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EMERGING CAD AND BIM TRENDS IN THE AEC EDUCATION: AN ANALYSIS FROM STUDENTS' PERSPECTIVE

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SUMMARY: As the construction industry is moving towards collaborative design and construction practices globally, training the architecture, engineering, and construction (AEC) students professionally related to CAD and BIM became a necessity rather than an option. The advancement in the industry has led to collaborative modelling environments, such as building information modelling (BIM), as an alternative to computer-aided design (CAD) drafting. Educators have shown interest in integrating BIM into the AEC curriculum, where teaching CAD and BIM simultaneously became a challenge due to the differences of two systems. One of the major challenges was to find the appropriate teaching techniques, as educators were unaware of the AEC students' learning path in CAD and BIM. In order to make sure students learn and benefit from both CAD and BIM, the learning path should be revealed from students' perspective. This paper summarizes the background and differences of CAD and BIM education, and how the transition from CAD to BIM can be achieved for collaborative working practices. The analysis was performed on freshman and junior level courses to learn the perception of students about CAD and BIM education. A dual-track survey was used to collect responses from AEC students in four consecutive years. The results showed that students prefer BIM to CAD in terms of the friendliness of the user-interface, help functions, and self-detection of mistakes. The survey also revealed that most of the students believed in the need for a BIM specialty course with Construction Management (CM), Structure, and Mechanical-Electrical-Plumbing (MEP) areas. The benefits and challenges of both CAD and BIM-based software from students' perspectives helps to improve the learning outcomes of CAD/BIM courses to better help students in their learning process, and works as a guideline for educators on how to design and teach CAD/BIM courses simultaneously by considering the learning process and perspectives of students.

1. INTRODUCTION

CAD drafting has been used for two-dimensional (2D) drawings since the 1980s, and for three-dimensional (3D) drawings for the past few years. BIM was introduced into the AEC industry a decade ago, and has continued to improve since then (Wang and Leite, 2014), as BIM can be applied to benefit the duration, cost, and environmental impacts of a project (Smith and Tardif, 2009). The main difference between CAD and BIM is that CAD works as fundamental drafting and representation tool, while BIM models buildings by considering the form, function, and behaviour of building systems and components (Sacks and Barak, 2010). In other words, transition to CAD to BIM becomes the transition from 2D drafting to 3D modelling by including the properties and information related to building elements. BIM results in benefits such as increased building value, increased total project quality, shortened project schedule, accurate scheduling time tables, reliable and accurate cost estimates with quantity take-offs, program compliance, market-ready facilities, and optimized facility management (Eastman et al, 2008).

BIM usage has significantly improved in the construction industry in the past few years (Nawari, 2012). According to McGraw Hill Construction's Smart Market Report, BIM usage has increased from 28% in 2007 to 71% in 2012 (McGrawHill, 2014). In another survey, the results showed that 70% of the respondents were either using or considering using BIM in their companies, and 75% considered students with BIM skills as having an advantage over candidates, who did not in the job market (Azhar et al, 2008). With this being said, recent studies showed that a significant constraint limiting the adaptation of BIM in the AEC industry is the lack of adequately trained BIM personnel (McGraw Hill, 2014; Sacks and Barak, 2010; Becerik-Gerber et al, 2011). In order to overcome this problem, BIM has started to be a core part of the undergraduate AEC curriculum in the recent years. BIM education is considered to lead the way in providing companies with fresh graduates, who are already BIM experts (McGrawHill, 2008). There are many researchers supporting the usage of BIM as a design and construction education tool in higher education institutions (Ibrahim and Rahimian, 2010; Sacks and Barak, 2010). The survey by Dean (2007) summarized two main reasons to teach BIM in construction. The first reason was that approximately 70% of the industry participants indicated that they were either using or considering using BIM in their companies. The second reason was approximately 75% of survey participants considered employing candidates with BIM skills to have an advantage over candidates who lack BIM knowledge. Becerik-Gerber et al (2011) revealed that 80% of the architecture programs, 60% of the construction management (CM) programs, and 44% of the engineering programs of all AEC programs in the U.S. have been incorporating BIM in their curriculum. On the other hand, of the programs without BIM courses, 57% have been planning to integrate BIM into their curriculum. Furthermore, researchers stated that BIM was one of the most challenging and recent trends for CM programs, while BIM pedagogy has not yet been consolidated (Johnson and Gunderson, 2009). The trend in BIM, as well as the shift from CAD to BIM tools created a need to provide appropriate techniques to teach CAD and BIM simultaneously to AEC students.

Construction education literature is rich in studies that investigate the shift from CAD to BIM (Berwald, 2008) and how BIM can be integrated into the AEC curriculum (Wang and Leite, 2014). However, there are not much in literature about the simultaneous teaching paradigm of CAD and BIM in the same course, as well as ways of teaching BIM specialty areas such as CM, Structure, and MEP. Additionally, instructors and/or curriculum developers design courses without having a complete insight of students' study habits or expectations, which needs to be addressed by obtaining students' standpoint on CAD and BIM. This paper aims to meet the need for an objective study to show the current perception of students in CAD and BIM-based software in terms of the benefits for the curriculum and construction industry. The uniqueness of this study lies beneath extracting the guidelines to teach students CAD and BIM simultaneously by considering their learning process and perspectives on both CAD and BIM. The paper also investigates the integration of BIM specialty areas of CM, Structure, and MEP into the AEC curriculum by a combined specialty course. The results show the benefits and challenges of both CAD and BIM-based software from students' perspectives, as well as their observations on strengths, weaknesses, and professional opportunities that may arise from learning Revit specialty (CM/Structure/MEP) modules. The additional goal is to create a guideline for institutions and educators to help them improve the learning outcomes and the detailed content of CAD and BIM courses in the AEC curriculum.

2. BACKGROUND OF CAD AND BIM EDUCATION IN AEC CURRICULUM

Many researchers are advocates of keeping up with the changing technical needs of the AEC industry and emphasize the need to implement related information technology (IT) concepts in the curriculum (e.g. Peña-mora et al, 2009). A variety of CAD and BIM courses has already been introduced into the AEC curriculum. In the U.S., many departments related to AEC such as Architectural Engineering (AE), Civil Engineering (CE), and Construction Management (CM) introduced BIM into their curricula. Some of the institutions kept the CAD courses as they were, while some decreased their content and substitute CAD information with BIM topics. Discussions were held in this regard on how to transit from traditional 2D CAD to BIM through the phased integration of BIM in the academic curriculum (Sah and Cory, 2009). For example, Berwald (2008) compared two classes of students using CAD and BIM programs. The study discussed the different experiences of each method, as well as the efficiency of both 2D CAD and BIM. Weber and Hedges (2008) investigated the CAD to BIM transition from the students' perspective in an AE degree program at the University of Wyoming. They recommended that CAD should be kept in the curriculum, and BIM should be introduced alongside CAD in the introductory graphics course. Sacks and Barak (2010) developed a mandatory freshman year course to teach both theoretical and practical aspects of BIM and to replace the traditional engineering graphics course at the Technion-Israel Institute of Technology, Haifa, Israel. They stated that BIM should be taught on its own, and not alongside CAD. Cory et al (2010) showed the use of BIM to facilitate the evolution of a construction graphics course at Purdue University. Denzer and Hedges (2008) presented educational strategies for the shift in education using BIM. Their study discussed major challenges and opportunities that BIM presents in education settings.

Although it is still a challenge to integrate new concepts of BIM (Wong et al, 2011), a number of approaches have been adopted to introduce BIM into the curriculum (Sacks and Barak, 2010). Two main approaches in integrating BIM into the curriculum are: 1) designing a stand-alone BIM course, and 2) incorporating BIM into existing courses. Even though the discussion is still on about the pros and cons of offering stand-alone BIM courses versus incorporating BIM in existing courses (Sacks and Barak, 2010), there are many examples of both approaches in the literature. For example, Taylor et al (2008) summarized their experiences teaching an introductory course in BIM in Auburn University. Hyatt (2011) reconstructed an undergraduate CM scheduling course to demonstrate the simultaneous use of lean construction, sustainability, and BIM aspects in California State University, Fresno. Kim (2012) designed a BIM-based teaching approach to teach a construction management course offered at California State University, Long Beach. Shen et al (2012) introduced an integrated, BIM-based building design and construction course to demonstrate some of the teaching and learning methods of BIM in University of Nebraska, Lincoln.

When standalone CAD/BIM courses are further investigated in various institutions in the U.S., it can be observed that the courses are different not only in terms of their content, but also in terms of the year they are introduced into the curriculum. Universities like Georgia Tech, Purdue, and University of Southern California are some examples that offer freshman year graphics courses that focus on CAD models, while universities like Michigan State and Penn State prefer to offer sophomore level CAD courses. MSOE offers a freshman CAD&BIM course, whereas Florida International University has its first BIM course in the sophomore year. Washington State University is an example having a junior level CAD course; where Oklahoma State University is another case, where a CAD&BIM combined class is offered in junior year. The detailed review of CAD/BIM courses offered in different institutions in the U.S. was created as shown in TABLE 1 and TABLE 2. The universities were selected randomly from the four geographical regions in the U.S.: Central, Northeast, Southern, and Western. The course descriptions and year of involvement in the curriculum are shown for freshman level courses in TABLE 1and for upper undergraduate level courses in TABLE 2.

TABLE 1: Review of Typical Freshman Level CAD/BIM Graphics Courses in Different Universities in the U.S.

Course Name	Institution	Department	Year	Description
AE 1312: Introduction to BIM I	Milwaukee School of Engineering	AE, CE, CM	Freshman	This first course in the graphics sequence for AE and CM students teaches the basics of CAD drafting and Building Information Modelling (BIM). The CAD programs used are AutoCAD and REVIT Building. CAD topics include basic drawing and editing of details in AutoCAD, 3D building modelling, and an introduction to the concept of utilizing REVIT Building to produce estimates.
CEE 1770: Introduction to Engineering Graphics and Visualization	Georgia Tech	AE, CE	Freshman	Introduction course to engineering graphics and visualization including freehand sketching, 2D/3D and solid CAD models. Development and interpretation of drawings and specifications for product realization are covered.
CGT 164: Graphics For Civil Engineering And Construction	Purdue University	CE	Freshman	An introductory course in the area of computer graphics documentation for civil engineering- and construction-related professions. The course emphasizes creation and distribution of graphics to enable communication.
CE 107: Introduction to Civil Engineering Graphics	University of Southern California	CE	Freshman	An introductory course on graphic communication and drawing; use of instruments, lettering, dimensioning, and detailing of engineering drawing; free-hand sketching, drafting, and modelling.
ENGR 2100: Intro to Engr/Computer Graphics	Clemson University	CE	Freshman	Introduction course to graphics applications or engineering and related professions. 2D and 3D drawings are used to visualize, communicate, rapid prototype and analyse engineering problems.
EGEN 116: ENGINEERING GRAPHICS LABORATORY	Montana State University	CE	Freshman	An introductory course on hands-on laboratory experience in two dimensional computer-aided design (CAD) for engineering design graphics.
ENGR 100: Beginning Computer Aided Drafting for Design	Drexel University	AE	Freshman	Introduction course to computer-aided graphics techniques and the use of a state-of-the-art, computer-aided design/drafting package. Students will learn 2-D and 3-D modelling techniques to support the design process. All students will be required to take a competency quiz on 4 of 6 available AutoCAD labs.

TABLE 2: Review of Typical Undergraduate CAD/BIM Graphics Courses in Different Universities in the U.S.

Course Name	Institution	Department	Year	Description
BCN 2253: Building Construction Drawing	Florida International University	CM	Sophomore	The course teaches students to prepare plans, elevations and sections appropriate to general construction using computer assisted modelling techniques.
IDES 240: Computer-Aided Design for Designers	Michigan State University	CM	Sophomore	The course is designed to help students use the software to represent 2D and 3D objects.
AE 222: Working Drawings	Penn State	AE	Sophomore	The course teaches students materials and methods of construction used in residences and commercial buildings; preparation of working drawings for small building.
CNMG 2318: Building Information Modeling	University of Arkansas at Little Rock	CM, CE	Sophomore	The course focuses on utilizing basic functions of Building Information Modelling (BIM) for residential and commercial construction. During the course, students will examine geometry, spatial relationships, geographic information, quantities and properties of building components. Students will create virtual models of buildings that can be used for quantity take offs.
AE 3311: Building Information Modeling II	Milwaukee School of Engineering	AE, CE, CM	Junior	This course prepares the student to utilize building information modelling (BIM) as a coordinated, integrated, and consistent approach to a building project in design and construction decision making. Students are provided the basics to produce high-quality 3-D designs and construction documents, along with cost-estimating, and construction planning. The students will use BIM in the Senior Project sequence. The course will utilize Autodesk Revit Building Systems.
JSTM 254: Construction Graphics	Washington State University	CE	Junior	The course teaches students visual literacy and details in construction documents using drawing techniques.
CMT 3633: CAD and BIM for Construction Managers	Oklahoma State University	CM	Junior	The course teaches students interpretation and production of construction drawings using computer aided drafting. Theory and use of Building Information Modelling software builds upon computer aided drafting skills.

Courses given in TABLE 1 are representative of how 2D modelling is still kept in the curriculum and 3D modelling is added to keep up with the changes in the industry. According to Buchal (2001), this process eliminated the descriptive geometry and instrument drawing content of the generic freshman year engineering graphics courses, and added instructions to cover for 3D modelling. Still, many universities are missing to teach 3D modelling with integrating the BIM content. Sacks and Barak (2010) argued regarding a mandatory freshman year course that teaches both theoretical and practical aspects of BIM, and that BIM can and should be taught as a course itself rather than as part of a traditional drafting course.

There are institutions that prefer to include graduate level BIM courses in addition to the undergraduate CAD/BIM courses. As an example, Penn State offers AE 597G: Building Information Modeling Execution Planning as a special topics course which is focused on an ongoing research project aimed at the development of BIM Execution Planning Guide. In a similar manner, University of Southern California has CE 570: Building Information Modeling for Collaborative Construction Management course to create multidisciplinary and virtual project teams that works together for projects selected in collaboration with industry partners.   Despite these examples, it is still common to include BIM only in the graduate level. For example, Polytechnic Institute of NYU has two graduate level BIM courses as CE 8243 Construction Modeling Techniques and CE 8303 Information Systems in Project Management. CE 8243 covers the development of 2D and 3D design documents with the development of BIMs. CE 8303 includes applying 3DBIM with four-dimensional (4D), fully integrated, and automated-project processes. Both courses require graduate standing to be enrolled in. Similarly, University of Washington offers CM 515 Advanced Project Management Concepts to reflect on emerging (BIM) technologies in the context of project management and integrated delivery, and includes visualization, 3D clash detection, fabrication automation, digital site layout, 4D modelling, as-built model generation, and digital information management. University of Oregon has its introductory BIM course available to both undergraduates and graduates to teach students how to use BIM for architectural design exploration, communication, and construction. Texas A&M University is another institution having an introductory BIM course at the graduate level to cover CAD, as well as BIM in architecture, BIM principles, methods, and applications in the design process and the building lifecycle.

Whether it is an undergraduate or a graduate course, BIM courses have faced great challenge sin their introduction to the AEC curriculum. One of the reasons for that is the need for a different teaching method to fully utilize and teach the extent of BIM in class. Project Based Learning (PBL) is one of the innovative teaching methods to teach BIM by using a student-centred approach. As software-based courses require students to control their own learning experience with the help of the instructor as a mentor, PBL works as a desired pedagogical approach. Another important property of PBL, is to include a real-world project in delivering the course content. In the undergraduate level, this may be a challenge for both CAD and BIM, as most freshmen and sophomore classes are designed to deliver theoretical content and software knowledge rather than utilizing experiential and critical-thinking activities. Additionally, the real projects in AEC may be too detailed and complex for undergraduate students. On the other hand, graduate students may greatly benefit from the PBL approach due to its self-directed and multidisciplinary nature.

Although CAD/BIM courses are thought in different times throughout the AEC curriculum, it is essential to cover the basics of the graphics content at the beginning of the degree, meanwhile integrating BIM into design courses wherever possible. This paper details an introductory CAD&BIM course as a key element of the AEC curriculum. Besides, the study analyses an upper level BIM course as a combined specialty course including CM, Structure, and MEP modules in the same course. The next section will give an overview about both courses and review the effectiveness of CAD/BIM as an integrated teaching tool in AEC education.

3. METHODOLOGY

CAD and BIM courses at MSOE were used as case studies to analyse the feedbacks of students about CAD and BIM education. Questionnaire surveys were distributed to students who are enrolled in the related courses in the Department of Civil and Architectural Engineering and Construction Management (CAECM).

3.1 Course Descriptions and Structures

The freshman level course, named "AE 1312 Introduction to BIM I", is the first graphics course for AE, CE, and CM students to teach the basics of CAD and BIM. The course is divided into two major parts: 1) how to create 2D models by using Autodesk AutoCAD; and 2) how to create BIM models by using Autodesk Revit. As the

students take this class on the first quarter of the freshman year, they are not required to have any previous experience on drafting or modelling. At the first class, the students are told about the content of the class, as well as the fundamental differences between CAD and BIM. The lecture material is instructed through a series of structured lectures and workshop hours. At the first class of each week, the related topic is introduced to the students, and the professor performs some part of the required work in class. At the second class of each week, students use workshop hours to practice the required work on their own laptops and ask the professor one-to-one questions to clarify unclear points and get help about the related topics. As the pace of each student is different in using the related software, one-to-one workshop hours enable the professor to help students better on their own timing.

The lecture program focuses on AutoCAD for the first 5 weeks of the quarter by using the AutoCAD Manual created by the MSOE faculty. The next 5 weeks cover Revit Architecture topics by using the textbook "Architectural Commercial Design Using Revit Architecture"(Stine, 2015a). The weekly schedule of topics is shown in TABLE 3.

TABLE 3: Weekly Schedule of Topics-Freshman BIM Course

Weeks	Topics
	MSOE network requirements, AutoCAD menu structure
Week 1	Coordinate systems, Entity creation, Deleting and basic editing of entities
	Saving drawings, Setting up a new drawing using limits
Week 2	Creating circles and arcs, using object snaps, Using layers
Week 3	Adding dimensions, Dimension options AutoCAD, Adding text, Crosshatching
Week 4	Moving and copying entities, Creating Blocks
Week 5	Block Attributes, Prototype Drawings, Title Block Creation and Use, Use of Viewports
Week 6	Getting Started with REVIT
Week 7	Wall types, Doors, Windows
Week 8	Wall types, Doors, Windows, Elevators
Week 9	Floors, Floor to Floor Height, Common Walls
Week 10	Roof Types, Skylights
Week 11	Final Exam

The expected learning outcomes of the class include but not limited to being able to: 1) practice drawing/modelling with software, 2) become familiar with the user-interface of AutoCAD and Revit, 3) create building plans and architectural systems, 4) detect and correct individual mistakes when creating plans, and 5) develop a basic knowledge on both software programs to be capable of using them in the forthcoming courses and in professional life. The assignments and exams test students' knowledge, as well as timing and organizational skills to determine whether or not they complete the course requirements successfully. Considering the fast speed of the quarter system, the students are expected to balance their time while learning both AutoCAD and Revit software tools. They are challenged to improve their technical skills and study habits by the simultaneous introduction of the two slightly different software tools.

The junior level course, named "AE 3311 Building Information Modeling II", is the second stand-alone graphics course in the AEC track for AE, CE, and CM students. This course is divided into three major parts: 1) how to create BIM models by using Autodesk Revit Architecture module; 2) how to add Revit specialty (CM/Structure/MEP) module content to the architectural model; and 3) how to practice the building design by a collaborative term project. The freshman course is introduced in the fall quarter of the first year, while the junior course is introduced in the spring quarter of the third year in the MSOE undergraduate curriculum. There is approximately 3-year time lag between these two courses, which enable students to take basic building design, materials, and technical-specialty courses. By this way, students gain basic technical knowledge and complete

one or more summer internships to obtain practical knowledge before they start using Revit specialty modules. Consequently, the course is thought more like a guided study instead of using regular lectures. This course teaches BIM as a coordinated, integrated, and consistent approach to a building project in design and construction decision making. Students are provided the basics to produce high-quality 3D designs and construction documents. BIM is integrated into other courses in the MSOE curriculum, specifically; the students use BIM in the Senior Design Project sequence in their last year. The course utilizes Revit Building Systems to prepare students collaborating in Senior Design courses.

The course focuses solely on Revit by using the textbook "Design Integration Using Autodesk Revit" (Stine, 2015b). The first 4 weeks of the schedule covers Revit Architecture content. This part serves as a reminder of the freshman BIM course and enables students to create the Master Revit file to be used for practicing Revit specialty chapters. The next 3 weeks students focus on different specialty chapters from the same textbook. As an example, CM students work on their area of expertise, which includes creating elevations, sections and details, and schedules. They are not required to cover any chapters related to Structural or MEP specialties. Other specialties work on their own areas of expertise in a similar fashion. The weekly schedule of topics is shown in TABLE 4.

TABLE 4: Weekly Schedule of Topics-Junior BIM Course

Weeks	Topics
Week 1	Getting started, Create Small Office
Week 2-3	Create Law Office Building Floor Plans, Exterior and Interior Walls, Install Doors, Windows, Stairs, etc.
Week 4	Create Law Office Building Roof, Floors and Ceilings
	Use Law Office building as Master File to start specialty chapters
	CM Students: Create Elevations, Sections and Details, and Schedules
Week 5-7	Structural Students: Create Structural Plans with Beams, Columns, Structural Framing, and Structural Foundation
	Mechanical Students: Create MEP Plans with Duct Systems and Plumbing
	Electrical Students: Create Electrical Plans with Lighting Fixtures, Switch Systems, and Circuits
Week 8-10	Work on the Final Project

Unlike to the freshman BIM course, there is no final exam in the junior level. Instead, students work on a collaborative final project in teams. Teams are created based on specialties. The ideal team includes four members, i.e. one CM, one Structural, one Mechanical, and one Electrical student. The students are assigned to create the Revit model of a 5-storey commercial building. The information provided to students is shown in TABLE 5.

The expected learning outcomes of the class include but not limited to being able to: 1) apply the advanced features of Revit including Architecture, CM, Structure, and MEP functions, 2) create specialty building plans and systems, 3) collaborate in Revit, and 4) use Revit specialty modules in the forthcoming courses and in professional life. The assignments and final project test students' knowledge, as well as their team-working skills to determine whether or not they complete the course requirements successfully.

TABLE 5 Provided Documents for the Term Project of BIM Junior Course

Category	Document	Type of File
Architectural	Details of Exterior and Interior Walls, Doors and Windows	MS Word
	Floor Plans	PDF
	Ceiling Plans	
	3D View	
	Elevation Views	
	Schedules for Floors and Roofs	MS Excel
CM	Floor Plans with Room Tags	PDF
	Schedules for Doors, Windows, Rooms, and Walls	MS Excel
Structural	Structural Floor Plans	PDF
	Structural 3D	
	Structural Elevation Views	
	Schedules for Structural Columns and Framing	MS Excel
Mechanical	HVAC Floor Plans	PDF
	HVAC Ceiling Plans	
	Domestic Water Plan	
	Details of Duct and Plumbing Systems	MS Word
Electrical	Power Floor Plans	PDF
	Lighting Ceiling Plans	
	Schedule for Electrical Circuits	MS Excel

3.2 The Freshman Level CAD/BIM Survey and Evaluation of Results

It is important to get feedback from students to analyse the effectiveness of CAD/BIM education. For this purpose, a dual-track survey is prepared for AEC freshman and junior students in the CAECM Department. Throughout the year, freshman course is offered once in fall quarter as regular sections and once in winter quarter as a mock/irregular section. The mock section is for students who fail the course in fall quarter and for transfer students who have irregular schedules. As this course is a prerequisite of both the junior BIM course and another architectural engineering graphics course, mock section is offered to keep students on track. Typically, three sections are offered in fall and one section is offered in winter. The capacity of each section sizes varies between 20-25 students. The first-track survey was given to the freshman students in both fall and winter quarter sections for four consecutive years, and more than 200 students were surveyed at the freshman level. The freshman survey questionnaire consisted of four major sections: (1) background of students, (2) link between construction experience and CAD/BIM tools, (3) comparison of AutoCAD and Revit, and (4) open-ended feedback on AutoCAD and Revit (Appendix A).

The first part of the survey included questions regarding the background of the students. As all AE, CE, and CM students are required to take this class, the students were asked about their degrees. The degree distribution of students is shown in Fig.1. As given in this figure, nearly half (45%) of the students were in the AE degree program, while 11% were CM, 13% were AE/CM, and 31% were CE. The students were also asked about their previous experience in the construction industry in this section. Only around 20% of the students had previous experience (such as internship, part-time, or full time jobs), while most of the class (around 80 %) did not have any experience.
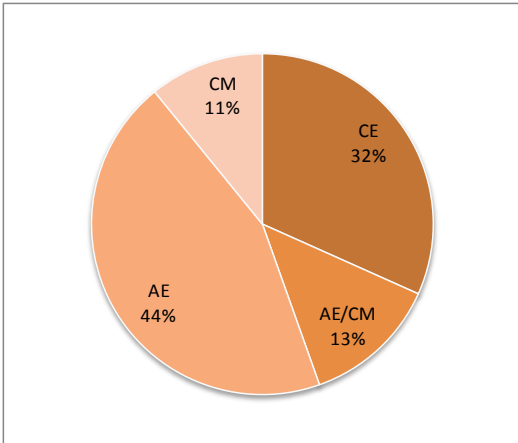
FIG.1: Degree Distribution of Students

In the second part, data regarding the link between construction experience and the drawing tools, and the benefits of CAD (AutoCAD) and BIM (Revit) for students' future career were collected. For the question of: "I think previous construction experience is needed to better use _____ to design a structure", most of the students (39%) voted for "Neither Revit nor AutoCAD" as given in Fig. 2.This shows that the majority of the students do not see previous experience as a requirement to cover the basics of AutoCAD and Revit. The remaining of the students was divided equally for being in favour of either AutoCAD or Revit in terms of the need of previous construction experience.
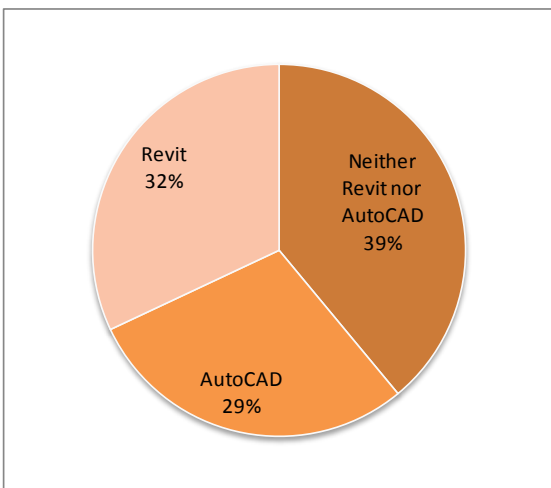

FIG.2: Results for "I think previous construction experience is needed to better use _____ to design a structure"

The following part of the survey included questions to compare AutoCAD and Revit from various perspectives such as ease of use, ease of learning, and benefits for the curriculum and construction industry. The students were given questions like "I think there is an increasing demand for graduates with _____ knowledge in construction industry" and "I believe learning _____ is beneficial for my future career" to choose between or select both AutoCAD and Revit. Around 76% of the students thought that there was a need for graduates with both AutoCAD and Revit knowledge, while around 82% of them believed that both AutoCAD and Revit would be beneficial for their future career. Only small amount of students chose between AutoCAD and Revit, showing that the students were aware of the increasing trend in BIM tools such as Revit and besides, they knew that CAD tools were still in the industry and would stay there for a while.

In terms of the ease of use comparison questions, 82% found it easier to create an architectural model with Revit compared to AutoCAD. In a similar fashion, 68% found it time consuming to generate the architectural model in AutoCAD compared to Revit. The results were dominant on the side of Revit in terms of the friendliness of the user-interface and help functions. Additionally, 68% of the students found it easier to self-detect mistakes in

Revit, while 31% voted or AutoCAD, as shown in Fig. 3. Students were also asked about the easiness of self-teaching (i.e. without training or workshop instructions) Revit compared to AutoCAD. Only 45% of students agreed Revit was easier to self-teach, while 55% disagreed. Although students were in favour of easiness, user-friendliness, and timely creation of models, they still thought they needed this course to learn Revit for the first time.
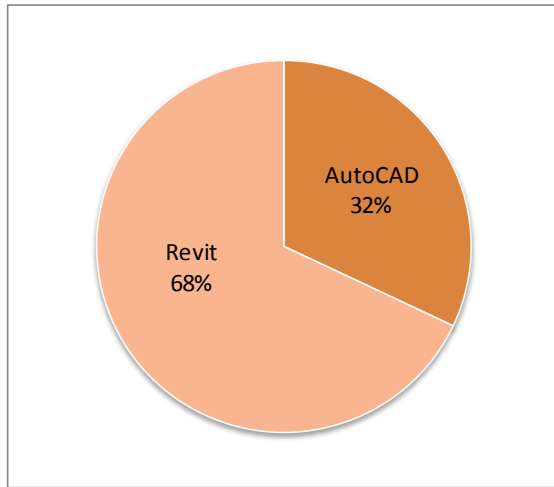

FIG.3: Results for "It is easier to self-detect mistakes in _____."

The dominance of Revit was apparent in the following questions, which asked about easiness of understanding the structures and architectural systems. 97% of students agreed that they could create a Revit model including floor plans, elevations, and 3D view by themselves, after taking this class. More importantly, 100% of students agreed that they could study on their own to improve their Revit skills, as they got the basics in this class. This result was one of the expected outcomes of this class, and it was fulfilled successfully with 100%. Similarly, 100% of the students thought that there is a need to integrate Revit into the related design courses in the curriculum. The result clearly shows students' expectations of both having a stand-alone CAD/BIM course and integration of BIM into other relevant courses in the curriculum.

For the final part, students submitted written feedback on what they liked most in AutoCAD and Revit. Regarding Revit, 45% of the students wrote positive comments about the ease of creating the 3D view and updating the design. More than 30% liked ease of use, and around 10% just put "everything" showing that Revit is their preferred software. On the AutoCAD side, around half of the students mostly liked the easiness of typing commands and using command bar. Some students also mentioned the benefits of level of detailing in AutoCAD (20%). There were also 23% of students, who put "nothing" and supporting the use of Revit instead of AutoCAD.

3.3 The Junior Level BIM Architecture and Specialty Survey and Evaluation of Results

The junior level course is offered only once in the spring quarter with three sections that typically have around 20-25 students. The students were surveyed for four consecutive years and more than 200 students were surveyed at the junior level to collect data for this study. The junior survey questionnaire consisted of four major sections: (1) background of students, (2) construction experience, (3) link between construction industry, Revit Architecture, and Revit specialties (CM/Structure/MEP), and (4) content of the course (Appendix B).

The first part asks questions about the background of the students such as their specialties. The specialty distribution of students is shown in Fig. 4. As it can be observed from the figure, the majority of students have structural and mechanical specialties. In the second part, the students were asked about their previous experience in construction industry (such as internship, part-time, or full time jobs) and their specific experience related to BIM/Revit. According to the results, most of the students had 0-1 year of experience (72%) (Fig. 5) and 69% had BIM/Revit related experience. The results show that most of the students used BIM to some degree before in their internships or jobs. This outcome is also consistent with the idea that BIM usage is rising in the AEC industry. The students were also asked to relate their previous experience with the ease of use and/or understand Revit Architecture and Revit specialties. The results showed that most of the students (72%) thought that

previous construction experience was not needed to better use or understand Revit Architecture. In a similar manner, most of them (62%) found previous construction experience irrelevant to effectively using and understanding functions in Revit specialties.
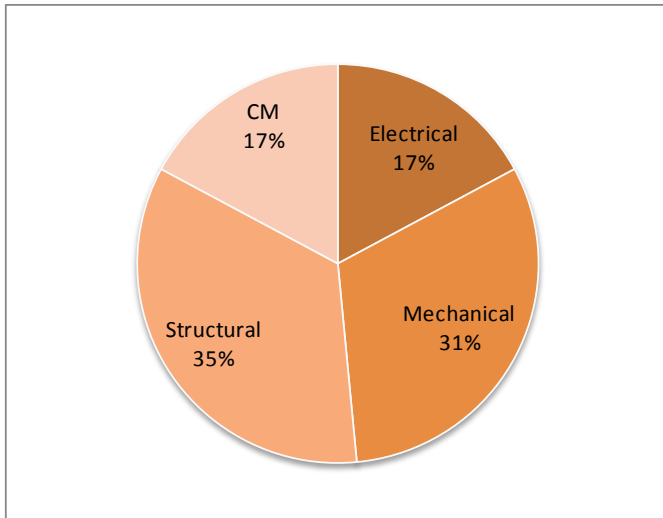

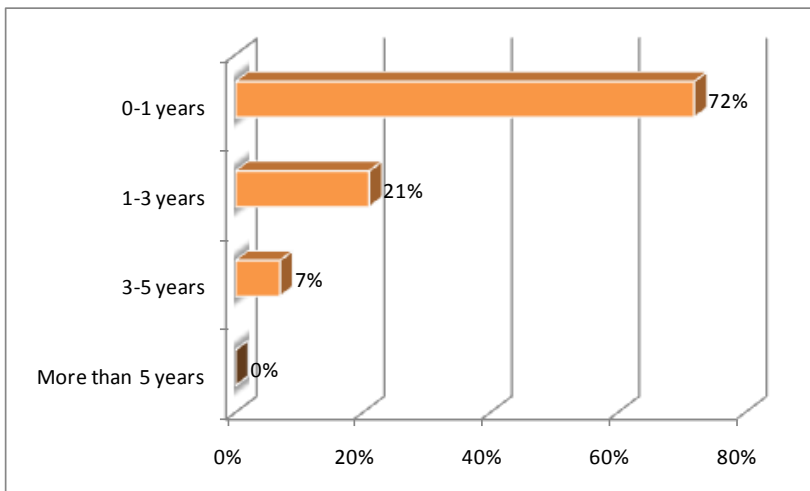*FIG.4: Specialty Distribution of Students*

FIG.5: Results for Previous Construction Experience

The next part gathered students' perceptions about the link between the construction industry and BIM/Revit. The questions in this area aimed to evaluate whether the students were aware of the industry's IT needs and opportunities for their future careers. For example, the students were asked if they agreed that the demand for Revit Architecture and specialty were increasing in the industry. 83% of students agreed that the demand was getting higher for Revit Architecture, while 79% said the demand was increasing for Revit specialty knowledge in the industry. The results stated that there were still around 20% of students, who believed Revit was not in rise in the construction industry. The counter opinions might be caused from students' experiences where they would have used AutoCAD instead of Revit. The students were also asked if they believed Revit Architecture and specialty were beneficial for their future career. The results in Fig. 6 show that 79% of students believed in the benefit of Revit Architecture, while even more, 86% voted for the benefit of Revit specialty in their future carriers. The results showed that the students were aware of the importance of architectural module, as well as specialty systems for their professional endeavours.
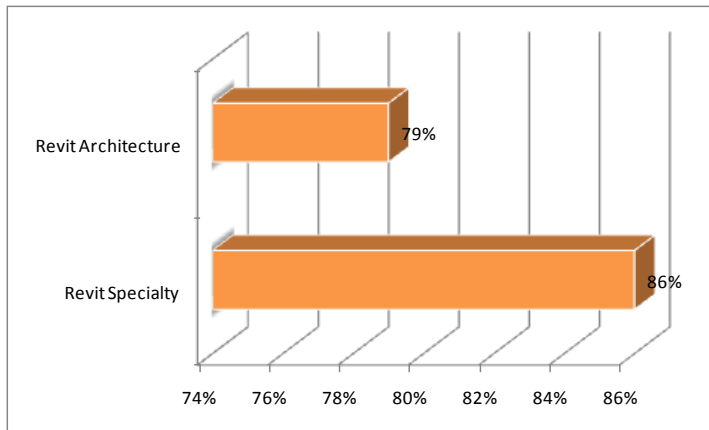
FIG.6: Responses for Students' Beliefs on the Benefits of Learning Revit for the Industry

The final part included questions regarding the content of Revit Architecture and specialty given in this course. For the question of: "I believe Revit Architectural/Specialty content given in this class is enough for an entry level position in construction", most of the students agreed for both Revit Architecture (76%) and Revit specialty (66%) as given in Fig. 7. Students were asked if they gained a better understanding in architectural and specialty systems after taking this class. Most of the students believed that they gained better understanding in architectural systems (55%) and specialty systems (69%). As one of the learning outcomes of this course was teaching BIM as a process model of building systems, the results showed that students were successful in gaining the knowledge of building systems and their relationships in the BIM concept. As a last item, students were asked about their preference between AutoCAD and Revit when they were given specialty systems. A vast majority of 90% found Revit specialty modules easier to operate that AutoCAD. The perception of students on BIM specialty revealed their interest in learning Revit specialty modules in the undergraduate AEC education.
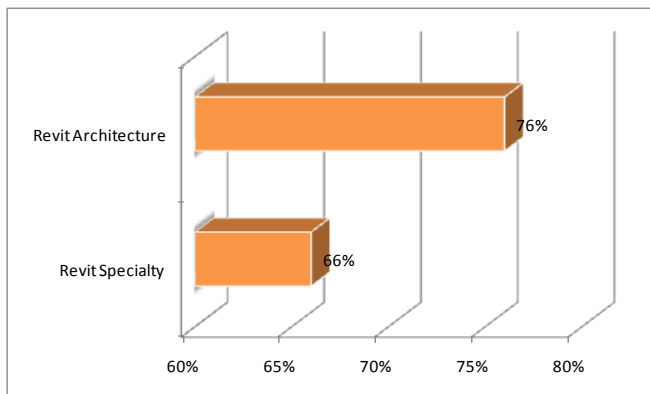

FIG.7: Results for the Link between Revit Architectural/Specialty Content Given in This Class and Entry Level Position

3.4 Analysis of Test Results

An additional analysis has been performed to see if the preferences of students correlate with their grades. In the freshman course, more than 80% of the students found Revit more user-friendly and easy to self-teach compared to AutoCAD. Therefore, the expectation was that more than 80% of the student body would exhibit a better average in Revit quizzes than in AutoCAD quizzes. The results surprisingly showed that only 57% of students scored higher in Revit quizzes compared to AutoCAD quizzes. One particular reason for that can be the students, who dropped the course after mid-quarter, and consequently missed Revit quizzes. As mentioned before, Revit was thought at the second-half of the quarter. Another reason can be the shift from AutoCAD to Revit, which does not give students enough time to adapt to the difference in drafting and modelling techniques. This result emphasizes the need and importance to provide appropriate techniques to teach CAD and BIM simultaneously to AEC students.

When the test performances of male and female students are analysed, there were no significant differences between two groups. 22% of the sample was composed of female students, 63% of which scored A, while 64% of male students received an A from the class. However, the success rate of the Revit quiz averages showed that males outperformed their female counterparts with 88% of male students versus 75% of female students showing 80% or better scores in Revit quizzes. This unexpected result opens room for future studies related to gender-based learning habits.

3.5 Analysis of Challenges and Opportunities for Development of CAD/BIM Courses

In terms of the evaluation from the professor's point of view, the main challenge of the freshman level CAD/BIM course was the time limit of the quarter system. The students had to cope with two dissimilar styles of software within 10 weeks of duration. At the time they got used to entering AutoCAD commands and using AutoCAD interface, they switched to Revit to create building models and elements in a different style. While in AutoCAD, only drawing elements were created, in Revit, building components were created as models including their properties. The students needed some time to digest the differences between AutoCAD and Revit. However, having weekly assignments forced them to pass this phase quickly. Although, the students were struggled with some problems in practicing the software, they appreciated workshop hours for the opportunity of getting hands on experience. Additionally, the students mentioned their appreciation of having one-to-one time to ask questions to the professor, in addition to regular lecture hours. Another issue was mentioned as technical problems that could occurred regarding AutoCAD and/or Revit. While the students were trying to adopt their first quarter courses, they had to figure out how to use software with network licenses. Even though the IT department was successful in solving network or other technical issues of students, the feedback showed that students were challenged by figuring out how to use software at the first days of their undergraduate education.

The survey results showed that they knew the importance and potential of BIM/Revit for future employment opportunities, and they were willing to improve their Revit knowledge in further courses as well as in the construction industry. Having a chance to see both CAD and BIM-based software in their freshman year gave them opportunity to compare both tools and have technical graphics knowledge at the beginning of their undergraduate education. This opportunity enabled them to receive potentially better internship offers at the end of their first year.

In the junior level BIM course, it was observed that the students were willing to work on specialty chapters as soon as they could. They were told that they needed the Revit Architecture file as a master file, so that they could work as a team of different specialties on the same project. One challenge they had was organizing their team for the final project. As they had to submit only one Revit file per team, including all architecture and specialty content, they had to look for collaboration tools within Revit. As the mentioned results pointed out, junior level students were aware of the importance of a Revit specialty course for their professional life and showed eager to learn details of specialty systems. One barrier of this class might be the limitation of specialty chapters given in the textbook. As the textbook includes both architectural and specialty content, it only had, one or two chapters dedicated to each specialty. With one or two chapters, the students could only get basics of each specialty. Therefore, when their Revit architecture knowledge became close to excellent, their specialty knowledge was only as good as the content given in the textbook.

Based on professor's one-to-one discussions with students from different specialties, the following points were gathered:

- CM students stated that they would like to learn creating site topography, renderings, and camera views for a successful virtual presentation of the project. As CM students work as project managers in the senior design project course, they are the team member to combine all specialty information and give a virtual tour of the project in the presentation that is given to the Owner in the senior year. In order to give students the opportunity to learn these topics, the related chapter from the textbook was given as an extra credit assignment. Besides, interior design content was assigned to teach students how to create interior objects. These topics could only be given as optional extra credit items due to time constraints of the quarter.
- Structural and Electrical students did not state specific items that they would like to be added to the content. One reason for that might be the extensive content of structural and electrical chapters in the textbook. As these chapters included all basic elements, the students did not request additional topics to be covered in this class.

- Mechanical students mostly covered duct systems in this course. Only a limited amount of piping system content was available in the textbook. Still, the students were experiencing problems in pipe connections, which might be the reason why AutoCAD is still popular in the plumbing side of the industry. In addition to the limited information given in plumbing, the textbook did not have any topics regarding fire protection systems. This item was also stated as a need from Mechanical students.

It should be noted that as seen among the topics of both the freshman and junior-level courses, the content was extremely focused on the software rather than the theoretical background of CAD and BIM. It is especially important in BIM-based courses to make sure students know the capabilities and uses of BIM, so they can be introduced efficiently to Revit. At MSOE, junior level Revit course was running simultaneously with other courses where BIM was integrated. For example, one topic of the junior-level estimating class included the details of estimating with Revit. By this way, students did not need a theoretical introduction to BIM. However, in institutions where BIM is not yet integrated among other courses, it is a crucial need to teach the theoretical background of BIM before having students practice Revit.

4. GUIDELINES FOR CAD/BIM EDUCATORS

- Although students can learn CAD and BIM-based software in the same course setting, it is better to separate them into two courses not to confuse students in their learning patterns, and to avoid making the content more intense than students can handle.
- After an introductory level BIM course, students are confident on their capabilities to create building models. However, they still do not believe they can learn the software by themselves with the reference materials given. Therefore, a BIM course is needed in the AEC curriculum.
- Considering the interest of students and future employers in BIM, an undergraduate BIM course would benefit graduates the most.
- The timing of the BIM courses is extremely important in the curriculum. They should be introduced (at least at the basic Architectural level) before students start their internships, so that they can get internships easily and practice what they have learned in class in a real setting. A second BIM specialty course can be introduced around junior/senior year to illustrate the collaborative use of BIM. Topics from professor's one-to-one discussions with students, as given above, can be used as additional specialty topics.
- It is advantageous to have Revit Architecture and Revit specialties (CM/Structure/MEP) as separate courses. This would increase the detail level of Architecture and CM/Structure/MEP related content given in each class. For example, Mechanical students can be offered a Mechanical Specialty BIM course, which includes details of plumbing, fire protection, and similar mechanical systems. By this way, students can learn to practice all mechanical content based on a mechanical system oriented textbook. Additionally, when CM, Structure, and MEP topics are distributed among different BIM courses, guest lecturers from the industry can be invited to share the problems they would have with BIM models and how these problems would be solved. Students would also develop more in-depth understanding for building systems when MEP topics are analyzed separately.
- The separate courses would have some challenges as expected. The availability of BIM specialty professors might be an issue. Even if the institution has had qualified professors for BIM specialty, offering multiple sections of the same course (for CM, structural, mechanical, electrical, and plumbing students) at different times might create scheduling problems with professors' and/or students' other courses. Apart from availability and scheduling issues, separate BIM specialty courses would serve better to different student needs, as it was revealed from the discussions with the CAECM students.
- Students should be aware of the need and usage of BIM in construction industry to show interest in class. So, educators should make sure to remind students the importance and applications of BIM/Revit in the AEC industry.

5. CONCLUSIONS

This paper approached graphics education in the AEC curriculum by analysing the student perspectives on both CAD and BIM software courses in terms of the benefits for the curriculum and construction industry. Two example CAD/BIM courses at freshman and junior level from MSOE's undergraduate curriculum were used to collect data from students through structured questionnaire surveys. While CAD and BIM software were assessed comparatively at the freshman level, ways of teaching BIM specialty areas such as CM, Structure, and MEP were analysed at the junior level.

Both surveys revealed that most of the students did not think past industry experience was required to fulfil the requirements of CAD and BIM courses. In terms of the freshman survey, most of the students were aware of the importance of both AutoCAD and Revit in their future processional career and kept track of the need in the industry for graduates with both AutoCAD and Revit knowledge. Comparing AutoCAD and Revit functions specifically, the majority found Revit easier to use than AutoCAD, and AutoCAD more time consuming compared to Revit. The ease-of-use of Revit mostly caused by the friendliness of the user-interface, help functions, and self-detection of mistakes. In overall, all students agreed that they could study on their own to improve their Revit skills, as they got the basics in this class. This was one of the expected outcomes of this class, and it was fulfilled successfully. When the grades are analyzed with an expectation of pertaining higher scores in Revit quizzes compared to AutoCAD quizzes, the results did not confirm the expectation and students' preference in Revit was not reflected in their grades on average.

Similar to freshman students, junior students thought that there is an improving link between the construction industry and BIM/Revit. They were aware of the increasing demand for Revit Architecture and specialty in the construction industry. Consequently, the students agreed on the benefits of learning both Revit Architecture and specialty for their future carriers. These results supported the importance of teaching architectural and specialty systems as a part of the AEC undergraduate curriculum. The junior level survey also revealed that most of the students believed in the need for a Revit specialty course and the junior BIM course were successful to give the basics of the CM, Structure, and MEP systems in Revit. That would help students to succeed in the forthcoming senior design course, as well as future job opportunities. Still, the students showed eager to have stand-alone BIM specialty courses, which might guide professors and curriculum developers for future development of the AEC curriculum.

The results demonstrated the benefits and challenges of both CAD and BIM-based software from students' perspectives, as well as their observations on strengths, weaknesses, and professional opportunities that may arise from learning Revit specialty (CM/Structure/MEP) modules. The current perception of students in CAD and BIM-based software were illustrated in terms of the benefits for the curriculum and construction industry. Two ways to integrate BIM specialty areas of CM, Structure, and MEP into the current AEC curriculum was mentioned as: (1) having a combined specialty course to give basics of Revit specialty modules or (2) having stand-alone courses for each different specialty to give details of Revit specialty modules. The output of this research can be used as a guideline for institutions and educators to decide on the timing, level of integration, and detailed content of CAD and BIM courses (including BIM specialty areas) into the AEC curriculum. The most important outcome from the entire process is that a need to embrace both CAD and BIM in the AEC curriculum by following the results and guidelines presented in this study in the development of CAD/BIM courses. As the literature review in this study were only limited to the higher-education institutions in the U.S., additional studies can be performed in the future to compare various CAD/BIM courses worldwide.

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7. APPENDICES

7.1 Appendix A: Freshman BIM Survey

1) My degree is _____.

  CM   AE   AE/CM

2) I have previous experience in construction industry (such as internship, part-time, or full time jobs).

  Agree   Disagree

3) I think previous construction experience is needed to better use _____ to design a structure.

  Revit   AutoCAD   Neither Revit nor AutoCAD

4) I think there is an increasing demand for graduates with _____ knowledge in construction industry.

  BIM (Revit)   AutoCAD   Both BIM (Revit) and AutoCAD

5) I believe learning _____ is beneficial for my future career.

  BIM (Revit)   AutoCAD   Both BIM (Revit) and AutoCAD

6) It is easier to create an architectural model with BIM (Revit) compared to AutoCAD.

  Agree   Neither agree nor disagree   Disagree

7) It is time consuming to generate the architectural model in AutoCAD compared to BIM (Revit).

  Agree   Neither agree nor disagree   Disagree

8) It is easier to self-teach BIM (Revit) compared to AutoCAD, i.e. without training or workshop instructions.

  Agree   Neither agree nor disagree   Disagree

9) It is easier to self-detect mistakes in _____.

  Revit   AutoCAD

10) The user-interface and help functions were friendlier in _____.

  Revit   AutoCAD

11) 3D architectural model in BIM (Revit) enables an easier understanding of the structure compared to AutoCAD.

  Agree   Neither agree nor disagree   Disagree

12) After using Revit, I gained better understanding in architectural systems (walls, floor, roof, etc.).

  Agree   Neither agree nor disagree   Disagree

13) After taking this class, I can create a BIM (Revit) model including floor plans, elevations, and 3D view.

  Agree   Neither agree nor disagree   Disagree

14) As I learned the basics of BIM (Revit) in this class, I can study on my own to improve my knowledge in BIM (Revit).

  Agree   Neither agree nor disagree   Disagree

15) I think there is a need to integrate BIM (Revit) into the related design courses in the curriculum.

  Agree   Neither agree nor disagree   Disagree

16) I liked _____ most in Revit.

17) I liked _____ most in AutoCAD.

7.2 Appendix II: Junior BIM Survey

1) My specialty is _____.

  CM   Structural   Mechanical

2) I have previous experience in construction industry (such as internship, part-time, or full time jobs) for:

  0-1 years   1-3 years   3-5 years

3) My previous experience is related to BIM/Revit.

  Agree   Disagree

4) I think previous construction experience is needed to better use/understand Revit Architecture.

  Agree   Disagree

5) I think previous construction experience is needed to better use/understand Revit Structural/MEP.

  Agree   Disagree

6) I think there is an increasing demand for graduates with Revit Architecture knowledge in construction industry.

  Agree   Disagree

7) I think there is an increasing demand for graduates with Revit Specialty (Structural & MEP) knowledge in construction industry.

  Agree   Disagree

8) I believe learning Revit Architecture is beneficial for my future career.

  Agree   Disagree

9) I believe learning Revit Specialty (Structural & MEP) is beneficial for my future career.

  Agree Disagree

10) I believe Revit Architectural content given in this class is enough for an entry level position in construction.

  Agree   Disagree

11) I believe Revit Specialty (Structural & MEP) content given in this class is enough for an entry level position in construction.

  Agree Disagree

12) After this class, I gained better understanding in architectural systems (walls, floor, roof, etc.).

  Agree   Disagree

13) After this class, I gained better understanding in Specialty (Structural & MEP) systems.

  Agree   Disagree

14) I find creating models in Revit Specialty (Structural & MEP) challenging compared to AutoCAD.

  Agree   Disagree

15) I think the term project is representative of the Revit content covered in this class.

  Agree   Disagree

16) I would prefer a more challenging project (such as pdfs retrieved from CAD file of a real project) even if it exceeds the content covered in this class.

  Agree   Disagree