a more widely preferred software for Structural analysis of construction elements and components, since it provides a simpler smoother link between BIM-to-FEA as compared to other software.

REFERENCES

Alizadehsalehi S., Koseoglu O. and Celikag M. (2015) "Integration of Building Information Modeling (BIM) and Laser Scanning in Construction Industry." *AEI 2015: Birth and Life of the Integrated Building conference.*

Azhar, S., Hein, M., & Sketo, B. (2008). "Building Information Modeling (BIM): Benefits, Risks and Challenges." *Proceedings of the 44th ASC Annual Conference (on CD ROM).*

Barazzetti L., Banfi F., Brumana R., Gusmeroli G., Previtali M., and Schiantarelli G. (2014). "Cloud-to-bim-to-fem: structural simulation with accurate historic bim from laser scans." *Simulation modelling practice and theory*, vol. 57, pp. 71–87.

Bosché F., Ahmed M., Turkan Y., Haas C. and Haas R. (2014). "The value of integrating Scan-to-BIM and Scan-vs-BIM techniques for construction monitoring using laser scanning and BIM: The case of cylindrical MEP components." *Automation in Construction*, vol 49, pp 201-213.

Bosché, F., and Guenet, E. (2014). "Automating surface flatness control using terrestrial laser scanning and building information models." *Automation in Construction*, vol 44, pp 212–226.

Demchak, G., Dzambazova, T., and Krygiel, E. (2009). Introducing Revit Architecture 2009: BIM for beginners.

Simscale blog (2016). FEA. Retrieved from: https://www.simscale.com/blog/category/fea/ (visited on 08/08/2018).

Ghaffarianhoseini A., Tookey J., Naismith N., Azhar S., Efimova O. and Rahemifar K. (2016). "Building Information Modelling (BIM) uptake: Clear benefits, understanding its implementation, risks and challenges". *Renewable and Sustainable Energy Reviews* , vol. 75, pp 1046-1053.

Kim M., Cheng J., Sohn H. and Chang C. (2014). " A framework for dimensional and surface quality assessment of precast concrete elements using BIM and 3D laser scanning." *Automation in Construction*, vol 49, pp 225-238.

McGuire B., Atadero R., Clevenger C. and Ozbek M. (2016). "Bridge Information Modelling for Inspection and Evaluation." *The journal of Bridge Engineering : American society of Civil Engineers.*

Nikishkov G. (2004). "Introduction to the Finite element method." *Lecture Notes, University of Aizu, Aizu-Wakamatsu 965-8580, Japan.*

Xiong X., Adan A., Akinci B., Huber D., (2013). "Automatic creation of semantically rich 3D building models from laser scanner data." *Automation in construction*, vol 31, pp 325-337.

Software Packages

Autodesk Revit: http://www.autodesk.com/products/revit-family/overview.
SolidWorks: https://www.solidworks.com/
FARO- SCENE: https://www.faro.com/products/product-design/faro-scene/
Edgewise: https://www.clearedge3d.com/products/edgewise-bim-suite/
Wind load calculator : https://www.engineeringtoolbox.com/wind-load-d_1775.html

CASE STUDY BASED BIM COURSE DELIVERY FOR CONSTRUCTION MANAGEMENT STUDENTS

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ABSTRACT

This paper presents the outcome of case study-based delivery of an Advanced Building Information Modeling (BIM), Scheduling and Estimating course. The course delivery consists of two tracks that are integrated throughout the semester; the first track consists of self-learning modules for software tools that can be used for integrating BIM with scheduling and estimating, and the second track is to identify and solve certain challenges related to estimating and scheduling that face construction companies. With the help of the course instructors and the Construction Management Department's Industry Advisory Boards, the students were teamed up with construction companies to identify certain technical challenges related to BIM, estimating, or scheduling that these construction companies are facing, and the students worked with these companies to find an innovative way to address these challenges. Each student then started the journey of advancing his/her technical skills to build the required technical competencies to find solutions for these challenges. Each student was teamed up with one company. In some cases, two students were allowed to team up to solve one challenge. The course work started first with preliminary assignments in BIM, estimating, and scheduling software along with literature reviews related to the latest development in BIM. Once the students engaged in discussions with their partner companies, they worked together to identify the scope of work to address these technical challenges, and each student started to research and build his/her knowledge base in order to address these issues. Students used available online tutorials, research articles, and books to learn the required skills. Students were also encouraged to contact the software developer and discuss these challenges with them to see if the available software can be used to address these challenges.

Since this course has a limited enrollment of not more than 10 student, the students were using a "collaborative suites" setting in which they could gather around a study table and connect their computers to a large screen and start the discussion for each project. In this way, students could share experience, learn to collaborate with their peers, share knowledge, and improve their communication skills.

Some of the challenges that were addressed in this class are: using BIM to automate shop drawings' production for partitions subcontractors, using BIM by masonry subcontractors for estimating building materials and labor, using BIM models in existing industrial buildings to improve the facilities management and maintenance, using BIM to schedule and coordinate building materials delivery to job sites, using BIM and scheduling software to provide visualization of construction activities for litigation purposes, and using BIM with structural analysis tools and 3D printing for feasibility studies of full scale 3D printing of low-cost and energy efficient homes.

The course outcome was outstanding; The students not only learned new BIM, advanced estimating and scheduling skills, but also learned how to address technical challenges that are facing the industry with the BIM evolving technology. The course also helps the students to relate what they learn in the class to the actual needs of the construction industry. As a result of this interaction between the students and industry, several students were offered jobs by the construction companies who they were partnered with, so they can continue their work beyond the scope of their coursework. Additionally, some of the students secured permanent jobs or promoted to leadership positions in their work.

Keywords: BIM, Learning Modules, Scheduling, Estimating

1. INTRODUCTION

Building Information Modeling (BIM) is the integration of “variety of activities in Object-oriented Computer Aided Design” (Ghaffarianhosein, 2017). BIM became the current trend in building representation especially in Design-Build projects. Major construction and architecture companies are moving from traditional Computer Aided Design (CAD) drafting to BIM. This move requires extensive efforts to migrate from 2D environment and adopt the new culture of using BIM. In order to adopt BIM, Architectural, Engineering and Construction companies need to build new libraries and templates of BIM models which are specific to their need. Adapting BIM also requires paying attention to certain legal risks, liabilities and challenges that comes with the benefits of using BIM (Azhar, 2001). These companies also need to develop training programs for their employees, and adopt new policies and procedures for creating and sharing BIM models. The reward for that is companies can taking advantage of the great potentials that come with BIM such as better coordination between trades and stake holders during the entire design process as well as integrating BIM model with project scheduling and estimating.

Much research was conducted to assess and propose BIM learning methodologies at college level; Cooksey examined the extent of teaching BIM to graduate and undergraduate Engineering students. The researcher found out that although integrating BIM across the curriculum will create a beneficial opportunity to teach BIM for engineering students especially for the Civil Engineers (Cooksey, 2011). However, the researcher did not address the teaching methodology that will prepare the students to adopt the different BIM needs for the different engineering areas.

Enshassi et al. conducted research on using BIM in Architecture, Engineering, and Construction industry in developing countries. They found out that BIM can benefit small and medium size companies in disarming life cycle cost, effective construction process, quality control, and decision making support (Enshassi, 2018). The research also highlighted the increasing use of BIM by Architecture and Engineering companies in developing countries such as Jordan. The researcher highlighted some of the challenges related to training and adopting BIM but did not provide details on how to address the required training for adopting BIM at these companies.

In his research “The integration of building information modeling (BIM) in sustainable architecture and construction education: case study in Pristina University”, Nushi accessed the integration of BIM development into the education system in Kosovo. Nushi argued that BIM should be integrated across the curriculum especially in Sustainable Architecture which was the subject of his study (Nushi, 2017). However, Nushi also did not provide a methodology on how to integrate BIM across disciplines, or how to integrate BIM teaching in the curricula so it can prepare the graduates for the relevant BIM related careers.

2. METHODOLOGY

The case-study based BIM teaching was introduced to graduate students in a graduate course at the Construction Management Department (CM) at Kennesaw State University (KSU). First, the students were given interactive multi-media instructions on the basics BIM skills. Second, the students were asked to complete BIM models for a small building. Third, the students were asked to contact Architecture, engineering, or Construction firms to identify a certain challenge that hinder their abilities to use BIM for their specific needs, and suggest BIM solutions for a design or construction problem that they face. The goal of this assignments is to prepare the students for advanced problem solving techniques especially adopting BIM in certain construction trades.

More than 20 students were enrolled in this course over a period of 5 years. The students addressed actual challenges that face the construction industry that can be overcome using BIM. These challenges related to design, estimating, scheduling, facilities management, constructability, value engineering, construction claims and construction visualization and clash detection. Below are some examples of these projects.

1.1 Case study 1: Scaffolding design and delivery

In this exercise, the student teamed up with a company that designs and construct commercial shelving for warehouses. The challenge was to generate BIM model to quantify and tabulate the different shelves components, create cost estimate, and schedule the delivery and construction. The BIM model will also help the contractor to schedule the delivery of thousands of pieces and locate them in certain locations for fast assemble. The BIM model was also imported to NavisWork software to integrate the model with the project schedule for planning and construction sequence visualization. In this case, the student not only learned how to use BIM, but also researched how to customize the estimating tables that was generated through the BIM model, and integrate it with the pay application and the scheduling. The contractor whom the student teamed up with also realized the advantage of using BIM to have a lean construction process and coordinate with the other construction trades.

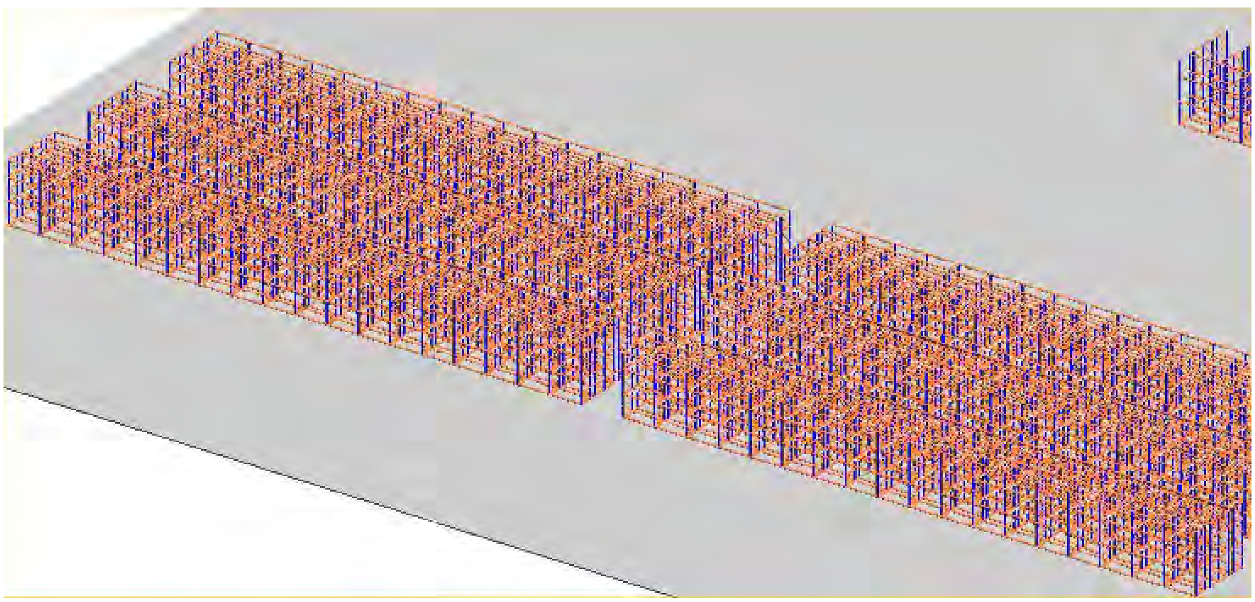

Figure 1: Three dimensional plan layout for the warehouse of pallet pushback racks

This research proved that BIM can be a valuable tool for shelving subcontractors if certain procedures were developed for the particular trade.

1.2 Case Study 2: Using BIM for design and estimating metal patrimonies.

In this case, BIM was used to estimate and schedule metal stud walls construction for commercial projects. Two students teamed up with a metal partitions subcontractor to develop Procedures for estimating, designing, and scheduling metal partitions construction. The challenges here are to integrate third party add-on modules to Revit software to quantify the different partitions' components. In this particular case, the Add-on module enabled the subcontractor also to generate structural analysis that optimize the metal studs structure, which resulted in significant saving in material and labor. Such structural analysis was not feasible through pen and paper time consuming structural analysis. The model was used to generate shop drawings, accurate cost estimate, and schedule the delivery of the materials to the jobsites.

The model also provided a clear visualization of the construction sequence that was shared with the general contractor and other subcontractors (Franco, 2015).

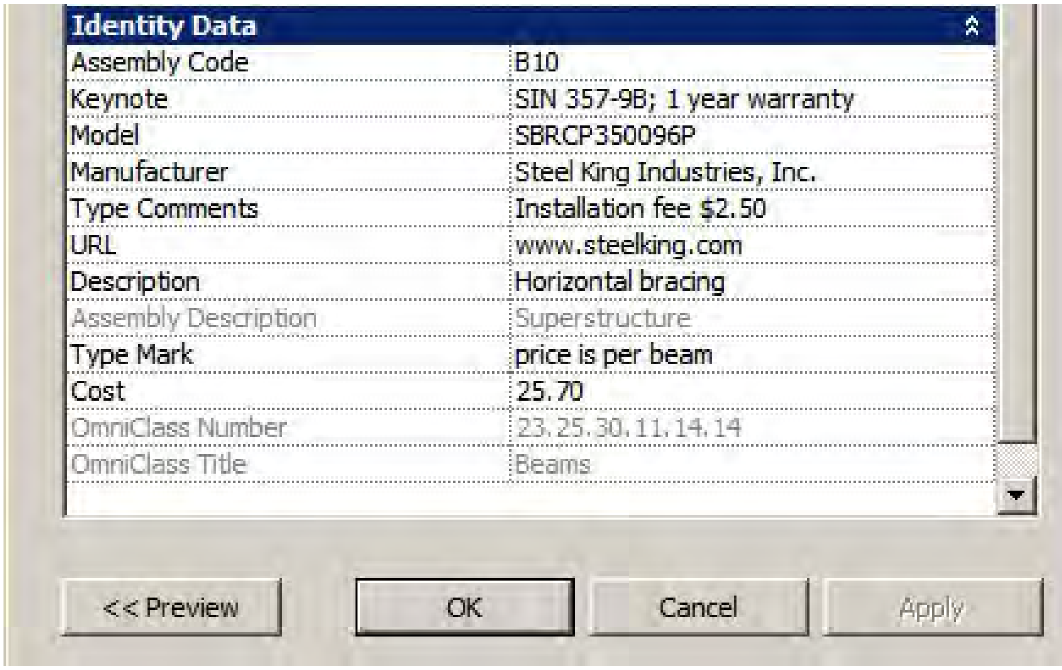

Figure 2: Identity Data for a component of the warehouse pallet pushback racks

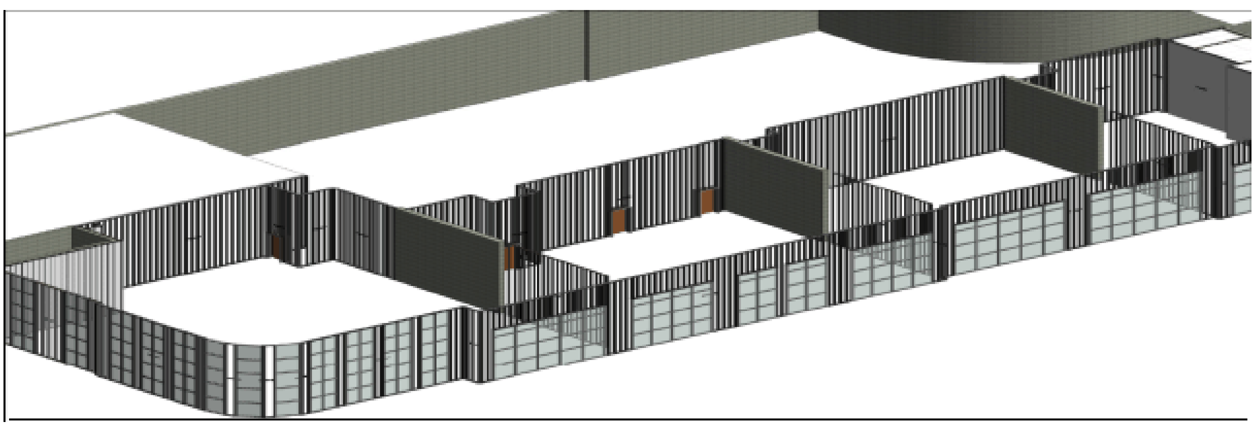

Figure 3: BIM light gauge metal framing 3D view

1.3 Case Study 3: Using BIM for facilities management.

In this project, the student teamed up with a facility management company to generate BIM model for a multi-million square foot auto parts warehouse. The warehouse contains many electrical rooms, central air conditioning and roof top units, and complex communication network. The challenge was to establish a procedure on documenting the different maintenance activities and schedule routine maintenance using BIM models. The models were used to generate electric control panel diagrams and help the maintenance crew to locate circuit breakers that serves the different electrical outlets and lighting fixtures. The student in this case gained in-depth knowledge on generating BIM models related to Mechanical, Electrical, and Plumbing (Kol, 2018).

Lbl	Qty	Member	Length	W(lbs)
C0	7	600S162-43(33)	10' 0"	106.4
C1	6	600S162-43(33)	2' 0"	18.24
C2	2	600S162-43(33)	8' 0"	24.32
T0	1	600CST250-33	12' 0"	0.0157
T1	1	600T125-43(33)	2' 0"	2.6
T2	1	600T125-43(33)	4' 0"	5.2
T3	1	600T125-33	7' 0"	0.0066
-	-	Grand Total:		156.7823

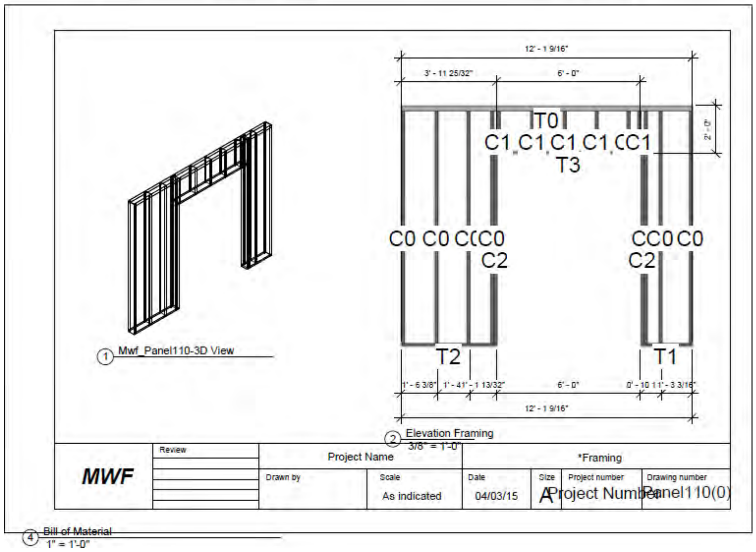

Figure 4: Shop Drawing with Material List

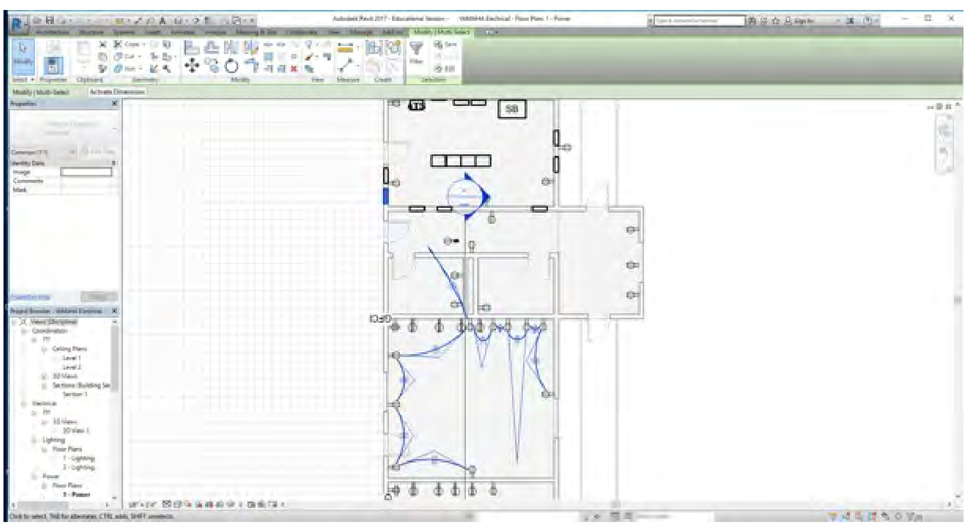

Figure 5: Electrical Circuit Connection

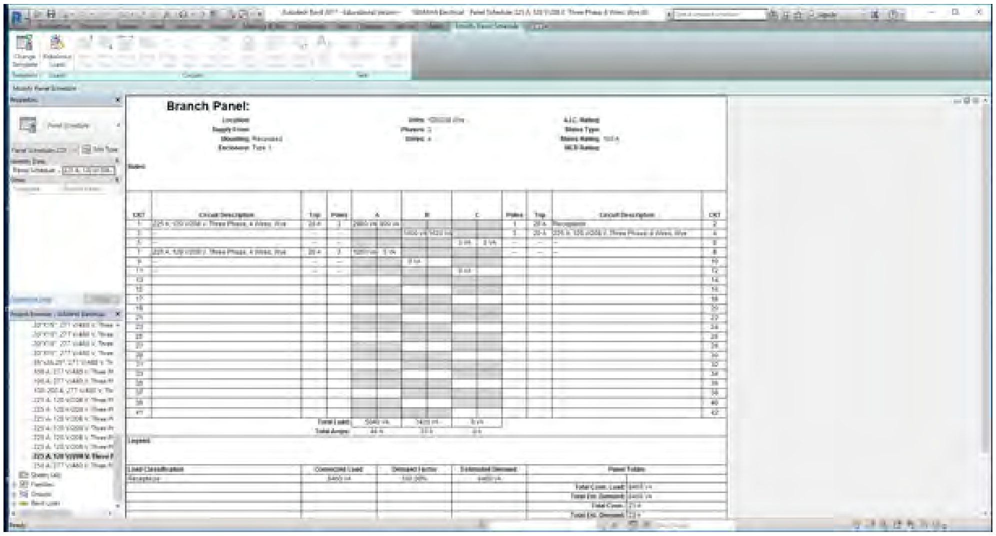

Figure 6: Panel Schedules

3. CONCLUSIONS

This paper present a case study based BIM teaching method. Students were challenged to learn BIM by addressing real industrial problem. In this method, the students were able to learn basic BIM modeling through self- learning study materials. The students also learned how to research and develop new solutions that is related to using BIM to address real industrial needs. The exploratory teaching method also prepared the students to address future problems that might face them in their professional career.

REFERENCES

Azhar, S, 2001; *"Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry*" Leadership and Management in Engineering, JULY 2011

Cooksey, 2011; *"The Integration of Building Information Modeling (BIM) Into Civil Engineering Curricula"* , A Thesis Presented to the Graduate School of Clemson University, Available online at https://tigerprints.clemson.edu/all_theses.

Enchassi, Adnan. Abu Hamra, Lina. Alkillani, Suhair. 2018; *"Studying the Benefits of Building Information Modeling (BIM) in Architecture, Engineering and Construction (AEC) Industry in the Gaza Strip"* Jordan Journal of Civil Engineering, Volume 12, No. 1, 2018. Page 87-98.

Franco, juan. Mahdi, faiza. Abaza, Hussein; *"Using Building Information Modeling (BIM) for Estimating and Scheduling, Adoption Barriers"*, Universal Journal of Management 3(9): 376-384, 2015.

Ghaffarianhosein, Ali. Tookey, John. Ghaffarianhosein , Amirhosein. Naismith, Nicola. Azhar, Salman. Efimova, Olia. Raahemifar, Kaamran, 2017; *"Building Information Modelling (BIM) uptake: Clear benefits, understanding its implementation, risks and challenges"* , Renewable and Sustainable Energy Reviews, Volume 75, August 2017, Pages 1046-1053.

Kol, Anes. Abaza, Hussein, 2018*; "Assessment of Using Building Information Modeling (BIM) for Maintenance of Existing Buildings"* Design Communication Conference , 2018.

Nushi, Violeta. Basha-Jakupi, Arta. 2017; *"The integration of "building information modeling" (BIM) in sustainable architecture and construction education: case study in Pristina University"* , Igra Ustvarjalnosti, Iss 5, Pp 52-57 (2017)

IMPACTS OF A ROTATIONAL BLENDED LEARNING MODEL ON BIM COURSE DELIVERY

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ABSTRACT

As BIM adoption increases in the construction industry, employers are increasingly seeking graduates with BIM skills. Many AEC education programs have responded to this demand by adding BIM to their existing curriculum, resulting in a need to understand what to teach, when to teach it, and how to *effectively* teach it such that students gain the appropriate knowledge and faculty are not overwhelmed with how to approach the new curriculum. This paper contributes to the growing body of literature that is helping to identify effective ways to teach BIM in AEC education programs. This paper reports on results from a study conducted in a Spring 2018 senior-level BIM course in which a combination of BIM concepts and software skills were introduced to students in two-week modules. Pre- and post-module surveys were administered to students at the beginning and end of each module. The data show increases in concepts knowledge and increases in students' confidence in their knowledge between the pre- and post-module surveys. The conclusions reached in this study are that (1) the educator should develop and/or curate software exercises that reinforce desired BIM concept learning outcomes and (2) module-based teaching with a rotational blended learning model is effective for increasing knowledge of concepts and student confidence in their knowledge.

Keywords: Building information modeling, rotational blended learning, AEC education, student learning outcomes, curriculum

1. INTRODUCTION AND BACKGROUND

As the use of building information modeling (BIM) becomes more prevalent on building projects, employers are increasingly seeking talent with BIM skills. While industry professionals surveyed by Wu and Issa (2013) indicated they prefer to recruit seasoned professionals for BIM staffing, many AEC education programs have responded to the increasing demand for BIM talent by incorporating BIM into their existing curriculum (Abdirad & Dossick, 2016; Wu & Issa, 2013), resulting in a need to understand what to teach, when to teach it, and how to effectively teach it such that students gain the appropriate knowledge and faculty are not overwhelmed with how to approach the new curriculum. This paper contributes to the growing body of literature that is helping to identify effective ways to teach BIM in AEC education programs. Literature indicates that effective BIM instruction should strike a balance between concepts and software skills, but tension exists over whether software skills should even be taught at the university level with some arguing that software used on the job will likely differ from that used in school and that faculty should be teaching theory, not software (Lee & Hollar, 2013). However, data from this study indicate that teaching software skills does enhance understanding of concepts when these concepts are intentionally reinforced within the software exercises. In this paper we argue for the importance of teaching both concepts and software with a rotational blended approach in which various teaching modalities such as face-to-face lectures, online material, and in-class tutorials, are “blended” and rotated through a two-week module —where concepts and software modules are explicitly related to each other.

This paper reports on results from a study conducted in a Spring 2018 senior-level BIM course in which a combination of BIM concepts and software skills were introduced to students. Concepts were divided into five primary categories: BIM Project Execution Planning, 3D Coordination and Clash Detection, 4D Modeling, 5D Model-Based Estimating, and COBie/Information Exchange.

1.1 Rotational Blended Learning Model

The blended rotational model differs from the traditional lecture-based model in that it rotates through several learning modalities with “blended” referring specifically to the blend of face-to-face learning with online learning (Garrison & Kanuka, 2004; Ghoul, 2013; Monson, Homayouni, Dossick, & Anderson, 2015; Staker & Horn, 2012). In a lecture/lab class typology, there is a need to blend concepts with software learning such that students can learn by doing. From personal experience, the authors have found that if not intentionally reinforced during hands on software tutorials or in class problem sets, the picks and clicks of the software learning can obscure the broader learning goals of concepts. In other words, we have found that it is vital to explicitly connect concepts from lecture to software usages both in lecture and in lab in a blended learning environment.

Most college courses are a combination of in class experiences, often lecture, and outside work, typically reading, writing and problem sets. With computer technology, in recent years, there has been an interest in “flipping the classroom” where students watch pre-recorded lectures as homework and work on problem sets in the classroom with the support of peers and the instructor (Monson et al., 2015). For undergraduate education, flip the classroom has had varied results and often breaks down when students do not do their ‘homework’ and come the class unprepared to do the in class exercises. The challenge then is to provide enough content at the beginning of the module to get the students going on the topic, then transition to the flipped model towards the end where they work on problem-sets in class.

The design of the module presented in this study begins with concept reading, and ends with hands on exercise in class (Figure 1). Throughout the connections between the concepts, (established in the reading and defined in the lecture), and the software functionality are reinforced. A concept like “database” is first introduced in the reading homework, then defined and explained in the lecture, and the students provide feedback from lecture in the form of a reflection—a quick low-stakes in-class writing exercise that helps them focus on the concepts. Then in the step-by-step tutorial, where the students are lead through the picks and clicks of the software, the instructor reinforces the concept by reminding the students of the concept when they find it in the software work flow. If database is the concept, then when the students learn to do a search in Navisworks, they would be reminded that because the model is a database, they can search it for objects. Software is then practiced as homework to reinforce the in class learning and get them to go beyond following a tutorial by having to think of the steps for themselves. An industry lecture deepens the learning by showing the students how these tools and concepts are implemented in practice, the guest often referring to the concept as the key to what makes the software useful. The module finishes with a hands on exercise in class where they practice the software work flow together with peers and instructors for support. This in class practice prevents the students from getting “stuck” on picks and clicks, with troubleshooting support from instructors.

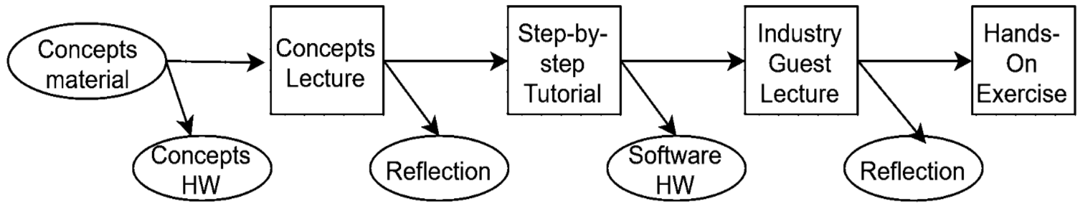

Figure 1: Rotational Blended Learning Model adapted for use the BIM course. Ovals represent work done by the student *outside* of the classroom and squares represent lectures or work that takes place *in* the classroom. The duration of this module is two weeks.

1.2 BIM Course Design

The BIM course described in this paper is a 3-credit senior-level elective offered in the construction management program and open to design and construction students. The class meets for one hour, three days per week. Because the students in our program learn to model (using BIM tools) in their sophomore year, this course is focused on BIM consuming rather than authoring. The first two weeks of the course are spent introducing basic BIM concepts and brief introductions to software they will be asked to use throughout the semester. After the basics are introduced, the two-week long blended rotational modules are introduced. The modules use a combination of concepts reading homework, face-to-face lectures, software exercises outside of class, and software exercises in lab with the instructor present. Each learning module covered one of five primary categories as shown in Table 1 below.

Table 1. BIM modules covered in the course

Module:	**Concepts include:**	**Software used:**
A - 4D Modeling	Level of Development, Construction Simulation, Search/Selection Sets	Autodesk Revit and Navisworks; and Excel or P6
B - BIM Project Execution Planning (PxP)	Mapping Project Goals with BIM Uses, Roles and Responsibilities, Information Exchange	
C - 3D Coordination and Clash Detection	CAD vs. BIM, Federated Models, Visualization and Navigation Strategies for Clash Detection	Autodesk Navisworks and BIM 360 Glue
D - 5D Model-Based Estimating	BIM as a Database, Data Export/ Import, Classification Systems	Autodesk Navisworks, Assemble, and Bluebeam Revu
E - COBie/Information Exchange	Interoperability, Industry Foundation Classes, Construction to Operations & Maintenance	Autodesk Revit

Four of the five modules followed the two-week rotational blended learning schedule as illustrated in Figure 1. The exception was the BIM PxP module which was one week in duration and covered concepts only (no software). Figure 2 shows a representative two-week module from weeks 11 and 12 of the course schedule. Students accessed all course material, including in-class tutorials and quizzes, through Blackboard.

Week	Sun	Monday	Tue	Wednesday	Thu	Friday	Sat
11	18 Submit module D concepts homework	19 **MODULE D: Model-Based Estimating (5D) *Concepts and Pre-Module Survey*** Submit post-lecture reflection	20	21 ***Tutorial*: Assemble QTO**	22	23 ***Tutorial Workshop*: Assemble QTO** Submit Module D Software Homework	24
12	25	26 **Model-Based Estimating *Industry Application*** Industry Guest Lecture Submit post-lecture reflection	27	28 ***Hands-on*: Model-Based Estimating**	29	30 ***Hands-on*: Model-Based Estimating *Workshop and Post-Module Survey***	31

Figure 2: Portion of the course schedule showing Module D: 5D Model-Based Estimating homework deliverables and class lectures/activities, representing a typical 2-week module schedule.

1.3 BIM Body of Knowledge

The recent development of a BIM Body of Knowledge (BOK) by the Academic Interoperability Coalition (Wu, Mayo, McCuen, Issa, & Smith, 2018a, 2018b) aims to provide a common framework for academia and industry to bridge the gap between education and industry needs (Mayo, Wu, McCuen, & Issa, 2018). This will allow BIM educators to deliver a more standardized curriculum with specific and common learning outcome goals. The goal of this BIM course, moving forward, is to update and align the curriculum to be consistent with the AiC's BIM BOK to ensure our students will be properly prepared for a BIM-enabled workplace and meet the expectations of potential employers.

2. RESEARCH METHOD

Pre- and post-module surveys were administered to students at the beginning and end of each two-week module to measure differences in concepts knowledge and confidence in their concepts knowledge. The surveys each comprised three questions: one exam-like question, one open-ended question asking the student to explain their answer to the first question, and a 5-point Likert-scale asking how confident they were in their answer to the first question. The pre-module surveys were administered after the concepts reading homework was submitted, but before the concepts lecture and software skills were introduced, thereby measuring the knowledge and confidence of the students after the concepts reading assignment. The pre- and post-module surveys were administered on Blackboard and student responses were anonymous. The surveys were developed at the University of Washington (Monson et al., 2015). To illustrate question structure, the pre-module survey for Module D – 5D Model-Based Estimating is shown in Figure 3. While the 3-question structure was consistent throughout all surveys, the pre- and post-module survey Question 1 varied slightly for each module. This was necessary because the pre-module survey question would often be discussed by students after the survey and brought into the general conversation during the concepts lecture and the goal was to measure evidence of learning (rather than memory).

Question 1
In a model of an office building appended into Navisworks, there is a cost schedule for interior finishes (including flooring, wall covering, doors, electrical and mechanical fit out). If the designer moves a wall 3 feet to make the office suite bigger, what attributes in the cost schedule will change for that particular office suite? (Check all that apply)
□ Area of Floors
□ Cost of Doors
□ Material Assemblies of Walls
□ Area of Walls

Question 2
Explain your answer to Question 1.

Question 3
How sure are you about your answer to Question 1?
□ Very sure
□ Somewhat sure
□ 50/50
□ Somewhat unsure
□ Very unsure

Figure 3: Pre-module survey for Module D: 5D Model-Based Estimating. Each pre- and post-module survey comprised three questions using the format shown above.

3. FINDINGS AND DISCUSSION

Data were analyzed for the following three modules: (1) Module A – 4D Modeling, (2) Module C – 3D Coordination and Clash Detection, and (3) Module D – 5D Model-Based Estimating. There were 26 students in the course: 23 seniors and 3 sophomores, all construction management majors. They were asked to take a pre-module survey at the beginning of each two-week module and a post-module survey at the end of the module. Participation was voluntary and the response rate varied from 58% to 92%. Survey results are reported in Table 2. No surveys were developed or administered for the one-week long Module B – BIM PxP, and due to a schedule change, the surveys for Module E – COBie/Information Exchange were not administered in Spring 2018.

Table 2. Pre- and post-module survey results

Survey	Number of Responses	Response Rate	Question 1 Correct Responses	High confidence in answer to Q1 (Very or Somewhat Sure)	Neutral confidence in answer to Q1 (50/50)	Low Confidence in Answer to Q1 (Very or Somewhat Unsure)
Pre-Module A	20	77%	40%	30%	40%	30%
Post-Module A	17	65%	65%	76%	18%	6%
Pre-Module C	21	81%	5%	62%	24%	10%
Post-Module C	24	92%	46%	92%	4%	0%
Pre-Module D	19	73%	26%	74%	21%	5%
Post-Module D	15	58%	67%	73%	20%	0%

The quantitative data show modest increases in concepts knowledge and, for modules A and C, increases in students' confidence in their knowledge between the pre- and post-module surveys. Because there are often many ways to approach a problem, the "correct" answers in the surveys were considered to be the "best-aligned" with the correct answer. So, for the 5D example shown in Figure 3, the best-aligned answer may or not include "Material Assemblies of Walls" depending on assumptions made. While consistent the increases are encouraging, the ambiguity of the questions and answers (i.e. that they were open to interpretation) may have contributed to lower than expected increases in concepts knowledge. The wording of the questions are consistent with the survey questions piloted at UW so results from both universities would be comparable, with the intention of refining questions in future iterations of the study. Because we plan to update the curriculum to align with the AiC's BIM Body of Knowledge, this will provide an excellent opportunity to refine the survey questions as well. Additionally, because the pre-module surveys were administered after the initial concepts reading homework, they may have gleaned some concepts knowledge prior to taking the pre-module survey.

Perhaps the most salient qualitative findings (from responses to Question 2 asking students to explain their answer to Question 1) were that the software tutorials, homework and hands-on exercises reinforced concepts learning and concepts *not* reinforced as part of the software exercises were considered irrelevant. This was indicated by comments made in the Question 2 "Explain your answer to Question 1" portion of the survey. For example, in the pre-module C – 3D Coordination and Clash Detection module, several students indicated they would use realistic rendering to make a clash more legible when it was difficult to see which objects were clashing. The rationale from all students providing explanations was very specific, such as, "Realistic rendering … would provide clarity as to what is clashing," and "Realistic rendering shows an actual depiction of what [the clash] will look like." In the post-module survey, the rationale regarding realistic rendering changed. Among those who did *not* choose realistic rendering as a way to make clashes more legible, explanations included, "We did not do a realistic rendering" and "We have never used [realistic rendering] in class so I don't believe it is an answer." Among the seven (out of 24) students who did choose realistic rendering as a way to make clashes more legible in the post-module survey, six of them chose *all* available answers, including "change colors and transparency," "change viewpoints," and "hide geometry," and all provided very general explanations such as, "Using all 4 of those tools will help…" and "All of these options are ways to make a clash more legible." As part of the clash detection software exercises, the students learned how to use three of the four options provided, specifically: change colors and transparency, hide geometry, and change viewpoints. They also used markup tools to highlight clashes, though that was not one of the options provided in the survey. As part of their exercises, students were *not* asked to use realistic rendering to highlight clashes and it was only addressed in passing during lectures (and not in the context of clash detection), so while the students' rationale for not choosing this option was correct, it could have just as easily been incorrect simply because something may have been omitted from the software exercises. It highlights the importance of developing software exercises that reinforce the concepts learned in class.

4. CONCLUSIONS AND FUTURE WORK

The quantitative findings in this study indicate that module-based teaching with a rotational blended learning model is effective for increasing concepts knowledge and student confidence in their knowledge. Primary findings resulting from analysis of the qualitative data are (1) that the software skills portion of the modules enhanced concepts learning and (2) concepts *not* reinforced during the software skills portion were assumed to be insignificant. The qualitative findings suggest that BIM educators should develop and/or curate software exercises that reinforce desired concept learning outcomes.

The senior-level BIM course in the construction management program at WSU has been part of the curriculum since Spring 2015. Being a course that focuses on emerging technologies in the industry, the course concepts and software are continually in flux as the industry develops and adopts new technology and workflows around those technologies. The findings in this study are encouraging for those who teach both concepts and software in BIM courses, but also limited due to the small sample size in this study. The BIM course at WSU is an elective, as of Fall 2018, which has historically limited the class size to 25-27 students each year due to multiple electives being offered in the 4th year. Because the course continues to develop and grow with industry needs, the AiC's BIM BOK will be instrumental in directing future development of the course. Alignment with the BIM BOK will also help prepare the BIM course for future adoption into the regular curriculum, due to the thorough vetting of the BOK by industry experts.

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REFERENCES

Abdirad, H., & Dossick, C. S. (2016). BIM Curriculum Design in Architecture, Engineering, and Construction Education: A Systematic Review. *Journal of Information Technology in Construction (ITCon)*, *21*, 250–271.

Garrison, D. R., & Kanuka, H. (2004). Blended learning: Uncovering its transformative potential in higher education. *The Internet and Higher Education*, *7*(2), 95–105.

Ghoul, S. (2013). A Rotational Blended Learning Model: Enhancement and Quality Assurance. *Journal of Educational Technology*, *9*(4), 46–50.

Lee, N., & Hollar, D. A. (2013). Probing BIM education in construction engineering and management programs using industry perceptions (pp. 467–476). Presented at the 49th ASC Annual Int. Conf. Proc., California Polytechnic State Univ., San Luis Obispo, CA.

Mayo, G., Wu, W., McCuen, T., & Issa, R. R. (2018). IMPLEMENTATION OF THE BIM BODY OF KNOWLEDGE (BOK) FRAMEWORK FOR PROGRAM PLANNING IN ACADEMIA. In *12th Annual AiC Conference*. Orlando, FL.

Monson, M. C., Homayouni, H., Dossick, C. S., & Anderson, A. (2015). Improving the Understanding of BIM Concepts Through a Flipped Learning Lab Environment: A Work in Progress. In *Proceedings of the 122nd ASEE Annual Conference and Exposition, June 14-17*. Seattle, WA.

Staker, H., & Horn, M. B. (2012). Classifying K-12 Blended Learning. *Innosight Institute*.

Wu, W., & Issa, R. R. (2013). BIM education and recruiting: Survey-based comparative analysis of issues, perceptions, and collaboration opportunities. *Journal of Professional Issues in Engineering Education and Practice*, *140*(2), 04013014.

Wu, W., Mayo, G., McCuen, T. L., Issa, R. R., & Smith, D. K. (2018a). Building information modeling body of knowledge. I: Background, framework, and initial development. *Journal of Construction Engineering and Management*, *144*(8), 04018065.

Wu, W., Mayo, G., McCuen, T. L., Issa, R. R., & Smith, D. K. (2018b). Building information modeling body of knowledge. II: Consensus building and use cases. *Journal of Construction Engineering and Management*, *144*(8), 04018066.

BIM CURRICULUM DEVELOPMENT

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ABSTRACT

Ever since the mid-eighties when CAD (Computer Aided Design) began to revolutionize how we design our buildings, forward thinking people have had a vision of a virtual construction world where we not only design in three dimensions but also schedule and estimate that same project from the information already assembled in the 3D electronic model. The potential benefits to all stakeholders were hard to overestimate. So what is the current progress of this vision and how do we, as college professors, deliver the best preparation for our students who will undoubtedly enter an industry that will continue to exploit the potential of what has come to be known as: BUILDING INFORMATION MODELING (BIM). This paper presents the process of our Undergraduate Construction Management program identifying the importance of BIM education for our majors and the initial steps we have taken in that direction.

Keywords: Building Information Modeling (BIM), Computer Aided Design (CAD), Schedule (4D), Estimate (5D), Sustainability (6D), Facility Management (7D)

1. HISTORY

John Brown University's Construction Management program consists of 3 full-time faculty and 60 students on average and is ACCE accredited. The first 2D Computer Aided Drafting was introduced in 1987. Then the program progressed to using Graphisoft's ArchiCAD but switched to Autodesk Revit in 2008. BIM technologies were already being used by many of the advisory board member companies and it became apparent that graduates needed as much experience with BIM as possible.

2. INTRODUCTION

The very first CAD (Computer Aided Design) systems began their development in the U.S. Air Force in the 1950's. They progressed for the next three decades without affecting the construction industry to any great extent until the founding of Autodesk in April of 1982. Autodesk's idea was to create a CAD program for the price of $1,000 that could run on a personal computer (PC). The following year, 1983, the first versions of AutoCAD were marketed in Germany and France (Bozdoc, 2006 [1]).

With the application of computer aided design and drafting to the building process, the inevitable move toward including more and more information in our electronic building models was assured. Those who were CAD designers in the 90's remember the regular promise of full 3D design capability in new softwares only to be disappointed by the glitchy limitations and painfully long screen regeneration times. Just being able to design in full 3D easily, with any speed, was the only goal many architects and designers could imagine. But, as the softwares that made 3D design easier kept developing, so did hardware configurations that could process that information without the long time lags of the 90's and early 2000's. As we realized 3D design ability on simple PC work stations, the idea of attaching even more information to the components in the model didn't seem as counterproductive because of continually improving processing speeds.

Visionaries saw the potential and teamed with IT personnel to start adding information that would let us schedule (4D) and estimate (5D) directly from the information we had already created in our 3D models. The idea that the electronic drawings could also give us accurate schedules and estimates was incredible, to say the least. Further additions of Sustainability (6D) and Facility Management (7D) round out the current applications of Building Information Modeling (BIM) by non-profit organizations, private, government and municipal agencies who are all trying to maximize the advantages of BIM in their practices. The chart below fleshes out sub-categories under the 5 main areas of BIM.

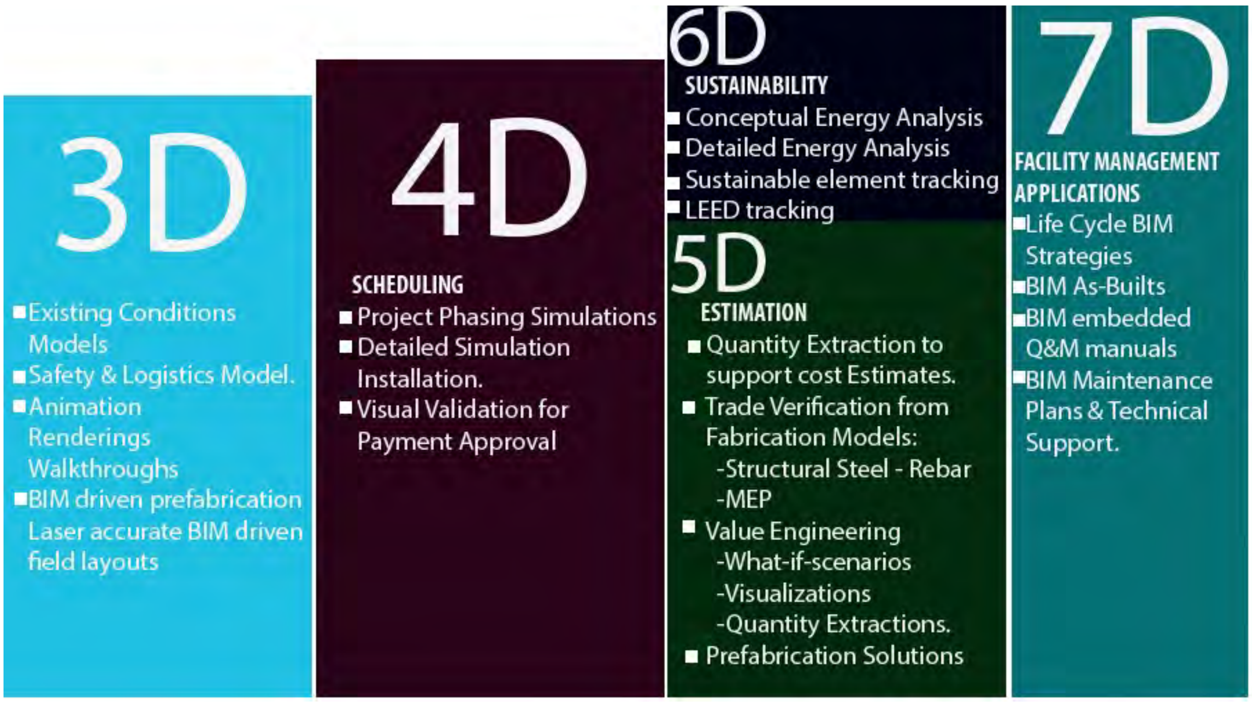

Figure 1: Dimensions of BIM

"'Expect the use of 4D and 5D building information modeling (BIM) technology to flourish in the future', Turner Construction's Treighton Mauldin told a group of construction professionals attending a webinar that WPL Publishing held April 17, 2012. He sees 4D, which addresses scheduling, and 5D, which involves estimating, 'taking off because they bring all of the aspects of a plan, an estimate, a model, and a schedule into one environment that can be easily monitored and managed and communicated to the rest of the team, which is a huge benefit, and it really starts to eliminate errors in communication, miscommunication, and, in the end, makes people more money (Rizer, 2012 [2]).'" These comments are typical of large commercial companies that plan on maximizing BIM in the future.

Before a program creates specific BIM training for their students, they need to answer the following questions:

- Is BIM really here to stay?
  "BIM Adoption Expands from 17% in 2007 to over 70% in 2012, According to New McGraw-Hill Construction Report (Malangone, 2012[3])".
- Is BIM just happening in the U.S.?
  Building and Construction Authority (BCA); "Singapore, 1 August 2013 - There has been significant progress in promoting Building Information Modeling (BIM) in Singapore. The adoption rate has gone up from 20% in 2009 to 65% today" (Press Release, 2013 [4]).

With confirmations like this that the growth rate is fast (about 10% per year) and almost the same in both the U.S. and on the other side of the world, we know our students need to be as familiar as possible with BIM technologies as they enter their careers. We also know we have to be asking the right questions as we set out to create curriculum that meets that goal. The body of this paper will state those questions and the progress JBU has made in implementing what we have discovered and learned so far.

3. WHAT DOES OUR CLIENT (INDUSTRY) NEED?

When the author first started talking about BIM to his students he made sure they knew what the acronym meant and that it was about clash detection and attaching scheduling/estimating information to the electronic model. This provides information in the planning stage rather than having to wait for the architect to finish the working drawings and then schedule/estimate and look for clashes the architect didn't identify during the design process.

In a job interview in 2008 a JBU graduate was asked what he knew about BIM and he said, "Oh, Building Information Modeling?", and went on to repeat some of the basic facts accurately. He was offered a job in their newly formed BIM department. That made it abundantly clear that the construction industry was eager for students with Building Information Modeling knowledge.

In a recent survey of our industry advisory board, they said they want our graduates to know about BIM. They usually say BIM is a great tool but they don't quite know how it's done. HR personnel are challenged in how to write job descriptions for these new positions. "'To start your formulation of Job descriptions your firm needs to ask and answer, how do you and your management team plan to deploy VDC-BIM on projects? Some firms look at BIM as a drafting activity meant to provide project teams 3D modeling services. Taking this view they would create a BIM department that would likely be staffed with specialized CAD users. Alternatively, other firms focus on integrating 3D technology into each project teams' management skill set. Thus the development of Job descriptions would be different for each management strategy.

The distinction between the specialized CAD manager approach versus a project management that is specialized in model management requires a unique job description for each position (Cousins, 2010[5]).'" This quote is from an article written by an HR professional who also did short interviews with BIM managers from 4 respected commercial construction companies. The conclusion is drawn that the better the student's ability in Autodesk Revit, the better they will be able to adapt to whatever system of using the electronic model for BIM in their respective companies.

The action plan for our program was for the instructor to get better at Autodesk's Revit since there are three classes that require the use of Revit in the program. BIM applications will make more sense when people have some level of mastery of Revit. Just as AutoCAD became the industry standard in the 2D drafting world, Revit is already the standard in the 3D/BIM world and will only solidify its position as time goes on.

4. WHERE DOES BIM CURRICULUM FIT INTO AN UNDERGRADUATE PROGRAM?

The introductory class using Revit (CM 1223 - see below) uses a text written by a designer from Minnesota named Daniel Stine. In it he reviews hand drafting methods and then launches into a preset exercise of drawing the plans for a residence. The class is split in half and the students alternate doing plan reading exercises one lab a week and the Revit chapter assignments on the other. Senior CM students work as Teaching Assistants and lead the plan reading assignments while the instructor focuses on the students doing the Revit lessons. The following is a link to a PDF copy of the syllabus from the spring semester, 2015. It includes a schedule of each lab period: http://www.jbu.edu/majors/construction_management/presentations/ This format is a very good way to get students right into the nuts and bolts of the software (Stine, 2015 [6]).

The following JBU classes are the ones that directly involve using Autodesk Revit software. They were the initial classes considered for alteration to accommodate dedicated BIM training. CM 1223 starts the process of Revit acquisition and CM 3613 furthers it with a residential project students design themselves (This is something they may legitimately do as professionals).

After consideration, the course that was chosen to be altered was CM 3623 (next page). This is the first JBU course catalog with the new references in the description to BIM design principles and software. These concepts have been incorporated into this class for the past three years but the course description change has only now, in the current year, gotten into the school catalog.

The reality is that, unless JBU grads go on and become licensed architects, they will never legally do the full design of a commercial building and that's what the original course described them doing until this catalog cycle. This has been one of the first steps toward BIM integration into the entire construction management curriculum.

4.1 CM 1223 Graphic Communication Skills Three hours

The study and practice of communicating ideas through manual and digital means. Emphases include the development of lettering and sketch abilities, communication through construction documents, an introduction to construction assemblies and an overview of three-dimensional model based design, and construction documentation. Two three-hour laboratory periods per week. An additional fee associated with this course.

4.2 CM 3613 Architectural Design I Three hours

The design, development, and presentation of an architectural program for a residence. Introduction to design principles and their influence in the development of a project is addressed. The architect, contractor and owner working relationships are emphasized. Two three-hour laboratory periods per week. An additional fee associated with this course. Prerequisites: CM 1223 and junior standing, or consent of instructor.

4.3 CM 3623 Architectural Design II Three hours

An introduction to commercial design principles combined with principles of Building Information Modeling (BIM). The course will include an exercise in commercial design presentation and an introduction to BIM software and theory. An additional fee associated with this course. Prerequisites: CM 3613 and junior standing, or consent of instructor.
(Course Descriptions, 2015 [7])

After the above course description change in 2015 the program here has continued to improve and refine this class to the extent that the new course listing below has taken the place of CM 3623 in the new JBU 2017-2018 catalog. The description follows:

4.4 CM 3723 Building Information Modeling Three hours

An introduction to the application of Building information Modeling (BIM) as it relates to managing construction projects. Software experience with 4D CAD and clash detection will be explored. Course includes a semester project and presentation. An additional fee associated with this course. Prerequisites: CM 3613 and junior standing.
Offered Spring semester

5. WHAT ARE THE STANDARD FORMS OF BIM BEING USED?

Once a program establishes the need for BIM training and dedicates at least part of a semester to it, what should they teach? The educator will find that more curriculum options have surfaced in the last couple of years that make it easier to design a course of study in BIM. In the Master of Engineering Technologies program at Pittsburg State University tutorial exercises are required in two softwares that are emerging as BIM applications in the construction industry. This has great appeal to construction companies that are late adopters of the technology. It also has strong appeal to educators who want to give their students comprehensive BIM exposure along with educating themselves. The JBU class was altered to include: DProfiler and Synchro. The feedback has been very encouraging as several former students have seen these softwares being used by their employers and were glad they were familiar.

"DProfiler is a unique BIM program that integrates 3D macro modeling and cost estimating. With this powerful program you easily build a model of your conceptual design and generate an accurate cost estimate without extra time or effort. An excellent marketing tool, with DProfiler you can give clients an impressive preconstruction package.

5.1 DProfiler features:

- 3D Modeling with easy importing from CAD programs
- Cost Estimating with integration from Excel, RS Means databases, and Timberline
- Energy Analysis
- Google Earth integration (Beck, 2012 [10])"
- DProfiler videos: http://www.beck-technology.com/products/destini-profiler/

Figure 2: DProfiler 3D model scaled on a 2D drawing

"Synchro PRO's real time visualization capabilities change the way projects are planned- the ability to see into the future, to communicate clearly and to create a shared understanding amongst the entire project delivery team, enables performance on a much higher level. Safety, productivity, quality, reliability and cost competitiveness all increase. As the industry works to close the skills gap, to effectively and successfully utilize new purpose built, digital technology, the Synchro Project Delivery Team is here to support the companies and people who are working hard every day to deliver great projects (Synchro, 2016 [11])."

Standardized BIM is trying harder to emerge in places other than the U.S. it seems. "'Although the number of project teams using BIM tools increases each year, the transformative potential of these tools remains checked by barriers that impede the information exchange among participants and across different software platforms. Getting the most out of BIM will require an open exchange of information, which in turn requires defining and implementing common protocols and standards. But who wants this arduous task?

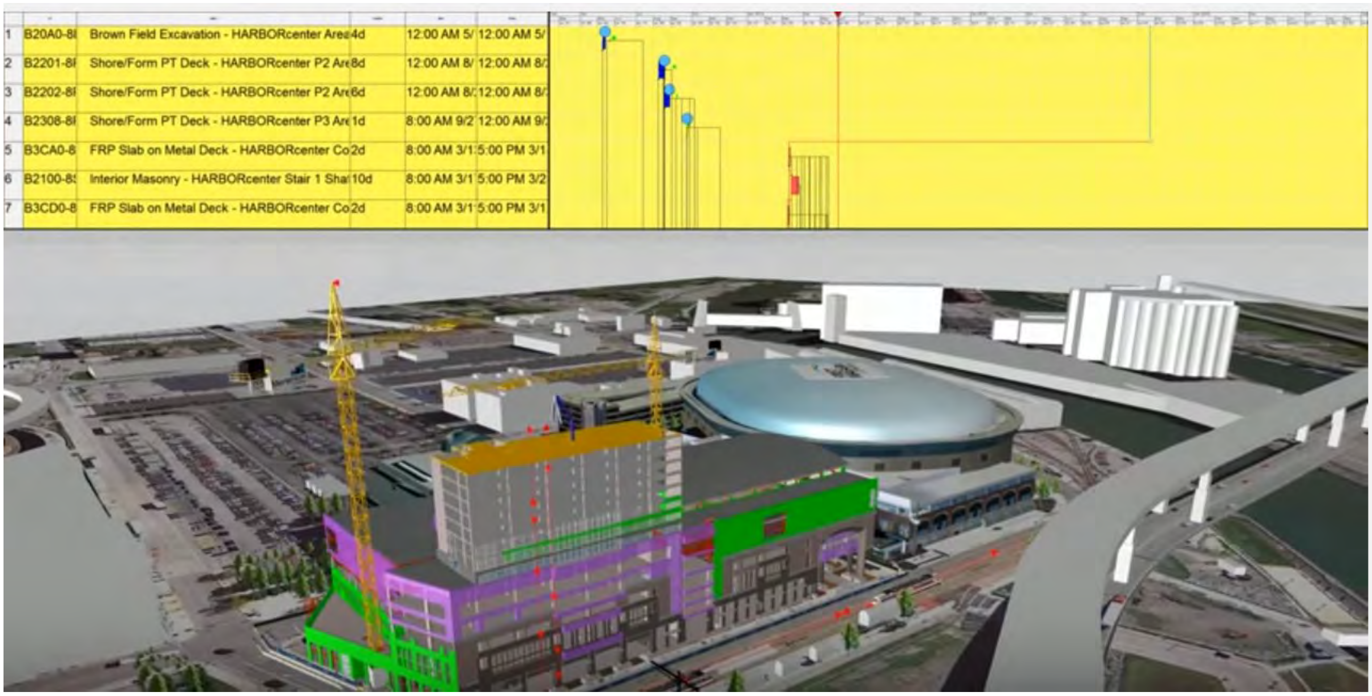

Figure 3: Synchro model with integrated schedule

In the United Kingdom, the answer is simple: the government. By 2016, all British government building contracts will require "fully collaborative 3D BIM," according to the country's 2011 Government Construction Strategy. The NBS National BIM library—yes, such a thing exists—already contains thousands of both generic and proprietary BIM objects. (These objects are virtual building components containing performance parameters and physical attributes that can be placed in digital building models.) Singapore, Finland, and Norway also have national BIM standards, and China has one in the works (Shapiro, 2014[8]).'" They have also produced a video about the status of BIM in the UK (National BIM Library, 2013 [9]).

6. OTHER RESOURCES I HAVE FOUND TO HELP INTRODUCE BIM

Reid Johnson (reid.johnson@autodesk.com) has been available to teach mock coordination meetings (via Go-To-Meeting) focusing on clash detection in the CM 3623 course using the autodesk cloud at no charge. There are 6 hours of lab time dedicated to these meetings and it has received great student feedback. The challenge of grading can be met by allotting an appropriate amount of points for participation and engagement during the actual contact time and some questions on the final that can only be answered by engagement in the original exercise or remedial experience.

7. CONCLUSION

First of all, students need to have the highest level of proficiency possible in the 3D software package they will most likely be using in their new jobs. That software should be the current version of Autodesk's Revit.

Because so many companies, especially early adopters, developed their own hybrid systems using softwares like Navisworks, or writing their own, there haven't been many standard protocols for educators to look at to create BIM curriculum. That is changing, however, and several new tools are being offered by Autodesk in specific disciplines like Construction Management:

https://academy.autodesk.com/curriculum/construction-management. In addition, DProfiler and Synchro tutorials, along with videos and classroom experiences in mock coordination meetings will continue to be some of the best ways to introduce BIM to construction management students.

The author hopes to start a connection with as many other undergraduate professors as possible so the group could go forward developing really effective BIM curriculum together. All universities can prepare students to hit the ground running in this new paradigm called Building Information Modeling.

REFERENCES

1. Bozdoc, Marian (2006). *History of Computer Aided Design.*
   Available at: http://www.thocp.net/software/software_reference/cad_bozdoc.htm
2. Rizer, Steve (2012). *Expert Sees 4D, 5D BIM 'Taking Off'*.
   Available at: http://constructionpronet.com/Content_Free/42612part1.aspx
3. Malangone, Kathy (2012). *McGraw-Hill Construction Report.*
   Available at: http://construction.com/about-us/press/bim-adoption-expands-from-17-percent-in-2007-to-over-70-percent-in-2012.asp
4. Building and Construction Authority (2013). *International experts: More benefits can be reaped from building information modeling*
   Available at: http://www.bca.gov.sg/Newsroom/pr01082013_IPE.html
5. Cousins, Bruce (2010). *Creating Job Descriptions for VDC-BIM*
   Available at: https://bimforum.org/2010/09/27/creating-job-descriptions-for-vdc-bim/
6. Stine, Daniel (2015). *Residential Design Using Autodesk Revit 2015.*
   ISBN-13: 978-1-58503-889-3, Available at: http://www.sdcpublications.com/pdfsample/978-1-58503-889-3-3.pdf
7. Course Descriptions (2015). *John Brown University Undergraduate Catalog.* Available at: http://www.jbu.edu/catalog/current/cm/
8. Shapiro, Gideon (2014). *Setting a Standard in Building Information Modeling.*
   Available at: http://www.architectmagazine.com/technology/setting-a-standard-in-building-information-modeling_o
9. National BIM Library (2013). *BIM Reality-Design, Construct Through to FM.*
   Available at: https://www.youtube.com/watch?v=Rqn_cImE-no
10. Beck Technologies (2012). *DProfiler Demonstration Video.*
    Available at: https://www.youtube.com/watch?v=5qUIlPqKszk
11. Synchro Software (2016). *Our Mission*.
    Available at: https://synchroltd.com/project-delivery-team/

INTEGRATING BIM TECHNOLOGIES INTO MEP CURRICULUM

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ABSTRACT

The need to educate students in advanced Building Information Modeling (BIM) knowledge is growing as more and more projects are expanding the utility of project data across the development lifecycle. Nowhere is this more evident than in the areas of mechanical, electrical, and plumping specialty trades. While basic knowledge to navigate Revit and Navisworks is important for all construction management students, the specialty contracting fields are seeking graduates with advanced BIM knowledge to lead projects with strict requirements for virtual design and construction. This paper details a proposed approach to integrating advanced BIM knowledge into an upper division construction management course at Missouri State University. Using guided estimating, trade coordination, and fabrication workflows, students in TCM 424 - Mechanical and Electrical Systems Estimating will be will be tasked with completing quantity takeoffs, clash detections, and BIM fabrication for mechanical and electrical systems that ultimately provide simulated work processes that are found on a growing number of projects across the world. The proposed content is presented in three distinct modules consisting of quantity takeoffs, trade coordination, and fabrication that align with the Level of Development (LOD) framework. While select elements have already been integrated into the current curriculum, the authors intent to implement the full proposed content in the next available academic period.

Keywords: BIM, Curriculum design, VDC, LOD, MEP systems

1. INTRODUCTION

Knowledge of building information modeling (BIM) technologies and applications is a highly desired skill when recruiting new construction management graduates. While basic knowledge to navigate Revit and Navisworks is important for all construction management students, specialty contracting fields of mechanical, electrical, and plumbing (MEP) trades are demanding graduates with advanced BIM knowledge to lead projects with virtual design and construction (VDC) requirements. In response to the growing demand for BIM capabilities relating to MEP systems, the construction management program at Missouri State University has developed BIM course work to be integrated into the existing MEP curriculum.

The proposed BIM curriculum is designed to provide an introduction of BIM technologies specifically relating to MEP construction. Additionally, an exposure to level of development (LOD) concepts is woven into the content. The authors present pedagogical content in three distinct modules with lecture topics, practical exercises, and reflective assignments. The content is structured to follow along with the specialty contractor preconstruction workflow from estimating to coordination and finishing with fabrication.

2. LITERATURE REVIEW

2.1 Background

Developing curriculum that addresses that wide range of building information modeling (BIM) tools and processes in an academic setting is a difficult challenge. Over the past decade, the literature has presented three common models that institutions are adopting to integrate BIM knowledge into the classroom (Barison & Santos, 2011; Clevenger, Ozbek, Glick, & Porter, 2010; Kim, 2012). The first approach looks to expose students to an in-depth course focusing on BIM concepts and specific software applications in a dedicated course. The second approach is aimed at spreading these same concepts across multiple courses in a program of study. The last approach is a hybrid of the first two systems whereby a dedicated BIM course is used as an introduction to the basic modeling concepts, but additional details and/or specific practice area expertise is introduced in subsequent coursework.

The authors of this paper have implemented this last strategy at their University to better prepare students for careers in specialty construction or in the growing area of virtual design/construction engineering. Over the past two years, the authors have developed modules for an upper division course class that focuses on mechanical, electrical and plumbing system estimating. These BIM-based modules generally fall into three practices: 1) using BIM models for estimating; 2) using BIM models for collision detection and analysis; and, 3) introducing standardized levels of development (LOD) into model development. The following sections will examine existing literature on integrating these practices into the classroom environment.

2.2 Using BIM for Estimating Education

The use of BIM to assist/aid the construction estimation process has long been a goal of its adoption (Azhar, Khalfan, & Maqsood, 2015). The ability to not only auto-generate material/equipment schedules but also visualize complex systems in-situ are two of the many proposed areas of productivity improvement and cost savings (Olatunji, Sher, & Gu, 2010; Shen & Issa, 2010). Faculty at California State University, Chico analyze the amount of time reduction realized in a concrete foundation estimate for BIM-based strategies versus traditional hard copy plan take-off (Gier, 2008). They found that the amount of time students spent performing quantity take-off was significantly faster using BIM or on-screen take-off methodologies. In addition, they also found that accuracy of the student results was within five percent of the instructor's target quantities – comparable to the traditional take-off method.

Similarly, Liu and Killingsworth (2012) analyzed the impacts of BIM processes into an introductory estimating course at Auburn University. Their study found the while student perceptions were favorable to both an increased understanding of the 2-dimensional construction plans/specifications and more preparedness for quantity take-off assignments, the actual performance of students was not significantly impacted with BIM content.

2.3 Using BIM for Collision Detection and Trade Coordination

One of the main uses of BIM for large construction companies is collision detection during subcontractor coordination efforts (Sattineni & Bradford, 2011; Sullivan, 2007). Many academic programs are touching upon these processes in their curriculum. Each program's approach to implementing collision detection (e.g., clash detection/avoidance) falls into different courses within a program of study and explore varying depths of coverage (Ahn, Cho, & Lee, 2013).

A few studies have analyzed the effectiveness of teaching collision detection processes in the undergraduate curriculum. Azhar et. al. (2010) examined student perceptions of using BIM for Auburn University's Capstone Thesis course. The authors found that while creating the digital models for coordination was difficult given the limited exposure to these MEP systems, the actual procedures and tools necessary for coordinating trade partner work was easy to learn and an invaluable tool for contractors. Similarly, Vinšová et. al. (2015) studied the use of BIM for multiple courses in an architectural program of study at Czech Technical University in Prague. Findings from study again highlighted the difficulty for students in creating digital models of MEP systems despite the ease of utilizing collision detection tools.

2.4 Development of BIM LOD StandardsD

As BIM adoption increases in both industry and academia, the need to develop standard practices, classification schema and communication standards has become more evident. In the U.S., the American Institute of Architects (AIA) was an early developer of a system to help define the various levels of detail and information required in BIM workflows (Bolpagni, 2016). With the introduction of the AIA E-202 in 2008, the groundwork for describing model content and allowable information uses began to take shape (AIA, 2008). The original five LODs (100, 200, 300, 400 and 500) would be expanded to include an additional level, LOD 350, in 2013 through the work of the BIMForum – a partnership formed between the Associated General Contractors (AGC) and the AIA (BIMForum, 2018).

Ultimately, the development of BIM LOD standards is a long-term effort to help project professionals communicate more clearly about the project development lifecycle and its information. The BIMForum (2013) states that the intent is to standardize industry practices in order to:

> Help teams, including owners, to specify BIM deliverables and to get a clear picture of what will be included in a BIM deliverable; to help design managers explain to their teams the information and detail that needs to be provided at various points in the design process; [and] to provide a standard that can be referenced by contracts and BIM execution plans (p. 8).

3. PEDAGOGICAL CONTENT

The proposed instruction and learning curriculum is designed to follow the general preconstruction BIM workflow of MEP contractors. The curriculum is divided into three modules consisting of developing quantity takeoffs for material and labor estimates, coordinating trades, and fabrication of modeled assemblies (Refer to Figure 1). Each phase is comprised of lecture content, practical exercises, and reflection assignments intended to foster critical thinking. While every company and employer utilize different BIM technologies and platforms, the curriculum is intended to provide students an introduction and foundation of BIM technology relating to mechanical, electrical, and plumbing systems to build upon when entering the specialty contractor industry.

The instruction is intended to be integrated into the mechanical, electrical, and plumbing estimating course within construction management curriculum. At Missouri State University, the instructional content will be integrated into TCM 424 - Mechanical and Electrical Systems Estimating. This course is an advanced estimating course. Prior to enrolling in TCM 424, students are required to complete a construction cost estimating course and are encouraged to complete TCM 313 - Facility Design. TCM 313 - Facility Design provides a basis of BIM knowledge and introduction to Autodesk Revit and Autodesk Navisworks. A prior introduction to BIM and Autodesk programs is critical as the presented content builds upon that base. Careful consideration must be made when considering the appropriate course for implementing the content as basic BIM competency is required along with technological classroom resources. As presented, the curriculum is structured to enable open discussions in a seminar instruction format best suited to junior and senior standing students.

The presented workflow generally aligns with the Level of Development (LOD) advancement from level 300 to 400 (Refer to Figure 1). While standard definitions of LOD are published by industry organizations, interpretations and specific requirements may vary amongst organizations and projects. It is common that only specifically defined elements achieve high levels of development. Oftentimes, small elements that are easily coordinated in the field are not modeled while large components such as ductwork and groups of conduits are heavily modeled. For the purposes of this course, the practical exercises are designed to meet the basic LOD guidelines.

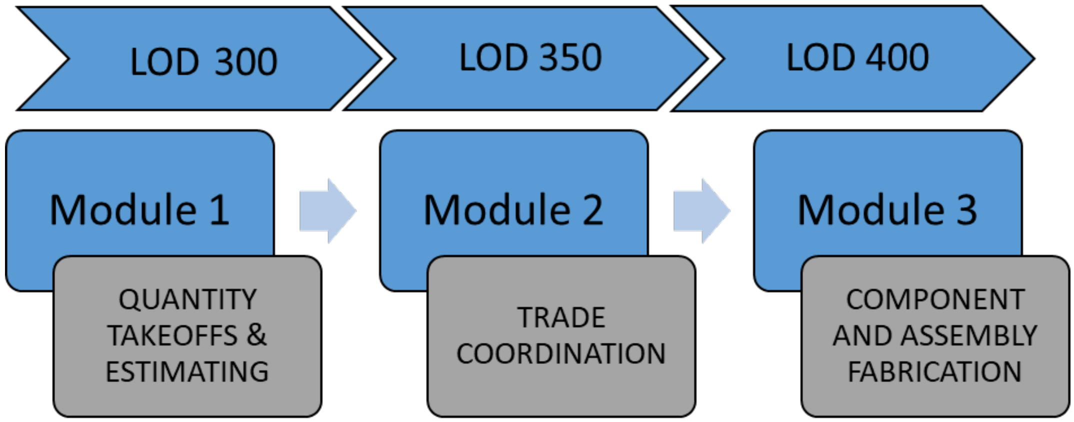

Figure 1: Framework of Pedagogical Content

3.1 Module 1: Quantity Takeoffs and Estimating

The first BIM learning module focuses on leveraging BIM technology to develop quantity takeoffs and estimates for MEP systems. Performing quantity takeoffs to which pricing will be applied is the foundation of developing a detailed estimate. Students must have a basic ability to read and understand MEP drawings and specifications of construction documents prior to beginning the first module. Students will use Autodesk Revit to model mechanical, electrical, and plumbing systems for estimating. The development of a BIM model with accurate quantities and sizes meets the intent of LOD 300 modeling.

The first module lecture is a combination of information content and practical demonstrations. The knowledge content emphasizes the concept of LOD 300 BIM requirements with examples of modeled elements. Additional lecture content presents techniques of modeling MEP systems for estimating, however much of the modeling instruction is taught through the demonstrations. Demonstrations for each general step are presented. The authors recommend completing a comprehensive example demonstrating each individual step to aid the students in understanding the overall process. The lecture, demonstrations, and comprehensive example may need to be divided into separate class periods dependent upon time constraints of the course.

The general steps to develop a BIM estimating model of MEP systems is presented as a process with three steps. In the first step, construction drawings must be imported into Autodesk Revit. Second, the respective trade content is modeled. Lastly, schedules are used within Revit to develop material lists and quantity counts. The scheduled content can then be exported out for estimating purposes.

The first module exercises are creating BIM estimating models for MEP trades. Students are given a set of construction documents and specifications for a single building to work through for the course. Starting with CSI MasterFormat Division 22, the students perform quantity takeoffs of the underground plumbing, venting, domestic hot and cold water, and all associated fixtures. Next the students move into Division 23 to perform quantity takeoffs for the hydronic piping, HVAC equipment, air devices, and ductwork systems. The last trade that is covered is Division 26. In this section, students perform quantity takeoffs of the electrical distribution equipment, receptacles, devices, conduit, conductors, and lighting fixtures. Each of the general BIM estimating modeling steps will be repeated for each trade. Divisions 27 and 28 are discussed in the class, but little estimating is performed given the limited time available.

The first step is a detailed approach on separating out a construction drawing sheet out into a single PDF document. Using Bluebeam Revu, a scaled door or common dimension is placed on the sheet. The PDF file is than saved in JPEG format to be inserted into Autodesk Revit. Autodesk Revit 2017 does not currently accept scaled PDF documents into the program. Next the students open Revit and create a new project using the default trade template. In an academic setting, the use of templates can be difficult. As the class progresses, the students are encouraged to develop their own template to be used after the class. Using the plumbing template, the JPEG document is inserted into Revit and scaled correctly.

Second, students begin modeling trade elements using the correct component family such as pipe types or fittings for the project. The appropriate element families need to be loaded into the project. The use of sectioning and 3D views in Revit are used to create a complete overlay of the system. Similar to estimators, the students will need to refer to the specifications and architectural drawings for elevations and floor heights to complete an accurate BIM model. Modeling MEP systems in Revit aids the students in learning the different component nomenclature that they will encounter after graduation such as fitting types. The 3D view gives the students a realistic view of the system to be installed helping better visualize and comprehend the project and scope.

The third and final step of BIM estimating is extracting the data for quantity takeoffs. Schedules are created and refined to show relevant data for use in estimating. Quantity parameters are added to create material lists and quantity counts. The scheduled content is then exported to Microsoft Excel enabling future data filtering and manipulation for estimating purposes.

Many mechanical and electrical contractors are accustomed to using Autodesk AutoCAD MEP in their estimating process. Similar to the design industry, smaller specialty contractors have found transitioning to Autodesk Revit for estimating to be a daunting undertaking and significant challenge. The BIM content presented familiarizes construction management students with Revit to assist in transitioning BIM platforms after graduation.

Reinforcing the lecture content and practical exercises, a reflective assignment will be implemented to promote critical thinking and deeper understanding. The essay assignment is ideal as students have the flexibility to tailor subjects and dive deeper into topics they find most interesting. The first module essay will focus on impacts of BIM in estimating. Students are asked to discuss appropriate applications and considerations when using BIM for estimating. Specific considerations such the required level of detail and effort required must be considered. Students will also be asked to address the impact of BIM in estimating with regards to quality and accuracy of estimates. While the course is tailored to MEP estimating, students interesting in general contacting or other specialty contacting may elect to elaborate upon applications for the use of BIM in estimating other trades and disciplines.

3.2 Module 2: Trade Coordination

Upon completing the estimate by leveraging BIM technology, the students will advance to module two concentrating on trade coordination. Trade coordination is often the next step for contactors in the BIM workflow after estimating and being awarded the contract. Using the LOD 300 model generated by the design team or contractor during bidding, the contractor would develop a LOD 350 model by coordinating trades. The students will develop a coordinated model to meet the intent of LOD 350 modeling requirements in the second module.

Similar to the first module lecture, the lecture will be a combination of information content and demonstrations. The knowledge content will emphasize the concept of LOD 350 BIM requirements with examples of modeled elements. Additional lecture content will present how BIM coordination plays into VDC and BIM strengths and weaknesses. Lastly, demonstrations should be presented. Demonstrations should include exporting the Autodesk Revit model into Autodesk Navisworks, basic refresher on Autodesk Navisworks, Autodesk Navisworks clash detective tool, and basic examples. At least one of the basic examples must include detailed steps.

The steps to resolve a clash are to be presented as a working process with four main steps. First, clashes must be identified, using Autodesk Navisworks. The second step is to identify potential resolutions and evaluate each option. Third, the option of clash resolution must be selected and assigned to the respective trade(s). The modeling change must then be implemented to resolve the clash in the fourth step. Lastly, the trade models must then be rechecked to ensure the clash is resolved. The cycle shall be repeated if the clash resolution was unsuccessful or another clash was initiated.

The exercise for the second module consists of performing clash resolution to produce a coordinated trade model. For the exercise portion, students will be divided into groups of three. Within each group, the students are assigned mechanical, electrical, or plumbing systems for coordination. While models developed in the first module may possibly be used, the authors believe starting with a new Autodesk Revit model that is consistent amongst the respective trades will likely reduce the technical difficulties. The models shall have a limited number of basic clashes between each trade. The students will load the mechanical, electrical, and plumbing trade modeling into Autodesk Navisworks and identify the clashes predetermined by the instructor. The students will next develop clash resolution action items and assign action items to the respective trade. The students may then continue the exercise outside of class by addressing the assigned action items of their respective trade. During the next class period, students will load their updated trade file into Autodesk Navisworks to run a new clash test determining if the clash resolutions were successful.

After determining the success of clash resolution within each group, the groups will be asked to share their level of success. The instructor will initiate a class discussion to identify the ideal clash resolution strategy for each of the predetermined clashes. While technical difficulties and challenges will likely be experienced and failures to resolve clashes are expected, these items should be capitalized upon as a learning opportunity. Discussion points regarding technical difficulties can highlight the importance of robust technology infrastructure uncommon on small jobsites and failure to resolve clashes showcase the need for multiple iterations as clash resolution is an iterative process. Ultimately, the class discussion is intended to reinforce the concept that BIM coordination is a fluid process and requires the consideration of numerous factors.

Upon completion of the trade coordination exercise, a reflection assignment will be implemented pertaining to challenges and lessons learned. The assignment consists of a reflection essay asking students to discuss challenges and lessons learned from the trade coordination exercise. Students may be challenged to think critically about thought provoking questions such as which trade is the least challenging to reroute and what are potential implications of rerouting specific systems such as ductwork, piping, or conduits. Construction management students may discuss implications related to cost as material and labor amounts my change. Engineering students may be encouraged to consider the implications of static pressure for ductwork, friction loss for piping, and voltage drop of electrical wiring.

3.3 MODULE 3: COMPONENT AND ASSEMBLY FABRICATION

The third module focuses primarily on introducing the concept of fabrication from BIM and developing the understanding of LOD 400 modeling. Much of the module will be dedicated to developing a general understanding of BIM fabrication through lecturing rather performing the actual process through practical exercises.

The intent of the lecture is to develop students' understanding of LOD 400 and BIM fabrication. The lecture shall focus upon three main topics. First, LOD 400 BIM requirements shall be presented. Specifically, the LOD 400 definition shall be presented with examples of model elements. Second, the concept of BIM fabrication shall be discussed. The instructor will emphasize that standard BIM families may be infinite lengths of materials whereas BIM fabrication parts represent the actual components such as 10' sections of pipe with couplings or ductwork segments with connection flanges. Lastly, additional programs are to be introduced to provide exposure to a variety of programs used by contractors in the industry. Additional programs could include Autodesk Fabrication CADmep, Autodesk Fabrication for Revit, Trimble SysQue, Applied Software eVolve, and DeWalt Hangerworks.

The practical exercise of module three will consist of fabricating a generic system family into a fabrication part ready for exporting to fabrication shops and equipment with Autodesk Fabrication in Revit. As discussed in the lecture component, the challenges of fabrication including contractor specific preferences and supplemental programs cause the actual BIM fabrication process to be complex and unfeasible for academic program curriculum. Given these challenges, the practical exercise is limited to an in-class exercise in which a generic Revit system family such as duct or pipe is converted to fabrication parts using Autodesk Fabrication for Revit. Advanced BIM fabrication strategies and techniques can be addressed through guest speakers from the industry or online video content.

The reflective assignment is a reflective essay providing commentary on the advantages and disadvantages of BIM fabrication. Specific advantages and disadvantages relating to schedule, cost, quality, and safety must be considered. Additional aspects including implementation challenges including resistance and setup costs should also be considered. Upon student submission of the assignment, the instructor should facilitate an open discussion with students regarding BIM technologies including fabrication. The instructor should encourage students to share BIM experiences from internships.

4. CONCLUSIONS AND FUTURE WORK

As BIM knowledge and workflows develop in the industry, it is crucial that construction management programs address these changes in their curriculum. While many college-level programs have successfully developed and implemented BIM curriculum, industry demand and challenges indicate that more focus on MEP systems is desperately needed. Programs looking to fill this gap between industry needs and educational offerings should examine BIM tools and technologies as a platform for change. The three modules presented in this paper addresses BIM technologies in estimating, coordination, and fabrication of MEP systems provide an introduction to BIM applications for specialty contractors. Further, the practical exercises of developing BIM models provides exposure to LOD concepts and standards. Integrating the content presented into an existing MEP estimating course may enable students to better understand the application of BIM technologies pertaining to MEP construction.

While faculty at Missouri State University have integrated BIM technology relating to MEP estimating as addressed within the first module, the structured content presented has yet to be fully implemented in the classroom. Additional opportunities including the implementation of the proposed content into related academic programs such as engineering technology within an elective course may also be explored. Findings and best practices shall be identified and presented in subsequent research and publications.

REFERENCES

Ahn, Y. H., Cho, C.-S., & Lee, N. (2013). Building Information Modeling: Systematic Course Development for Undergraduate Construction Students. *Journal of Professional Issues in Engineering Education and Practice, 139*(4), 290-300.

AIA. (2008). Building Information Modeling Protocol Exhibit, AIA E202. In. Washington, DC: American Institute of Architects.

Azhar, S., Khalfan, M., & Maqsood, T. (2015). Building information modelling (BIM): now and beyond. *J Construction Economics Building, 12*(4), 15-28.

Azhar, S., Sattineni, A., & Hein, M. (2010). *BIM undergraduate capstone thesis: Student perceptions and lessons learned.* Paper presented at the Proceedings of the 46th ASC Annual Conference, Boston, MA.

Barison, M. B., & Santos, E. T. (2011). BIM teaching: current international trends. *Gestão e Tecnologia de Projetos, 6*(2), 67-80.

BIMForum. (2013). Level of Development Specification - Version 2013. In: BIMForum.

BIMForum. (2018). LOD Spec 2018 Part I. In: BIMForum.

Bolpagni, M. (2016, July 19, 2016). The Many Faces of 'LOD'. *BIM ThinkSpace*.

Clevenger, C. M., Ozbek, M., Glick, S., & Porter, D. (2010). *Integrating BIM into construction management education.* Paper presented at the Proc., The BIM--Related Academic Workshop.

Gier, D. (2008). *What Impact Does Using Building Information Modeling Have on Teaching Estimating to Construction Management Students.* Paper presented at the ASC Conference 2008, Auburn Univeristy.

Kim, J.-L. (2012). Use of BIM for Effective Visualization Teaching Approach in Construction Education. *Journal of Professional Issues in Engineering Education and Practice, 138*(3), 214-223.

Liu, J., & Killingsworth, R. (2012). *A Study of Using BIM as an Innovated Teaching Tool in an Estimating Class – A Preliminary Report* Paper presented at the 48th ASC Annual International Conference Proceedings Birmingham, UK.

Olatunji, O., Sher, W., & Gu, N. (2010). Building information modeling and quantity surveying practice. *J Emirates Journal for Engineering Research, 15*(1), 67-70.

Sattineni, A., & Bradford, R. H. (2011). *Estimating with BIM: A survey of US construction companies.* Paper presented at the Proceedings of the 28th ISARC, Seoul, Korea.

Shen, Z., & Issa, R. R. (2010). Quantitative evaluation of the BIM-assisted construction detailed cost estimates.

Sullivan, C. (2007). Integrated BIM and design review for safer, better buildings. *Architectural Record Journal, 6*, 191-199.

Vinšová, I., Achten, H., & Matejovská, D. (2015). *Integrating BIM in Education: Lessons Learned.* Paper presented at the Real Time Proceedings of the 33rd eCAADe Conference.

FACILITY DATA PROJECTS

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ABSTRACT

Whiting-Turner is interested in solving the issue of collecting facility knowledge through student involvement and education. As a building ages, it becomes a larger maintenance task to keep it up. Universities, Hospitals, Developers, and many other types of building owners have many staff members on their payroll to maintain these facilities. Their staff is unfortunately ill-equipped to deal with many of the recurring and new maintenance issues because of a lack of facility knowledge. In part, this lack of knowledge stems from inexperience of some staff, but on a larger scale – the issue lies in the true lack of information. All too often, the building information, such as submittals, Operations and Maintenance documents, testing reports, and other critical documentation are lost over time. Historically this was due to usage of the files. For example, the first guy to maintain an air handling unit would grab the binder off the shelf, use it, and forget to return it to the same place. The next guy to maintain the unit would suffer from that missing knowledge. In recent times, this issue is more relevant with lost data on share drives or flash drives – or it's a case of too much data and technology through Computerized Maintenance Management Systems (CMMS), or Integrated Work Management Systems (IWMS). On new projects, contractors are able to collect that critical information and deliver it to facility operators.

On our existing stock of buildings – there lies a tremendous opportunity for students to collect facility information and provide it to the operators. Students across universities could have projects to collect facility information. These projects would include learning about different building systems, such as plumbing, heating ventilating and air conditioning, electrical, and other commonly maintained systems. After they were familiar with the broad terminologies and understanding of building systems they would be tasked with surveying an existing building and creating a BIM model, and a data model. This data model would include all of the turnover information historically available in addition to any new information for the same equipment within the building.

Through our hiring experiences, Whiting-Turner has found that students should be better educated at the basic components of buildings. Beyond understanding scheduling and budgeting, it is important for students coming out of universities to better understand equipment, and how it operates. This suggested course would challenge educators to teach students about equipment and solve an industry wide issue. It would further modernize our building stock and yield vast amounts of workable data for review. This workable data could be used for advanced maintenance related research projects. Analyzing this data in aggregate could provide changes to the way buildings are operated and maintained throughout their life cycle.

Facility owners would happily engage with their students for the creation of this information. Facility departments are often short on staff and time to usefully track this information. With the help of students this information could be collected, and these students would be better prepared to take on the working world ahead of them.

Keywords: BIM, Facilities Management, CMMS, Life Cycle

1. CONTENT

1.1 The Problem

Whiting-Turner is interested in solving the issue of collecting facility knowledge through student involvement and education. It is clear from our perspective that the architecture, engineering, construction, and operator (AECOO) industry faces several challenges over the coming years. These challenges revolve around people, products and processes. There are three major issues impacting facility owners. An aging workforce, aging buildings, and shrinking maintenance/operations budgets. These factors hinder facility owners from optimally operating their new and existing buildings.

The first aspect of this challenge revolves around people. It is well known across the industry that the facility operations workforce continues to age without being replaced with younger talent. This wave of retirement poses many issues by itself. Many members of the current workforce have been working in the same facilities for most of their years in the workforce. It is not uncommon to hear about the electrician who never leaves his building, or the plumber who knows every inch of hers. These people are a huge asset to their facility because they are the lifeline. What happens when they retire, or take a well-earned vacation? Ideally nothing, but in reality, because of their absence, a minor issue may turn into a catastrophe very quickly. To avoid widespread issues, this institutional knowledge must be captured before the current generation of facilities experts moves onto their next phase of life.

With the aging workforce, we cannot expect that all facility managers, plumbers, electricians and other tradespeople will be replaced in kind. Younger generations are more adept at technology, and often less likely to get theirs hands dirty. Interest in building trades seems to continue to wane as students become employed. The biggest issue here is that more an more buildings are built and will continue to age. It is important that the AECOO industry continues to appeal to younger generations to support the industry and maintain the new and existing facilities.

To compound this workforce issue, existing buildings continue to age. As a building ages, it is expected that maintenance costs will increase, and the task of upkeep becomes larger and harder. At first, these maintenance tasks range from simple filter changes to larger equipment replacement and rebuild projects. Some take a few minutes, but many of these projects take a few days, and multiple skilled people. As the problems with older facilities continue to grow, they are put on a list of deferred maintenance tasks. Eventually these tasks are compiled into a larger capital project to redesign and renovate, and replacement components beyond their useful life. These minor, and major tasks take time and energy from the entire AECOO industry.

Universities, Hospitals, Developers, and many other types of building owners have many staff members on their payroll to maintain these facilities. Their staff is unfortunately ill-equipped to deal with many of the recurring and new maintenance issues because of a lack of facility knowledge. In part, this lack of knowledge stems from inexperience of some staff, but on a larger scale – the issue lies in the true lack of information. All too often, the building information, such as submittals, Operations and Maintenance documents, testing reports, and other critical documentation are lost over time. Historically this was due to usage of the files. For example, the first guy to maintain an air handling unit would grab the binder off the shelf, use it, and forget to return it to the same place. The next guy to maintain the unit would suffer from that missing knowledge. In recent times, this issue is more relevant with lost data on share drives or flash drives – or it's a case of too much data and technology through Computerized Maintenance Management Systems (CMMS), or Integrated Work Management Systems (IWMS). On new projects, contractors can collect that critical information and deliver it to facility operators.

Facilities that are recently construction, and larger capital projects pose a unique challenge as well. These facilities are often much more complicated than their predecessors. Unfortunately, the facility information turned over to owners and operators is often less than ideal. This knowledge gap prevents operators from optimally maintaining even these newer buildings.

One final issue to note is the ever-shrinking budgets of facility operators. Most facility operators in today's environment understand the necessity for a robust maintenance program. Unfortunately, at most institutions, limited resource management requires that most funding is directed towards day to day front end operations, and not back end maintenance. Facility operators do not have the staff, to collect the necessary information for themselves once a building is operational. Maintaining the high level of information in their CMMS becomes a near impossible task. BIM has helped with the availability of information in several ways, but it has also overwhelmed many operators. A large amount of BIM data must be ignored by owners – either because it is inaccurate, or because they simply don't have the time to maintain it.

These people, product, and process related issues are easily considered insurmountable. The good news is that students at universities can solve all these issues with the help of industry involvement!

1.2 The Educational Opportunity

In a broad stroke, on our existing stock of buildings – there lies a tremendous opportunity for students to collect facility information and provide it to the operators. Students across universities could have projects to collect facility information. These projects would include learning about different building systems, such as plumbing, heating ventilating and air conditioning, electrical, and other commonly maintained systems. After they were familiar with the broad terminologies and understanding of building systems they would be tasked with surveying an existing building and creating a BIM model, and a data model. This data model would include all the turnover information historically available in addition to any new information for the same equipment within the building.

How does this solve the three major issues presented above?

The people dilemma is directly solved by providing students additional hands on learning experiences. As students grow throughout their education they will appreciate and better understand what facility owners need and their workload. Students who experience the workforce, will join into the workforce with more excitement.

The product issue is solved through student projects throughout their time at university. Each student will have a positive impact on the information lifecycle of facilities across their campus and possible across other industries.

Process and budget related issues are aided using student labor. In return, a student is provided with a wealth of real world knowledge that is otherwise difficult to obtain.

What is the solution?

Development of a program to collect and maintain facility information through student educational experiences is the main goal of this process. Industry involvement in this process is crucial for the success of this goal. If proper buy-in is obtained from industry partners, and universities, this outline has potential to be a key tool in helping push AECOO, BIM, and other technologies forward. Multiple courses or projects would need to be developed at different levels of education throughout a traditional college experience.

To start their curriculum, a younger student such as Freshman or Sophomore level, would obtain basic industry level knowledge. To start the curriculum, students in the AECOO industries should be tasked with interviewing and shadowing industry professionals. The requirement from the industry here is an openness to sharing with students their experiences. University operations and maintenance teams are the best place to start this process. Each student should be given a task to not only learn from an industry professional, but also to summarize their role in the greater AECOO industry. Either in teams, or as an individual, students should all experience each phase of a building life. Whether the student be a future architect, or building operator, it is critical for them to understand how a designer thinks, what a contractor considers, and the everyday issues of maintenance personnel. Although not mentioned as an issue in the problem above, it is an industry wide issue that different parties across our industry do not understand one another. The classic example is the adversarial relationship between designers and contractors. Exposing students to people from across the industry on a deeper level will help them gain interest in the industry, and better understand the role of their future peers. The suggested class project for this would be to spend time with industry personnel from a designer, a contractor, and a building owner throughout the semester. As an added aspect, these young students will build relationships with industry partners, experience each role in the industry, and better understand what they personally want to do in the industry when their schooling is complete. In the current academic curricula, many students are unaware of the roles and responsibilities of a facility manager, or other roles even once they graduate. At this point in a student's career, it is most important that they be excited about the industry and understand where they fit. Though technical knowledge including BIM is important, it is not as important that they personally provide that value to the industry.

As students' progress with their educational career, they should be exposed to more hands on and technical facility knowledge – and begin to provide real value to facility owners and operators. Students at the Junior and Senior level of their curriculum will be assigned facilities for which they are responsible to collect facility data of existing buildings. Industry partners who own facilities would need to participate in this activity. University operations teams are a great place to start with this because many university buildings are old and have missing information. For this to be most successful, groups should be formed across students from varying specialties. This includes students of architecture, mechanical engineering, civil engineering including structural and construction managers, facility managers, and other specialties. The specifics of this will vary for each university, but the cross-discipline nature of this course project is important for its success. If students of hands-on schools are nearby they should also be included in this process, surveyors, HVAC technicians, and other similar technical jobs have a tremendous ability to help and learn through this. This facility data will span across all components of the building, including plumbing, heating ventilating and air conditioning, electrical, architectural, structural. A focus will be put on the maintainable equipment and components. All facility data will be collected by these students. As this is a major undertaking, it should likely take on the role of a capstone project for students.

The collected facility data includes everything from the lifecycle of that building, with a priority given to actionable information for the day to day facility operations. That will come in two forms, data and documents:

Regarding the data side, that information will include an asset matrix with formatting to be provided by the specific facility owner. That asset matrix may or may not be in the COBie format, but it will include all the basic data on assets within the building. Generally, it may include asset name, number, location, model number, serial number, among others, and specific product data. For an example of specific product data, an air handling unit may require filter size, belt size, bearing information, fan speeds, etc. in addition to the standard product data. The requirements of this information will vary for each facility owner, but the general concept should hold true across all owners. With this information, facility managers in the industry can populate their CMMS or IWMS software systems to aid with their day to day operations. Students will need onsite access to obtain some of this information. Pictures of the equipment will need to be taken to help students verify.

Document information collection will provide students additional opportunities to provide value and learn about facilities. For any project in a facility, design, construction and operations documentation will need to be collected. Design information may include project drawings, record changes, and other contract administration documentation. Construction information may include RFP's, as-builts, submittals, Operations and Maintenance documents, and other relevant information. Operations documentations may include testing reports, work order histories, photo documentation of existing conditions, and more. Each project will be unique in the documentation available for students to collect. Some facility data, such as operations and maintenance instructions will be available online through manufacturers websites.

As an additional component to this information collection – BIM models should be created for each of these facilities. These models should contain basic level information, about geometry, and data. These models should not necessarily contain all the data and documentation available to students, but rather focus on the information that provides value to the facility owner. The data, and document deliverables should be separate from the BIM deliverable where necessary.

As some students continue their education beyond a BS/BA level of education, this framework provides opportunities for research opportunities for post-grad level students as well. At this level of education, students will be tasked with analyzing the collected data from the earlier capstone projects and working directly with AECOO personnel at dissecting facility information. These projects will be customized for each owner, and each student – but the general idea is that the students take a deep dive into data collected for the facility and develop a solution. For example, with collected work order data history, a student may be able to identify that on specific types of equipment always breakdown in summertime. With that information they will be able to develop a prescriptive plan with industry personnel on how to resolve that issue or specify a different type of equipment. The same concept could be applied to a construction management student paired with a contractor.

As required by each building owner, all this information may be compiled and turned into actionable information for building operators. Industry factors and individual universities will need to drive the deliverable requirements, but certain expectations should be standardized across universities wishing to implement this process.

1.3 The Industry Impact

Through our hiring experiences, Whiting-Turner has found that students need to be better educated at the basic components of buildings. Beyond understanding scheduling and budgeting, it is important for students coming out of universities to better understand equipment, and how it operates. This suggested curriculum would challenge educators to teach students about equipment, building assets and management and solve an industry wide issue. It would further modernize our building stock and yield vast amounts of workable data for review. This workable data could be used for advanced maintenance related research projects. Analyzing this data in aggregate could provide changes to the way buildings are operated and maintained throughout their life cycle.

Facility owners would solve their dilemma of having poor information for their existing facilities through this educational program. Having this information will enable them to do better maintenance, operate more efficiently, and ultimately serve their tenants and society better. This is especially true for campus facility owners – who often struggle to keep up with even the newer facilities information because of the volume of it that comes through their doors.

By utilizing the approach of gradual learning throughout a student’s tenure at school – we will be able to encourage growth and interest. As early as their first collegiate year, students will be able to learn from facilities personnel, and begin to have an impact by learning from the more senior members of the industry. As the students grow in breadth of knowledge – they will have a larger impact by surveying existing facilities and providing real operational data to building owners. At the highest level of education – students will be challenging the industry to operate facilities at their highest level through data analysis.

Facility owners would happily engage with their students for the creation of this information. Facility departments are often short on staff and time to usefully track this information. With the help of students this information could be collected, and these students would be better prepared to take on the working world ahead of them.

There is a tremendous opportunity for university curricula and students to impact the AECOO industry through its people, its facilities, and the process by which they are maintained and managed.

2. CONCLUSIONS AND FUTURE WORK

This paper address a potential solution for collecting facility information, although there are multiple potential roadblocks to implementation. It is understood that students are not industry experts. This hurdle is addressable through a few key ideas. The primary method of dealing with this is to have industry professionals implementing a thorough QA/QC process. This process would vary by organization. One drawback to this would be the cost to universities of developing and maintaining a quality department. A second way to deal with this issue to is to have multiple student groups procure information for the same building. Over time, student projects would be compared to one another and aggregated into a complete and accurate set of information. One other potential issue to this method is the access levels required by students at universities. One way to solve this issue is to provide keycard access to students which is traceable, this accountability would encourage students to be excellent stewards of their facilities. In reality, each university will need to develop their own solution to these issues. Further research could yield a community of available professionals, or other viable solutions.

One final issue to consider is the time required to complete these tasks and the availability of student curricula time towards these projects or research. Students have a relatively short time on campus available to them for new courses. Though this is an issue, this curricula could either be weaved into existing courses through projects or added on as elective courses within the framework of their degree. Here again, universities will each have to make their own decision regarding implementation.

As it stands today, this paper highlights a need based on industry experience and demand. This paper does not proclaim to be a thorough research document, but rather an opinion paper based on this experience. If there is sufficient interest in this topic, a more complete set of research could be performed to solidify this theory. Industry partners should be excited about working with academics on developing this further!

REFERENCES

None

A JUST IN TIME, CONTEXTUAL EDUCATIONAL MODEL FOR INTRODUCING BIM TO UNDERGRADUATE CONSTRUCTION MANAGEMENT STUDENTS

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ABSTRACT

In the Architecture, Engineering, Construction (AEC) industry, building information modeling (BIM) is increasingly being implemented throughout the construction project lifecycle. It is an important tool in the collaborative process of designing and constructing multi-party projects and is significantly affecting the manner in which contractors manage construction projects. Many construction organizations, such as the Associated General Contractors and the Carpenters Union have recognized the importance of BIM in the construction industry, developing curriculum to teach their members BIM best practices. BIM education in University programs has paralleled industry use and development. Curricula models for BIM education vary widely among Universities. This paper focuses specifically on implementing BIM curricula in undergraduate construction management (CM) degree programs. In particular, small programs with limited BIM resources and teaching capacity. The educational model presented includes a scaffold approach in which BIM is introduced across the CM curriculum in a just in time, contextual approach, with increasingly rich content as students matriculate through the program. This paper discusses the just in time, contextual based education model, details the specifics of each course within the model where BIM is covered, and summarizes implementation and outcome observations.

Keywords: BIM, construction management education, BIM curricula

1. INTRODUCTION

The necessity for implementing building information modeling (BIM) education in construction management (CM) programs and its subsequent growth is well documented (Barison and Santos 2010, Huang 2016, Joannides et al. 2012, Lee and Hollar 2013, Pavelko and Chasey 2010, Sacks and Barak 2010, Taylor et al. 2008). Notably, in the Architecture, Engineering, Construction (AEC) industry, BIM is increasingly being implemented throughout the construction project lifecycle. It is an important tool in the collaborative process of designing and constructing multi-party projects and is significantly affecting the manner in which contractors manage construction projects. Many construction organizations, such as the Associated General Contractors and the Carpenters Union, have recognized the importance of BIM in the construction industry and have developed curriculum to teach their members BIM best practices. BIM education in University programs has paralleled industry use and development. The rapid growth in BIM education has spawned various pedagogical approaches among CM programs. Initial efforts focus primarily on stand-alone courses emphasizing technology aspects of BIM (Ghosh et al. 2013, Joannides et al. 2012, Liu and Hatipkarasulu 2014). Larger, well-resourced CM programs offer a larger palette of BIM courses in more advanced topics. However, smaller CM programs with limited faculty and resources have a greater challenge to prove a rich BIM curriculum to meet the growing industry need.

This paper focuses specifically on implementing BIM curricula in undergraduate CM degree programs. In particular, small programs with limited BIM resources and teaching capacity. The educational model presented includes a scaffold approach in which BIM is introduced across the CM curriculum in a just in time, contextual approach, with increasingly rich content as students matriculate through the program.

The scaffold approach vertically builds BIM education throughout the CM curriculum. Aligned with the American Council for Construction Education (ACCE) accreditation requirements, BIM instruction begins at the introductory level in lower division courses to address the student learning goals of ‘remember’ and ‘understand’. Remember requires students to list or name an idea or concept. Understand requires students to demonstrate understanding by explaining, summarizing, classifying, or translating given information. As students matriculate vertically through the curriculum, BIM topics are expanded in upper division courses to align with ACCE requirements of ‘apply’, ‘analyze’, ‘evaluate’ and ‘create’. Putting information into context demonstrates students applying knowledge. Analysis begins the process of comparing and contrasting. Evaluating BIM models allows students to begin critiquing and predicting design and management plans. At the highest level, students create new ideas that integrate the knowledge they have gained. The vertical integration of BIM instruction in the CM curriculum facilitates a project (contextual) based, just in time delivery of BIM.

The just in time delivery of BIM instruction is a powerful pedagogical approach for student learning. BIM concepts are introduced during discipline specific courses within the curriculum. For example, 3-dimensional visualization is introduced in the introductory laboratory where students gain an understanding of how BIM can be used to increase the efficiency of construction field operations. The general overview of how BIM is used across the industry is covered during an introductory course that introduces the general topic of construction management. BIM as a construction engineering tool is delivered in a temporary structures course where students can apply and analyze design functions. The model and construction document development process is discussed in an early course focused on plans reading and overall materials and methods of construction. The function of BIM to evaluate energy efficiency; heating and cooling design; material fabrication and similar functions are introduced in electrical and mechanical construction courses. BIM use for quantity take-offs and calculations are used in scheduling and estimating exercises. BIM use for specialty trade integration and as a collaboration and communication tool is covered in a higher-level project management course where students can actually integrate the learned knowledge into a project based example.

2. JUST IN TIME MODEL IMPLEMENTATION

A just in time BIM implementation model is well suited for small, low resource CM departments. Providing BIM concepts throughout the curriculum in appropriate levels of complexity provides an efficient implementation method. An initial implementation strategy mapped specific BIM learning outcomes to overall program outcomes using the ACCE pedagogical levels. This mapping of BIM learning outcomes to program outcomes provides a scaffolded framework to determine where each outcome would fit best into the program (refer to Figure 1). For example a level one learning outcome (knowledge of BIM) would most likely be included in a course that occurs early in the program, while a level six outcome (creating) would most likely be included later.

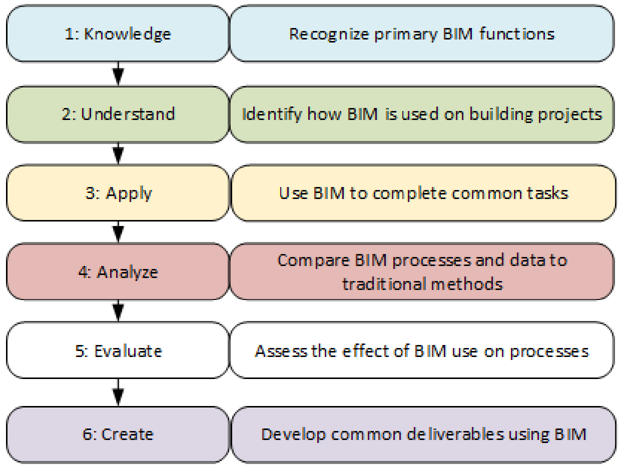

Figure 1: Scaffolding of overall BIM learning outcomes

The scaffolded framework facilitates the analysis of each individual course to determine where the BIM learning outcomes are most appropriate. Refer to Figure 2.

Course	BIM learning outcome	Scaffold
CM111: Materials & Methods	Examine a simple 3-dimentional building model	1
CM120: Intro to CM	Recognize the primary functions of BIM	1
	Identify benefits and issues related to BIM use	2
CM210: Construction Communication	Differentiate how BIM software for document management is different from traditional methods	2
CM245: Drawings & Specs	Interpret a 3d BIM model and compare it to traditional 2d drawings	3
CE210: Surveying	Use a laser scanner to create a 3d image	4
CM350: MEP	Analyze BIM models for MEP coordination and fabrication	3
CM367: Estimating	Complete and compare cost estimates using BIM software and traditional methods	4
CM374: Operations & Improvements	Measure productivity of construction methods using a BIM model and compare to traditional methods	5
CM385: Contracts & Law	Assess risk associated with using a BIM model for design and construction.	5
CM:410: Temporary	Create a BIM model with parametric data for a scaffolding system	6
CM417: Scheduling	Develop a construction schedule using BIM software	6
CM420: Concrete & Steel	Use BIM model for structural analysis of structural steel building system	6
CM460: Cost Controls	Estimate construction cost using BIM model parametric data	5
CM475: Project Management	Evaluate methods for using BIM for team collaboration	5

Figure 2: Example of specific BIM curriculum implementation strategy

A discussion of the BIM learning to course map is presented in the next section.

3. DISCIPLE SPECIFIC COURSE EXAMPLES

3.1 Recognize Primary BIM functions

The first introduction to BIM in the CM program is 3d visualization in a freshman level hands-on laboratory. The students in this lab engage with physical activities that involve applications such as concrete formwork, structural steel, and light gauge steel wall framing. Using a tablet, the students access two dimensional plans in order to construct each project. Once they are familiar with reading the 2d drawings students are introduced to a 3d drawing from a BIM model. Students use the 3d drawings to complete their project and to verify that it was constructed correctly. The CM department requires each student to purchase a tablet pc during this early course to use throughout the curriculum. The BIM model in this course is a simple light gauge steel structure drafted by a student using Revit in a separate stand-alone BIM class. Students view the structure from different angles and zoom in on specific areas of interest using several different free apps. Additionally, throughout the semester, students use various software to perform tasks such as document control, communication and drawing coordination. Demonstrations of these tasks using associated BIM models is a component of the course.

3.2 Identify How BIM is used on Building Projects

During the first year in the program the students take a class, Introduction to Construction Management, to introduce them to the design and construction industry. A BIM learning objective in this course is for students to gain a basic understanding of what BIM is and how it is used. This course offers a high-level study of construction management in a global environment. The course includes topics such as contract delivery methods; the overall design and construction process; project teams and basic scheduling and estimating. Once the students have a basic understanding of the overall course topics, then they are introduced to BIM towards the end of the semester in lecture format. They are given an overall definition of BIM capabilities along with how and why it is used. The BIM material is specifically related to the other topics in the course so that it is not just an "add-on" without relevance. For example, how and why each member of the design and construction team (which they just learned about) might use BIM on building projects.

3.3 Use BIM to Complete Common Tasks

Demonstrating the use of BIM to complete common construction management tasks can be implemented into many classes across the curriculum. For example, a class on drawings, specifications and building codes. This first year course covers reading and interpreting construction drawings including orthographic views; pictorial drawings and interpreting specifications and building codes. In this course the students learn to read and interpret information with exercises using 2d plans and specifications initially. Once a solid foundation and understanding of the plans and specifications is achieved, interaction with a 3d model to find similar information and further understand the interpretation can be provided. With a BIM model that has specification and code parametric data imbedded students see the interrelationship between each of the study areas. With a base model the software to accomplish this task along with training is readily available.

3.4 Compare BIM Processes and Data to Traditional Models

As students progress through the CM curriculum, there are several classes in which they can use BIM software to compare processes and data to traditional methods for common construction tasks such as document control, estimating and scheduling. An estimating course uses processes (quantity take-off) and produces data (cost estimate) and is a natural place to use BIM to compare the processes and data to traditional methods for common construction tasks. In this course students produce different types of cost estimates for various types of projects. Initially students complete material take-offs and the associated cost estimate using paper drawings, a scale and a spreadsheet. Students then complete quantity take-offs using digital drawings, measurement software (i.e. measure areas and lengths from a pdf drawing) and estimating software. Once they have completed tasks using “traditional” methods, students can use a BIM model with parametric data and estimating software to complete a cost estimate. The results can be evaluated, compared and discussed. Cost estimating software is readily available that will interact with a Revit model to complete a quantity take-off and the associated cost estimate. Software companies are available that will provide educational software licenses, base Revit models with parametric data and training. This method is straightforward to implement and does not require a high level of computer knowledge from the instructor. As of today this method has been implemented into a stand-alone BIM course with great success but has not yet been attempted in an estimating course.

3.5 Assess the Effects of BIM use on Processes

The impact of BIM on legal processes occurs during the third or fourth year during a course titled Construction Contracts and Law. In this course, students assess how different types of BIM use on a project affects the legal processes. This course covers topics such as construction contract language, claims, and common issues in construction law. BIM use is introduced later in the semester once the students have covered topics such as different types of contracts and evaluating construction claims. In the BIM section of this course students study standard contract agreements related to the use of BIM on a project such as those produced by ConsesusDocs and AIA. Associated risk and court precedence evaluation occurs once students understand the likely contract provisions related to the use of BIM. For example, how is the designer’s standard of care affected if there is a BIM model that is shared by the entire project team, or where is the liability when the contractor is responsible for clash detection.

3.6 Develop Common Deliverables Using BIM

Until students develop basic construction management knowledge, creating a BIM model is both challenging and non-contextual. Therefore, developing BIM models is deferred until late in a student’s course of study. One class in which it fits well, and occurs in the senior year, is a course on temporary construction structures. In this course students study temporary structures such as concrete formwork, scaffolding, and earth retaining with an emphasis on factors affecting cost and the basis for the design of the structures. BIM software in this course is used to design a scaffolding system and to produce a material take-off. Using software students follow step by step directions to develop an initial scaffolding design. The students then use the software to design a larger scale scaffolding structure in 3d. Once the model is complete they use the software to develop a material quantity take-off of each scaffolding part that will later be used to complete a cost estimate. By completing the design in 3d the students are able to better visualize how a building’s scaffolding system specially works after learning about it in a lecture format. Interacting with the 3d model allows the students to better understand the relationship of scaffolding to the building and how it is configured with ancillary parts such as ladders. Using BIM software to produce a material take-off demonstrates other BIM functions besides just 3d modeling.

4. OBSERVATIONS AND CONCLUSIONS

This paper address an example of a just in time pedagogical model for implementing BIM learning outcomes into an existing undergraduate construction management degree program. The assessment of student learning related to new BIM outcomes has been successful in the courses where they have been implemented and measured. In order to initially begin this process a new clinical faculty member was added to the faculty who has extensive experience working with BIM professionally. The inclusion of someone who understands how BIM is used throughout the industry made this process more obtainable. In the absence of in-house knowledge of specific BIM information, industry advisors were consulted and involved in the planning and process. While the implementation of this is still a work in progress, several barriers have emerged in the process. Early-on in the process the availability and cost of software was a barrier. However, all of the software currently used is either free and readily available or used under an educational license. One of the largest current implementation barriers has been lack of faculty knowledge in general about BIM and specifically in using the new software. Training for all of the software packages is readily available, however, it has been a challenge for some faculty to learn and more of a challenge to learn well enough to teach it. It is also observed that faculty resistance to changing their classes, new technology and BIM specifically has emerged as a barrier to the overall implementation.

REFERENCES

Barison, M.B., and Santos, E.T. (2010). “Review and Analysis of Current Strategies for Planning a BIM Curriculum”. *Proceedings of the 27th CIB W78 International Conference*, Cairo, Egypt, November 16-19.

Ghosh, A., Parrish, K., and Chasey, A. (2013). “Implementing Vertically Integrated BIM Curriculum in an Undergraduate Construction Management Program”. *International Journal of Construction Education and Research*, 11(2), 121-139.

Huang, Y. (2016). “Integrating Building Information Modeling in Existing Courses: A Systematic Framework for Undergraduate Construction Management Programs”. *Proceedings of the 123rd ASEE Annual Conference and Exposition*, New Orleans, LA, June 26-29.

Joannides, M.M, Olbina, S., and Issa, R.R.A. (2012). “Implementation of Building Information Modeling into Accredited Programs in Architecture and Construction Education”, *International Journal of Construction Education and Research*, 8(2), 83-100.

Lee, N. and Hollar, D.A. (2013). “Probing BIM Education in Construction Engineering and Management Programs Using Industry Perspectives”. *Proceedings of the 49th ASC Annual International Conference*, San Luis Obispo, CA, April 10-13.

Liu, R. and Hatipkarasulu, Y. (2014). “Introducing Building Information Modeling Course into a Newly Developed Construction Program with Various Student Backgrounds”. *Proceedings of the 121st ASEE Annual Conference and Exposition*, Indianapolis, IN, June 15-18.

Palvecko, C. and Chasey, A. (2010). “Building Information Modeling in Today’s University Undergraduate Curriculum”. *Proceedings of the 2010 Ecobuild America*, Washington, D.C December 6-10.

Sacks, R., and Barak, R. (2010). “Teaching Building Information Modelling s an Integral Part of Freshman Year Civil Engineering Education”. *Journal of Professional Issues in Engineering Education and Practice*, 136(1), 30-38.

Taylor, M., Liu, J., and Hein, M. (2008). “Integration of Building Information Modeling (BIM) into an ACCE Accredited Construction Management Curriculum”. *Proceedings of the 44th ASC Annual International Conference*, Auburn, AL, April 2-5.

THE NEEDED SKILLS IN TEACHING BIM AND SUSTAINABILITY IN HIGHER EDUCATION INSTITUTIONS

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ABSTRACT

The construction industry consumes enormous amounts of energy, water, and materials. The use of resources by the industry can be significantly reduced by incorporating different sustainability initiatives, such as, Green Building, and Net-Zero Energy Building (NZEB). NZEB is defined as an energy-efficient building where the actual annual consumed energy is less than or equal to the on-site produced renewable energy, and which is typically grid-connected to transfer any surplus of on-site renewable energy to other users. The emergence of Building Information Modeling (BIM) as a design and analysis tool is considered an important addition to the construction industry as it forms a reliable basis for decisions during the life-cycle of a facility. BIM facilitates sustainability to become a key component of the design, construction and delivery of a building and enables the corresponding decisions that affect its environmental performance, to avoid costly redesign or engineering waste.

Net-Zero and BIM led to transformation within the architecture, engineering, and construction (AEC) industry. This paradigm shift has set up new expectations on recent graduates for their competencies in sustainability and BIM. While it is a necessity that educational curricula maintain resemblance to the practices of the industry to align student learning outcomes with career-specific competencies desired by industry partners, keeping the curriculum in line with the needs of industry is a challenge as the AEC industry is rapidly transforming. Though many higher education institutions have already incorporated sustainability courses and BIM in their curricula, they are typically taught separately. In light of these developments, the higher education institutes now require instructors to have different knowledge than in the past. This paper reports the findings from a content analysis of recent non-tenure and tenure track faculty job announcements distributed to Associated Schools of Construction (ASC) member programs over the course of five academic years from fall 2013 through spring 2018. The analysis focused on the requisite knowledge, skills and abilities (KSA) of applicants as it related to BIM and sustainable construction. This study will provide a valuable reference for pedagogy design to integrate BIM for net-zero building analysis and construction.

Keywords: BIM, sustainability, job announcement analysis.

1. INTRODUCTION

With the increase of global warming, the necessity to achieve a sustainable built environment is gradually being recognized. The construction sector consumes a significant amount of energy and emits greenhouse gas (GHG) which are among the key factors for global warming. In 2016, construction activities consumed about 40% of the total U.S. energy consumption (U.S. Energy Information Administration [EIA], 2017). In addition to consumption, nearly 40% of GHG emissions were caused by the design, construction, and operation of buildings (WBDG, 2016). In this context, construction industry is beginning to address the need for buildings with reduced levels of energy consumption and natural resources required to operate across the building life cycles.

The possibility of using construction information technologies, such as BIM, in attaining building sustainability and overall performance has been an area of interest for researchers since early 2000s (Wu & Issa, 2013, October). Building information modeling provides users with options to model a building and its components in a way that enables the integrated design of energy efficiency and the assessment of energy consumption over the building's life cycle. Connecting the BIM model to sustainability metrics allows for detailed sustainability trade-off analysis by referring to real project data (Wong & Zhou, 2015). Therefore, BIM is increasingly being used throughout a building's lifecycle, including building renovation, energy simulation, and the building system analysis in an effort to improve the energy efficiency of construction projects (Zhang, Schmidt, & Li, 2016).

Over the last decade, many higher education institutions have introduced BIM contents into their curriculum either as standalone course, interdisciplinary or distance collaboration. These contents range from design studio and digital graphic representation to building technology and construction management (Woldesenbet, Ahn, Kim, & Rokooei, 2017). Given the AEC industry's acceleration of sustainability in the built environment, the integration of practical sustainable building education is essential nowadays to meet the challenges and opportunities for future employment. Hence, the demands for the two emerging fields of BIM and sustainability in construction education are continuously increasing (Kim, 2015). Though many higher education institutions have already incorporated sustainability courses and BIM in their curricula, they are typically taught separately (Luo & Wu, 2015). As a result of the increase in sustainable facilities and BIM use by industry, the need for instructors knowledgeable in both areas is expected to increase.

This paper reports the findings from a content analysis of faculty job announcements distributed to ASC member programs over the course of five academic years from fall 2013 through fall 2017, to understand the requisite knowledge, skills and competencies of applicants in the area of BIM and sustainable construction. According to Kureková, Beblavý, and Thum-Thysen (2015), internet-based data collection is a growing research area with a strong potential to widen our knowledge about various socio-economic issues. Many aspects of traditional job searches have been transformed due to the availability of online tools. These changes present new opportunities to collect and analyze web-based data about labor market demand and supply, which can enrich our understanding of pertinent issues such as skill and task requirements of employers, occupational change, wages and working conditions.

2. BACKGROUND

2.1 Literature Review

Building sustainability is an applied concept of the global sustainable development initiative. Hence, it is not only about building performance, but also the environmental, economic, and social impacts of the building industry (Luo & Wu, 2015). To support the supply, integration, and management of the needed information throughout the building life cycle, BIM arose as a solution. Along with identifying any potential design, construction, or operational issues, BIM helps to integrate sustainability regulations and assessment measures. According to Zhang et al (2016), BIM provides an accurate automated sustainability compliance checking of a proposed building. Hence, BIM is essential to sustainable design and assists with the design and measurement of a building's environmental performance.

There are several sustainability assessment methods for buildings. In 2000, the U.S. Green Building Council (USGBC) developed green building criteria, Leadership in Energy and Environmental Design (LEED) rating system, initially for new construction (WBDG, 2016). Soon it gained prominence and later included rating systems for existing buildings and entire neighborhoods. LEED is applicable for construction, operation, and maintenance work. It assesses the performance in integrative process, location and transportation, sustainable sites, water efficiency, energy and atmosphere, material and resources, indoor environmental quality, innovation in design, and regional priority through a set of prerequisites and credits (Chen, Yang, & Lu, 2015). According to Luo and Wu (2015), there are various scholarly research on BIM and green building design and construction. Many researchers have addressed BIM/LEED synergies by implementing BIM in LEED design, credit analysis, and documentation. In the United States, the General Service Administration (GSA) led efforts to leverage BIM for high performance buildings by establishing its national 3D-4D BIM program in 2003 (The General Services Administration [GSA], 2017). The program encourages all GSA projects to deploy BIM to the maximum extent. The GSA program requires model-based design, and facility management data as a project deliverable

As different sustainability initiatives are gaining importance in the construction industry, sustainability is increasingly being emphasized in construction education (Rahman & McCuen, 2018). For a subject that is open to various interpretations, teaching BIM has its challenges and opportunities. According to Eadie, Comiskey, and McKane (2014), BIM modules are preferred to be standalone and in collaboration with other built environment courses dealing with both theory and software, therefore acknowledging the collaborative aspects of BIM and making the teaching as close to the "construction project team" in practice as possible. Wang and Leite (2014) described the process-oriented BIM teaching that covers many fields such as Cost Estimating; Scheduling and 4D Simulation; Mechanical, electrical and plumbing (MEP) Design Coordination; 3D Point Clouds; and Energy Simulation.

According to Adamu and Thorpe (2016), teaching BIM generally requires the subject to be considered in the contexts of sustainability and whole lifecycle performance of buildings. Methods for teaching BIM include teacher-led instruction in traditional lectures and/or lab tutorials, problem-based projects/coursework, and use of web-based tutorials for acquiring practical skills in BIM technologies. However, no single module can satisfy the multi-faceted scope of BIM. All BIM instructors should be capable of situating BIM in their courses, and this may require continuous up-skilling (Adamu & Thorpe, 2016).

2.2 Purpose

Competencies required to be a successful BIM and Sustainability instructor are complex and demanding. It is crucial to identify core competencies, in that knowing the competencies through accurate job analysis enables the applicants to prepare for the job more efficiently. Thus, the purpose of the study is to identify the core competencies of BIM and Sustainability instructors currently desired by construction programs in the United States. An analysis of job announcements posted to the Associated Schools of Construction website during the time period of fall 2013 to spring 2018. It was expected that this study would contribute to the theory and practice of training and development, performance appraisal, job descriptions, and job design for construction management and construction science faculty.

3. METHOD

3.1 Sample

The tenure and non-tenure track faculty job announcements were collected over the course of five academic years from fall 2013 through spring 2018. To identify the requisite knowledge, skills, and abilities (KSA) of applicants to teach BIM and sustainability in construction management, the researchers selected one online job search database, Associated Schools of Construction (www.ascweb.org), in which academic job announcements exclusively in construction management are posted. A total of 245 job announcements were used for this study.

3.2 Content Analysis

A total of 273 job announcements were originally collected from the database. However, job announcements solely for administrative positions, such as Chair, Director, Head, or Dean, were removed so that the final 245 relevant faculty job announcements were selected for the analysis. The announcements were first open coded and categorized under the common themes within the collected job descriptions.

According to Kang and Ritzhaupt (2015), there are no standard rules for coding data, but an inductive process of narrowing down meaningful and segmented data into broad theme.

There were three basic techniques for analyzing the job announcement data: grouping, matching and comparing, and counting (Kang & Ritzhaupt, 2015). The announcement dataset was then grouped based on the required KSA for the applicants. The researchers reviewed all the job announcement data under the name of the job titles. This process allowed the researchers to get general information about each job title. Similarly, KSA statements were grouped based on similar concepts and functions. The job descriptions were recorded into a database file. The data were analyzed descriptively across the KSA domains using the database file.

The data analyzed were organized into three categories: 1) teaching BIM (without Sustainability), 2) teaching Sustainability (without BIM), and 3) teaching BIM and Sustainability.

3.2.1 Category 1: Teaching BIM (without Sustainability)

In this category, the job announcements generally mentioned the requirement to teach two or more courses in the construction management program including BIM. For example, one job announcement for an Assistant Professor of Construction Management position stated, *"Ideal candidates will demonstrate strong teaching and/or research experience in at least two of the following priority areas of emphasis: project management, building information modeling (BIM), estimating, and integrated project delivery"*.

3.2.2 Category 2: Teaching Sustainability (without BIM)

Teaching Sustainability requires the successful candidates to teach sustainability courses along with other construction management courses except BIM. For example, one Assistant Professor position stated," *...need expertise in one or more of the following areas: sustainability for building and/or infrastructure; sustainable construction; electrical and mechanical systems; heavy civil construction."*

3.2.3 Category 3: Teaching BIM and Sustainability

In this category, the requirement is to teach both BIM and sustainability courses. For example, one Assistant/Associate Professor position stated requirements as, *"the successful candidates should have background in a construction related specialization; including but not limited to Building Information Modeling (BIM), Integrated Project Delivery (IPD), Lean Construction, building services, and sustainability. It also stated that "experience with Virtual Reality hardware/software and/or Continuing Education Programs a strong plus"*.

Following the coding process, common KSA statements were identified from the job descriptions. The two major knowledge domains were BIM and Sustainability. The authors reviewed each job description and identified 60 job announcements specific to teaching BIM and Sustainability. Knowledge statements regarding these two domains were as follows (Table 1).

Table 1: KSA Requirements

BIM Domain	**Description**
BIM Construction Management Software Virtual Design Advanced Computer Applications Project Management Software Computer-aided Technology Computer Applications Information Technology	BIM digitally represents the physical and functional characteristics of a facility, and acts as a shared knowledge resource. (Suermann & Issa 2009). BIM is used for many purposes, including visualization, fabrication/shop drawings, code reviews, energy simulations, design validation, facilities management, cost estimation, construction sequencing, and constructability reviews (Ahn, Cho, & Lee,

Construction Technology Revit, Navisworks	2013). Required knowledge includes knowledge of model aspects and federating techniques; knowledge of discipline-specific modeling practices; knowledge of trade coordination needs, process and best practices (Mayo, Wu, McCuen, Issa, & Smith, 2018, March).

Sustainability Domain	**Description**
Sustainability Sustainable Construction Sustainable Built Environment Sustainable Design and Management Net-Zero Green Building Green Engineering Lean Lean Construction	In the context of construction education and practice, *Sustainability* is synonymous to *Sustainable Construction*, *Sustainable Built Environment*, and *Sustainable Design and Management*. Both *Net-Zero* and *Green Building* are the sustainability initiatives to reduce the energy and resource consumption by the construction industry. *Green engineering* is defined as the design, construction, operation, and use of techniques, which are feasible and economical while minimizing the generation of pollution at the source and the risk to human health and the environment (Glavič, & Lukman, 2007). Lean construction is a process that aims to maximize the use of materials and labor of construction and avoid any waste and non-value-added activities (Li, Wu, Zhou, & Liu, 2017).

3.3 Results

The job announcements were for positions in the United States. Of the 245 job announcements, 24.49% were identified specific to teaching BIM, Sustainability, or BIM and Sustainability. Within each of the five academic years, this percentage varied between 23% and 30%, with the exception of 14% in 2015-16 academic year (Table 2). BIM (without Sustainability) was included in 50% of the total job announcements analyzed for this study, as shown in Table 3. Both BIM and Sustainability were mentioned in 36.67% announcements, and Sustainability (without BIM) in 13.33% announcements. The educational requirements for approximately 67% of the positions announcements required a Ph.D. degree (Table 4), followed by M.S degree (23.33%) and B.S. degree (3.33%). Approximately 7% of the job announcements did not list educational requirements. Around 28% of the job announcements required 3 or 5 years of experience, and 30% preferred some experience, as shown in Table 5.

Table 2: Year-wise Job Announcements.

Year	**Total Job**	**Teaching BIM and/or Sustainability**	**%**
2013-14	43	13	30.23
2014-15	55	13	23.64
2015-16	57	8	14.04
2016-17	42	12	28.57
2017-18	48	14	29.17
Total	245	60	24.49

Table 3: Job Announcements in Each Category.

	2013-14	2014-15	2015-16	2016-17	2017-18	Total	%
Category 1: BIM (without Sustainability)	7	4	6	5	8	30	50
Category 2: Sustainability (without BIM)	2	2	1	2	1	8	13.33
Category 3: BIM and Sustainability	4	7	1	5	5	22	36.67

Table 4: Educational Requirements.

	2013-14	2014-15	2015-16	2016-17	2017-18	Total	%
Ph.D.	10	10	4	6	10	40	66.67
M.S.	2	3	2	3	4	14	23.33
B.S.	1	0	0	1	0	2	3.33
Not Listed	0	0	2	2	0	4	6.67

Table 5: Experience in Professional Position.

Years of experience	Frequency	%
Desirable	18	30
3	6	10
5	11	18.33
Significant	2	3.33
Not Listed	23	38.33

3.4 Limitations

The major limitation of this study is its analysis of a single online job search database. As a result, other job announcements may exist. The inherent problems with job announcement analysis in that the appearance of a statement within a job announcement is in the control of the person or people writing the job announcement (Kang & Ritzhaupt, 2015). It could lead to exclusion of some important statements. Some job announcements in our dataset were rich and descriptive with content while others were written using vague and unclear language about the expectations of the individual they wish to employ, which influenced the coding process to identify relevant competencies.

4. DISCUSSION AND CONCLUSION

The data suggests that faculty teaching BIM and Sustainability in construction management programs must be proficient with many related competencies. This has implications for construction professionals, industry associations, and academic programs. For example, 67% of the positions announcements required a Ph.D. degree, which indicates a growing demand of research work in academia for the advancement knowledge about BIM and Sustainability domains. The data also reveals the importance of having some professional experience, indicating strong ties between industry practice and academic learning in this area. Moreover, having some practical experience in the field prepares the job applicants to become a better instructor.

While 36.67% of the job announcements included a requirement or preference for BIM and Sustainability knowledge, the relationship between BIM and Sustainability is not clear from the data. The instructor may need to teach either BIM or Sustainability, or both, along with other construction management courses. On the other hand, having BIM skills was a requirement for 86.67% of the BIM and Sustainability job announcements (Category 1 and 3 in Table 3). Our data suggest that instructors must be competent in their BIM knowledge and have skills with a wide variety of software packages.

However, as BIM technology and sustainability domain continue to emerge and evolve, research should periodically check on the status of the KSAs required for construction faculty. This study highlights several areas that should assist administration with professional development of construction faculty, training and certification, job descriptions, and hiring decisions in the future.

5. REFERENCES

Adamu, Z. A., & Thorpe, T. (2016). How universities are teaching bim: A review and case study from the UK. Journal of Information Technology in Construction, 21, 119-139.

Ahn, Y. H., Cho, C. S., & Lee, N. (2013). Building information modeling: Systematic course development for undergraduate construction students. *Journal of professional issues in engineering education and practice*, 139(4), 290-300.

Bynum, P., Issa, R. R., & Olbina, S. (2012). Building information modeling in support of sustainable design and construction. Journal of Construction Engineering and Management, 139(1), 24-34.

Chen, X., Yang, H., & Lu, L. (2015). A comprehensive review on passive design approaches in green building rating tools. Renewable and Sustainable Energy Reviews, 50, 1425-1436.

Eadie, R., Comiskey, D., & McKane, M. (2014). Teaching BIM in a multidisciplinary department. Proceeding of Education, Science and Innovations.

EIA (2017). Retrieved October 05, 2017, from https://www.eia.gov/tools/faqs/faq.php?id=86&t=1

Glavič, P., & Lukman, R. (2007). Review of sustainability terms and their definitions. Journal of cleaner production, 15(18), 1875-1885.

GSA (2017). 3D-4D Building Information Modeling. Retrieved November 01, 2017, from https://www.gsa.gov/real-estate/design-construction/3d4d-building-information-modeling

Kang, Y., & Ritzhaupt, A. D. (2015). A job announcement analysis of educational technology professional positions: Knowledge, skills, and abilities. *Journal of Educational Technology Systems*, *43*(3), 231-256.

Kim, J. L. (2015). Closing Achievement Gaps using the Green-BIM Teaching Method in Construction Education Curriculum. age, 26, 1.Kureková, L. M., Beblavý, M., & Thum-Thysen, A. (2015). Using online vacancies and web surveys to analyse the labour market: a methodological inquiry. IZA Journal of Labor Economics, 4(1), 18.

Li, S., Wu, X., Zhou, Y., & Liu, X. (2017). A study on the evaluation of implementation level of lean construction in two Chinese firms. Renewable and Sustainable Energy Reviews, 71, 846-851.

Luo, Y., & Wu, W. (2015). Sustainable design with BIM facilitation in project-based learning. Procedia engineering, 118, 819-826.

Mayo, G., Wu, W., McCuen, T., Issa, R. R., & Smith, D. K. (2018, March). Implementation of the BIM Body of Knowledge (BOK) Framework for Program Planning in Academia. Proceedings of the 12th BIM Academic Symposium & Job Task Analysis Review, Orlando, FL (pp. 2-9).

Rahman, M., & McCuen, T.L. (2018). Net-Zero and BIM: The Current State and Future Needs. Proceedings of the 12th BIM Academic Symposium & Job Task Analysis Review, Orlando, FL, March 26-27, 2018, pp 83-90.

Suermann, P. C., & Issa, R. R. (2009). Evaluating industry perceptions of building information modelling (BIM) impact on construction. Journal of Information Technology in Construction (ITcon), 14(37), 574-594.

Wang, L.; Leite, F. (2014) Process-oriented approach of teaching building information modeling in construction management, Journal of Professional Issues Engineering Education and Practice, Vol. 140, 9–12.

WBDG. (2016). Retrieved October 04, 2017, from http://www.wbdg.org/

Woldesenbet, A., Ahn, C., Kim, H. J., & Rokooei, S. (2017). Faculty Learning Community (FLC) for BIM Education in a Multidisciplinary School. In AEI 2017 (pp. 39-48).

Wong, J. K. W., & Zhou, J. (2015). Enhancing environmental sustainability over building life cycles through green BIM: A review. Automation in Construction, 57, 156-165.

Wu, W., & Issa, R. (2013, October). Integrated process mapping for BIM implementation in green building project delivery. In Proceedings of the 13th international conference on construction application of virtual reality, London (pp. 30-31).

Zhang, J., Schmidt, K., & Li, H. (2016). BIM and sustainability education: Incorporating instructional needs into curriculum planning in CM programs accredited by ACCE. Sustainability, 8(6), 525.

BUILDING INFORMATION MODELING (BIM) IMPLEMENTATION IN THE RESIDENTIAL SECTOR

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ABSTRACT

A multitude of actualized benefits with the implementation of Building Information Modeling (BIM) on construction projects has incentivized construction companies towards the adoption and implementation of BIM. Such realization by design-build residential companies led to an increase in BIM implementation with the intention of lowering costs, increasing efficiencies spanning cross-functional departments and site, improving accuracy, and ultimately offering better products with acceptable profit margins. However, concerns with interoperability, lack of buy-in from multiple project stakeholders, amount of financial investments, design customization, among other concerns, have the potential to cause complications during the BIM implementation. Thus, the study presents a case study of BIM implementation at an organizational level in a small residential design-build company geographically located in the southern United States. The study utilized a direct observation method in which the researchers observed BIM implementation over a period of three years.

The analyzed company had numerous departments working cohesively, executing about 200-220 residential projects annually, and an average project price ranging from 200,000 – 250,000 USD. The information, presented in a case-study format, identifies BIM Implementation at an organizational level. The case study further identifies challenges with BIM Implementation at the organizational level and the steps the company incorporated to mitigate the challenges. The study presents an opportunity for small residential firms to review BIM implementation strategies adopted by its peer.

Keywords: BIM, Residential industry, BIM implementation, Innovation adoption

1. INTRODUCTION

Building Information Modeling (BIM) has been defined in numerous ways, as per researchers (Miettinen and Paavola 2014, Succar et al. 2012). Based on numerous definitions identified in the literature (Gu & London 2010, Succar et al. 2012), BIM can be identified as a paradigm where series of synchronous/interoperable digital technologies, processes, and protocols, adopted both at organizational and project level by various project stakeholders (such as owner, architect, contractor, and others), leads to assimilation of project information in a digital environment for the project over various project phases to successfully address the Owner Project Requirements. Holistic implementation of BIM involves the aggregation of complementing technologies and software, company and project policies, and protocols that help achieve a project's goals and vision. Holistic BIM implementation can also help meet project and organizational success criterion. The benefits of holistic BIM implementation are higher as it involves the use of complementing technologies, processes, and protocols in cohesion, rather than just using software (such as Revit) that support BIM.

A multitude of actualized benefits, such as higher visualization and coordination, increased efficiencies spanning cross-functional departments and site, high return on investments, reduced clashes between building components, errors, and redundancies, among others, have been associated with BIM implementation (Giel and Issa 2013, Lindblad 2013) on construction projects. Realization of these benefits has incentivized design and construction companies towards the adoption and implementation of BIM at the organizational and project level (Ku and Taibet 2011, Langar and Pearce 2017, McGraw-Hill 2010, McGraw-Hill Construction 2009). These benefits offer stakeholders the ability to predict and control multiple on-site issues about worker safety, use of material, time and other resources.

However, the very nature of construction industry, i.e., poorly developed R&D capability, fragmented nature of the construction industry, silo mentality, risks associated with projects, and others (Arayici et al. 2012, Kulatunga et al. 2006), can impede the ability of companies to implement BIM holistically. Holistic BIM implementation requires not only the adoption and implementation of digital technologies/software but also a change in the work process within the company that complements the implemented technologies. The change can expose the company to substantial risk (Lindblad 2013). Criminale and Langar (2017) used content analysis to identify 36 challenges that impact BIM implementation at organizational and project level. A majority of the identified barriers were associated with the organization. *Time needed for hiring/training people to use BIM, cost of hiring or training of employees, lack of national standards for BIM in the US*, and *software interoperability* were the most commonly identified challenges faced for an organization, as per Criminale and Langar (2017). On a similar context, Giel and Issa (2012) indicate that holistic BIM implementation involves high initial investment for the potential adopter. These initial investments may impede BIM implementation and could act as an impediment for contractors operating in the residential construction industry.

1.1 BIM Implementation in Residential Industry

Generally, the assumption with BIM adoption costs is that certain expenses might be offset with owners' interest (Giel and Issa 2012), which is not necessarily the case for a residential/home building industry that falls under the category of small-medium businesses. Poirier et al. (2015) citing Gao and Fischer (2008) states that implementing BIM poses a substantial risk for small/medium organizations as the proposed benefits obtained by BIM are "*either anecdotal, intangible or based on conjecture*" and cannot justify the adoption and implementation. Fabris (2010) states that even though the commercial sector and other sectors have observed significant BIM adoption and implementation, the residential industry has been passive. Garcia et al. (2016) also identified numerous factors, such as, the perception among potential adopters that BIM should be used for complex projects and the inability to perceive BIM adoption and implementation beyond certain technologies/products to inculcate an interdisciplinary and collaborative process for slow adoption among the residential industry. In addition, the national residential crisis resulted in resource conservatism among the contractors (Garcia et al. 2016) and could have impacted the ability to invest in holistic BIM implementation. Silvero et al. (2015) also found that the majority of the international residential projects, including a project in the US, did not adopt BIM holistically. The analyzed projects only involved the implementation of software such as Revit or ArchiCAD (Silvero et al. 2015).

BIM adoption and implementation within the residential sector is going to increase, as per multiple research studies (Fabris 2010, Garcia et al. 2016, NAHB 2016, Silverado 2015). At the same time, the question that emerges is if BIM adoption and implementation are going to be fast or slow. On the one hand, research studies indicate that BIM adoption and implementation has been increasing consistently and has great potential in the residential industry (Fabris 2010, NAHB 2016), whereas, other studies indicate that adoption and implementation of BIM among residential projects is going to be slow and will take time (Silvero et al. 2015, Garcia at al. 2016) due to multiple barriers such as cost, employee training, and the need of experts associated with implementation (Garcia et al. 2016). Residential projects on an average are small and utilize less complex systems within projects, so they are perceived to be less complex than other facilities. An exception to this would be the design and construction process associated with custom or semi-custom residential projects. Such projects are complicated to a certain extent, driven by owners'-

initiated modifications that develop during the design phase and sometimes extend to the construction phase. The continuous process of changes influence quality control, resource management, and make standardization difficult. Constantly changing and evolving design may further strain company resources. In addition, some of the other factors that can impact holistic BIM implementation, specifically to the residential industry, would be software interoperability and the extent to which subcontractors and vendors are willing to be supportive. This can be a concern, given that the industry is slow towards innovation adoption and also financially smaller than other industries.

Hence, the problems that small custom/semi-custom residential construction companies face necessitate the need for a study that investigates the implementation of BIM within these smaller companies. Thus, the study presents the implementation of BIM by the small residential design-build company over a period of three years (early 2012-early 2015). The selected company executed about 200-220 projects annually with an average project cost ranging from 200,000 – 250,000 USD. The next section discusses the methodology used to complete the study.

2. METHODOLOGY

When the scope of a study intends to investigate decisions, organizations, processes, events, and others, case study research is a useful tool (Yin 2014). Since the study aimed to understand how to implement BIM in small residential firms, a case study method was used as a tool to conduct the study. For multiple reasons, the unit of analysis (Residential Design Build Company) was purposely selected as a case for the research:

- Provided researchers the ability to observe the process of BIM implementation
- Researchers were interacting with the company before BIM adoption and understood the policies, procedures, and expectations
- The case was representative of other small residential design-build companies in the country

The selected company had separate departments (Design, Sales, Accounting, Estimation, and Production) that were analyzed for the study. These were also the major departments that interacted with the owners and each other over the project lifecycle, thus, providing a unique opportunity to the researchers to observe how software and altered business processes interacted during the BIM implementation across multiple departments.

For the research, the direct observations method was primarily utilized. Information gathered in this process was documented for over three years. Most of the compiled data was qualitative. The information, presented in a case-study format, identifies concerns with the initial implementation of BIM at the project and company level.

3. RESULTS

3.1 BIM Implementation in the Company

Before the adoption of BIM, the company was using a combination of General CAD, Job Accounting Plus (JAP), Buildsoft, Adobe, Takeoff Plus, Sales Builder Plus, Microsoft Excel, and other software among departments for execution of residential projects. Hand drawings were also used on specific projects. Table 1 represents the tools used by each department within the company pre-BIM and post-BIM implementation, at the time of the study. All communication between various departments occurred via phone, on a personal basis, or email. Prior to BIM adoption, most of the software were not interoperable; considerable company resources were lost in the translation of information; the accuracy of information was always questioned; and at times, this impacted the profit margin for the company. As such, an atmosphere was created that discouraged collaboration among the departments and encouraged departmentalization within the company.

With the advent of multiple tools that promulgated the concept of BIM, the company began deliberating on the adoption and implementation of BIM software in late 2011. Some of the benefits of transitioning from a line-based system to a fully automated and integrated BIM system provided an opportunity for higher collaboration and automated flow of information between departments, enhanced accuracy, and efficiency that was warranted by upper management. In addition, there was an expectation that with automation and the use of interoperable software, various errors and losses associated with projects would be minimized considerably.

As the BIM implementation began, it was realized that just by adopting software that helped facilitate automation and implementing concepts of BIM, holistic benefits could not be accrued. The upper management, in discussion with professionals in charge of BIM implementation, agreed that company processes would also need to be evaluated. Thus, a BIM roadmap was created that aimed at holistic BIM implementation within the company. As depicted in Figure 1, the roadmap could be divided into three distinct phases.

Table 1: Software use by each department Pre-BIM and Post-BIM implementation

Department	Major Software used Pre-BIM Adoption	Software used Post-BIM Adoption
Accounting	JAP and Buildsoft	Sage Timberline 300
Designer	General CAD Pro 8.1, RES-check, Adobe, Photoshop, and Sketch-up	Revit
Estimating	Microsoft Excel, Adobe Professional Suite, General CAD 8.1, Takeoff Plus	BIM Pipeline and Workflow Management Suite (WMS)
Production and Purchasing	Microsoft Excel and drawings in print format	WMS
Sales	ACT, Photoshop Elements, Sales-Builder-Plus, and drawings in print format	Sales Simplicity

The first phase aimed at generating a consensus within the company with regard to BIM implementation. The first step in the first phase was to update the company vision and mission that was reflective of BIM implementation. This exercise was conducted with the company's upper management and was aimed to be one of the guiding principles for BIM implementation. After updating the company vision and mission that was reflective of a new paradigm that involved BIM implementation, SWOT analysis of BIM implementation and existing company work processes was conducted with all employees across all departments. This helped identify the areas of concern and potential improvements. In addition, detailed work processes for the company and projects, before BIM implementation, was created using process mapping. The goal was to then identify opportunities for improvement within the existing work processes by analyzing the detailed process map. Simultaneously, a list of software (*ones that supported BIM*) for each department were identified. At the same time, a list of 35 criterion were identified that would dictate the selection of the software, that supported BIM, for each department. The identified 35 criterion were printed on flashcards and then subjected to a quicksort process. The process of quicksort was conducted with upper management and involved participants randomly selecting a flashcard from the pile of 35 cards and identifying it as the standard card. Then, all remaining 34 cards were compared to the standard card and divided into two piles: "*greater than*" and "*less than*" the standard card. The process was repeated until all flashcards were placed in order based on the relative importance they had for the upper management. At the end of the process, results of the ranking were shared with the upper management and a consensus was achieved. Based on the ranking, the following criterion played a significant role in software selection:

1. The initial cost of the software
2. The interoperability between software
3. The learning curve associated with the proposed software

The second phase majorly aimed at establishing the company and project processes that supported the identified BIM software. This was achieved by analyzing the pre-BIM process map that depicted company and project processes. The process map was evaluated with the intention of identifying redundancies, incorporate efficiencies, and make it lean. Certain areas of the company and project processes were realigned, and adoption of BIM software was also incorporated. This resulted in the creation of a proposed process map that supported the BIM software, that was lean, and considerably reduced the average project duration. After the creation of the proposed process map, it was subjected to a companywide review, which lasted about three weeks. During this duration, the proposed process map was placed in a separate room, and employees from all departments reviewed it and provided feedback separately. All feedback was duly noted and discussed with the upper management. All approved comments/feedback were incorporated and it led to the creation of the company and project processes. In addition, the protocols that supported the agreed upon processes were also implemented.

The third and the final phase aimed at ensuring that the departmental staff was trained in respective software usage, transitioning existing projects from old software to software supporting BIM, and ensuring that all new projects were completed in the holistic BIM environment. Also, the creation of manuals and training materials for company employees, vendors, and subcontractors were implemented at this time. The software companies offered the employee training. The cost of employee training was offset by obtaining state grant. The training of employees was not restricted to specific departments, and employees throughout the various departments were encouraged to attend most of the trainings. The goal was to ensure that the employees were not only trained with the software with which they were directly interacting, but also that they were aware of the capabilities of the software implemented by other departments.

The second part of the third phase aimed at pilot testing a completed project to ensure that the systems were working as intended. After the completion of the pilot test, all new projects were completed in a BIM environment and projects that were in-progress were transferred into the new system from the original system. During the period in which the company was operating in both the original and the new system, it was observed that some productivity declined. The declined productivity could be attributed to factors such as, employees working in two systems, the learning curve associated with the software, and slow development of confidence on the new systems. Also in this phase, manuals and training materials were created not only for the company employees but also for the vendors and subcontractors. On-site training was also offered to the vendors and subcontractors that had been working with the company. The goal of creating manuals and training materials for subcontractors and vendors was to ensure that they were aware and vested into the BIM implementation and to achieve consistency in the completion of the tasks.

Figure 2 and 3 depict the software usage and communication overview pre-BIM and post-BIM implementation respectively. As depicted in Figure 2, the Sales Department was the primary point of contact between the customer/owner and other departments. In addition, communication was conducted at one level, and no priority was associated. Also, loss of information occurred when Sales was not involved in inter-departmental discussions about projects. There were instances where information would be accidentally not conveyed or would get lost in translation to or from Sales resulting in inaccuracies and losses. Furthermore, most of the software used by departments across the company pre-BIM implementation required manual input of information and had the potential for errors.

With the implementation of BIM, new company and project processes resulted in a realignment of communication lines, as depicted in Figure 3. Some of the major changes involved the creation of a new central position called the "*BIM Manager*." The goal of the BIM Manager was to facilitate the exchange of major communication and project information among various departments within the company. In addition, the company adopted two levels of communication for any project. All *major information* was to be processed through the "*BIM Manager*." Finally, even though the position of the Sales Department did not change, they were no longer the intermediary between the owner and other company departments. Instead, the Sales Department shared all owner requirements to the BIM Manager who would then share information with the respective departments. The BIM Manager was responsible for compiling all the information and sharing it with Sales who in turn would provide information to the owner, thus, bringing order into the communication system.

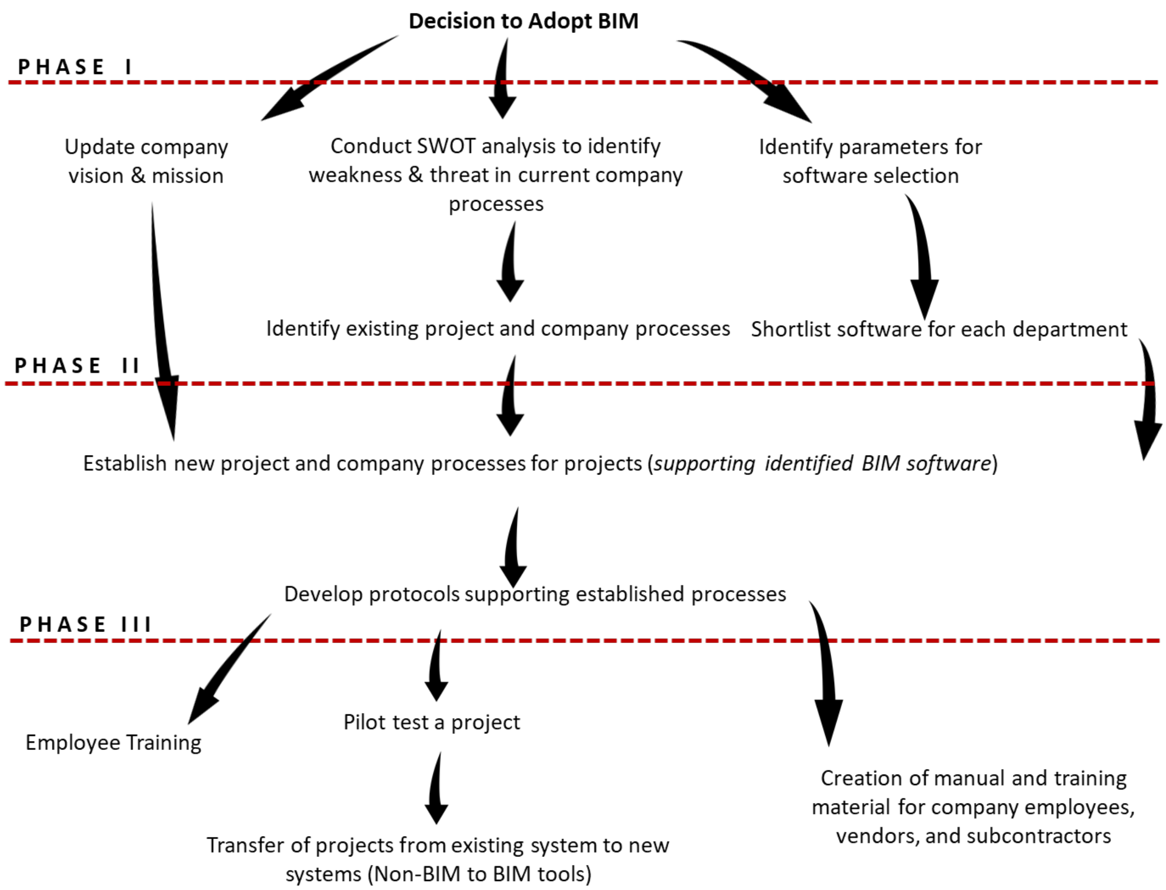

Figure 1: BIM roadmap adopted by the company

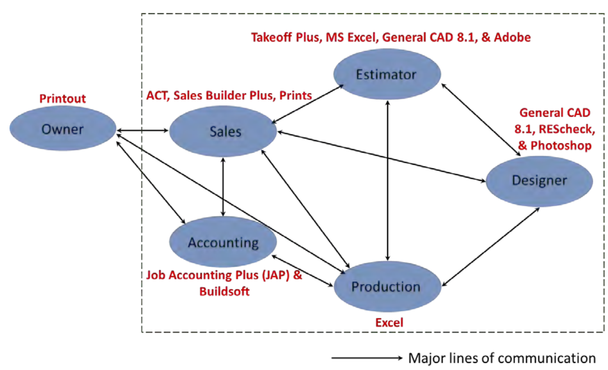

Figure 2: Software usage and communication overview pre-BIM implementation

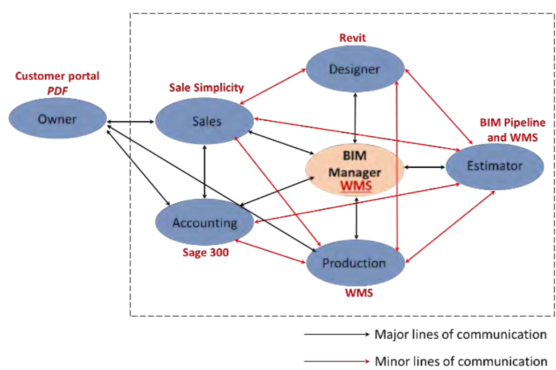

Figure 3: Software usage and communication overview post-BIM implementation

3.2 BIM Implementation Challenges at Company Level

This section discusses the challenges faced with BIM implementation at an overall company level. Before BIM implementation, it was recommended to company management that all existing company workflow be reviewed, after which suggested changes were made. In this process, the company's core competencies and business objectives were critically evaluated, employees were interviewed, and SWOT analysis with each employee was conducted and taken into consideration in the formulation of the new processes. Upon the completion of an alternate company process, it was open for an employee review and projected efficiency gains were tested. The new process proposed an increase in efficiency of 30%. After confirmation of the processes, the appropriate strategic selection of software was made. Except for the Design Department, which involved the adoption of Revit, there was no congruence on the product type to be adopted. Once the implementation started, there were two processes running parallel, the original and the new. The transition was radical for the company involving changed workflow, investment, and expectation(s). In this process, substantial initial investment for the first year was incurred by the company which included, but was not limited to: software purchase, supporting hardware, employee training for implemented software, and others. In this process, some of the existing human resources were redirected towards implementation, and work flow-processes were altered, thereby straining the ability of the company to conduct business on a day-to-day basis. At the same time, the company was able to secure a grant from the Small Business Employee Training (SBET) program to offset some of the initial investment. The grant offered financial support for the employee training; and was designed to benefit small businesses and reimbursements for tuition, required textbooks, and manuals. The program reimbursed the company after the completion of the employee training and submission of the required documentation.

Conversion of existing plan inventory, used for semi-custom and production homes, to software supporting BIM among designers (such as Revit), proved to be a challenge for the company. Production homes can be defined as projects built from stock plans on land owned by the builder (Cavern 2017), Whereas, semi-custom projects included building plans that are modified as per the client requirements. In the case for custom homes, client(s) provide the idea that forms the Basis of Design for the project. Alternatively, they interact with the designer to generate a design. The company observed a productivity decline for conversion of existing projects and plan inventory that could potentially be used for stock and semi-custom homes, the reason being that the company could not allocate additional resources for the transition of the information from one system to another as a result of the expenses incurred during the initial implementation and software purchases. This resulted in the over-burdening of the company resources causing schedule impacts on the existing projects. The solution, although not implemented, would either involve hiring additional specialized resources or outsourcing the conversion to specialized firms in data conversion from non-BIM to BIM software. One important reason for not outsourcing the data conversion was to ensure that all drawings in the new system were consistent with the company's design & construction practices and met the quality standards established by the Design Department and the upper management. In addition, the Level of Development of 3D models were also a concern. Therefore, a formula for the amount of information to be modeled in a 3D environment was created in collaboration with other departments and the upper management.

Transitioning from the old software platform to the new software platform created complications during the initial months, as projects were operating in both the original and the new system. As time progressed, more and more projects were transferred from the old system to the new system. Every department was maintaining two separate systems during the transition period because existing projects had already been started and were far along in the older process. Also, much work was duplicated as data from the old software could not be transferred. Furthermore, a few glitches emerged during the transitional phase to indicate that most likely the newer process was not extensively pilot tested. Thus, the process had to be revised a few times midway, thereby adding a layer of complexity to the existing scenario. During the same time, each department had multiple training sessions, and the learning curve was found to be higher than expected for some more than others, thus, resulting in reduced productivity for a certain duration, ultimately increasing the project duration.

During the initial BIM implementation analysis phase, nearly half of the company staff and the entire upper management were in favor of BIM implementation. Mitropoulos and Tatum (2000) identified that commitment from the top level is a precondition for the success of an innovation. The innovation, in this case, is the BIM, and it was realized that commitment support was necessary and crucial at times within the company for the successful BIM implementation. At the same time, the company's upper management also ensured that there was enough buy-in from middle management while designing the implementation strategy. Further, while designing the BIM implementation strategy, the geographic location of the company also played an important role. The company was geographically located in the southern US, and most subcontractors, traders, and vendors lacked BIM expertise. Very few stakeholders were on-board with the proposed changes regarding the BIM implementation and unwilling to go through an extensive training process. In addition, being located in a small community limited the availability and choice of technologically skilled subcontractors and vendors. In order to resolve the problem, the company created a short technical manual that included protocols and explained step by step processes. Also, the company also offered multiple training sessions to the subcontractors and vendors. The company further provided manuals in the sessions and encouraged a collaborative atmosphere to identify ways to work together. Finally, the company also renegotiated pricing contracts with vendors and sub-contractors.

4. CONCLUSION AND FUTURE WORK

Each company is unique due to multiple factors such as geographic location, potential markets, resources available, and others. There cannot be a fully developed off-the-shelf solution for BIM implementation. Also, the implementation process for every company is different due to factors such as the nature of the business, level of participation by champions within the company financial support, and readiness of the stakeholders. Factors such as these determine the success of the implementation process. The presented study examined and explained the implementation process of BIM in the small-scale residential design-build firm by case study method .over the period of three years. It focused on the impact of BIM implementation on a companywide level, along with challenges faced during the implementation. During the study it was identified that successful holistic BIM implementation in a small scale residential design-build firm depends on a lot of factors, including financial support; accurate understanding of resources required; impact of implementation on the existing processes and all the project participants involved; buy-in from most or all stakeholders, including the subcontractors and vendors; and an understanding of how and if the software solution complements the existing business practice. During the study, it was noticed that limited research had been conducted to analyze BIM implementation with the residential industry within the US.

REFERENCES

Arayici, Y., Egbu, C., and Coates, P. (2012). "Building information modeling (BIM) implementation and remote construction projects: Issues, challenges, and critiques." <http://www.itcon.org/data/works/att/2012_5.content.03794.pdf> (4/27/2018, 2018).

Cavern, J. (2017). "What Is a Production Home Builder?" <https://www.thoughtco.com/what-is-a-production-home-builder-175921> (9/15/2018, 2018).

Criminale, A., and Langar, S. (2017). "Challenges with BIM Implementation: A Review of Literature." Proceedings of 53rd Associated School of Construction International Conference, Seattle, WA, April 5-8.

Fabris, P. (2010). "BIM for home builders." Professional Builder Magazine. <http://www.probuilder.com/bim-home-builders> (9/20/2018, 2018).

Garcia, A. J., Korkmaz, S.M., and Syal, M. (2016). Adoption of Building Information Modeling in Small Size Home-Building-Businesses. School of Planning, Design, and Construction, Michigan State University, East Lansing, MI.

Giel, B. and Issa, R.R.A. (2013). "Return on Investment Analysis of Using Building Information Modeling in Construction." *Journal of Computing in Civil Engineering*, 27(5), 511-521.

Gu, N. and London, K. (2010). Understanding and facilitating BIM adoption in the AEC industry, *Journal of Automation in Construction*, 8(19), 988–999.

Ku, K. and Taiebat, M. (2011). "BIM Experiences and Expectations: The Constructors' Perspective." *International Journal of Construction Education and Research*, 7(3), 175-197.

Kulatunga, K.J., Amaratunga, R.D.G., and Haigh. R. (2006). “Construction Innovation: A Literature Review On Current Research.” <http://usir.salford.ac.uk/9886/1/205_Kulatunga_KJ_et_al_CONSTRUCTION_INNOVATION_A_LITERATURE_REVIEW_ON_CURRENT_RESEARCH_2006.pdf> (8/15/2018, 2018).

Langar, S. and Pearce, A. R. (2017). “Implementation trends for Rainwater Harvesting Technologies and Strategies (RwHTS) and Building Information Modeling (BIM).” *Journal of Architecture Engineering*, 23 (1).

Lindblad, H. (2013). “Study of the implementation process of BIM in construction projects: Analysis of the barriers limiting BIM adoption in the AEC-industry.” <http://kth.diva-portal.org/smash/get/diva2:633132/FULLTEXT01> (01/06/2018, 2018).

McGraw-Hill (2010). *Green BIM- How Building Information Modeling is contributing to Green Design and Construction*, Bedford, MA, McGraw-Hill Construction.

McGraw-Hill Construction (2009). *The Business Value of BIM: Getting Building Information Modeling to the Bottom Line*, New York, NY, McGraw-Hill Construction.

Miettinen, R., and Paavola, S. (2014). “Beyond the BIM utopia: Approaches to the development and implementation of building information modeling.” *Journal of Automation in Construction*, 43, 120-142.

Mitropoulos, P. and Tatum, C.B. (2000). “Forces Driving Adoption of New Information Technologies.” *Journal of Construction Engineering and Management*, 126(5), 340-348.

National Association of Home Builders (NAHB). (2016). "Residential builders adopt commercial building tools to increase sales." NAHB-Now, National Association of Home Builders, Washington, D.C. <http://nahbnow.com/2016/01/residential-builders-adopt-commercial-building-tools-to-increase-sales/> (9/3/2018, 2018).

Poirier, E.A., Staub-French, S., and Forgues, D. (2015). “Assessing the performance of the building information modeling (BIM) implementation process within a small specialty contracting enterprise.” *Canadian Journal of Civil Engineering*, 42(10), 766-778.

Silverio, K.A., Suresh, S., Renukappa, S., and Eason M. (2015). Challenges of BIM Implementation in Sustainable Residential Projects in the UK and Future Perspective.” CIB Proceedings 2015: Going north for sustainability: Leveraging knowledge and innovation for sustainable construction and development, London, UK, November 23-25, 566-576.

Succar, B., Sher, W., and Williams, A. (2012) Measuring BIM performance: five metrics, *Journal of Architecture Engineering and Design Management*, 8 (2) 120–142.

Yin, R.K. (2014). Case Study Research: Design and Methods, 5th Edition, Sage Publication, CA.

USING REVIT LIVE IN CONSTRUCTION MANAGEMENT EDUCATION

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ABSTRACT

The advancement of information technology in the Architecture, Engineering, Construction, and Operations (AECO) industry has resulted in the creation of new information visualization techniques. Virtual and augmented reality environments were developed to examine design and construction procedures and to visualize building models. As these technologies continue to become a standard in the AECO industry, it is of utmost importance for Building Information Modeling (BIM) educators to incorporate them in their classes. Revit Live is an Autodesk visualization service that allows a one-click transition from a BIM modeling environment into a fully-rendered environment. Moreover, Revit Live allows the user to explore the model in a virtual reality (VR) environment. This research has two main objectives, first, assess the impact of using Revit Live on the learning experience of students in a graduate BIM course. The second objective of this research is to explore how educators can use Revit Live to help them grade class assignments and projects. Students were given a chance to explore their projects in Revit Live before final submission. Using a VR headset and Revit Live, students could walk through their projects and detect modeling errors or missing building components. In addition, students found Revit Live very user-friendly since it did not require them to have any previous gaming or programming knowledge to explore the model in an immersive environment. The class teaching assistants also used the VR functionality in Revit Live to grade the projects and concluded that the use of Revit Live enhanced the BIM learning experience of students.

Keywords: AECO, BIM, VR, Revit Live, Education

1. INTRODUCTION

The construction industry relies heavily on information exchange between project stakeholders. For the success of a construction project, adequate communication of information is of utmost importance. In the last few decades, new visualization techniques have evolved from research efforts to increase the efficiency of information communication. Moreover, visualizing this information helps project parties in the decision-making processes. Traditional communication methods have been centered on the use of two-dimensional drawings and plans. However, with the advancements in information technology, there has been a shift towards visualization techniques based on BIM. In the educational field, construction students should be able to acquire the necessary competencies and use advanced construction information technologies. In order for students to be prepared, educators must be able to effectively deliver BIM education along with all advancements in the virtual design and construction (VDC) field of study. This paper explores the use of VR in construction management education, and how Revit Live can help students create immersive environments to enhance their knowledge.

2. LITERATURE REVIEW

2.1 BIM in Education

Over the years, construction practices have developed from master craftsmanship to split responsibility design and construction (Nawi et al. 2014). In recent years, project team members have used collaborative systems to expand the measure of data shared between the different parties involved in the construction. BIM is an intelligent 3D model-based process that was developed to combine the disperse information shared between project team members (Jacoski and Lamberts 2007). Accordingly, implementing BIM on construction projects can tackle a number of the challenges in the construction industry related to budget overruns, contingencies in schedule forecasts, safety, and overall quality of the project (Gallaher et al. 2004).

Considering the vast potential and numerous advantages to the implementation of BIM on construction projects, the technology can be used as a learning tool in institutions of higher learning. Construction jobsites can be virtually incorporated into classrooms with computer-generated models hosted in virtual environments that simulate design and construction processes. This BIM-based pedagogic technique equips AECO students with the necessary skills and abilities required to complete construction tasks successfully, eliminating the limitations from the lack of practical exposure to real-time situations on construction jobsites (Lu et al. 2013). Furthermore, BIM has proven to be effective in assisting students in reading, understanding, and interpreting 2D drawings (Kim 2012). Computer and information technologies have significantly influenced the abilities and achievements of students as they promote interaction between students and instructors, and also increase student problem-solving and inquiry skills while fostering collaboration (Behzadan and Kamat 2011).

On the other hand, several government regulations stipulate the use of BIM on public construction projects, which has led to an increase in demand for BIM professionals in the construction workforce. This demand has resulted in the development of several strategies to support institutions of higher learning in integrating BIM into their curriculum in freshman courses (Sacks and Barak 2010), undergraduate courses (Woldesenbet et al. 2017) or even through graduate education (Dossick et al. 2014). Different literature has presented the use of BIM as an educational tool for diverse construction activities such as the operation of construction machinery (Fox and Hietanen 2007), occupational health and safety (Eastman et al. 2008), logistics planning (Sacks et al. 2009), and jobsite training (Becerik-Gerber and Kensek 2010). One of the broad applications of BIM is the facilitation of project visualization, particularly when used together with VR and AR technologies (Behzadan and Kamat 2009).

2.1 Virtual Reality

VR is a three-dimensional interface that allows the users to walk through a building model and interact with its elements in a virtual environment by wearing a head-mounted audio-visual display built-in with tactile interface devices, position, and orientation sensors (Kensek et al. 2000). According to Brooks (1999), the engineering of a successful VR experience is based on four essential technologies: the visual and aural system, the graphics rendering system, the tracking system, and the database construction and maintenance system. With the visual system, the user is completely immersed in the virtual world without any interruptions of the different sensory influences from the real world. The graphics rendering system enables the generation of the 20-30 frames per second required for the immersive experience. The tracking system records and communicates the position of the head and limbs of the user through the use of an array of position and orientation sensors. Lastly, the database construction and maintenance system manage and store comprehensive, realistic, and updated models of the virtual world.

Asides from the four systems mentioned above, some of the latest VR experiences also integrate input devices that allow a hand to eye coordination which gives the user a sense of the actual scope and measurements of the virtual model. An otherwise visualization of the model in a 2D environment or through 3D computer renderings would not be as apparent (Fogarty et al. 2018). VR is a productive environment for understanding spatio-temporal constraints and for visualizing and analyzing three-dimensional arrangements of construction assemblies. With the aid of a VR headset, users can navigate through the building by walking around, climbing the stairs and even flying up and around the virtual model for an overview. The ability to navigate through the building in a virtual environment enables the user to experience the essence of a BIM model visibly and understandably, allowing the user to interact with the model and manipulate some of its properties (Fogarty et al. 2018).

Despite the enormous potential that VR offers in improving visualization and communication between project team members, there is still a lot to be done regarding information exchange and human interaction in the virtual environment (Du et al. 2018; Yan et al. 2011). Three critical VR-driven interactions should be considered for a compelling VR experience (Du et al. (2018). The first is the interaction with BIM-data concerning the automated transfer of data from BIM platforms to VR visualization environments. There are limited research projects directed at automating data transfer (Du et al. 2017). The second interaction to be considered is that between the human and the building in a VR environment. This interaction has been the focus of recent research projects directed at modifying the building model in VR (Fogarty et al. 2018). The last interaction is the interaction between humans that fosters collaboration and enhances communication between remote VR users thereby bettering the decision-making process. The dominant aspect of VR research in construction is directed towards single-person VR experiences, not multi-user VR. Multi-user VR has the potential to solve several challenges that confront virtual construction teams such as ineffective communication, distrust, and poor quality control of the building assemblies (Du et al. 2018; Nayak and Taylor 2009).

2.1.1 Virtual Reality in Education

In the educational sector, previous research projects discussed different use cases for VR as a learning tool. These projects discussed how VR and serious games enhance the construction education by creating authentic construction tasks and activities. Moreover, gaming and VR simulate deeper learner, allow situational awareness, and promote student interaction. In the construction management field, the use of VR was proven effective as a cognitive learning platform helping students explore virtual site environments and associated safety hazards, as well as perceiving the consequences of their actions without harmful real-life consequences (Pedro et al. 2015). Dickinson et al. (2011) utilized interactive VR to communicate safety information and help learners visualize different site scenarios and hazards related to construction processes. Mastli and Zhang (2017) used construction simulations in VR environments to facilitate student's understanding of construction processes. The developed platform facilitated planning crane routes during the construction planning phases to minimize trip length and time. Furthermore, VR construction was utilized in the education sector to help learners create and review construction schedules, and visualize the construction progress of the project (Nikolic et al. 2011).

In addition to its use in construction management education, VR is also used in different engineering curricula. Fogarty et al. (2015) developed a VR environment to explore all aspects of a structure and help students better visualize structural behavior at the member and system level. The developed environment can be seen in either a CAVE-like immersive environment or using a head-mounted device. Fogarty et al. (2018) further developed their VR experience to focus on structural buckling response because of the breadth of buckling modes that can occur. Students and educators in that research reported the positive effect VR has on structural engineering education. Multiple VR techniques were used in the research projects previously mentioned. Kasireddy et al. (2016) summarized these techniques and evaluated their use on the different tasks of construction projects. Immersive CAVEs, cardboard VR, and Oculus Rift VR were compared; it was concluded that the highest number of accurate interactions from the user were obtained using the CAVE; however, the Oculus was proven to be the most efficient in completing construction-related tasks and navigating in the virtual world.

Two main limitations to the use of VR in the construction management and engineering education can be identified from the literature. First, creating a VR environment can be tasking procedure to export the model from a modeling environment to a gaming environment where a programmer has to create the virtual environment. Furthermore, previous studies have not looked at how VR can help educators teach

BIM, and how students can benefit from VR in better understanding the process of creating a BIM model. To address these limitations, this paper will discuss the use of Revit Live in a graduate construction information systems class. Revit Live can easily create VR environments without the need to go into a gaming environment. This paper will also explore how the virtual model can be visualized in a CAVE-like environment and on a head-mounted VR device. Finally, the paper will summarize the feedback of students and educators who used VR and Revit Live in the class and will discuss the benefits brought by these technologies to the construction management education.

3. METHODOLOGY

3.1 Description of Revit Live

Revit Live is a cloud service that converts Revit BIM models into immersive virtual environments, helping users better understand, explore and share their designs. Revit Live is BIM smart and powered by the cloud, all data from the BIM model is automatically prepared and transferred in the cloud to give the user easy access to all the model information in the immersive environment. Furthermore, Revit Live is a user-friendly software. Using only one click, Revit Live processes the model and gives the user a fully rendered environment that can also be seen using VR headsets. Finally, Revit Live allows users to see the impact of lighting and shadows on their designs in function of the time of day or the time of year.

Figure 1 shows a comparison between Revit Live and the traditional method used to obtain a VR environment. Using the traditional method, the user has to export the model from Revit and then import it into 3DMax to fix the appearance of the building. Once the building looks rendered, the model is imported into a gaming environment where the user has to code some scripts in order to project the model onto a VR headset. More scripts have to be written if the user wants to navigate through the model. However, all this process is done automatically in Revit Live, and the user can be exploring the model in VR within minutes.

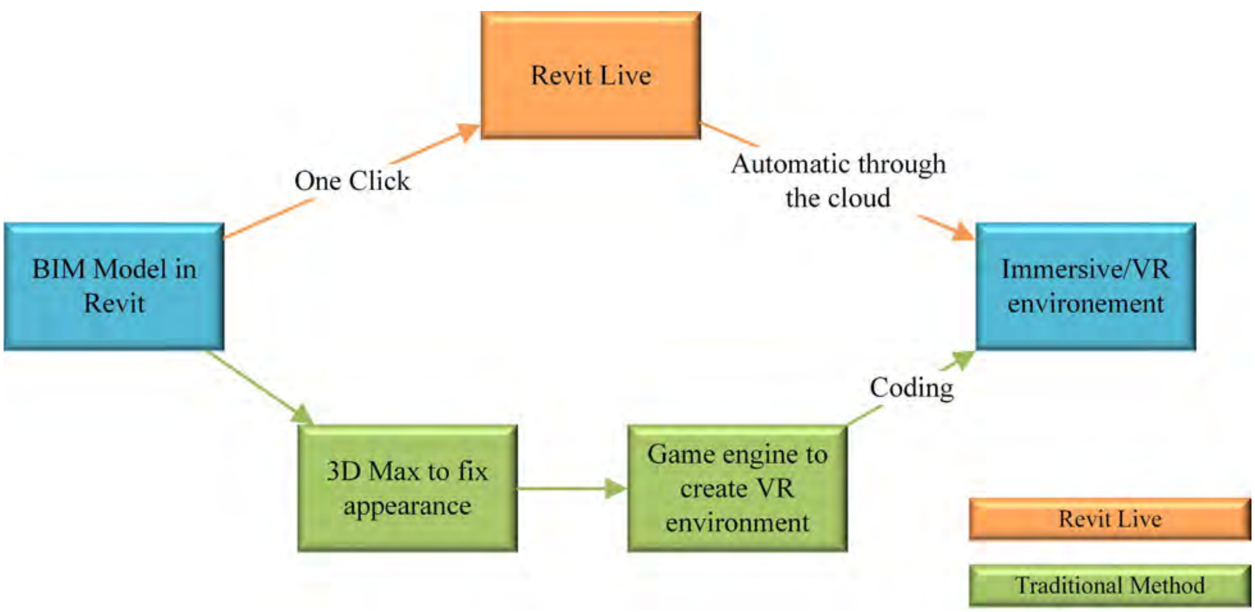

Figure 1: Comparison between Revit Live and the traditional method

3.2 Use of Revit Live in the Class

The Center for Advanced Construction Information Modeling at the M.E. Rinker, Sr. School of Construction Management at the University of Florida offers a graduate construction information systems class covering VDC technologies. The first eight sessions of the class cover modeling concepts in Revit, students are asked to complete architectural, structural, and mechanical models of a building. The remaining eight sessions of the class elaborate on how to use a BIM model for scheduling, estimating, point layouts, and visualization. In addition to the class assignments, students are expected to develop BIM models using original blueprints of buildings.

Over two semesters, Fall 2017 and Spring 2018, Revit Live was introduced to the class, with a total of 40 students enrolled. Students had the chance to explore their models in VR during the modeling process using Revit Live. Since Revit Live is a user-friendly environment, students were able to check their work on a regular basis without any previous knowledge in gaming environments. Students were also able to visualize the virtual world in a CAVE-like environment and using VR headsets. Instructors also used Revit Live to grade the students' assignments and projects. Figure 2 shows how Revit Live was used to create immersive environments.

At the end of each semester, students were asked to evaluate the ease of use of Revit Live, how it helped them better understand BIM models, and how it enhanced their construction management education as a whole. Also, instructors compared the time it took them to grade assignments and projects with and without the use of Revit Live and reported the benefits of using Revit Live in preparing and giving lectures.

Figure 2: Students using immersive environments created in Revit Live

4. RESULTS AND DISCUSSION

4.1 Benefits to the Students

At the end of each semester, students were asked to evaluate the experience of using Revit Live and discuss how it enhanced their construction management education. Below is a list of the benefits discussed by the students,

- Revit Live is a user-friendly platform that did not require students to have any previous gaming or programming experience. Creating immersive environments was automatic and quick, and students were able to continuously visualize the progress of their work.
- Revit Live helped the students walk through the model using easy-to-use commands and detect modeling errors and clashes between the different disciplines of the model.
- Revit Live allowed students to easily create renderings of their projects and better showcase their work during presentations.
- Students saved time working on their projects since it was easier for them to visualize the building in an immersive rendered environment.

- The ability of Revit Live to project the building model onto a VR headset was very beneficial to students since it helped them position themselves on a construction site and thus enhanced their understanding of the construction process.
- Students were also able to model some building components and procedures they learned in other courses in the curriculum and visualize them in VR or using the CAVE environment. Students said that using Revit and Revit Live has improved their construction education experience.

4.2 Benefits to the Instructors

Among the benefits of using Revit Live in the class, the instructors focused on the following,

- Using Revit Live while teaching Revit was a valuable resource because it assisted in conveying key concepts of the class to the students. The instructors could easily go to an immersive environment and manipulate the model and focus on different components of the building.
- Revit Live helped instructors grades assignments and projects. Because of the ability of Revit Live to visualize the BIM model in VR, it took the instructors less time to grade the students' submissions. Moreover, instructors were able to give students thorough and accurate feedback on their projects.

Figure 3 summarizes the benefits of using Revit Live in construction management curricula.

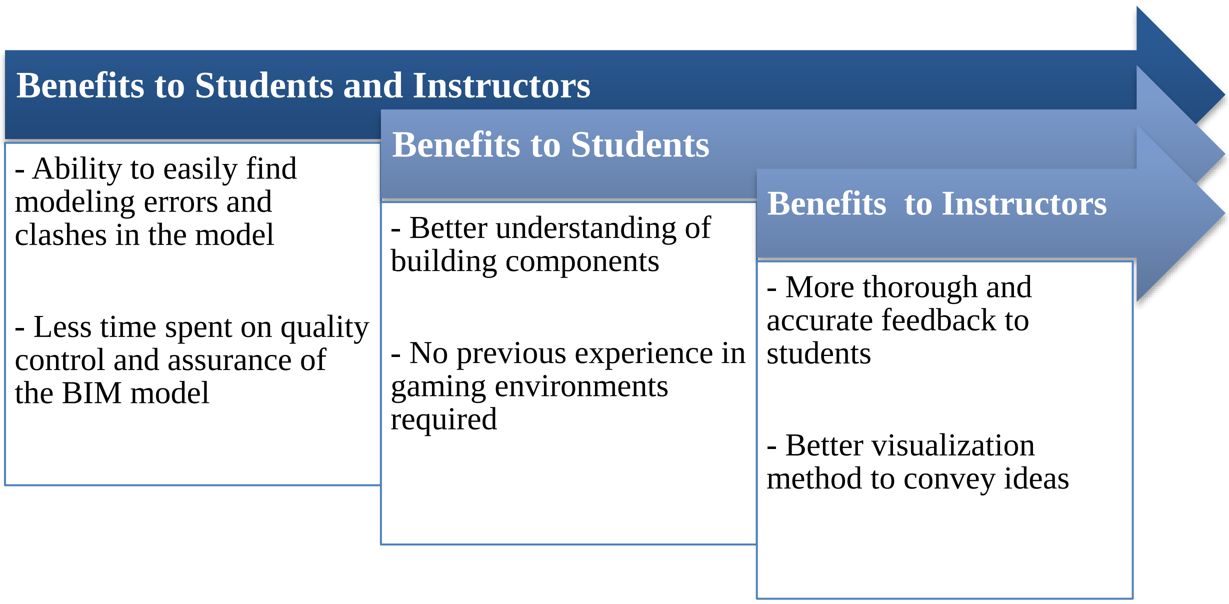

Figure 3: Benefits of using Revit Live in Construction Management Education

5. CONCLUSIONS AND RECOMMENDATIONS

With construction projects becoming more complex and multidisciplinary, the amount of information exchanged between project parties has increased the need for more advanced communication methods. BIM and VR have the ability to aggregate the dispersed information and enhance communication between project stakeholders. In addition to their use in the construction industry, BIM and VR can also be used to improve the learning experience of construction management students.

This paper explored the use of Revit Live in a construction information systems graduate class. Over two semesters, 40 students reported the benefits of Revit Live and how it can be used to better visualize a BIM model in a virtual environment. Students also stressed the ease of use of Revit Live, and how they can get their models into a VR headset within minutes. Revit Live was also beneficial to instructors who used it to grade assignments and projects and were able to give better feedback to students.

In addition to their use cases in the education field, Revit Live and VR can also be used in the industry. For instance, exploring the models in a virtual world can help construction workers identify safety hazards (Shi et al. 2018), it can also be used for rapid assessment of earthquakes (Kamat and El. Tawil 2007), maintenance of underground infrastructures (Behzadan and Kamat 2011), and construction equipment operations (Lu et al. 2013). Finally, Revit Live can also be used to apply a unique render style to the visualization to communicate design intent and focus presentations with clients.

REFERENCES

Becerik-Gerber, B., and Kensek, K. (2010). "Building information modeling in architecture, engineering, and construction: emerging research directions and trends." *J. Prof. Issues Eng. Educ. Pract.*, 136(3), 139–147.

Behzadan, A. H., and Kamat, V. R. (2009). "Automated generation of operations level construction animations in outdoor augmented reality." *J. Comput. Civ. Eng.*, 23(6), 405-417.

Behzadan, A. H., and Kamat, V. R. (2011). "Integrated information modeling and visual simulation of engineering operations using dynamic augmented reality scene graphs." *J. Inform. Technol. Constr.*, 16, 259–278.

Brooks, F. (1999). "What's real about virtual reality?" *IEEE Comput. Graphics Appl*., 19 (6), 16–27.

Dickinson, J. K., Woodard, P., Canas, R., Ahamed, S., and Lockston, D. (2011). "Game-based trench safety education: Development and lessons learned." *J. Inform. Technol. Constr.*, 16, 119–134.

Dossick, C.S., Lee, N., Foleyk, S. (2014). "Building information modeling in graduate construction engineering and management education." *Computing in Civil and Building Engineering*, 2176-2183.

Du, J., Shi, Y., Zou, Z., and Zhao, D. (2018). "CoVR: Cloud-based multiuser virtual reality headset system for project communication of remote users." *J. Constr. Eng. Manage.*, 144(2).

Du, J., Zou, Z., Shi, Y., and Zhao, D. (2017). "Simultaneous Data exchange between BIM and VR for collaborative decision making." *Computing in Civil Engineering*, 1-8.

Eastman, C., Teicholz, P., Sacks, R., and Liston, K. (2008). BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors, John Wiley and Sons, NY, 2008.

Fogarty, J., El-Tawil, S., and McCormick, J. (2015). "Exploring structural behavior and component detailing in virtual reality." *Structures Congress*, 2557-2564.

Fogarty, J., McCormick, J., and El-Tawil, S. (2018). "Improving student understanding of complex spatial arrangements with virtual reality." *J. Prof. Issues Eng. Educ. Pract.*, 144(2).

Fox, S., and Hietanen, J. (2007). "Interorganizational use of building information models: potential for automational, informational and transformational effects." *Constr. Manage. Econ.*, 25(3), 289–296.

Gallaher, M. P., O'Connor, A. C., Dettbarn, J. L., and Gilday, L. T. (2004). "Cost analysis of inadequate interoperability in the U.S. capital facilities industry." National Institute of Standards and Technology, Gaithersburg, MD.

Jacoski, C., and Lamberts, R. (2007). “The lack of interoperability in 2D design — a study in design offices in Brazil.” *J. Inf. Technol. Constr.*, 12(17), 251–260.

Kamat, V. R., and El-Tawil, S. (2007). “Evaluation of augmented reality for rapid assessment of earthquake-induced building damage.” *J. Comput. Civ. Eng.*, 21(5), 303-310.

Kasireddy, V., Zou, Z., Akinci, B., and Rosenberry, J. (2016). “Evaluation and comparison of different virtual reality environment towards supporting tasks done on a virtual construction site.” *Construction Research Congress*, 2371-2381.

Kensek, K., Noble, D., Schiler, M., and Tripathi, A. (2000). “Augmented Reality: an application for architecture.” *Computing in Civil and Building Engineering*, 294-301.

Kim, J.-L. (2012) “Use of BIM for effective visualization teaching approach in construction education.” *J. Prof. Issues Eng. Educ. Pract.*, 138(3), 214-223.

Lu, W., Peng, Y., Shen, Q., and Li, H. (2013). “Generic model for measuring benefits of BIM as a learning tool in construction tasks.” *J. Constr. Eng. Manag.*, 139(2), 195–203.

Mastli, M., and Zhang, J. (2017). “Interactive highway construction simulation using game engine and virtual reality for education and training purpose.” *Computing in Civil Engineering*, 399-406.

Nawi, M. N. M., Lee, A., Azman, M. N. A., and Kamar, K. A. M. (2014). “Fragmentation issue in Malaysian industrialized building system (IBS) projects.” *J. Eng. Sci. Technol.*, 9(1), 97–106.

Nayak, N. V., and Taylor, J. E. (2009). “Offshore outsourcing in global design networks.” *J. Manage. Eng.*, 4(177), 177–184.

Nikolic, D., Jaruhar, S. and Messner, J. (2011). “Educational simulation in construction: virtual construction simulator.” *J. Comput. Civ. Eng.*, 25(6), 421–429.

Pedro, A., Tuan Le, Q., and Sik Park, C. (2015). “Framework for integrating safety into construction methods education through interactive virtual reality.” *J. Prof. Issues Eng. Educ. Pract.*, 142(2).

Sacks, R., and Barak, R. (2010). “Teaching building information modeling as an integral part of freshman year civil engineering education.” *J. Prof. Issues Eng. Educ. Pract.*, 136(1), 30-38.

Sacks, R., Treckmann, M., and Rozenfeld, O. (2009). “Visualization of work flow to support lean construction.” *J. Constr. Eng. Manage.*, 135(12), 1307–1315.

Shi, Y., Du, J., Ragan, E., Choi, K., and Ma, S. (2018). “Social influence on construction safety behaviors: a multi-user virtual reality experiment.” *Construction Research Congress*, 174-183.

Woldesenbet, A., Ahn, C., Kim, H.-J., and Rokooei, S. (2017). “Faculty learning commUnity 3D (FLC) for BIM education in a multidisciplinary school.” *Architecture and Engineering Institute*, 39-48.

Yan, W., Culp, C., and Graf, R. (2011). “Integrating BIM and gaming for real-time interactive architectural visualization.” *Autom. Constr.*, 20(4), 446–458.

APPLICATION OF THE BIM BOK FOR THE DEVELOPMENT OF A CONSTRUCTION CAPSTONE PROJECT

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ABSTRACT

The BIM Body of Knowledge (BOK) overarching goals include advancing BIM competencies through common curriculum and standardizing expectations for job task performance. To accommodate the multidimensionality of tasks performed by BIM professionals, the BOK categorized competencies by Levels of Implementation (LOI), Roles of User (ROU), Level of Performance (LOP), and Types of Knowledge (TOK). The LOI category items are at the organization level and may be within an organization or between organizations. The ROU category lists roles as Designers, Contractors, Facility Managers/Operators, and Consultant/Generalist. The LOP category includes entry level, middle level, and expert level. Finally, TOK identifies knowledge items as either organization general knowledge or project specific knowledge. The BIM BOK served as a guide to design the construction capstone project at the University of Oklahoma. The capstone course is project-based and coordinated with an industry sponsor who provides the project materials; participates in the assignment development; and assists with evaluation of student submissions. The capstone course serves as a point of assessment for three Student Learning Outcomes (SLOs) for the American Council of Construction Education (ACCE) accreditation.

In spring 2009 the University of Oklahoma Construction Science program integrated BIM in select courses, which was later expanded to the capstone course with the implementation of curriculum changes during the 2011-2012 academic year. Since its integration the use of BIM has been required for 3D coordination, cost estimation, and 4D planning tasks and deliverables. The coordination of expectations for project tasks listed in the BIM BOK with the cost estimation and construction schedule deliverables for assessment were the focus when designing the 2018 capstone project assignment.

The 2018 capstone project was designed around the construction of a new 75,550 square foot biomedical research and teaching facility on the University of Oklahoma main campus. The project industry sponsor was JE Dunn, the company selected by the university to provide at-risk construction management services. Students were given the project architect's schematic design model, full set of two-dimensional drawings, specifications, required tasks and deliverables. Cost estimating requirements were designed as a task for which entry level BIM professionals would be expected to perform. Estimating is listed as a task under the *LOI: Do It* and achieved Strong Agreement by the expert panel in the third round of the BOK. The task of Model Validation was also included for the capstone as it a necessary predecessor task that achieved Early Strong Agreement under the *LOI: Manage It*. The capstone requirement to create a construction schedule does not appear to be a task clearly identified in the BOK as one a BIM professional would perform, but 4D planning was required for the assignment. This paper reports on the use of the BIM BOK to develop project requirements in conjunction and assess student learning for program accreditation.

Keywords: BIM Body of Knowledge, Construction Education, Construction, Capstone

1. INTRODUCTION

The BIM Body of Knowledge (BOK) is the result of a two-year study designed to explore expectations of BIM professionals within the architectural, engineering, construction, owner, and operator (AECOO) industry. In particular, industry's expectations related to BIM practices and performance outcomes of BIM professionals. The BIM BOK was developed based on the findings from a Delphi panel of 20 BIM experts representing private companies, government organizations, and academia across all disciplines in the architectural, engineering, construction, owner, and operator (AECOO) industry. The BIM Body of Knowledge (BOK) description of purpose is to provide a set of common values that BIM educators, curriculum developers, and corporate trainers could reference as a starting point (Wu, Mayo, McCuen, Issa, & Smith, 2017). The study was designed to address the need to design BIM curriculum that will align with the knowledge, skills, and abilities needed to fill the BIM expert role across multiple dimensions in the AECOO industry. The resulting BIM BOK is organized in accordance with the classifications and categorizations shown in Figure 1.

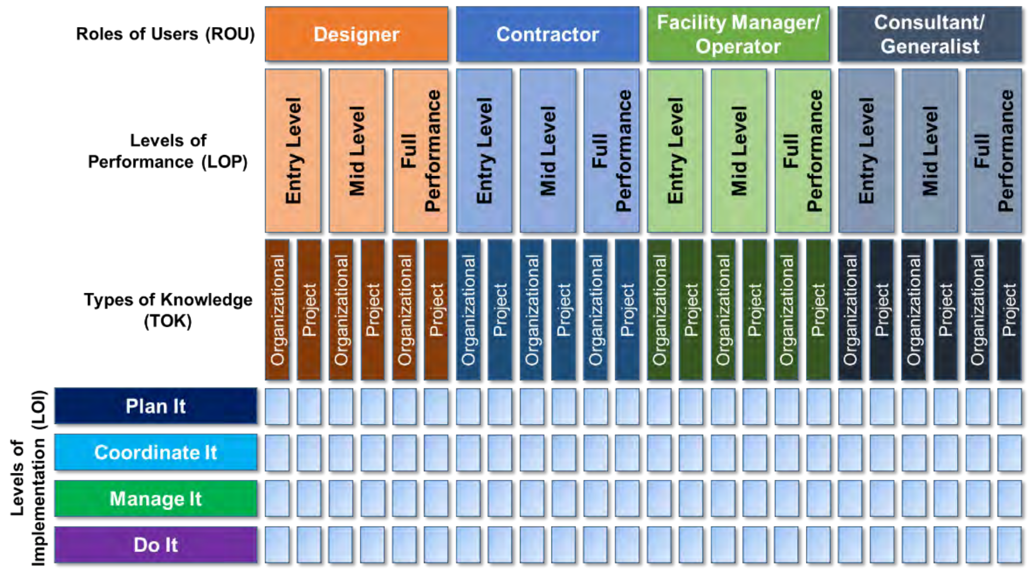

Figure 1. BIM BOK Classifications and Categorization (Wu et al., 2017).

2. BACKGROUND

2.1 Program accreditation and curriculum

The University of Oklahoma Construction Science Bachelor degree program was first accredited by the American Council for Construction Education (ACCE) in 1990 and has sustained its accreditation since that time. The ACCE criteria for an accredited Bachelor degree program identifies 20 student learning outcomes (SLOs) for which the program is evaluated. It is the responsibility of each program to design its curriculum and identify the points of student assessment and metrics for each SLO. The University of Oklahoma Construction Science Bachelor degree program requires students to successfully complete 120 credit hours, of which 40 hours are university-wide general education requirements. Four of the courses selected by the program to meet the university's general education requirements also meet the ACCE general education criteria. Included in the university-wide required general education credit hours is a three-hour Senior Capstone course and is the course selected by the program to assess three of the 20 ACCE SLOs.

The university describes the purpose of the Capstone as a course that is designed to culminate a student's field of study and place it in a larger social, intellectual and professional context. Furthermore, it emphasizes that the Capstone course should be an intensive experience in the major and must include an in depth writing component (http://www.ou.edu/gened/courses/requirements). As a result of the ACCE accreditation criteria and the university-wide requirements, the Construction Science Capstone is the point of assessment for three SLOs and the point of reinforcement for another 12 SLOs as shown in Table 1.

Table 1. ACCE SLO implementation in Capstone course

ACCE SLO	**ACCE Description**	**Level of Implementation**	
		Reinforced	**Assessed**
1	Create written communications appropriate to the construction discipline.		X
4	Create construction project estimates.		X
5	Create construction project schedules.		X
3	Create a construction project safety plan.	X	
7	Analyze construction documents for planning and management of construction processes.	X	
8	Analyze methods, materials, and equipment used to construct projects.	X	
10	Apply electronic-based technology to manage the construction process.	X	
12	Understand different methods of project delivery and the roles and responsibilities of all constituencies involved in the design and construction process.	X	
13	Understand construction risk management.	X	
15	Understand construction quality assurance and control.	X	
16	Understand construction project control processes.	X	
17	Understand the legal implications of contract, common, and regulatory law to manage a construction project.	X	
18	Understand the basic principles of sustainable construction.	X	
19	Understand the basic principles of structural behavior.	X	
20	Understand the basic principles of mechanical, electrical and piping systems.	X	

2.2 BIM Body of Knowledge (BOK) Levels of Performance

The BIM BOK classification of performance into three levels indicates the stratification of individual performance based on educational background and industry experience. Additionally, it was developed to associate the progression of performance for BIM specialists (Entry, Middle, and Full) in accordance with their development of BIM knowledge based on Bloom's Taxonomy of learning as shown in Table 2.

Table 2. Level of Performance aligned with Bloom's Taxonomy

Level of Performance	Performance Expectation	Bloom Taxonomy
Entry Level	Performance expected for users with a Bachelor's degree or equivalent technical education	Remembering Understanding
Middle Level	Performance expected for users that meet *Entry Level* qualifications plus 3-5 years of experience in BIM practices	Applying Analyzing
Full Performance	Performance expected for users that meet *Middle Level* qualifications plus 5 or greater years of experience in BIM practices	Evaluating Creating

This paper describes how the BIM BOK was used as a guide in the design of a Construction Capstone project. The Role of User (ROU), Level of Performance (LOP), and Types of Knowledge (TOK) categories were referenced and the Contractor (ROU); Entry (LOP); along with the Project (TOK) selected to guide the design of the project assignment. It is important to note that both the course instructor and industry partner were involved with the original research that led to the development of the BIM BOK. The instructor was a member of the original research team and the industry partner a member of the Delphi panel of BIM experts.

The coordination of expectations for project tasks listed in the BIM BOK with the cost estimation and construction schedule deliverables required for ACCE assessment guided the Capstone project design. However, additional BIM tasks from the BOK were also required as project deliverables and are included in this paper as well.

3. THE CONSTRUCTION CAPSTONE PROJECT

3.1 Project background and objectives

The 2018 Capstone project was designed around the construction of a new 75,550 square foot biomedical research and teaching facility on the University of Oklahoma main campus. The project industry sponsor was JE Dunn, the company selected by the university to provide at-risk construction management services. Students were given the project architect's schematic design model, full set of two-dimensional drawings, specifications, required tasks and deliverables. Students were expected to demonstrate their ability to execute a thorough review of a real-world project, provide a detailed analysis, and a plan for executing the project in a manner that meets the project requirements, is a safe project site, and profitable for the company. The assigned tasks were all typical pre-construction tasks within the general contractor's domain.

Along with the BIM BOK, the BIM Project Execution Planning Guide list of 21 BIM Uses was also referred to during the project design (Computer Integrated Construction Research Program, 2011). In particular, the Cost Estimation, 4D Phase Plan, and 3D Coordination BIM Use descriptions guided the task development. A total of 11 deliverables were required from students, of which BIM was required to complete the analysis of the four tasks in Table 3.

Table 3. Capstone project BIM tasks

Capstone BIM Task	Description
Model Validation	Validate the architectural and structural design models for accuracy of geospatial/dimensional and material properties related to each work package to be self-performed.
Cost Estimation	Complete a cost estimate for all work packages to be self-performed.
4D Phase Plan	Sequence, phase, and schedule the Structural Concrete work package to be self-performed.
3D Coordination	Perform a clash analysis for each level of the duct models against each level of the 1) structural models, 2) plumbing models, and 3) electrical models.

Although 4D Phase Planning was required as a project BIM task, the 4D deliverable was not used as evidence for the construction schedule assessment. The sequence and schedule from the 4D Phase Plan was however used as a component of the overall construction schedule delivered for assessment, and could be used for Project Controls tasks during construction.

3.2 Project mapped to BIM BOK

To ensure reasonable expectations for task deliverables, the project requirements were mapped to the Delphi Panelist Level of Agreement (LOA) in the Entry LOP category for Contractor's Project knowledge. The BIM BOK line items identified in the project design, LOP for the Contractor at Project TOK, and the LOA among the Delphi panelists are shown in Table 4. The relationship of each line item to the BIM Project Execution Planning Guide BIM Uses is also included in the table (Computer Integrated Construction Research Program, 2011).

Table 4. Capstone project tasks mapped to BIM BOK

BIM BOK Line Item	Level of Performance	Delphi Panel Level of Agreement	BIM Use
Model Validation	Entry	Early Strong Agreement	NA
Estimating	Entry	Strong Agreement	Cost Estimation
Project controls – Scheduling/time	Entry	Partial Agreement	4D Phase Plan
Pre-construction issue resolution	Entry	Strong Agreement	3D Coordination

While the BIM BOK task definitions were still in development at the time the assignment was distributed, however the draft task definitions and BIM skills for each task were used as a guide in the development of instructions for the Capstone BIM tasks. Given the context was a Capstone course, students were expected to have the prerequisite construction knowledge, along with the appropriate level of BIM knowledge and skills to complete the task as instructed. The task definitions and skills required for each are shown in Table 5.

Table 5 BIM Task Definition and Skills

Capstone Task	BIM BOK Definition	Skills Required
Model Validation	Validation checks the accuracy of the model's representation of the real system. Model validation is defined to mean "substantiation that a computerized model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model".	Skill with BIM tools. Checking models for possible data loss, data corruption or incompatibility with defined specifications. Skill with data processing, code-checking and building information management.
Cost Estimation	Construction estimating in this instance is the application of computer software using a BIM as the input source for contractors to estimate construction costs for a specific project. An estimator will typically use estimating software to estimate their bid price for a project, which will ultimately become part of a resulting construction contract.	Skill with BIM tools. Skill with model data extraction and management.
4D Phase Plan	Project controls are the data gathering, management and analytical processes used to predict, understand and constructively influence the completion time of a building information modeling project or program; through the communication of information in formats that assist effective management and decision making to effectively reduce the overall time for project completion.	Scheduling tool skills. 4D tools and procedures
3D Coordination	The act of coordinating the resolution or determining an action, course of action, methods, procedures, and the next steps to take to mitigate an issue using a building information model prior to construction of a structure.	Automated model checking, model-checking software, BIM model reviewing. Skills with applicable BIM tools in preconstruction design review, constructability review, cost estimating, scheduling, team-building, coordination and communication.

4. RESULTS

Both direct and indirect assessment methods were used to measure learning outcomes. Each of the twenty-one students enrolled in the course successfully submitted all of the required deliverables. Submissions were evaluated and assigned a score from 1 to 10, which were organized into three categories. The first category of scores were those between 1 and 6 and was considered *Poor*. A score between 7 and 8 was classified as *Average*. The third category classified scores between 9 and 10 as *Excellent*. Scores were also weighted in the final calculation, however this paper only reports the raw scores from the direct assessment. Table 6 displays the Capstone task, evaluation criteria, and the average raw score.

Table 6: Results from Capstone project BIM Tasks

Capstone Task	Evaluation Criteria	Average Score
Model Validation	Revised models accurately represent geospatial/dimensional and material properties for each work package to be self-performed. Model revisions log is complete with model name, location of revision, description of revision, reason for revision, assumptions (if applicable), and comments (if applicable) for each revision.	7.3
Cost Estimation	QTO in Assemble for all work to be self-performed is complete and aligns with the revised Architectural and Structural models submitted. QTO items correspond with construction schedule activities. QTO backup from Assemble to Excel for all work to be self-performed is complete and aligns with the revised Architectural and Structural models submitted. QTO items correspond with construction schedule activities.	8.0
4D Phase Plan	4D structural concrete sequence model corresponds with construction phasing in site logistics plan, construction schedule, and revised Revit model. Site Logistics plan includes all aspects of the site layout, construction phasing, and construction traffic by phase of construction. Includes a logistics plan for each phase.	8.2
3D Coordination	Clash analysis includes all required tests and HTML clash reports, description of relevant/irrelevant clashes, and recommendations of reasonable solution(s)	9.7

5. DISCUSSIONAND CONCLUSIONS

Evaluation of the students' submissions revealed the need for more emphasis on the importance of completing a comprehensive model validation. Although students were required to log issues addressed during model validation, it appears many students either lacked the depth of knowledge and skills required to transition the architectural model to a construction model in a timely manner or they lacked the motivation to do so. In addition to improving the accuracy of the completed task, a model validated and revised for construction would ultimately save time and improve the quality of subsequent tasks. It is important to mention that the reference to 'depth of skills' extends beyond BIM software skills to include knowledge about construction and skills necessary to represent a revision in the model. For example, sectioning concrete slabs in the 4D Phase Plan to correspond with the planned areas and sequence of work was left to the student to create a plan and divide the design models into segments that would represent the sequence of work.

In future Capstone project designs, a structured process for model validation will be distributed to guide students through the task. It is expected that the process will have a positive impact on the quality of BIM task deliverables.

REFERENCES

Computer Integrated Construction Research Program, (2011). "BIM Project Execution Planning Guide – Version 2.1." The Pennsylvania State University, University Park, PA, USA.

University of Oklahoma, General Education Requirements, http://www.ou.edu/gened/courses/requirements

Wu, W., Mayo, G., McCuen, T., Issa, R., and Smith, D., (2017). "The BIM Body of Knowledge (BOK): A Delphi Study", downloaded from https://dcp.ufl.edu/dcp/uploads/sites/43/2017/06/BOK.pdf

EMERGING TECHNOLOGY COURSE OFFERING: LESSONS LEARNED, OBSERVATIONS, AND IDEAS FOR IMPROVEMENT

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ABSTRACT

The growing use of BIM and related technologies in the construction industry has pushed universities to better prepare their students in terms of how technology is explored in the classroom. This has led to the creation of an undergraduate course at Clemson University that models the workflow of processes commonly seen on a project within the classroom setting . This course prepares students for technology use upon graduation. The lecture and hand-on lab combination allows for discussing the appropriate adoption and uses of technologies and processes while also providing relevant experience in how the technology can be implemented on a job. This paper discusses the developed course with some samples of assignments and types of work students were asked to complete, lessons learned from the instructor after its first full semester of implementation, and observations from both the students and faculty with ideas for future improvement.

Keywords: BIM, Undergraduate Education, Curriculum, Sample Lessons

1. INTRODUCTION

Building Information Modeling (BIM) and related technologies have been widely adopted over the last 10 years by the industry for planning and construction monitoring because of the realized benefits of higher production in the field, reduction of requests for information and change orders, schedule savings, and a potentially high return on investment (Hartmann and Fischer 2008; Azhar 2011; Giel and Issa 2011). With the growth of BIM throughout all sectors of the construction industry it is important that students are adequately prepared with BIM-related skills and knowledge needed upon entering the workforce (Molavi and Shapoorian, 2012; Sacks and Barak, 2012).

Within the Department of Construction Science and Management (CSM) at Clemson University, BIM was taught informally in multiple courses with very little depth and connection to the processes related to BIM. Recently, based upon a self-assessment of the curriculum in response to changes in accreditation standards from the American Council for Construction Education (ACCE) and feedback from industry partners, faculty determined a dedicated required course in construction technology is more appropriate. The course was first taught in the fall of 2017 and interlinks the processes of a BIM-based project workflow into a lecture-lab learning environment. The lectures were used to discuss concepts and practical application of the technology to support construction management processes throughout the lifecycle of the facility.

The labs were used for hand-on learning of software to demonstrate to the students how the technology can augment traditional paper-based or 2D processes.

This paper presents the modules of the course involving basic modeling, preconstruction planning and model coordination, and field management. The course utilizes Autodesk Revit, Navisworks, and BIM 360 within the laboratory portion of these modules. Feedback from students and other observations about the course are included with recommendations for improving the classroom based learning related to BIM.

2. COURSE DESCRIPTION

The CSM 3060 – Emerging Technologies course is taken by students in their first semester of their Junior year. The course exposes students to methods of planning and managing construction projects with technology. Various classes and uses of technology are discussed and students gain hand-on experience utilizing the technology in completing construction planning activities. The objectives of the course include:

- Distinguish between the different classes of technology used in construction and their uses.
- Explain the importance of different information protocols while discussing the importance of standards for information exchange (including Level of Development standards).
- Identify appropriate uses of technology for planning and managing construction projects.
- Identify appropriate methods for improving a company's project management abilities with the introduction of new technologies.

To support these objectives, hands-on computer based lab assignments were given that allowed students to work through the various processes commonly used to support the planning and management of construction projects. Lectures and discussions were utilized to support conceptual understanding of material before the labs.

Since only one three credit course is offered in the curriculum to cover the material not every aspect of technology in construction can be taught in great depth. Program specific outcomes including recommendations for types of software to use were identified through consultation with the industry advisory board and past students who recently entered the industry. To best prepare the student for their future work the outcomes specified by the industry were used as a baseline for developing the course. Since technology and the industry are both constantly changing careful consideration was given to what "future" technology in construction might consist of. The course also contains a module to look at trends and new technology. The intent of this module is that it will be updated every time the course is taught to highlight trends and technology on the horizon that may impact the future of the industry.

3. FLOW OF THE COURSE

The conceptual organization of the course follows the typical project workflow starting with the design of a building in model form, utilizing the model for coordination/planning purposes, and then managing the construction in the field through data tracking and QA/QC applications. Additional discussions on the use of robotics, drones, laser scanners, augmented/virtual reality, and what the future might hold in construction are also incorporated. Figure 1 shows the semester workflow with the subject matter, stage of the project, and incorporated lab assignment.

Workflow	**Design**	**Pre-Construction**	**Construction/ Field Management**	**Facilities Management**
Lecture/ Discussions	*Project Setup* *BIM/Tech. Adoption* *BIM Ex. Planning* *BIM Contracts*	*Coordination* *Logistics Planning* *Model-based est.* *4D Scheduling*	*Mobile and cloud based computing* *Central document management*	*Data turnover* *COBie* *Reality Capture (Drones & Laser sc.)*
Lab Topics	*Basic modeling* *Model visualizations*	*Extract model data* *Coordination/Clash* *Redlining models*	*Cloud based coordination, doc. management, and progress tracking*	*Point clouds and photogrametry*
Software Support	*Revit*	*Revit and Navisworks*	*BIM 360 (Glue, Docs, and Field)*	*Recap*

Figure 1. Semester Workflow

4. COURSE TOPICS, ASSIGNMENTS, AND LAB SETUP

Autodesk's Education Community (https://www.autodesk.com/education/home) and Autodesk Design Academy curriculum (https://academy.autodesk.com/curriculum) were widely referenced when creating the course and the lab materials. Because the department does not have a designated computer lab all students entering the program are required to have a windows based computer to run the software used to support classroom learning. Students were provided access to the educational licenses for Revit and Navisworks. Additionally, Clemson University was provided log-in access and administrative rights to BIM 360 for educational use of Plan, Glue, Docs, and Field. Only Glue, Docs, and Field were utilized for the course.

4.1 Basic Modeling and Model Organization

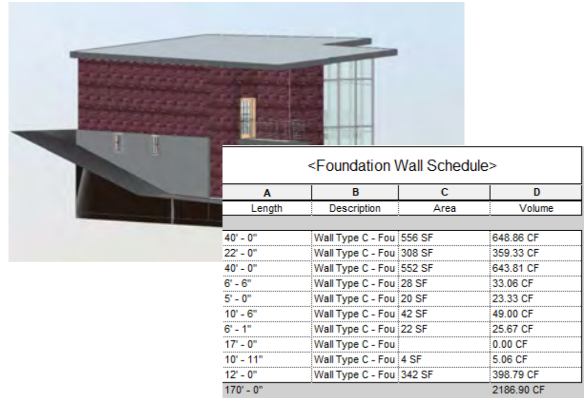
Autodesk Revit was first used to introduce the basics of modeling to the students. This provided foundational knowledge to the students about model creation and how the model data is organized. It also provided students with experience in navigating the model. Autodesk's "Getting Started for Revit" tutorial was utilized for the lab section.

4.2 Design vs. Construction Model - Extracting Data for Pre-construction Planning

Once the students were familiarized with the model's organization within Revit the discussion extended to the differences between the needs of a designer and contractor when using the model to support various processes. The second lab assignment included modifying elements within the model to more accurately reflect what the contractor would need for construction. In addition, the assignment included working with quantity schedules to capture and sort data that can support the construction planning process.

Additionally, there were discussions that included the use and organization of model-based estimating and scheduling. Because the foundational courses for estimating and scheduling also occur during the junior year the only activity related to scheduling was to learn functions of Navisworks with 4D Simulation.

Lab 1 – Create model from tutorial



<Foundation Wall Schedule>

A	B	C	D
Length	Description	Area	Volume
40' - 0"	Wall Type C - Fou	556 SF	648.86 CF
22' - 0"	Wall Type C - Fou	308 SF	359.33 CF
40' - 0"	Wall Type C - Fou	552 SF	643.81 CF
6' - 6"	Wall Type C - Fou	28 SF	33.06 CF
5' - 0"	Wall Type C - Fou	20 SF	23.33 CF
10' - 6"	Wall Type C - Fou	42 SF	49.00 CF
6' - 1"	Wall Type C - Fou	22 SF	25.67 CF
17' - 0"	Wall Type C - Fou		0.00 CF
10' - 11"	Wall Type C - Fou	4 SF	5.06 CF
12' - 0"	Wall Type C - Fou	342 SF	398.79 CF
170' - 0"			2186.90 CF

Lab 2 – Create wall types and extract data to quantity schedules

Figure 2. Revit Lab Assignments

4.3 Simple 4D Simulation

4D simulation, as discussed within the lecture portion of the class, demonstrated how temporary features can be modeled and tied to a time-based clash detection. Tracking of the schedule with a 4D simulation was also demonstrated. To familiarize themselves with the features of Navisworks and 4D simulation the students were provided a model and a simple schedule to follow. The students were required to create search sets that would work on an updated model. Common problems for the students were defining the most appropriate search sets. Many had saved sets or manually selected elements that then caused issues once the model was updated. However, this reinforced the importance of properly setting up the model analysis processes to allow for easier updating and managing the workflow of the model later in the project.

4.4 Collision Detection

Additionally with the preconstruction planning discussions was a lab activity for collision detections (figure 3). The students were provided the component models representing the architecture, structure, and mechanical design of a building. The lab required defining rules for the clash detective within Navisworks based on specific search sets and providing a collision report of the findings. Complete component models with specific clashes were provided to the students to complete this activity.

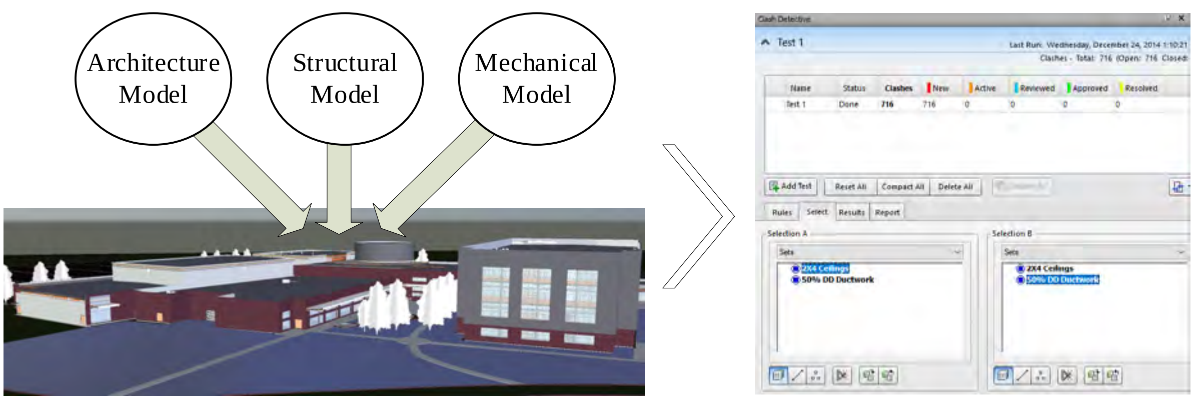


Figure 3. Clash Detection Assignment

4.5 BIM 360 and Mobile/Cloud Based Document Management

BIM 360 was used as platform to support discussion and also provide hands-on experience for documentation management and version control, producing and tracking RFIs, monitoring equipment installation status, and conducting QA/QC processes. Within BIM 360 Docs the students created the structure of a project by uploading a set of models and drawings. Students then reviewed the drawings to identify areas that needed clarification by creating redlines and RFIs. Within BIM 360 Glue, the students conducted another collision detection utilizing the same models they used from the Navisworks assignment. Within Glue, students were able to bring the component models together, create some redlines, and identify clashes. They were then asked to compare the types of clashes they were able to identify between Navisworks and Glue. Lastly, BIM 360 Field was used. The students were able to load equipment from the model that was created in Glue and apply status updates. The students were also charged with creating QA/QC checklists and completing mock inspections to see how issues are tracked within the system.

4.6 Facility Management Data and Reality Capture

From the beginning of the course a properly planned process utilizing BIM execution planning methods was discussed. At the end of the course this discussion flowed into how owners can typically use BIM or the data from the model. Additionally, methods for reality capture including laser scanning and photogrammetry were discussed. For one lab period the use of Recap was demonstrated with a previously created point cloud data set. One of the biggest barriers for students running the software on their own computers was the ability of their computers to process and manage the size of the data set.

4.7 Other concepts not incorporated in lab

Other topics discussed beyond the hands-on experiences offered in the lab were what to keep an eye on as emerging and current new adoptions of technology for construction. This included the use of drones and the appropriate federal regulations linked to their use, the use of augmented, mixed, and virtual reality for construction and where it most appropriately has a place, and the exploration of robotics in construction.

5. STUDENT FEEDBACK

The students were given an opportunity to provide feedback about the course offerings including both the lecture and lab. Less than 15% of the students had exposure to BIM 360 applications or Navisworks in a previous internship. Additionally, those who had prior exposure did not have exposure to the majority of what the programs functionally were capable of doing. Most of the information presented during the course was new to all of the students.

Overwhelmingly, the students expressed appreciation that the course was added and they saw value in the concept of the course for their future careers. The students were about equally split for those who thought the exposure to the software in the lab was appropriate to those who though it was too much and had trouble keeping up and the remaining who would have liked to explore some to greater depths.

Some common complaints were that the students had to use their own computers and they did not have enough space to install the required software. Additionally, some students, even though they were required upon admission to the program, to have a Windows-based laptop, have Mac laptops which do not natively run Autodesk Revit or Navisworks and can cause issues when run on a partitioned drive.

Overall there was not one lab that was identified as “too difficult” by a majority of students. Some students were able to pick up some software packages quicker than others and vice versa.

6. INSTRUCTOR OBSERVATIONS

Since this was the first time teaching the complete course the schedule was left flexible to respond to the students' needs. The original lab assignment for Revit took significantly longer for students to get through than originally planned. The average expected time that Autodesk suggested for the project was used as a baseline. However, since most students did not have any prior modeling or CAD experience, the user interface and general navigation of the program took some time to get comfortable with. Lab assignments were expected to be finished for homework with designated time in the classroom. For the first Revit lab, two lab periods (each of 1 hour and 15 minutes) were designated with the expectation that students would work for additional 2 hours maximum for homework. In total, most students spent more than the original 4-5 hours that were planned though some reported 8 or more hours to complete the first lab.

The following labs with new software, such as Navisworks and BIM 360 applications were not as difficult for the students. They had learned terminology and model organization with the first lab that they were able to transfer to other labs while becoming more comfortable with working in the model environment.

Another observation was that the students relied heavily on the tutorials. They liked to have things clearly laid out for a click-by-click operation of the software. These types of tutorials were provided for preliminary use of the software but later in the projects the students were given tasks to complete without step-by-step instructions and they had difficultly relating what they already completed in the tutorials to the new assignments. It was expected that once they were shown once and then given a follow up task that they should be able recognize which processes they were taught are applicable to the new tasks needing completion.

For several of the labs, the same model was used as a basis for the assignment. For others, new models were provided to the students because of the integrated features within the models relevant for the lab assignment. In general, if the students had already been familiarized with the model they more easily adapted to the next assignment. Moving forward, keeping the models that are used consistent will be a goal to whatever extent possible.

7. GOING FORWARDS

One of the observations that several students had also identified was that most of the labs because they had tutorials supporting the process, ended up as a point-and-click easy to follow exercise. When an activity was referred to in the next lab, many students had issues performing the task. Even though the point of the class is to understand the concepts of how technology augments the construction management process it is important that the students are able to perform basic tasks in preparing them for future careers in the industry. With that in mind, future lab assignments will have detailed instructions for the first part to describe the process before requiring students to practice the processes on a follow up assignment. Finally, computer-based quizzes during lab will be utilized to test student ability to adequately perform assigned tasks. For instance, one lab assignment where data is to be filtered and extracted by way of a schedule to support the procurement or estimating processes will have written instructions for students to go through and get comfortable with the process but then a similar scenario will be given in class with different models for students to extract data and perform the tasks.

In all, considering the course was offered for the first time it was successful. The students responded highly in post-course evaluations as they recognized the importance of better understanding the technologies used for managing construction projects. Many students, and industry members, recognize the need for students to have a basic understanding of these concepts to be marketable upon graduation and be successful in their future careers.

Expanded incorporation of BIM-based technologies in other courses is constantly being explored, however, the technical skill of faculty teaching those courses has been a challenge. An advanced course may be offered as an elective in the future.

REFERENCES

Azhar, S. (2011). “Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry”, *Leadership and Management in Engineering*, 11(2011): 241-252.

Giel, B. and Issa, R.A. (2011). “BIM Return on Investment: A Case Study”, *Journal of Building Information Modeling*.

Hartmann, T., and Fischer, M. (2008). “Applications of BIM and hurdles for widespread adoption of BIM.” *2007 AISC-ACCL eConstruction Roundtable Event Report*. Stanford University, CA.

Molavi, J. & Shapoorian, B. (2012) “Implementing an Interactive Program of BIM Applications for Graduating Students. ICSDEC 2012: Developing the Frontier of Sustainable Design, Engineering, and Construction (Chong et.al, Ed.), Fort Worth, Texas. Pg 1009-1016.

Sacks, R. and Barak, R. (2010). “Teaching Building Information Modeling as an Integral Part of Freshman Year Civil Engineering Education,” *Journal of Professional Issues in Engineering Education and Practice,* 136(2010): 30-38.

DEVELOPING ACTION PLANS FOR BIM EDUCATION

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ABSTRACT

Construction educators are trying to find a way to prepare construction management (CM) graduates by integrating BIM/VDC into their curriculum as a tool to achieve student learning outcomes. Although there are resources, teaching materials, or case studies available, it has still been a challenge to incorporate BIM/VDC into construction curricular due to many different reasons including cultural resistance, fast technology change and lack of clear vision on technology adoption. As new BIM/VDC technologies are introduced to the industry daily basis, teaching materials are quickly outdated. Educators don't have time to update or revise course plans accordingly.

This paper aims to address the issues mentioned above and help CM educators devise an effective BIM/VDC teaching strategy with suggestions for future direction. The paper begins with a comprehensive review of literature discussing concerns related to BIM education. A conceptual framework of BIM teaching plan is proposed base on the strategical approaches that the authors have used for BIM/VDC education.

Keywords: BIM, VDC, construction education

1. INTRODUCTION

The fast adoption of building information modeling (BIM) or virtual design and construction (VDC) technologies in the construction industry have disrupted the way of communicating and collaborating to manage a construction project. The power of cloud technologies with BIM/VDC is radically transforming BIM/VDC workflow and helping us collaborate more effectively within a multidisciplinary team environment. Over the next decade, emerging revolutionary technologies will disrupt how we design, build, and operate buildings. It is expected there will be a continuous flux of new technologies such as: 3D printing, augmented reality, and reality capture, to name a few.

Construction educators are trying to find a way to prepare construction management (CM) graduates by integrating BIM/VDC into their curriculum. Many different teaching strategies have been employed to include various aspects of BIM into CM curricula. Although there are resources, teaching aids or case studies available, it has still been a challenge to incorporate BIM/VDC into construction curricular due to many different reasons including cultural resistance, fast technology change and lack of clear vision on technology adoption. As new BIM/VDC technologies are introduced to the industry daily basis, teaching materials are quickly outdated. Educators don't have time to update or revise course plans accordingly.

This paper aims to address the issues listed above and help CM educators devise an effective BIM/VDC teaching strategy. The paper begins with a comprehensive review of literature and interview with CM educators about their needs, expectations or concerns related to BIM education. The strategical approaches that the authors have used for BIM/VDC education are described.

2. CHALLENGES OF BIM EDUCATION

BIM has become an integral part of the construction industry. Previous studies show that BIM can nurture student learning in a creative way. However, Inclusion of BIM into CM curricula is challenging and the high expectations have not always been met. Literature review was conducted to understand key challenges of BIM inclusion in CM curricular and determine the main problem areas pertaining to BIM education. The findings are summarized into four categories as shown in Table 1 - 4.

Table 1: Studies reported curriculum-related issues of BIM education

Problem Area	Explanation	Authors
Curriculum	52.90% of the faculty and industry professionals said conventional curricula hindered the adoption of BIM.	Abbas A.
	Scheer noted, “BIM requires space in the curriculum that CAD does not. What do we sacrifice to make room for teaching BIM?”	Scheer D.
	Some of the barriers identified by the authors, in their attempt to introduce BIM courses, are serious. The questions raised by the authors are, “Will BIM endure, or is it another fleeting disruption? What happens to subjects such as descriptive geometry and 2D construction documents? Is the new paradigm implicitly critical of the old paradigm, raising territorial issues among faculty? What time commitments are required of instructors to learn the software?”. This “cultural resistance” shows the inability to include BIM in the curriculum.	Denzer A.
	In a survey of colleges and universities in the Associated Schools of Construction members, participants were asked about BIM courses offered at their institutions. One of the responses received was the unwillingness of faculty to add more courses. They felt that current schedule didn’t provide time for it.	Sabongi F.
	A study conducted at University of Wisconsin Madison showed that the faculty members are not willing to add more courses to their current teaching load.	Dupuis M.
	In a survey targeted for deans, department chairs, and program directors of 488 accredited AEC schools, 140 responded back. A major reason stated by 36% of the respondents was that there simply was no room to include BIM in the curriculum.	Becerik-Gerber et al.

Table 2: Studies reported software-related issues of BIM education

Problem Area	Explanation	Authors
Software	BIM software, at the time of the research, were found to be imperfect. There were some incompatibility issues.	Dupuis M.
	Willem pointed out that learning and teaching BIM software is difficult. There may be some misinterpretation in understanding the processes	Willem K.
	After introducing BIM courses at National University of Singapore, the main challenge found was that the software	Raphael B.

	used seemed complicated and the user interface was difficult to use.	
	The authors studied the implications of introducing BIM courses in Kent State University, Ohio and University of Florida, Gainesville. The limitation as expressed by them was, "Academic institutions however, are customarily slow to adopt change especially if it pressured by a continuous flux of new technologies. The speed at which curricular changes take place in universities and the efforts needed to maintain professional accreditation limits the ability of architecture and engineering programs to match the speed at which the AEC industry is advancing in this arena."	Sharag-Eldin A.
	The authors in their work about BIM in curricula identify the following issue, "Students may possess knowledge of BIM tools, however, formal instruction in required to navigate complex processes. Too often students are allowed to set technological standards due the rapidly changing state of technology and the effort of faculty to stay current. As we define construction curricula for the 21st Century, students must be able to create and analyze BIM models to meet current and future needs of the construction industry."	Sylvester K.

Table 3: Studies reported faculty expertise-related issues of BIM education

Problem Area	Explanation	Authors
Faculty Expertise	Due to the lack of faculty expertise, industry professionals need to actively participate by bringing in news and problems with using BIM to the education sector.	Dupuis M.
	Too often students are allowed to set technological standards due the rapidly changing state of technology and the effort of faculty to stay current.	Sylvester K.
	Projects have to be assigned to students for a better understanding of BIM concepts. For such complex scopes, construction companies need to be contacted for their help and requirements.	Barison M.
	At Auburn university, the author implemented a thesis project course at the undergraduate level. After completion of that course students had to fill out a survey. One of the comments received was, "It would be helpful to have the thesis requirements to reflect what the industry is currently using BIM for, from a standpoint of a general contractor." This shows the lack of communication between academics and industry professionals.	Azhar et al.

Table 4: Studies reported faculty teaching material-related issues of BIM education

Problem Area	Explanation	Authors
Teaching Materials	According to the findings in their research, the author believes that software applications are a problem with BIM education. Detailed diagrams cannot be integrated into construction documents. The main reason being lack of detailing options.	Livingston C.
	During their research the author found several benefits of integrating BIM into AEC curriculum. The current limitation found at the time of their research were, material take-off is only 1/3rd of the requirements, with the compatibility issues of scheduling software. This hinders in case of using full potential required off any software.	Wright J.
	91.93% responded that there is lack of training among faculty to help in teaching BIM to students.	Abbas A.
	The problem found was that there were not enough reading materiasl. It was desirable by the faculty but was deemed unnecessary. The students felt that reference books would have been helpful.	Dupuis M.
	BIM is resource intensive. With the lack of teaching materials, it is hard to even teach educators. This turns out be a challenge especially for people with weak computer skills.	Gordon C.
	A questionnaire was sent out to 200 AEC academics (150 students and 50 faculty). The response rate was 71% for students and 66% for faculty. One of the questions asked was about the barriers in BIM education containing the option of amount of resources available for study. On a scale of 1-5, 5 being the least availability, 78.2% agreed that there was a lack of education resources available.	Hedayati A.
	At the Hong Kong Polytechnic University, a BIM course was introduced with 4 theory lectures and 6 practical lessons. After completion of the course students were asked about the satisfaction from learning this course. Most of the students gave a positive reply, but about 10% were not satisfied. A few students needed more clear explanations about certain concepts. It may be due inadequate learning materials available.	Wong K.

3. ACTION PLAN FOR BIM EDUCATION

Construction educators have put effort into resolving the pedagogical issues related to BIM inclusion. Previous studies reported various implementation strategies, but they experienced difficulties related to policy, technology, and process. The lacking is a holistic view of the pros and cons of the strategies in place before proceeding. Settling on a strategy that solves one problem without thinking through the whole perspectives can lead to more problems.

This section suggests a concept model of strategical approaches that the authors have used for BIM/VDC education are described here. The strategies are summarized into four problem categories**:** curriculum, software, faculty expertise, and course materials. CM educators could use this concept model as they develop their own BIM implementation strategies and a course of actions in their own institutions.

Figure 1 lists key problem areas of BIM education, and Figure 2 lists action items under each problem category.

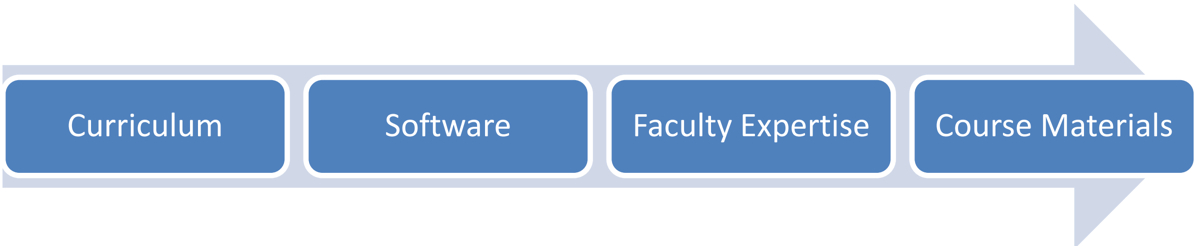


Figure 1: Key problem categories of BIM education

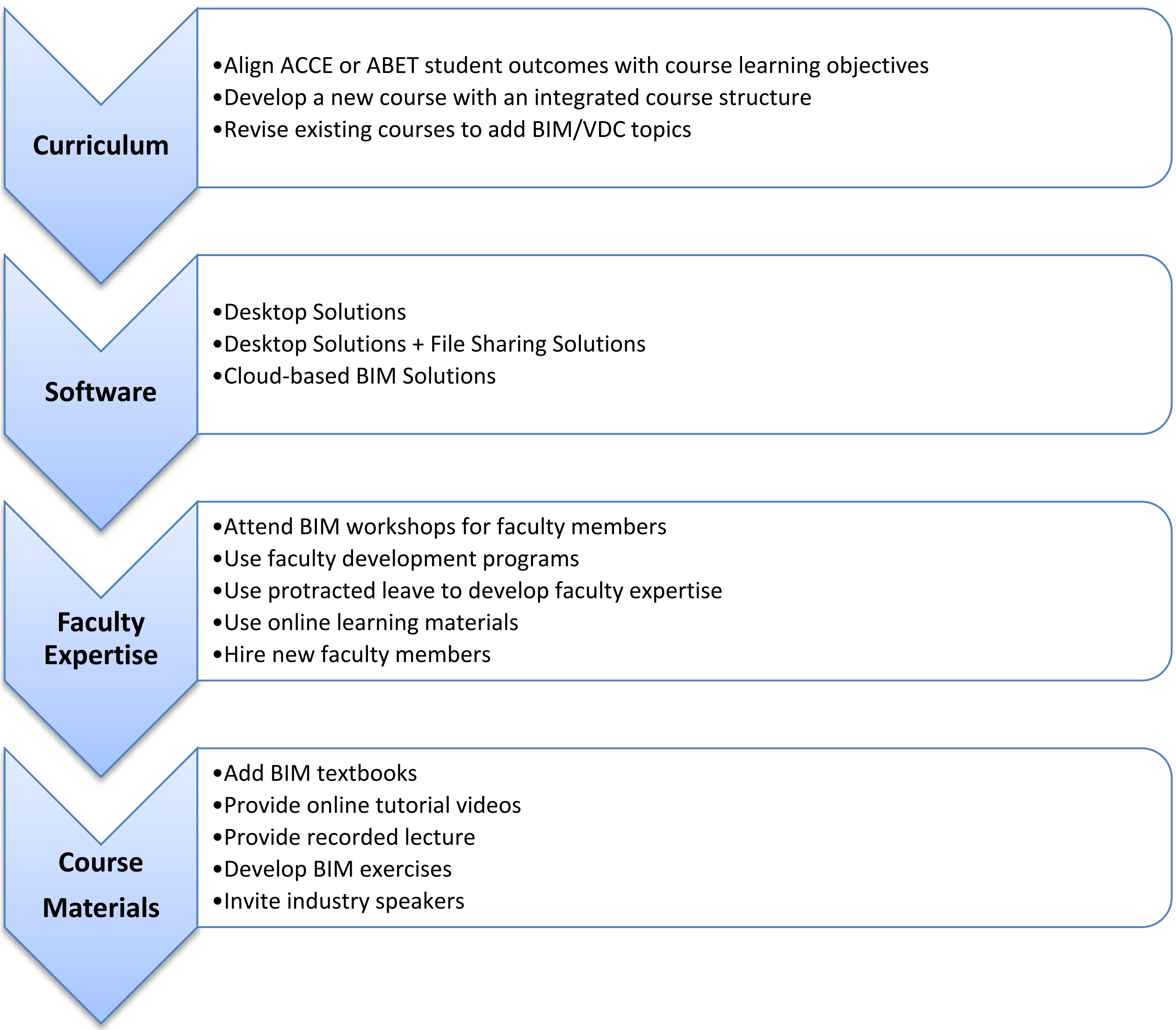


Figure 2: Action items of BIM strategies

3.1 Curriculum Issues

Previous studies revealed that the most common challenge of BIM education is related to curriculum changes. Most CM curricular are designed to meet the standards of various accreditation boards such as ACCE and ABET, and it is hard to add new topical contents into existing curricula due to the lack of room for new courses. It is relatively easy to revise existing courses to add BIM/VDC topics. Figure 3 shows that traditional CM learning modules can be easily replaced by BIM learning modules while achieving course learning objectives.

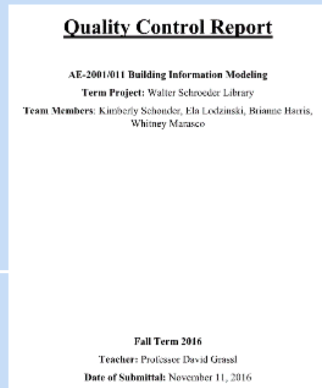
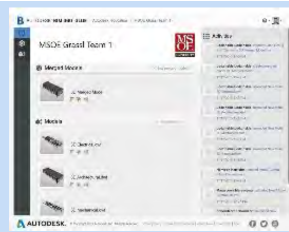
Course Learning Objectives	ABET SLO	ACCE SLO	Data Collected	Example
Facilitate communication and interaction with other design professionals in the development and execution of civil and architectural engineering projects	**(g)**	**1**	Copies of Notification emails	 **Quality Control Report** **AE-2001/011 Building Information Modeling** **Term Project:** Walter Schroeder Library **Team Members:** Kimberly Schonder, Ela Lodzinski, Brianne Harris, Whitney Marusco **Fall Term 2016** **Teacher:** Professor David Grassl **Date of Submittal:** November 11, 2016
Be able to work effectively in a team environment	**(d)**	**9**	Copies of term project reports	
Be able to use the techniques, skills, and modern scientific and technical tools necessary for professional engineering practice	**(k)**	**10**	Copies of BIM 360 Glue website	

Figure 3: Aligning student learning outcomes

3.2 Software Issues

Willem (2008) pointed out that learning and teaching BIM software is difficult due to complicated user interfaces. After introducing BIM courses at National University of Singapore, the instructor requested for feedback from students. The main challenge found was that the software used seemed complicated and the user interface was difficult to use (Raphael, 2009).

As cloud computing is transforming BIM technologies, there is a broader range of BIM technologies that can be adopted for construction education. Herridge (2018) highlighted that BIM software over the past decade has produced a portfolio of solutions that span every phase of a project, from design through to operations. Furthermore, software vendors provide cloud-based BIM solutions so that the users can leverage the power of cloud computing such as remote desktop and vast amount of storage spaces. Figure 4 shows the cloud-based BIM solution developed by Autodesk.

The institutions need to consider economic, cultural, and administrative situations to select a software platform from the options listed below:

- Desktop Solutions
- Desktop Solutions + File Sharing Solutions
- Cloud-based BIM Solutions

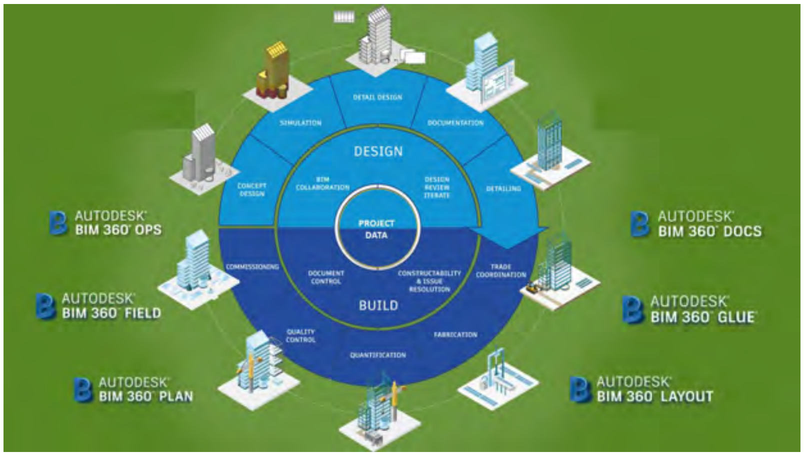


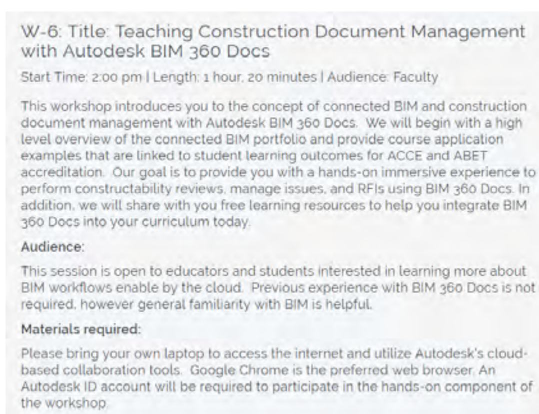
Figure 4: Connected BIM concept of Autodesk

3.3 Faculty expertise

Faculty members are expected to teach and adopt new discoveries in order to keep the course up-to-date. This calls for faculty development to invest their abilities to create and sustain BIM education. It has been obvious that BIM experts in academia is lacking due to cultural, funding, or administrative reasons. In addition, There is a high level of resistance when they are asked to add more courses on the top of their existing workload (Sabongi, 2009). Recently, there are more faculty development opportunities for BIM education as outlined below:

- Attend BIM workshops for faculty members
- Use faculty development programs
- Use protracted leave to develop faculty expertise
- Use online learning materials

The resources can be used to develop BIM exercises and update course concepts. ASC (Associated Schools of Construction) provides several BIM workshops at international conferences. Figure 5 is the workshop description of a BIM workshop at the recent international conference of ASC. Figure 6 shows an example of BIM online course offered at Lynda.com.



W-6: Title: Teaching Construction Document Management with Autodesk BIM 360 Docs

Start Time: 2:00 pm | Length: 1 hour, 20 minutes | Audience: Faculty

This workshop introduces you to the concept of connected BIM and construction document management with Autodesk BIM 360 Docs. We will begin with a high level overview of the connected BIM portfolio and provide course application examples that are linked to student learning outcomes for ACCE and ABET accreditation. Our goal is to provide you with a hands-on immersive experience to perform constructability reviews, manage issues, and RFIs using BIM 360 Docs. In addition, we will share with you free learning resources to help you integrate BIM 360 Docs into your curriculum today.

Audience:

This session is open to educators and students interested in learning more about BIM workflows enable by the cloud. Previous experience with BIM 360 Docs is not required, however general familiarity with BIM is helpful.

Materials required:

Please bring your own laptop to access the internet and utilize Autodesk's cloud-based collaboration tools. Google Chrome is the preferred web browser. An Autodesk ID account will be required to participate in the hands-on component of the workshop.

Figure 5: BIM workshop offered at ASC

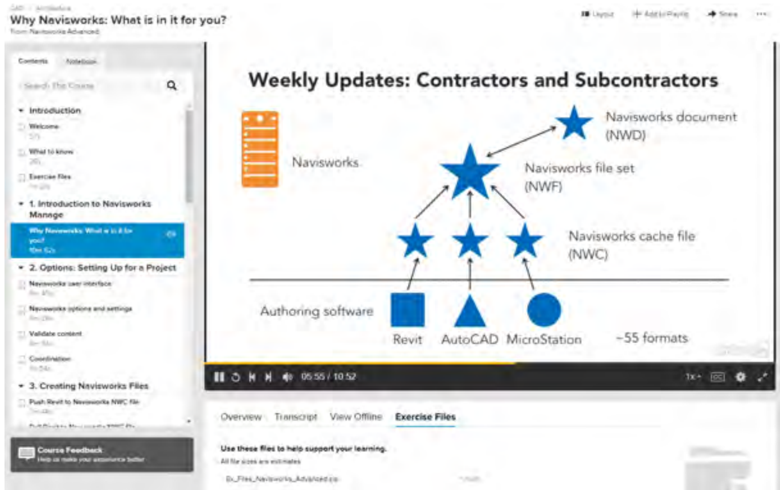


Figure 6: BIM online course at Lynda.com

3.4 Course Materials

CM educators typically adopt BIM not for technical skill development but for problem solving in a practical setting. Therefore, the adoption of existing materials is preferred for technical skill development. Depending on the course learning outcomes and logistical situations, there are several course materials options including:

- Adopt BIM textbooks
- Adopt online tutorial videos
- Provide recorded lecture
- Develop BIM exercises
- Invite industry speakers

Figure 7 introduces an example of online courses for student learners available at Autodesk Design Academy. Several courses provide data set and step-by-step tutorial videos for self-paced learning. Faculty members can adopt these resources into the course structure so that the students can learn new BIM technologies to work on class projects or assignments.

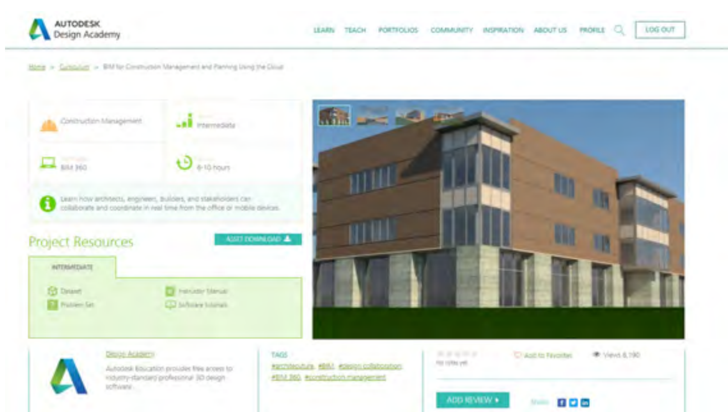
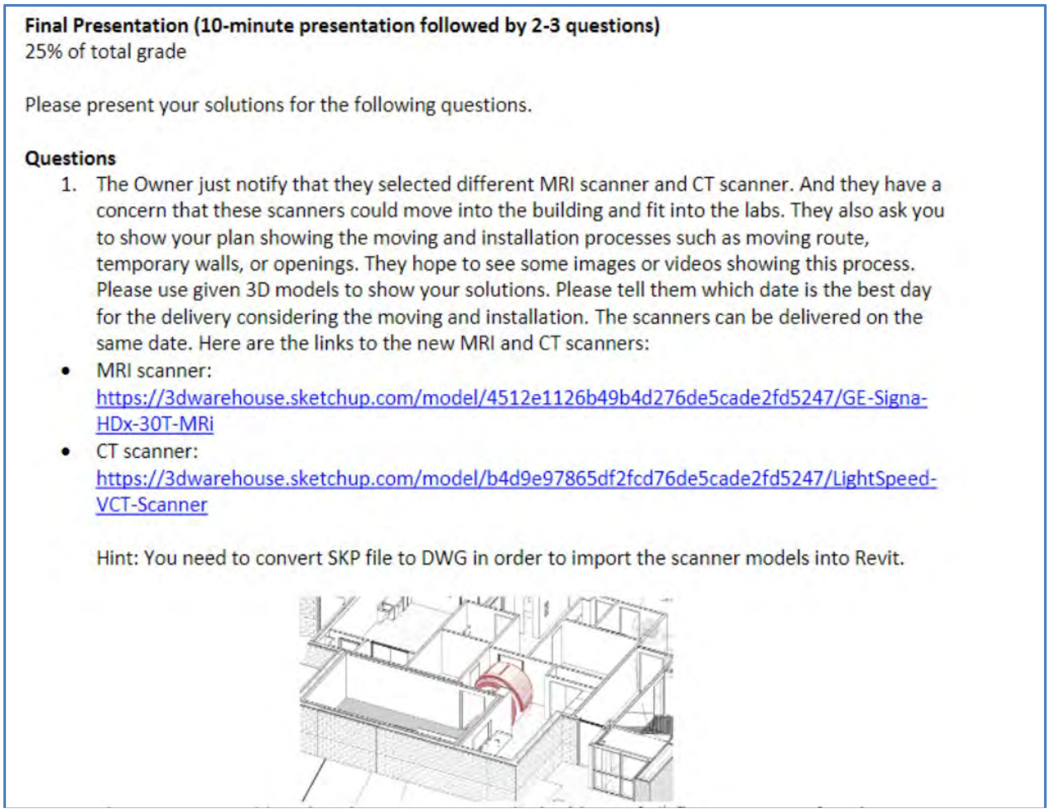


Figure 7: Screen shot of BIM course at Autodesk Design Academy

If BIM is used in senior-level courses, it is important to use BIM for problem solving. Figure 8 is an example of using BIM to resolve site logistical issues in health care projects. The students had to develop a plan to install MRI and CT scanner. The students were able to use given Revit and SketchUp models for visualization. Figure 9 is an example of their solutions.



Final Presentation (10-minute presentation followed by 2-3 questions)
25% of total grade

Please present your solutions for the following questions.

Questions

1. The Owner just notify that they selected different MRI scanner and CT scanner. And they have a concern that these scanners could move into the building and fit into the labs. They also ask you to show your plan showing the moving and installation processes such as moving route, temporary walls, or openings. They hope to see some images or videos showing this process. Please use given 3D models to show your solutions. Please tell them which date is the best day for the delivery considering the moving and installation. The scanners can be delivered on the same date. Here are the links to the new MRI and CT scanners:

- MRI scanner: https://3dwarehouse.sketchup.com/model/4512e1126b49b4d276de5cade2fd5247/GE-Signa-HDx-30T-MRi
- CT scanner: https://3dwarehouse.sketchup.com/model/b4d9e97865df2fcd76de5cade2fd5247/LightSpeed-VCT-Scanner

Hint: You need to convert SKP file to DWG in order to import the scanner models into Revit.

Figure 8: BIM assignment for CM students

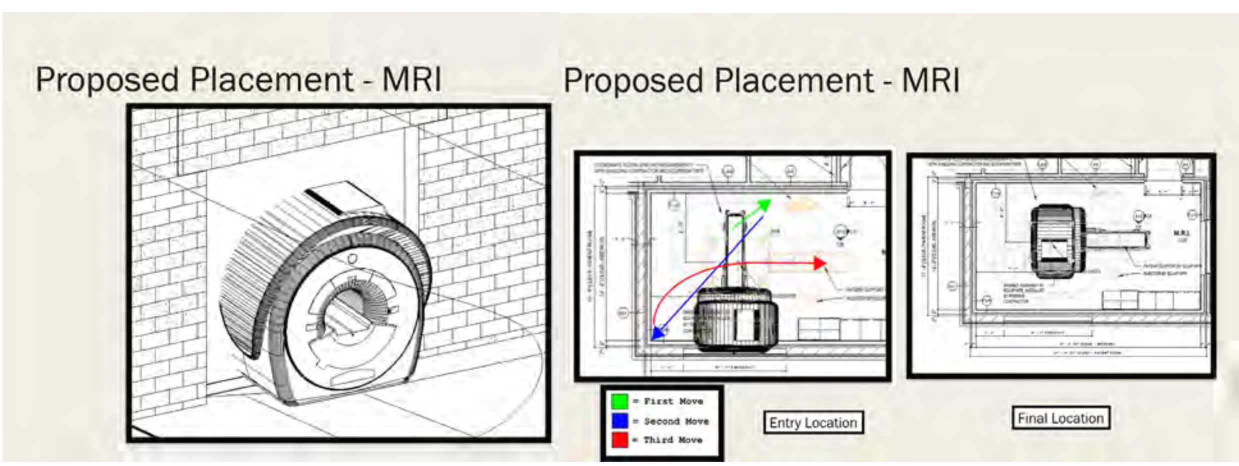


Figure 9: Solutions for MRI scanner installation

4. CONCLUSIONS

This paper address the pedagogical problems of BIM education by proposing an action plan for CM educators. New and experimental teaching approaches to BIM education is also discussed. The action plan could be utilized by all CM educators who are interested in adding or developing BIM courses. Many of the action items listed in the plan have been used by the authors, and It is expected for CM educators to adjust. The action plan will be tested by multiple educators for improvement.

REFERENCES

Abbas, A., Din, Z. U., & Farooqui, R. (2016). "Integration of BIM in Construction Management Education: An Overview of Pakistani Engineering Universities." https://www.sciencedirect.com/science/article/pii/S1877705816300388

Azhar, S., Sattineni, A., & Hein, M. (2010). "BIM Undergraduate Capstone Thesis: Student Perceptions and Lessons Learned. Retrieved from ascweb.org" http://ascpro.ascweb.org/chair/paper/CEUE200002010.pdf

Barison, M. B., & Santos, E. T. (n.d.). "Review and Analysis of Current Strategies for Planning a BIM Curriculum." http://itc.scix.net/data/works/att/w78-2010-83.pdf

Becerik-Gerber, B., Gerber, D. J., and Ku, K. (2011). "The pace of technological innovation in architectural, engineering, and construction education: Integrating recent trends into the curricula." *J. Inform. Technol. Constr.*, 16(1), 411–431

Denzer, A.S. and Hedges, K.E. (2008). "From CAD to BIM: Educational Strategies for the Coming Paradigm Shift." Proceedings of the 2008 Architectural Engineering National Conference, September 24- 27, Denver, Colorado.

Dupuis, M., Thompson, B., Herridge, J., & Lawrence Bank. (2015). "Experiences Implementing an Undergraduate Civil Engineering Course In BIM." https://peer.asee.org/experiences-implementing-an-undergraduate-civil-engineering-course-in-bim

Gordon, C., Azambuja, M., and Werner, A. M. (2009). "BIM across the construction curriculum." Associated Schools of Construction, Region III 2009 Conf., M. El-Gafy, ed., Southern Illinois Univ., Edwardsville, IL.

Hedayati, A., Mohandes, S. R., & Preece, C. (2015). Studying the Obstacles to Implementing BIM in Educational System and Making Some Recommendations. *Journal of Basic and Applied Scientific Research*. Retrieved from https://www.textroad.com/pdf/JBASR/J. Basic. Appl. Sci. Res., 5(3)29-35, 2015.pdf.

Livingston, C. (2008). "From CAD to BIM: Constructing opportunities in architectural education." Proc., Architectural Engineering National Conf., ASCE, Reston, VA.

Raphael, B. (2009). "Promoting efficient use of visualization tools through education." J. Comput. Civ. Eng., 23(6), 428–435.

Sabongi, F. J. (2009). "The integration of BIM in the undergraduate curriculum: An analysis of undergraduate courses." Proc., 45th ASC Annual Int. Conf., Associated Schools of Construction, Gainesville, FL.

Scheer, D. R. (2006) "From an Educational Perspective: BIM in the Architectural Curriculum", Government/Industry Forum, October 31, 2006, Washington: National Academies' Federal Facilities Council.

Sharag-Eldin, A. and Nawari, N.O. BIM in AEC Education. Structures Congress Proceedings, American Society Civil Engineers, 2010.

Sylvester, K.E. and Dietrich, C., Evaluation of Building Information Modeling (BIM) Estimating Methods in Construction Education. Proceedings of the 46th ASC Annual International Conference, Associated Schools of Construction, 2010. Retrieved from http://ascpro.ascweb.org/chair/paper/CEUE221002010.pdf

Willem K. (2008). *Building Information Modeling: Planning and Managing Construction Projects with 4D CAD and Simulations* (McGraw-Hill Construction Series). Learning BIM Chapter (McGraw-Hill Professional, 2008).

Wong, K. A., Wong, K. F., & Nadeem, A. (2011, February 01). Building information modelling for tertiary construction education in Hong Kong. Retrieved from http://hdl.handle.net/10397/5769

Wright, J. A. (2012, June), *The Integration of Building Information Modeling and Integrated Project Delivery into the Construction Management Curriculum* Paper presented at 2012 ASEE Annual Conference & Exposition, San Antonio, Texas. https://peer.asee.org/22074

Woo, J.-H. (2007). “BIM (Building Information Modeling) and Pedagogical Challenges.” International Proceedings of the 43rd Annual Conference of the Associated Schools of Construction, Flagstaff, AZ.

BUILDING PERFORMANCE OPTIMIZATION AND ENERGY MODELING IN BIM CURRICULUM

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ABSTRACT

Connected with the power grid, most of the buildings are passive consumers of energy and creating a negative impact on Earth. New technologies are disrupting every industry and more efficient delivery methods and sustainable design and construction are needed. The Building Energy Modeling (BEM) with the advent of new tools and technologies is considered as a solution to reduce energy costs and the environmental impacts of power generated for buildings. In this sense, Building Information Models (BIMs) based workflow became crucial for systems design. The Architecture, Engineering, Construction and Operation (AECO) industry has well placed benefits from BIMs for building performance optimization through captured, visualized, simulated, monitored and managed spaces and data used for renewable energy systems, controls and sensors, remote access tools, batteries, and building automation/management systems.

Therefore, there is a need to prepare our students early in the process and engage them for this industry sector by equipping them with technical skills and relevant issues and concerns on building energy consumption, as well as the challenges and opportunities that comes with such a workforce associated with changes in the energy segment that affects building energy professionals (building owners and operators, design and construction professionals, policymakers, energy-performant building consultants, net-zero energy building operators, etc.). Cultivating a technology embracing community is key in developing and maintaining a successful BIM program that empowers the needed workforce both in industry and academy. Aligned with the needs of target learners, this paper will present a combined effort to include building performance optimization with BIM and BEM applications in the engineering curriculum of two research universities. The leveraging literature and curriculum exploration performed at Georgia Southern University (GSU) will be introduced. In-class practices of the related BIM courses at Armour College of Engineering at Illinois Institute of Technology (IIT) and their outcomes will be shared and discussed.

Keywords: Building Information Modeling, Building Energy Modeling, BIM Curriculum, Building Performance Optimization, Experiential Learning.

1. INTRODUCTION

The global building industry is one of the largest industries in the world and will grow from approximately an $8 trillion industry in 2013 to a $12 trillion industry by 2020. Yet, building construction is still quite often a low-tech environment that can be extremely inefficient and wasteful. Indeed, it may be the only industry that has actually declined in efficiency over the past 20 years. As building requires an enormous amount of resources, the industry has substantial effects on the environment (Schilling, 2014).

Most projects run over time and budget. Research (Autodesk, 2017) shows 93% of building owners report projects as running over time, and 85% say projects exceed their agreed budget. In an EIU survey from 2017, 32% of construction professionals cited "poor communication and collaboration" as the single biggest hurdle to improving productivity. The nature of much of today's design and engineering work requires multidisciplinary teams working together. The increasing importance and use of building information modeling (BIM) in AECO represents a promising step towards modernization and solutions for the inefficiency and safety issues.

According to Autodesk's The Inefficiency Problem Report (2017) Clients increasingly require BIM on their projects, with government mandates becoming a catalyst for change in many countries. The General Services Administration and US Army Corps of Engineers require BIM on all major projects. UK government projects must use BIM Level 2 as part of a program to cut capital costs, delivery schedules, and carbon usage. Germany is planning for a BIM mandate by 2020. The EU BIM Task Group is aiming to harmonize BIM in public works across the EU. Other governments already adopting BIM at least partially include France, Italy, Spain, Finland, Denmark, and the Netherlands. Authorities across Asia, Singapore, China and Australia are all increasingly using BIM. In the UAE, Dubai municipality requires BIM for government buildings that are higher than 20 floors.

Besides the increased complexity of spaces and internal expectations, the governments and private project owners are challenging the industry to deliver the projects more efficiently. The cost of many of the natural resources used in construction is rising. These resources are also becoming less desirable to climate-conscious clients, therefore the demand for more sustainable design increasingly influences the types of construction materials being used, boosting the performance of buildings and infrastructure over their lifetime. The regulatory agencies and industry associations see immense value in the project information, data documentation, and collaboration made possible through building information modeling (BIM).

The technology is advancing in a rapid fashion. Although knowledge and skills can always be acquired and learned, the real skill needed is to adapt the change and see possibilities in new situations. A BIM process needs competencies based on a technology environment consisting of software platforms and tools. However, BIM is a human activity that ultimately involves broad process changes in the construction industry based on both user skills and experience. Furthermore, delivery of building projects has become more complex and technically demanding (Bozoglu, 2016).

The only obstacle related to technology deployment selected as having a significant impact on the success of complex projects by more than half of owners, architects, engineers and contractors is lack of team member skills at using advanced tools and methods. A high percentage of engineers in particular (63%) consider this obstacle significant. The second most significant obstacle for AEC firms is insufficient technology training for inexperienced team members. The two top obstacles for AEC firms demonstrates that knowledge of how to use the technology across the project team, rather than the technology itself, is the most important obstacle for these firms (McGraw-Hill 2014; Dodge Data & Analytics, 2015).

Professional bodies, industry and academia are the key stakeholders of BIM education. It is the role of the professional bodies to represent the BIM professionals and create attractive job positions in the construction industry for those who are skilled and talented. They need to ensure that BIM is a career choice. The professional bodies accredit degree courses provided by Universities, and then inspect them to ensure that they come up to their required published standards. There should be a dynamic interaction between the professional bodies and academia, which should be informed by the requirements of industry as the end user (Demirdoven and Arditi, 2014; Demirdoven, 2015, Bozoglu, 2016). Wu and Issa (2013) indicates that the underlying supply-demand relationship between universities and the industry has been more reliant on students' intellectual and technical readiness, especially in the case of BIM. Therefore, the effective inclusion of BIM into college curriculum has become both a pedagogic and practical imperative in preparing future employees for the AEC industry (McGraw-Hill 2009; and, Crumpton and Miller 2008).

To equip current and future industry professionals with the necessary knowledge and skills to engage in collaborative BIM workflows and integrated project delivery, it is first important to identify the competencies that need to be taught at educational institutions or trained on the job (Bozoglu, 2016). Succar and Sher (2013) describe the individual BIM competencies as the personal traits, professional knowledge and technical abilities required by an individual to perform a BIM activity or deliver a BIM-related outcome.

This paper will present a combined effort to include building performance optimization with BIM and BEM applications in the engineering curriculum of two research universities. The leveraging literature and curriculum exploration performed at Georgia Southern University (GSU) will be introduced. In-class practices of the related BIM courses at Armour College of Engineering at Illinois Institute of Technology (IIT) and their outcomes will be shared and discussed.

2. LITERATURE

Building information models (BIMs) are more than just geometric representations of buildings – they are also a repository for a wealth of information. Data sources in construction industry are exploding. Innovations in digital technologies are disrupting every industry, and the AECO industry is no exception. 90% of world's data generated over last two years through sensors and devices, social media, VoIP and enterprise data and there will be a 50 times higher growth in data from 2010 to 2020 (Science Daily, 2013). Throughout the design and construction phases of a project, it is created and captured information that is extremely valuable to an owner for use in operating the building. Finding best ways to store and extract this data is still an issue. The industry needs better tools and processes to benefit owners. The Smart Market Report (2014) conveyed that 81% of US companies consider BIM capabilities when making their selection for project teams. Consequently, transitioning to more efficient, model-based workflows is not just a key to win more work, it is crucial for project success.

The developments in building design and analysis software over the last decade, coupled with advances in desktop and laptop computational power, have led to the emergence of new digital models for the design and documentation of buildings: virtual buildings or building information model(s)/(ing) (BIM). Thanks to these advances, BIM - authoring software applications combine three - or four - dimensional models with embedded, intelligent building objects related in a contextual database. As a result of BIM's data-rich 3D modeling, various design disciplines can extract and manipulate relevant tabular or graphical building views such as reports and drawings. According to Levy (2012) such an approach can improve building construction and operational performance, increase design efficiencies, and foster an integrated design workflow, among other benefits. BIM creates opportunities for the quantitative assessment of design options. Therefore, the data bound to the virtual building model can be defined, analyzed, and parameterized by the designer, with the ultimate goal of positively influencing building performance.

BIM is appropriate for sustainable design. Leadership in Energy and Environmental Design (LEED) for example, dictates the measures to be taken to achieve sustainability. Such prescriptive measures serve as proxies for actual building and occupant performance. The benefit of early analysis— even as early as conceptual design—is that it allows the most influence on building performance with the least effort. BIM's adaptability is compatible with performance-driven (sustainable) design. BIM becomes a sustainable design environment, then, as it potentially integrates quantitative analysis in the design decision-making process (Wong and Fan, 2013).

Connected with the power grid, most of the buildings are passive consumers of energy. The Building Energy Modeling (BEM) with the advent of new tools and technologies is considered as a solution to reduce energy costs and the environmental impacts of power generated for buildings. In this sense, Building Information Models-based workflows became crucial for systems design. The AECO industry has well placed benefits from BIMs for building performance optimization through captured, visualized, simulated, monitored and managed spaces and data used for renewable energy systems, controls and sensors, remote access tools, batteries, and building automation/management systems (Nahan Communications, 2018).

3. CURRICULUM EXPLORATION AT GEORGIA SOUTHERN UNIVERSITY

In the Civil Engineering and Construction Management Department at Georgia Southern University (GSU) Statesboro campus, the TCM 5333 Building Information Modeling for Construction Management plays an important role as one of the learning modules involves development of critical thinking skills relative to energy efficiency and modeling of the most common residential units in this area. The construction engineering relative to our new energy future holds great promise, and buildings professionals will be critical to realize new opportunities and identify and then solve the challenges ahead. Buildings professionals will be essential in safeguarding wellness and sustainability for the built environment and the people it serves. The curriculum exploration for this field started with Design-for-Aging (DfA) project (Maghiar, 2016), which intends to respond to an emerging market demand on senior-friendly housing by a rapidly increasing senior population, trend recognized everywhere in this country. The proposed housing design requires the students to take into account the specific design features (e.g. Universal Design criteria) and applicable code requirements (e.g. ADA) and complete the design with an *energy efficient building envelope*. Students are also required to think and model a power production and efficient system that may save on the long-term energy consumption for the residential unit.

The proposed senior-friendly housing design needs to reflect realistic needs of senior people with a total usable area of the house up to a maximum of 3000 SF. It is suggested in the introduction of the Project that students should focus on the level of details, the code compliance and energy-efficient design of the proposed unit instead of the overall appearance and therefore explore creative designs that fit into the context of local community. The following checklist is to be considered by the students when conducting their design:

- Accessibility (e.g. entrance, hallway, exit);
- Maintenance of building envelopes (e.g. wall materials, landscaping, balcony);
- Floor plan (e.g. single story vs. multistory, layouts of rooms);
- Furnishing (e.g. kitchen, bathroom, flooring, living room);
- Indoor environmental quality (e.g. day lighting, number of windows, shading);
- Other applicable criteria (codes, state requirements, etc.);
- Mechanical HVAC system: air diffusers, ducts (supply and return), air handling units with connections, as applicable into an *efficient and energy-saving design*.

Project Deliverables consists of a completed senior-friendly housing energy-efficient design model using Autodesk BIM 360 Team and Collaboration for Revit and/or Autodesk Revit latest version; a basic design documentation including site plans, floor plans, elevations, sections views, detail views and renderings (including construction drawings); and a five-six pages narrative report on design process and outcomes for the entire team. This project is graded as teamwork and it is peer-evaluated on multiple criteria for efforts and contributions. Teams can achieve as many as 100 points and the grading is based on a designated rubric taking into account code related compliances, senior-friendly features of the interiors and the energy-efficient design of the building as a whole (materials placed in the building envelope, design of the envelope, roofing considerations and potential influence of the HVAC systems integrated in the residential unit).

Lecturing details are provided on semester basis and varies from time to time to consider integration to a more complex external environment (including landscape). Undergraduate teams are mixed with graduate students (at times) from different majors, including civil engineering, interior design and/or construction management. Guest speaking sessions are conducted during most of the Project lectures to present the details of an energy-efficient housing unit from Savannah area: design of a PV system mounted on the roof, EIFS of the exterior load-bearing walls, details of lath and stucco, insulation of the window frames, termite barriers, attic spray foam insulation, garage ceiling insulation, PV system analysis on costs and energy production measures, etc. (see Figure 1 below for a sample resulting student work, and Figure 2 for real case-scenario of the residence energy-related improvement, by guest speaker).

By assessing the knowledge key points of this collaborative project, students have the chance to realize and to be exposed to the need of preparing early in the process and engage with owners from industry sector. Also, this exercise is a starting point for them to acknowledge some of the required technical skills and relevant issues or concerns on the residential energy consumption, as well as the challenges and opportunities of the workforce associated with changes in the energy segment that affects residential energy professionals (systems operators, design and construction professionals, policymakers, energy consultants, net-zero energy residential owners, etc.).

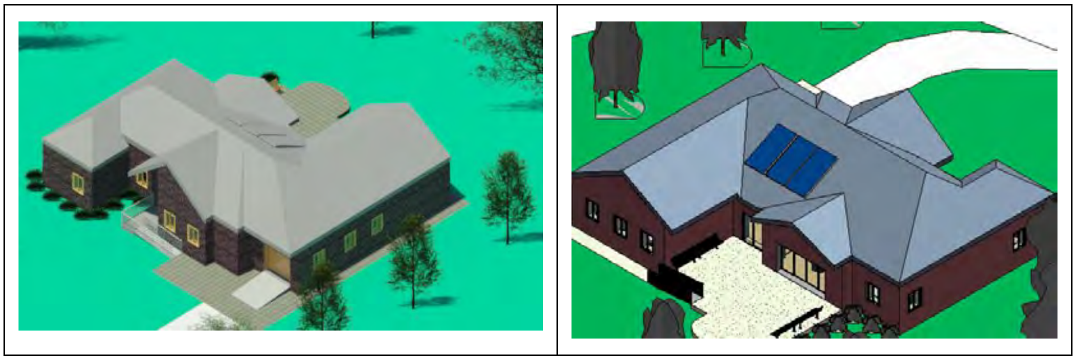

Figure 1. Interactive ray-trace mode and the shaded-graphics of the energy-efficient residential design

Figure 2. Completion of the insulation system (EIFS) and installation of the PV system on the unit roof

4. BIM LEARNING MODULES AT ILLINOIS INSTITUTE OF TECHNOLOGY

The increased use of BIM has brought about new roles such as the BIM specialist, manager, coordinator, leader, champion, trainer, consultant, expert, technologist, etc. The BIM professional's competency could cover technology, process, commercial, and personal skills. Those skills define the professional's role depending on the entry conditions into the construction industry and the qualifications and background of
the professional.

The Department of Civil, Architectural and Environmental Engineering incorporated BIM into its curriculum through the introduction of three course offerings: (1) EG 430 -Introduction to BIM, the senior level elective in the Engineering Graphics Program; (2) CAE 573 - Construction Management with BIM, a graduate level elective in the Construction Engineering and Management Program; and (3) CAE 515 – BIM Applications for Building Performance.

The objective of a modular approach adopted by the Department of Civil, Architectural, and Environmental Engineering (CAEE) at Illinois Institute of Technology (IIT) to promote BIM-enabled learning is to educate both the future engineers and architects who will be actively using BIM routinely.

The strategy relative to BIM Learning Modules is expected to help architecture, engineering, and construction professionals be prepared for the needs of the industry in the future (Bozoglu, 2016).

The BIM Learning Modules created for Department of CAEE at IIT targets improving BIM software skills (ability to create, understand and interpret building information models) for whole life-cycle processes, respectively collaborating and coordinating with models; and, performance modeling, optimizing the design and use in an integrated-communication environment, and stimulating students' interaction with BIM professionals. Gaining the momentum of three different BIM learning modules, this program helps students to understand the plurality in the construction professions.

4.1. Method: Experiential Learning

BIM Learning modules are planned and created to cover the abilities and deliverables expected from or realized by the students (as future design and construction professionals), organizations and projects when using BIM tools and workflows. These modules are based on the experiential learning which is defined by Felicia (2011) as the process of learning through experience, and is more specifically defined as "learning through reflection on doing". Early in the 1970s, the theory was proposed by David Kolb (1984) who was influenced by the work of other theorists including John Dewey, Kurt Lewin, and Jean Piaget.

The experiential approach adopted to BIM-enabled learning (1) allows the students to experience a BIM learning module namely collaboration module, coordination module and optimization module; and (2) helps them to learn how BIM and BEM tools and Building Performance Analysis (BPA) methods integrate with each other.

Experiences in integrating BIM in terms of learning by doing into graduate and undergraduate level courses and an undergraduate immersive research program at IIT are briefly presented and discussed aligned with early AI knowledge and practices including *hands-on lab sessions* and activities by industry support. To keep it simple and adoptable with less access and license related issues, the software programs and the suggested tools, equipment and/or technologies in the practices and examples are mostly selected from Autodesk BIM platforms which are in use at the existing curriculum. Besides, the other platforms are introduced to learners by supporting the program with invited guest speakers for interactive sessions and workshops.

4.2. Learning Module: BIM Applications for Building Performance

The learning module is an ongoing experimentation applied in "CAE 515 – BIM Applications for Building Performance" course with mostly undergraduate-senior or graduate standing- and some graduate students from different majors including civil/structural engineering, MEP engineering, architectural engineering, architecture, and construction management. This course aims to demonstrate how architectural and engineering design and analysis functions are impacted by BIM. It helps students to understand the fundamentals and practical uses of information technologies in design and analysis.

BIM is at the core of building performance optimization and sustainability, making it possible to model performance while tracking construction of the building in sequence. This module is used in the CAE 515 course which builds essential knowledge of building performance optimization using BIM processes and provides the necessary background and skills to use BIM with building energy simulation software tools. Autodesk Revit with Insight is used as the primary design authoring, manipulation, and analysis tool. Secondary Autodesk BIM tools such as Formit for building massing and orientation; Recap for existing conditions capturing; Navisworks for interference checking and design collaboration; Revit Live for Virtual Reality visualizations and presentations; and BIM 360 Ops for facility management and operation are also used in class. Proven methods for using BIM to address essential building performance and sustainability issues are presented using real-world examples, placing emphasis on using BIM for analysis of design alternatives for the life cycle of a building. Complete with coverage of sustainability, integrated design, and lean construction requirements, this is a valuable course for architects, architectural engineers, MEP engineers, facility managers and other construction professionals involved in building performance modeling and optimization.

Knowledge Set: The primary competencies practiced in BIM Applications for Building Performance Module include: (1) sustainable design and building life cycle, (2) building information modeling, (3) collaboration and coordination with building information models, (4) building physics and equations of modeling, (5) environmental strategies and baselines, (6) components of building and energy systems, (7) sustainable building forms, (8) sustainable building systems, (9) building performance optimization with design, (10) building performance optimization with systems, and (11) enabling technologies: the future of BIM for building performance optimization.

Skill Set: New software, technologies, tools and equipment can be used with Building Information Models (BIMs) for all phases of projects where data is (1) visualized, (2) simulated, (3) captured, (4) monitored and (5) managed. It is possible to adopt optimized processes to the BIM learning modules with BIM software and applications used with related technologies. The early possibilities to consider or use in the BIM curriculum are shown in the following scheme of Figure 3.

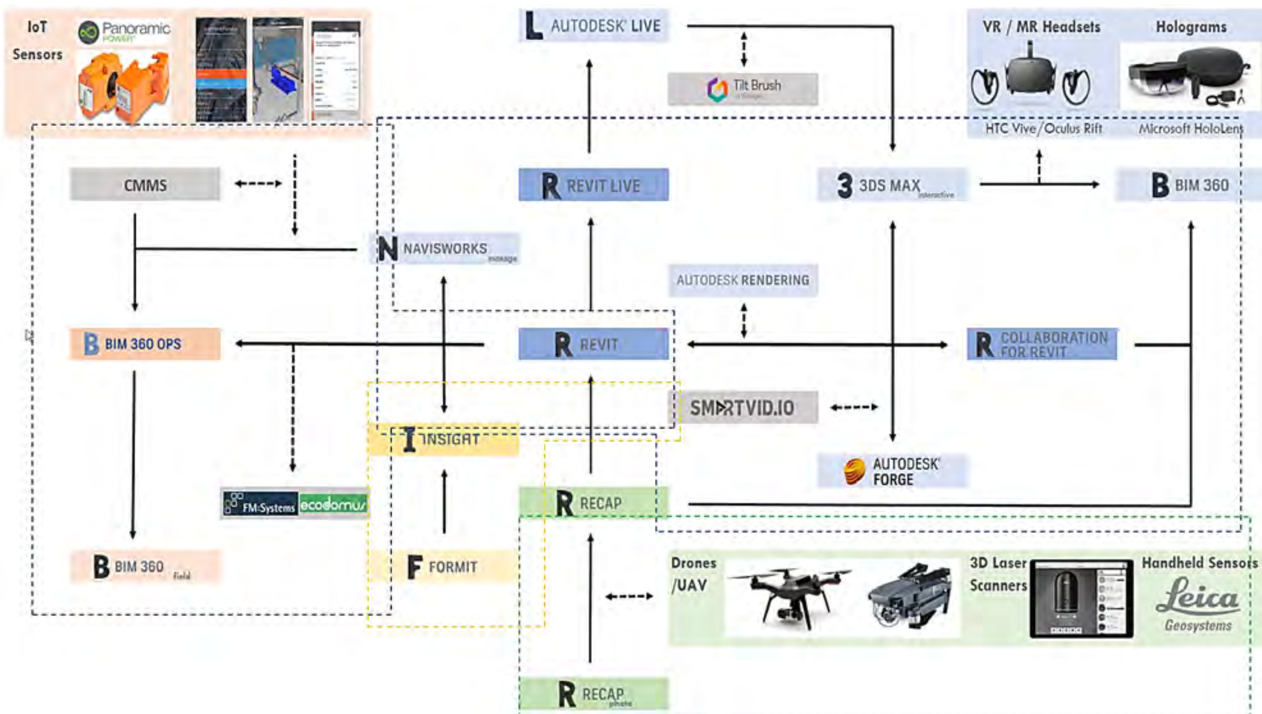

Figure 3: Optimized Processes with BIM Software and Applications

Learning Outcomes: The objective of this course is to build essential knowledge of building performance optimization using BIM processes and introduce students to building energy modeling methods and procedures commonly used in industry by providing the necessary background and skills to use. In this context, the course covers the followings:

- Lecture series founding a knowledge-set including BEM methods and tools, baselines, and building science basics
- Skill-set including practices with various software and technology as learning tools which promote learning methods for accomplishing the competencies in the knowledge-set of BEM
- Case studies for performance-based design analysis and energy simulations for design optimization by using BIMs
- A guest speaker session connecting the students with industry experts and vendors

By taking this course students will be able to:

- Gain strong analysis and teamwork skills for developing and executing a BEM and performance optimization strategy
- A broader perspective of social, environmental and economic issues
- Sustainability and building science know-how that goes along with BEM practice
- Work on building energy model projects that reflect the real-life practices in engineering consulting
- Create energy models by using an industry wide ASHRAE baselines and optimize the models targeting LEED and Architecture 2030 outcomes
- Learn to critically analyze energy conservation measures using parametric energy models
- Learn to make realistic modeling assumptions
- Learn to integrate quality control procedures in energy models and to analyze energy model results.

Course Format: The first half of each class is dedicated to lectures and the remaining time is used to create practice energy models and use BIMs to analyze building performance in hands-on lab sessions. Students apply what they learn in class to create two final energy models to be submitted for the mid-term and final exams. The final projects are presented by the students in the class with open reviews of students' energy models and supporting documentation. Students are encouraged to collaborate and to exchange ideas.

Course Assessment: The assessment is held through key measures such as (1) grades in online mid-term exam (40%), (2) performance in preparing and presenting assignments (%20); (3) performance in creating a term report (20%); and, (4) performance in creating a team project (20%) in terms of given criteria. All knowledge-set competencies are covered as subjects in the mid-term exam. Practices in primary skill-set are evaluated by the EAM submitted as the individual term report which is created by using the selected software design, analysis and documentation tools. All knowledge set competencies and skill sets are evaluated by the team project which is essentially a research study on BEM.

5. CONCLUSIONS AND FUTURE WORK

As the industry continues to digitalize, data-driven, reality-altering technologies provide paradigm-shifting in and transmogrified reality functions and, by many indications, pay for themselves rather quickly. This is the future of construction, and it is those AECO firms who are willing to embrace change and innovation that are ultimately going to win out in the end. This also means that there is a need to think creatively about training and recruiting – the skills and backgrounds that made a great construction manager yesterday will be vastly different in the future.

The AECO industry is on a precipice of change, and to truly forge ahead we need the ideas and energy of the next generation. A key challenge is attracting and retaining talent in an industry that has been historically slow to change and adapt new technology. There is a need to establish and improve BIM knowledge, skills and experience of current engineering professionals. To sustain the momentum of BIM, effective workforce development that aims to balance the supply-demand equation in the labor market is essential. For many, experience with BIM begins in academia. The challenges reside in the classic knowledge gap between academic focus on disciplinary principles and the industry needs for specific application proficiency.

An academic framework informed by BIM research, BIM professionals and other industry stakeholders is a prerequisite for delivering BIM education in Universities. The rising market demand for competent BIM professionals would eventually force companies to adjust their recruiting practices through enhanced and more proactive collaboration with BIM educators. Critical steps need to be taken via an academia-industry partnership for a continuity to improve BIM education in universities with more direct input of established BIM professionals to bridge the gaps between theory and empirical experience.

Advanced training of current workforce through competency and skill-based programs leads to mastery and performance improvement. Furthermore, a safer industry attracts more workforce. The IIT and GSU strategy relative to BIM education by using the learning modules approach is successful and expected to help architecture, engineering, and construction professionals to be prepared for the needs of the industry in the future. Efforts should continue and expand to provide exposure, skills and opportunity to students.

Some of the challenges, difficulties and future work for energy performance learning in related BIM design and practice courses will be driven by industry uses of BIM to improve energy efficiency in buildings. Case studies of related projects presented by guest speakers emphasizing on metrics stemmed from measurable benefits can provide the basis for further development of modules for classroom teaching. Application of BEM cases to building energy performance management may focus on the design, however they may enable deep learning by connecting knowledge and skill sets between BIM and performance analysis tools along with the exchange of data between these over the building lifecycle. Educators in this field are facing new challenges by assessing students in understanding the effectiveness of BIM as a performance management tool focusing on applied skills to create designs and/or operation processes which will produce a reduction in energy costs. Also, instruction about the roles of the energy professionals and facility managers has to be incorporated in the learning modules, as they are changing drastically by analyzing and handling data rather than written documentation during design and management phases of entire building performance.

REFERENCES

Autodesk (2017). www.autodesk.com

Autodesk (2017) "The Inefficiency Problem: Cracking the Code for AEC Business Success." https://pages.autodesk.com/rs/918-FOD-33/images/Q2_MoveToBim_eGuide_layout_FINAL.pdf

Bozoglu, J. (2016) "Collaboration and Coordination Learning Modules for BIM Education." *ITcon* Vol. 21, pg. 152-163, <http://www.itcon.org/2016/10>

Demirdoven, J. & Arditi, D. (2014) "Advancing BIM in the Construction Management and Engineering Curriculum." *Proceedings of 11th International Congress on Advances in Civil Engineering*, 21-25 October, Istanbul, Turkey.

Demirdoven (2015) "An Interdisciplinary Approach to Integrate BIM in the Construction Management and Engineering Curriculum." *Proceedings of 9th BIM Academic Symposium & Job Task Analysis Review*, April 7-8.

Crumpton, A., & Miller, B. (2008). "Building Information Modeling: State of the A&D Industry and BIM into design education." *Proceedings of the Interior Design Educator's Council Annual Conference*, 1175–1188.

Dodge Data & Analytics. (2015). "Study Finds BIM Offers Substantial Benefits for Construction Industry". Press Release on December 9, 2015. NY. Media Contact: Susan Peterson

Felicia, Patrick (2011). "Handbook of Research on Improving Learning and Motivation." p. 1003. ISBN 1609604962.

Kolb, D (1984). "Experiential Learning as the Science of Learning and Development." Englewood Cliffs, NJ: Prentice Hall.

Lévy, F. (2012) BIM in Small-Scale Sustainable Design. By John Wiley & Sons, Inc., Hoboken, New Jersey.

Maghiar, M. (2016). "Knowledge Transfer into A BIM Course Through Technology-Driven Solutions for Real-World Construction Projects", Academic Interoperability Coalition, *Proceedings of 10th BIM Academic Symposium & Job Task Analysis Review*, Orlando, FL, April 4-5.

McGraw-Hill. (2009). "The business value of BIM: Getting BIM to the bottom line". *SmartMarket Report* McGraw-Hill Construction.

McGraw-Hill. (2014). "The business value of BIM for Construction in major Global Markets". *SmartMarket Report*, McGraw-Hill Construction

Milgram, P. & Kishino, A. F. (1994). "Taxonomy of Mixed Reality Visual Displays." *IEICE Transactions on Information and Systems*. pp. 1321–1329. Retrieved 2013-10-17.

Nahan Communications (2018). “Building Our New Energy Future - What Buildings Professionals Need to Know about Changes Coming to the Electricity Sector”, *Technical report*. <www.ashrae.org/File%20Library/About/Leadership/new_energy_future_web_061518.pdf>

Schilling, D. R. (2014) Global Construction Expected to Increase by $4.8 Trillion by 2020. Industry Tap. March 08, 2013. Web. November 10, 2014.

Science Daily (2013). "Big Data, for better or worse: 90% of world's data generated over last two years." SINTEF. ScienceDaily, 22 May 2013. <www.sciencedaily.com/releases/2013/05/130522085217.htm>

Wong, K. & Fan, Q. (2013) "Building information modelling (BIM) for sustainable building design", *Facilities*, Vol. 31, Issue: 3/4, pp.138-157, <https://doi.org/10.1108/02632771311299412>

Wu, W. & Issa, R. (2013). “BIM Education and Recruiting: Survey-Based Comparative Analysis of Issues, Perceptions, and Collaboration Opportunities”. *Journal of Professional Issues in Engineering Education and Practice*. Vol. 140, Issue 2, Online Dec. 2013