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An Assessment of the Graphic Communications Skills Needed by Construction Management Graduates

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Introduction

Significant change in the area of graphic communication has taken place over the last couple of decades. More user-friendly graphical user interfaces have been developed for two-dimensional computer-aided design/drafting (CAD) graphics packages, and significant growth has happened with three-dimensional building information modeling (BIM). Such change requires that the undergraduate construction management curriculum at institutions of higher education (both 2- and 4-year colleges) keep pace with this in order to continue to meet the needs of the construction industry. The paper outlines the current state of practice in the industry regarding graphic communication and presents the results of a survey of 22 contractors. The results are compared with previous work in this area.[1,2] The results and analysis reveal that the needs of the industry are still fluid dues to changes in graphic software capabilities, and that continued updating of the curriculum is necessary to reflect this.

The Importance of Graphic Communication in Construction

On all construction projects the contract comprises of both written and graphic information for both the engineering/architectural, procurement, and construction phases, among others.[3] Project documentation during construction comprises of the form of contract which is the legal agreement between the two parties and may include both general and special conditions. It also comprises of the drawings which convey extent of work in terms of location, size, lines and grades, and interaction between parts of work. There are also the specifications which define quality of work, types of material, workmanship, testing procedures; and the schedule of Values or bills of material which itemize the work breakdown, may provide basis for measurement and payment. While all of this information is important in communicating the owner's needs to the contractor, the accuracy, specificity and clarity of the drawings and other graphical data is paramount in articulating the owner's needs. Also, the ability of the contractor to be able to modify such graphical information to reflect change orders, as-built conditions and other changes that occur as the project progresses is necessary to provide accurate information to the end user and for any future work to be done on the project.

Care must be taken, however, in respecting the intellectual property rights and copyrights of the original author of the date, including the drawings. Many contracts contain language protecting the engineer/architect by specifically indicating the limits of the use of such data. This, though, does not generally restrict the contractor from using the data on the specific project and certainly does not remove the requirement to accurately read and interpret the drawings.

Recent Changes in Graphic Communication

Over the past two decades a greater use has been made of electronic communication at the job site. While computer-aided design/drafting (CAD) has been used since the 1970s, it was not used to communicate with a contractor. Most construction projects until recently relied on transmitting graphical information to the site in hard (paper) copies. Today it is much more common for data to be distributed electronically from the bidding phase onwards, and it appears that this trend is growing. Both the ConsensusDocs and AIA Forms of Agreement now include protocols for electronic data distribution and its control over the life of the project.[4,5]

Much of the growth in electronic graphical communication has been the result of the switch from 2-dimensional (CAD) software to 3-dimensional (BIM) software. BIM has been defined as the process of creating and using digital models for design, construction and operations of projects.[6] This definition does not restrict BIM to just geo-spatial images representing the geometry of the project as would normally be associated with Computer Aided Drafting (CAD) packages. While Autodesk's AutoCAD software has dominated the 2D market, it is still unclear what the future holds. The two major software companies are Autodesk and Bentley,[7,8] both having a significant share of the construction industry. Currently it appears that approximately 80% of the building sector uses the AutoDesk products while 80% of the infrastructure sector prefers the Bentley products. The main difference appears to be that designers prefer the terrain mapping capabilities of Bentley whereas they prefer the verticality of AutoDesk. There still some lack of interoperability between these and other software provisions, though both of the companies have made some progress in this area. It is still necessary for companies in the Architectural/ Engineering/Construction community to use a variety of software to produce graphical information and link this together using a program such as Navisworks.[7]

The current state of best practice in BIM utilization to integrate all project information still relies on an array of software packages which are improving in terms of their ability to transfer information without loss of data.[2,9]. This range of packages is illustrated in Figure 1 below. This includes design software 3D BIM modeling software, scheduling software to produce 4D models, and digital document control software to track changes in information during the construction phase.

The CAD industry, including construction is expected to continue to grow at a rate of approximately 2 percent per annum, and is expected to result in revenues of over $8.2 billion by 2016.[10] The existing market itself is experiencing a rapid evolution due to cloud, social and mobile technology, and this is likely to continue. In order for construction companies to remain competitive in this area it is necessary for higher education institutions to provide a balance and up-to-date curriculum in graphic communications.

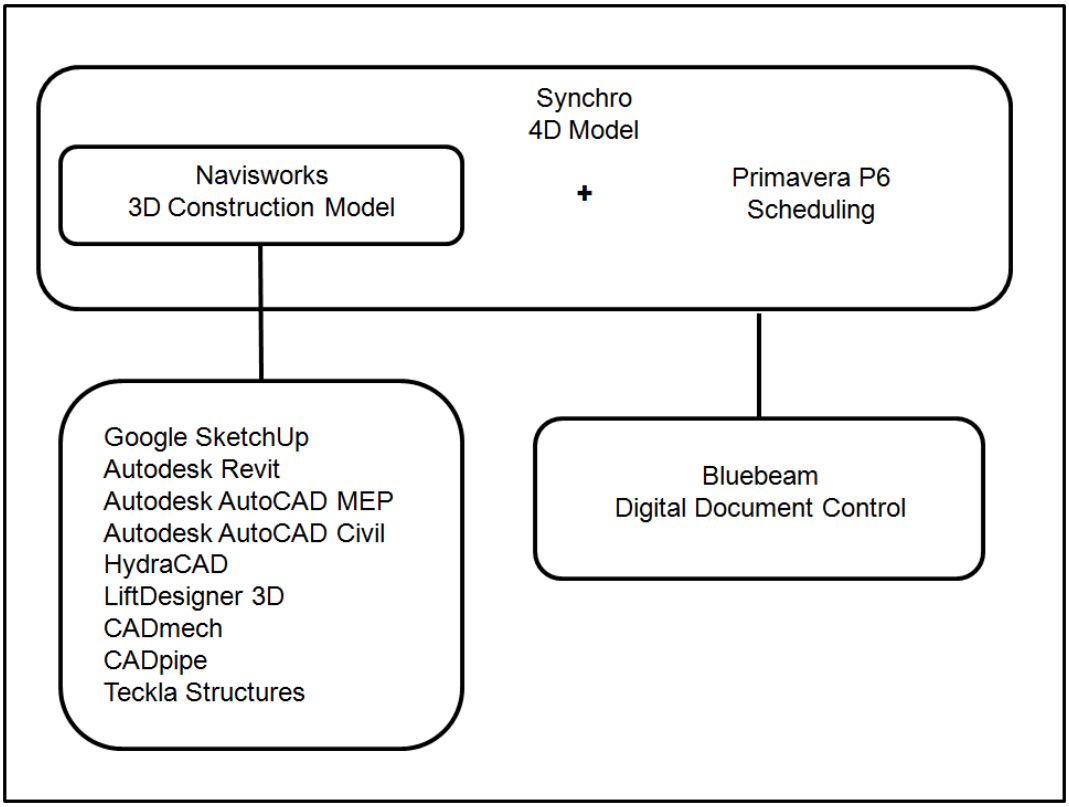

Figure 1 The BIM Maze.[8]

The Questionnaire

A questionnaire was devised using Qualtrics, an online survey tool[11,12] to assess the degree to which the construction curriculum addresses the needs of industry in the area of graphic communications. The survey consisted first of a series of questions about the respondent. Each was asked to classify their company in accordance with the industry sectors used by ENR in its annual report of the top 400 contractors.[13] The nine categories are: general building, manufacturing, power, water supply, sewer/waste, industrial/petroleum, transportation, hazardous waste and telecommunications. Respondents were also asked to classify themselves as either general contractors, specialty contractors or subcontractors, and to indicate the size of their company. Three questions were asked regarding their desire to have construction management graduates who could sketch a plan or elevation, a plan and elevation in orthographic projection, and a 3-dimensional object in isometric or perspective projection.

The main body of the questionnaire asked respondents to indicate their desire to have baccalaureate graduates who had graphic communication abilities with 16 drawing types as indicated in Figure 2. Respondents were also given the opportunity to add other drawing types. They were asked to indicate for each type whether they wanted graduates who could produce

drawings from original raw data, read and interpret drawings, and/or modify them to include field (as-built) data. They were asked this for both 2-dimensional drawings and 3-dimensional models. For any drawing type that they considered unimportant to their lines of business they could also indicate this. Finally they were asked about any specific software packages they considered useful for graduates to be familiar with.

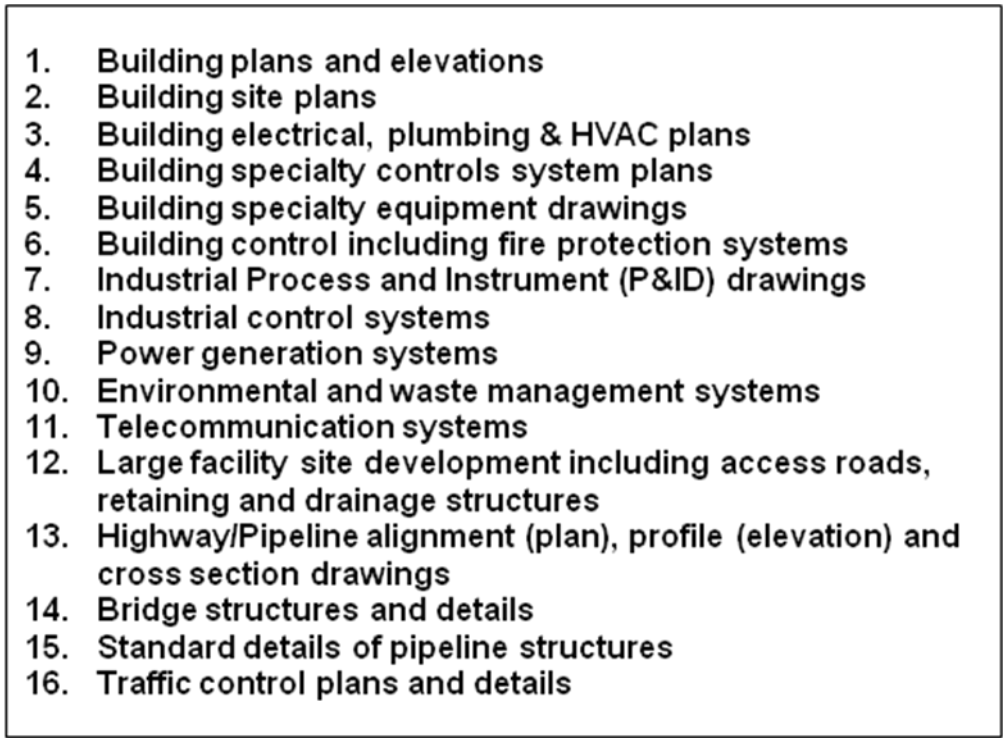

Figure 2 – Drawing Types Surveyed

The Survey Sample

The survey was distributed to 35 companies who have representatives on the University of Wisconsin - Stout Construction Advisory Board. Of these 22 responded, a 63% return. Figure 3 provides a breakdown of the respondents by type of project using the ENR classification, their, generalization of specialization, and their size. Three project types have been added: health, education and mechanical as identified by some under the category "other." With the exception of mechanical, the other two may be considered as specialized building projects and thus could be included in category 1.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
General Building	●	●		●	●	●	●	●			●	●	●	●	●			●	●	●	●	●
Manufacturing											●							●	●		●	
Power Generation		●	●					●	●		●						●					
Water Supply			●								●											
Sewer/Waste			●					●														
Industrial/Petrochem			●					●			●	●					●					
Transportation							●				●					●		●				●
Hazardous Waste																						
Telecommunications			●					●			●											
Health											●								●			
Education											●											
Mechanical										●												
General Contractor	●			●	●	●	●	●			●	●	●	●	●	●		●	●	●	●	●
Specialty Contractor		●							●	●							●					
Subcontractor			●																			
Large				●			●	●	●			●	●					●		●		●
Medium	●	●	●			●					●				●	●	●		●		●	
Small					●					●				●								

Figure 3 – Summary of the Respondents' Work

Responses Regarding Graphic Communication Ability

Respondents were solicited about the importance of graduates being able to sketch. They were asked three questions: The ability to sketch a plan or elevation was considered very important by 50% of the respondents and somewhat important by 50%. Nobody considered this skill to be unimportant. The ability to sketch a plan and elevation in orthographic projection was considered to be somewhat important by 82% of the respondents, with 9% considering it very important and 9% considering it to be not important. The ability to sketch a three-dimensional object in isometric or perspective projection was considered somewhat important by 50%, very important by 18% and not important by 32%. This appears to strongly indicate that, while there have been many advances in computer-generated graphic communication packages, construction graduates still need to possess the ability to quickly produce sketches in order to communicate effectively.

The survey then solicited responses regarding 16 different drawing types as presented in Figure 2 and rate them for both two- and three-dimensional models (CAD and BIM) in terms of whether graduates should be able to draw originally from raw data, read and interpret such drawings or

modify to reflect as-built (field) conditions. Respondents were also given the opportunity to add other drawing types, though none did.

Some of the drawing types received a 50% or less interest from the respondents. They are Numbers 6, 7, 8. 13, 14, 15 and 16 identified in Figure 2. Cross-correlating these drawing types with the project types specified by the respondent companies as shown in Figure 3 reveals that interest in these drawing types is associated with particular project types or industries in construction. Building control including fire protection systems are identified as needed for the power generation and industrial/petrochemical industries; industrial process and instrument (P&ID) drawings and industrial control systems are identified as needed for the industrial/petrochemical industries; and highway/pipeline alignment/profile drawings, bridge structures and details, standard details of pipeline structures and traffic control plans and details are identified as needed for the transportation industry.

Of the positive responses to the graphic communication skills required by construction graduates, the aggregate of all responses for all drawing types is revealing. This data is presented in Figure 4.

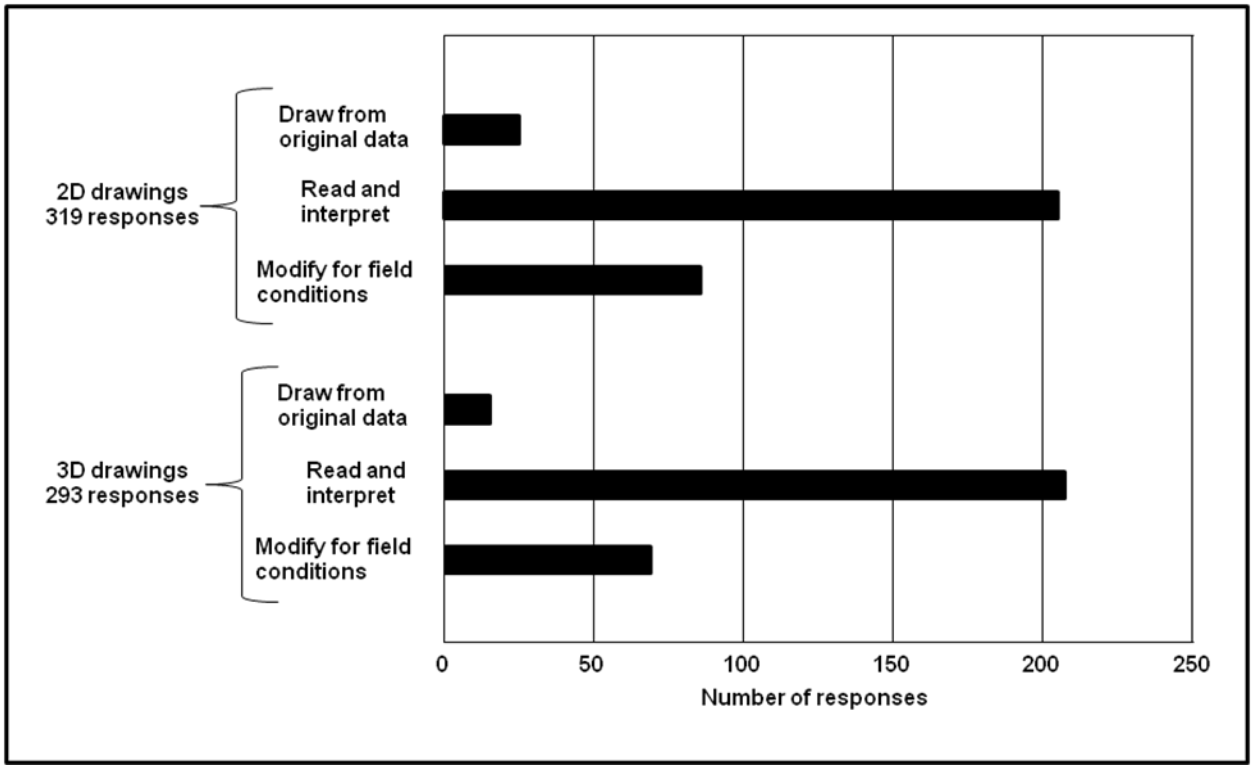

Figure 4 – Aggregated Results of Construction Graduates' Desired Abilities

A total of 319 responses were received for 2D drawings and 293 for 3D drawings. This strongly indicated that the profession has now embraced three-dimensional modeling as much as 2D CAD

drawings. For both 2D and 3D models, though, the strongest desire is for graduates who can read and interpret such drawings rather than for them to be able to produce original models. The need for them to be able to modify drawings to represent as-built field conditions is a secondary desire.

Looking at the results for each drawing type, Figure 5 shows the responses for the first five drawing types in the survey, which relate chiefly to the building industries. It may be seen that interest in these is very high, especially for the first three. However, there appears to be very little interest in having construction management graduates who can produce either 2- or 3-dimensional models from original data. This is most probably resulting from the particular survey sample who are mainly contractors specializing in the building sector. The chief desire is for graduates who can read and interpret both 2D and 3D drawings/models, and, to a lesser extent, modify drawings to reflect as-build conditions.

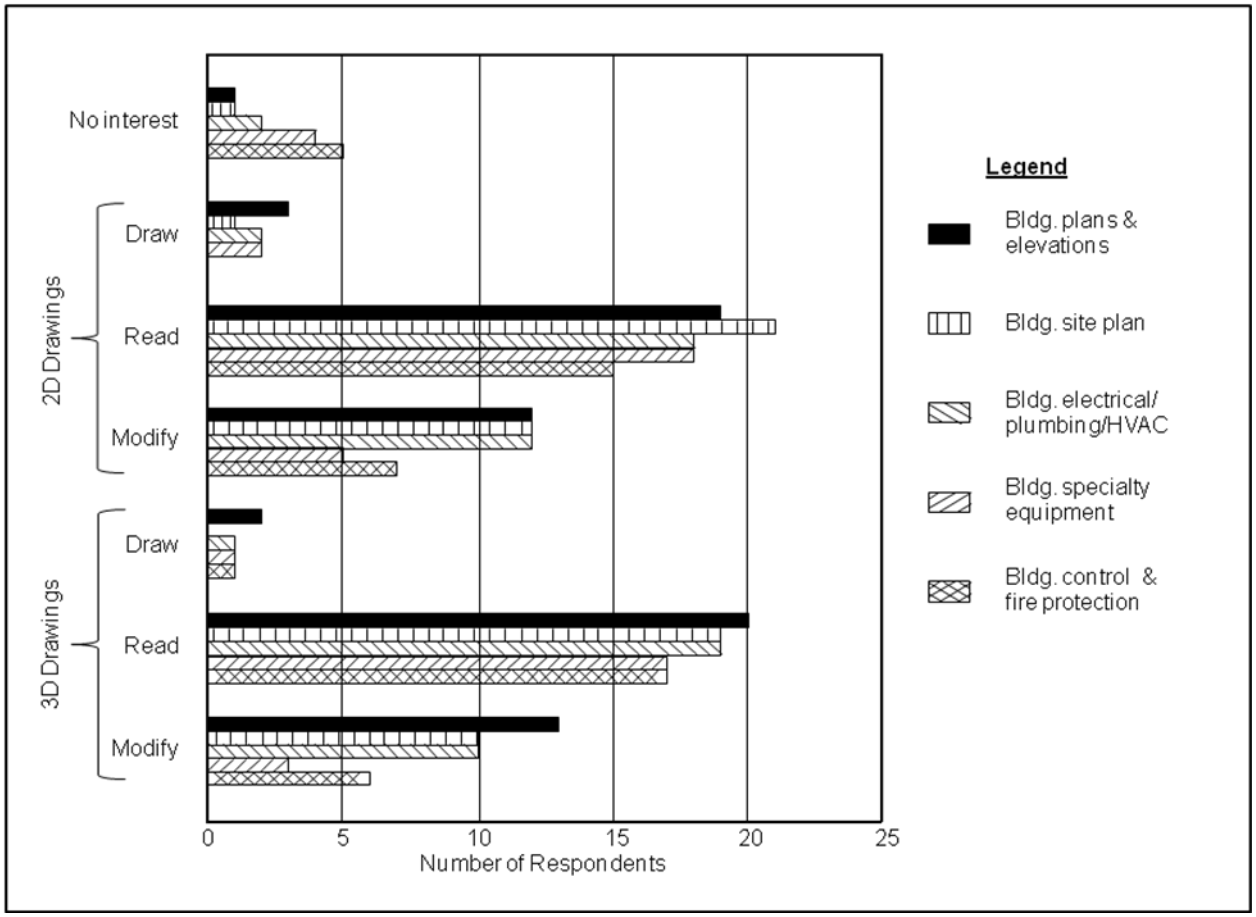

Figure 5 – Responses for Building Drawing Types

Of the five drawing types it should be noted that the maximum number of responses is 21, 21, 20, 18 and 17 respectively because of the respondents expressing no interest in these types. Therefore between 88% and 100% of all respondents expressing an interest in these drawing

types stated that graduates should be fluent in reading such drawings. Between 48% and 62% express a desire for graduates to be able to modify both 2D and 3D drawings/models for the first three drawing types. Lower percentages are shown for building specialty equipment drawings and building control/fire protection drawings which is perhaps due to the specialty nature of such drawings.

Figure 6 shows the responses to drawing types 6 through 11 in the survey, these drawings being more appropriate to heavy industrial applications. There are a higher number of respondents uninterested in these drawing types except for telecommunications and large site development drawings. Again there is little to no interest in graduates being able to produce drawings/models from original data and more interest in reading and interpretation, and modifying to reflect field conditions.

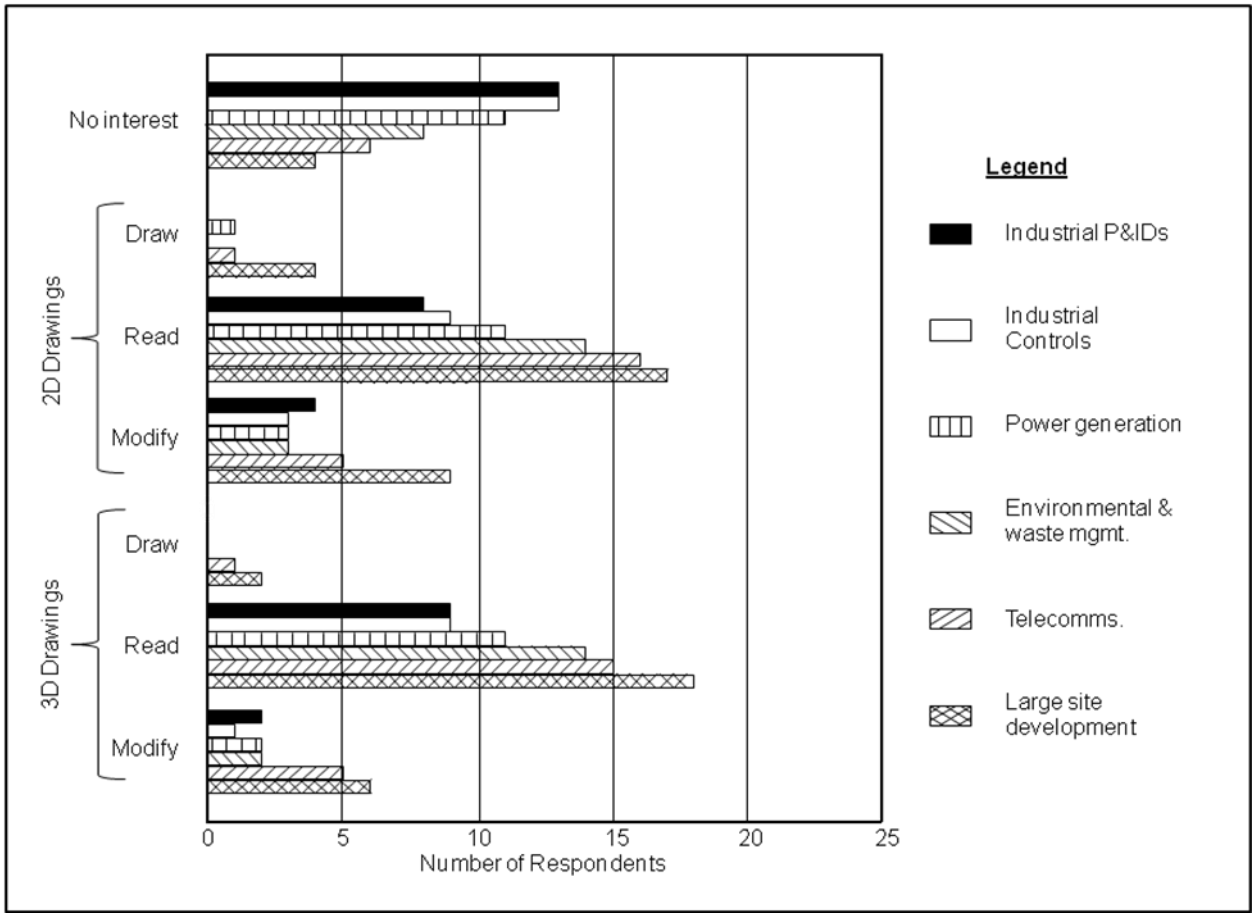

Figure 6 – Responses for Heavy Industrial Drawing Types

Of the six drawing types it should be noted that the maximum number of responses is significantly reduced because of the high number of respondents expressing no interest in these types. Again though, between 88% and 100% of all respondents expressing an interest in these

drawing types stated that graduates should be fluent in reading such drawings. Between 21% and 44% express a desire for graduates to be able to modify 2D drawings, and between 11% and 33% express a desire for graduates to be able to modify 3D models. The only exception to this is 50% of the respondents expressed a desire for graduates to modify 2D large site development drawings. This higher percentage is possibly due to the more general nature of such drawings.

Figure 7 shows the responses to drawing types 12 through 16 in the survey, these drawings being more appropriate to infrastructure applications. There are again a higher number of respondents uninterested in these drawings. For these types only 12, 8, 5, 5, and 11 respondents respectively expresses interest in these areas. There is less that 25% interest in graduates being able to produce drawings/models from original data, except for 2D traffic control drawings, at 50%.

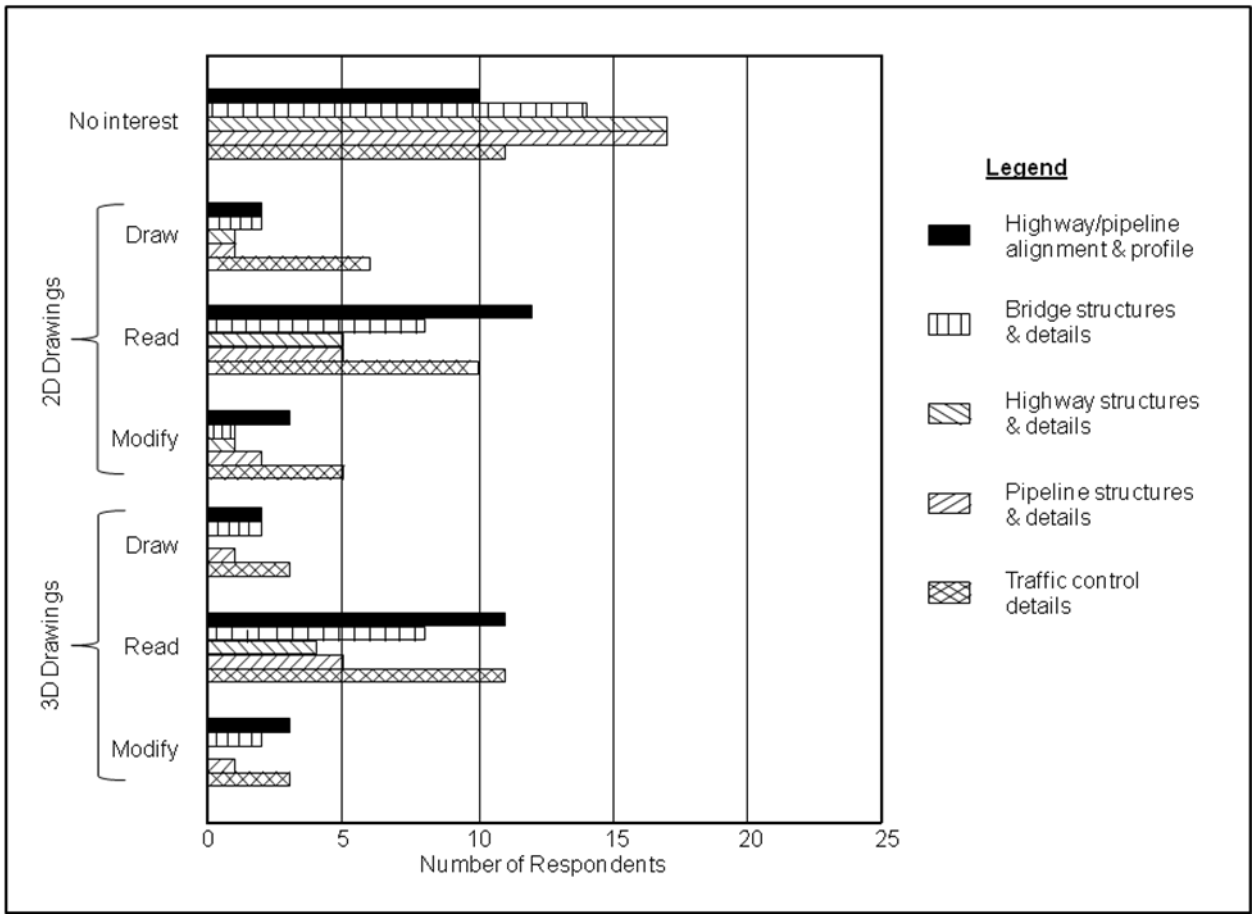

Figure 7 – Responses for Infrastructure Drawing Types

Of the five drawing types between 90% and 100% of all respondents expressing an interest in them stated that graduates should be fluent in reading such drawings. The desire for graduates to modify such drawings is significantly less for these types, most garnering less than 25% interest. The exception is that 45% of the respondents expressed a desire for graduates to modify 2D traffic control drawings. It appears that there is greater interest in both drawing traffic control

types from original data and modifying them for as-build conditions, possible due to their use on many different project types and their temporary nature.

Analysis of the Results

Cross correlating the data, there are only a few instances where there is some distinction between the preferences of large companies over medium/small companies. There is greater interest among large companies for sketching ability by approximately 12%, though it should also be noted that most respondents identified this as an important skill. There is less interest among small companies for building control including fire protection systems, and power generation systems by approximately 15%. Large companies show more interest in graduates being able to modify building electrical, plumbing and HVAC, and building specialty equipment drawings to reflect as-built conditions by approximately 15%. It is also noted that some of the drawing types are specific to certain industries such as power generation, industrial/ petrochemical and transportation. There is little interest shown in these drawing types by other respondents.

The most significant result of this survey is the strong desire for good drawing/modeling reading and interpretation skills among graduates. This appears to be almost equally desired for both 2-dimensional drawings and 3-dimensional models. The growth in the use of 3D modeling in construction lately is significant. There is secondarily a need for graduates to be capable of modifying both 2D and 3D models to reflect actual as-build field conditions, and much less interest in their ability to produce such models from original data. This is possibly due to the continued lack of involvement of the contracting sector during the initial design phase. The growth in newer forms of procurement such as Design-Build and Integrated Project Delivery may continue to change this.[1,2]

This lack of desire for construction management graduates to produce models should not be interpreted to mean that there is a lack of desire for them to be familiar with graphic communication software. Considerable skill is still needed to modify such data. While few companies actually noted the use of specific software, the use of programs such as Navisworks and Bluebeam were specifically mentioned as being used currently.

Previous work in this area has demonstrated that there has been significant flux in the construction industry's use of graphic software packages. Since 2001, both AutoDesk and Bentley have made significant changes such that they are now much more compatible, though different sectors of the industry favor one over the other. It will continue to provide challenges in higher education to address these areas of concern. It is clear from this survey that the construction management curriculum at higher education institutions must continue to evolve to reflect the changing market needs in graphic communication. The emphasis, though, seems to be more on the understanding and interpretation requirements and less on the ability to manipulate

specific software packages. Perhaps this will also evolve as software packages become more interoperable, a trend that is already underway.

Conclusions

The results of this survey have revealed that the use of graphic communication software in the construction industry has evolved since previous work in this area.[1,2] It continues to evolve, but the industry has embraced the use of both 2D and 3D graphic. Indeed it is clear that the use of 3D BIM has grown to the point of being as popular of project today as 2D drawings. The survey has revealed that a construction management curriculum should focus on the use of software to enhance a graduate's ability to read and interpret both 2D and 3D data in the field. There should also be an emphasis on a graduate being able to make field changes. It should also be noted that, even with all the advances in computer-aided graphic communication. The need for a graduate to be able to produce a clear and readable sketch in orthographic and perspective/isometric projections is still a required communication skill.

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