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Digital Graphics Literacy for 21st Century Constructors

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Abstract
In recent decades, new digital graphics technologies have been invented and significantly improved. These technologies have been adopted by almost every industry affecting our daily lives. In the world's largest industry, some contractors have started taking advantage of these new tools, such as documenting construction problems and project progress with digital images, developing site utilization plans and building layouts with 2-D graphics, demonstrating projects to clients and checking for interferences using 3-dimensional digital models. The most recent developments are merging graphics with construction information in 4d drawing and planning and controlling the lifecycle of a building with Building Information Modeling (BIM). However, acceptance and utilization of the latest digital graphics technologies in the construction industry still has a long way to go. This paper will review data gathered from a survey of the applications of digital visualization software programs in the commercial construction industry in the southeast US. Specifically the survey samples the industry for use of digital image management, 2-dimensional drawing, 3-dimensional modeling, and BIM. Also, this paper will present some successful cases of using digital graphics tools on construction projects and provide recommendations to constructors on how to select appropriate digital graphics software and use it efficiently. The paper will also share lessons learned from a course in digital graphics for constructors developed and delivered for the last three years in a leading higher education construction curriculum.

Keywords
Digital Graphics, Digital Visualization, Information Technology, Commercial Construction, Construction Education

1. Introduction

What is digital graphics literacy? Constructors operate in a sophisticated and complex 3d world. Until relatively recently, building plans have been limited to two dimensional drawings, based on the paper document; a portable and affordable media that we have used to communicate our ideas for centuries. Around 30 years ago computer aided design and drafting (CADD) came into being as a result of more affordable hardware and software capable of accurately producing graphic objects – lines, arcs, and basic geometric figures and annotations. These were initially limited to 2d drawings by 1) computing power and hardware limitations and 2) by a much more affordable and well established portable media, i.e. paper. Even as hardware and software took on 3d models, it was still hard to beat a set of plans on a

jobsite. The advent of more portable computing devices and more intuitive 3d software has been pushing computer graphics into the offices of architects and engineers and even onto construction jobsites.

Today's construction offices use a wide variety of advanced technologies, such as 1) digital cameras and scanners that create high resolution images, including accurate satellite images of landforms and software for cataloging, naming, enhancing, and combining these images, 2) 2d sketching tools for enhancing communication of visual ideas, 3) CAD drawings for precise 2d and 3d lines, surfaces and solid models of buildings, 4) 3D sketching tools for quick modeling of construction, and 5) 4d and 5d capable software for Building Information Modeling (BIM). These technologies could be considered necessary for constructors to communicate effectively in today's competitive construction environment, and as such they comprise a language in which today's constructors should be conversant. They are essential elements of digital graphics literacy for 21st century constructors.

2. A Survey on the Applications of Digital Visualization in Construction

In an effort to identify elements of digital graphics literacy, the authors launched a survey in September of 2006 to over fifty companies with major construction activities in the Southeast US. This survey provided an understanding of exactly which applications of digital visualization programs have found their way into construction offices and how they are being used. The authors believe that the sample size, though not large, is significant since it specifically targeted and reached IT directors or knowledgeable users of information technology in these companies. (Zoomerang, 2006)

2.1 Development and Implementation of the Survey

Today, survey authoring software and online service providers make survey research easy and fast. Advantages of online surveys include access to individuals in distant locations, the ability to reach difficult to contact participants, the convenience of having automated data collection, which reduces researcher time and effort (Wright, 2005), the possibility of allowing the participants to view the survey results immediately, and the anonymous function, which allows participants to keep information confidential. Given these advantages, the authors decided to develop their survey using an Internet-based commercial survey tool (Zoomerang: www.zoomerang.com).

The survey, which consisted of twenty questions grouped in seven categories, was conducted to gather current data on digital visualization in the construction industry. It was also designed to be completed by participants with minimum effort. Most questions were in multiple-choice format, which allowed participants to quickly select one or multiple answers that best applied. Also, a comment field for any additional input or other possible answers that were not listed was employed at the end of each question. Scopes of questions covered by the survey included:

- General information of the participant and the company with which he/she works;
- Applications of digital image editing/managing;
- Applications of 2-dimensional digital drafting;
- Applications of 3-diemnsional modeling;
- Applications of Building Information Modeling (BIM);
- Other applications of digital graphics;
- General comments on the application of digital graphics in the construction industry.

In order to obtain reliable information through the survey, a small group of fifty professionals known to be active users of IT applications within their companies was targeted. Most in the target group were in commercial construction, and many of them were IT directors. Through years of teaching, and continuous close ties to the construction industry in the Southeast US the authors were able to call upon

knowledgeable graduates and industry contacts to gain access to accurate information. The survey methodology involved: 1) A personal phone or email contact containing a link to the online survey to known users of graphic software in the region inviting them to take the survey. 2) Participants were asked to enlist the help of their colleagues to assist in getting all questions answered as accurately as possible. 3) A follow-up email was sent thanking the participant. Reminder phone calls or email were rarely needed. Occasionally, an in depth discussion or visit occurred when the respondent showed more interest on graphics related topics. This provided the authors with more specific information as well as a number of excellent examples of current software use. 4) A post survey message was sent to participants containing a link that shared the survey results with all participants. The authors believe that the better than 63% response to the survey was a direct result of this personal approach to engaging participants in the study.

2.2 Review and Analysis of Survey Results

Forty days after its launch, the survey ended with a satisfactory result: 52 visits and 33 completed responses. A study of the data collected from the responses followed. Some of the findings of this study are explained below.

2.2.1 The respondents

The first few questions of the survey addressed information about a respondent's background and their attitude related to applications of digital graphics. Among the 33 respondents, about 80% of them were completed by professionals from the construction industry in companies ranging from commercial/industrial as a majority to residential, light civil and specialty trade contractors. The remaining respondents were from other industries, such as higher education, government and a software reseller to the construction industry.

A distribution chart (see Figure 1) of gross revenue generated using the survey data shows that more than half of the respondents are from large companies with revenues over $100 Million in fiscal year 2005; another chart (see Figure 2) demonstrates that construction project management, information technology and estimating comprise a large majority of respondents' occupations.

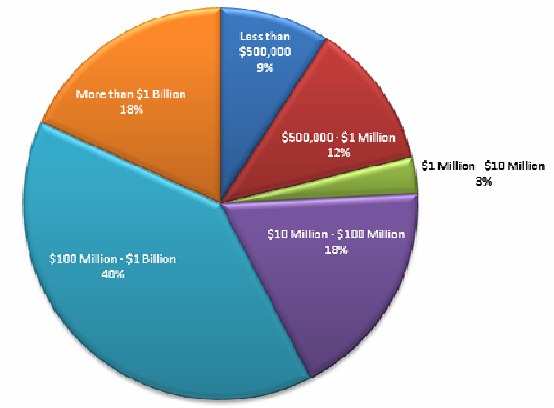

Figure 1: Distribution of Gross Revenue of Respondents' Companies

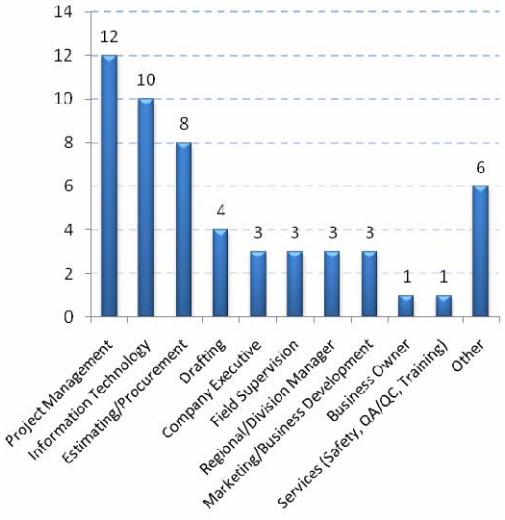

Figure 2: Respondents' Positions

Data gathered from two questions on popularity of graphics software programs illustrated that more than 90% of respondents used graphics applications in visualizing and communicating issues and problems, and 88% of all the respondents believed that graphic communication is a very important or extremely important issue within their companies.

2.2.2 Applications of digital image editing/managing

Digital photographs have been broadly used for a multitude of reasons in the construction industry. The increasing affordability, portability and ease of use of high quality digital cameras and storage media are generating tremendous numbers of images (both good and bad) from construction sites. The Chief Information Officer of a large commercial construction company in the Southeastern U.S. when asked during an interview about the amount of digital images taken by his company said the following: “In our 700GB server up to 60% of the space has been taken by images. That could get worse as the popularity of higher quality (resolution) digital cameras increases.” Digital photographs are used for communication among members of the design/build team; for recording data for building maintenance and facilities management; and for documenting as-built information or for tracking job progress. Digital photos can reduce the number of site visits by project decision makers. Easily attached to email, they allow designers and builders to view problems or job progress from wherever they are. As one of the most popular utilizations of graphics in the construction industry, editing/managing digital images has been employed by 97% of the respondents. Among those digital image tools, Adobe Photoshop, Adobe ImageReady, Microsoft Office Picture Manager, and Windows Paint were identified as the most popular programs, and those tools were mostly used for three major purposes: (see Figure 3)

- Manipulating images with fundamental editing features
- Viewing, renaming, sorting images
- Annotating images with text, dimensions, graphics

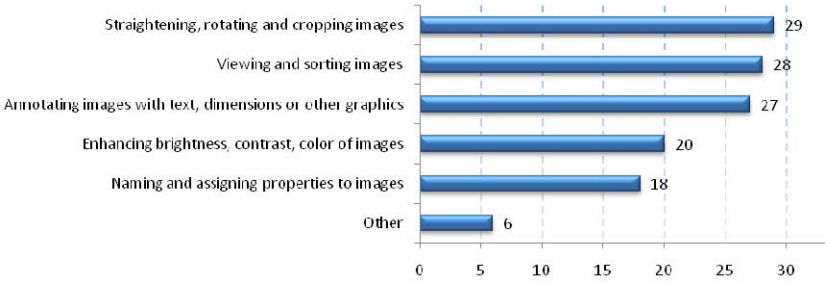

Figure 3: Number of Users of Digital Image Editing/Managing

2.2.3 Applications of 2-dimensional drawing software programs

Numerous 2-dimensional drawing applications have been adopted by the construction industry for many purposes, such as developing flow charts and conceptual diagrams, making PowerPoint illustrations, viewing and printing CAD drawings received from architects or engineers, extracting distances and areas from CAD files, creating templates for building layout, producing construction site utilization plans, developing erosion control plans and temporary structures sketches, checking accuracy of architectural drawings, and obtaining counts, areas, and volumes for quantity take-offs. Some other uses of 2-dimensional drawing applications include: creating construction scheduling models, developing as-built drawing markups and detailed views for subs, and developing project preliminary design.

Figure 4 explains the sharing of software applications for creation of 2-dimensional drawings. According to the survey, the standard drawing tools in MS Office Excel, Word and PowerPoint were used by more than 80% of the respondents; AutoCAD was used by the same number of respondents; MS Visio was chosen by more than 40% of respondents, with other applications including OnCenter On-Screen Takeoff, Bentley Microstation, Graphisoft Constructor, and DataCAD were each used by one or two respondents. Furthermore, 16 out of 19 large construction companies, whose revenues were more than $100-million in the past fiscal year, used Autodesk AutoCAD products for 2-d drawing creation. This coupled with the

import/export capability of all other CAD programs to AutoCAD suggests that AutoCAD remains the de facto standard CAD application for producing 2D technical drawings within the sample group.

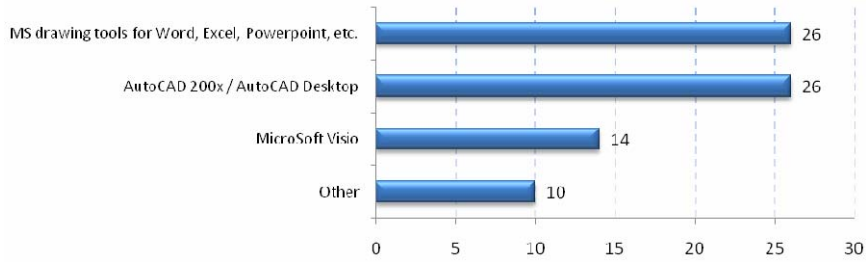

Figure 4: Number of Users of 2-Dimensional Drawing

2.2.4 Applications of 3-dimensional modeling

Besides the rapid popularization of Building Information Modeling (BIM) , for which 3-dimensional modeling technology is fundamental, more and more computer-generated 3-dimensional models have been created by contractors for various purposes, such as visualizing building construction sequencing, identifying conflicts among trades, developing preliminary conceptual designs for clients, creating clarifications for scopes of work from multiple perspectives; developing logistics planning, and providing an alternative option for estimating quantity take-off, etc. However, fewer than 60% of the respondents in the survey marked 3-d software as one of the graphics tools used by their companies, perhaps due to a lack of construction-oriented 3-d modeling experts. Figure 5 displays the distribution of users of some of the popular 3-d modeling programs used in the construction industry. The majority of respondents indicated AutoCAD, followed by SketchUp for generating 3D drawings.

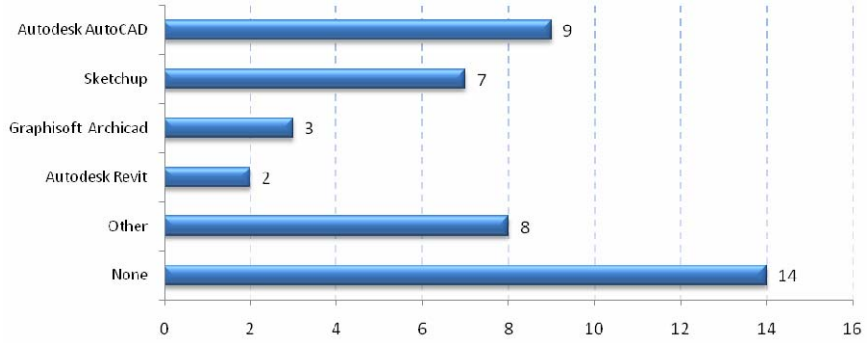

Figure 5: Respondents' Pick on 3-Dimensional Modeling Software Programs

2.2.5 Applications of BIM

The few BIM related questions conducted in the survey revealed that currently there is not a single comprehensive software program in the market capable of covering all activities involved in BIM. Generally, contractors utilize a variety of software programs to develop, view, manipulate and share BIM models. According to the survey, to approach the full functionality of BIM, an ideal combination of software programs would include the following key components:

- A 3-d modeling program. Graphisoft ArchiCAD, Graphisoft Constructor, and Autodesk Revit have been identified for this feature by respondents.

- A 3-d model review tool. NavisWorks JetStream is such a tool that allows users to view, navigate, compile and share 3-d models, furthermore, its collision-detection and sequencing features may be the main reason for its popularity among BIM users.
- Miscellaneous supporting tools. Depending on their own needs and available resources, contractors may choose a tool for a very specific task with BIM. For example Graphisoft Estimator can be used to extract quantity information from construction models and produce estimates quickly and accurately.

As a new technology and process, BIM comes with a learning curve for all involved and a not yet established track record of cost/benefit for construction companies. Only 36% of the respondents indicated the use of BIM in their companies; two thirds of these BIM users were from large construction companies with at-least $100-million revenue in the past fiscal year. However, some respondents who had not yet experienced BIM expressed a keen interest in exploring this technology. Only one of the companies represents what the author's consider a leading effort in BIM use within commercial construction.

2.2.6 Applications of other digital graphics software programs

Besides those programs addressed above, the survey provided data on two other types of graphics applications that have been widely used in construction, including Portable Document Formatting (PDF) tools (see Figure 6) and on-screen take-off technology (see Figure 7).

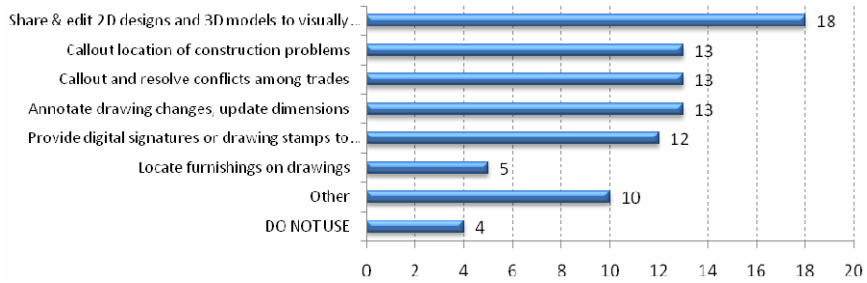

Figure 6: Uses of PDF Tools

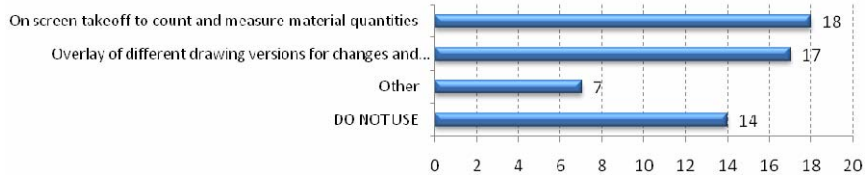

Figure 7: Uses of On-Screen Take-off Tools

Other advantages of PDF and on-screen take-off tools include e-invoicing, document report sharing, and digital archiving, maintaining a visual history of quantities as design progresses, and communicating project scope, etc. Several respondents indicated the extremely valuable application of onscreen take-off to track drawing changes over the course of a project through overlay of plan revisions and addenda.

3. Successful Applications

As evidence of the rapid advance of digital graphics in construction the authors have been able to collect a number of example applications from their former students now in the industry.

Figure 8 is a sample of using digital photos and annotations for planning a construction activity. The project is located downtown in a major U.S. city. The site is very congested, requiring good communication and planning to coordinate various construction activities carried out simultaneously by multiple subcontractors. The project field engineer took a series of digital photos of the site, and added annotations to identify construction activities. On Figure 8, superimposed lines and text drawn with Microsoft PowerPoint drawing tools illuminate location of existing and proposed tunnels, with an arrow indicating a tunnel under construction.

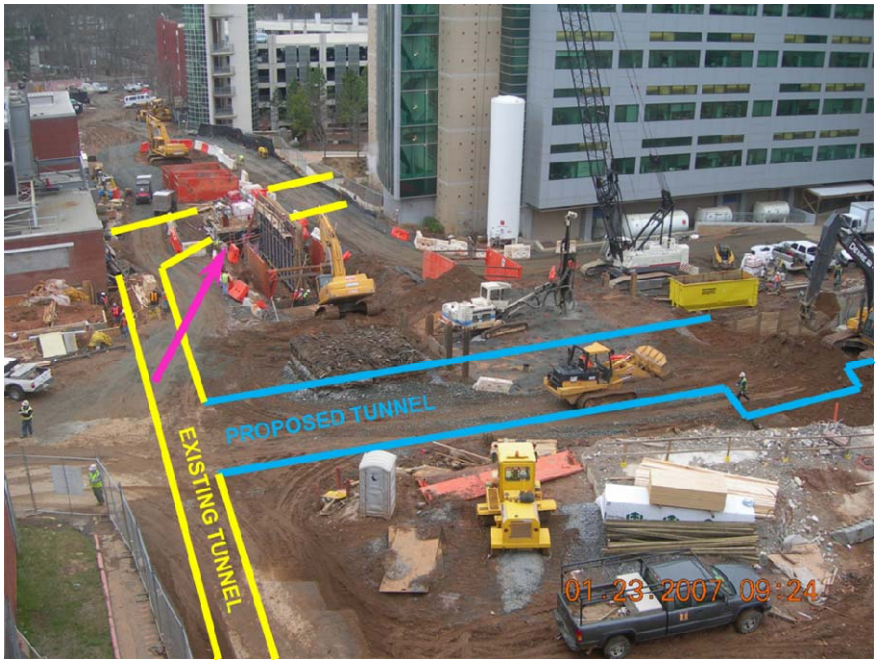

Figure 8: A Sample of Using Digital Image

Change is the only constant during the design and construction of a building project. Digital graphics can simplify the task for a constructor of indicating and tracking changes from construction documents. Figure 9 demonstrates an overlay feature provided by On-Screen Take-off software. In this application, two versions of a drawing from the same project are overlaid allowing quick visual comparison and recognition of revisions. In the screen shot, items on the first version of the drawing are in red, items on the second one are in blue, and the purple lines show items common to both versions.

In the U.S., Autodesk's AutoCAD is still the drafting software standard, which is used by nearly every architect and engineer for building design. Besides using its printing, viewing and drafting features, constructors have also discovered some other uses in AutoCAD that could help them improve construction productivity. "I use CAD everyday on this project," said a field engineer on a high-rise condominium project in Orlando, Florida. "I use some commands (in AutoCAD) to measure distances and to do building layout, which helps me a lot. I'm glad I've learned AutoCAD".

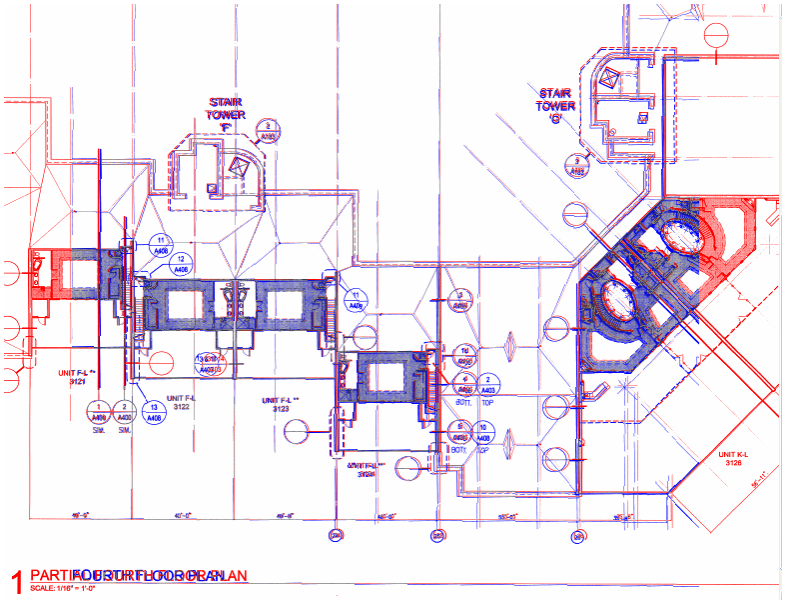

Figure 9: A Sample of Overlaying Construction Plans to Identify Changes

Figure 10 is a screenshot of a foundation layout plan developed by a contractor in AutoCAD to identify the location of each point required by a field person to layout a building foundation. The brief process of developing this plan and using it to layout a column footing (green rectangular shape) includes:

- Mark each corner of the column footing with a point object (yellow dot) in AutoCAD, and give a corresponding label (black number) to the point as its identification
- Extract the relative coordinates between the building layout control point (that has been set up on the project site) to the footing corner points, and export these coordinates to a data file
- Transfer the layout data file to a total station survey instrument
- Use the total station to layout the column footing corners on the project site

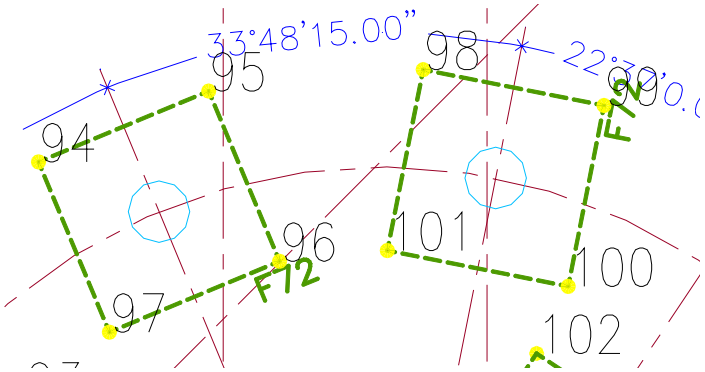

Figure 10: A Sample of Use of AutoCAD for Construction Layout

4. Teaching Digital Graphics Literacy

The survey conducted by the authors suggests wide application of some of the elements of digital graphics literacy in one geographic region of the construction industry. Given the ubiquity of computing tools, the international range of some of the companies surveyed, and the highly competitive nature of construction across regional boundaries, the survey results could be representative of a global trend.

Today's digital graphics tools are complex yet incredibly useful to communicate and visualize construction projects in many ways. In order to achieve the full capacity of these tools, specific training and practice are required (Liu and Hein, 2007). It has been learned that the more familiar constructors are with digital graphics applications, the more likely they are to find a productive use for them at work. The authors believe that the graphic applications identified in the survey represent the tools of emerging graphics literacy for constructors.

As faculty members at a four year ACCE accredited construction management program in the Southeastern U.S., the authors have been developing and teaching a digital visualization course in their undergraduate curriculum since 2003. This course incorporates many modern forms of digital graphics communication and visualization appropriate for construction, including digital photography, simple animation, digital video, 2-dimensional CAD, and 3d sketching applications. More importantly, this course illuminates the importance of digital literacy to construction students, and equips those soon-to-be constructors with skills to employ graphics applications early in their careers.

Since the implementation of this digital visualization course, incorporation of digital graphics by students has increased significantly throughout the curriculum. This is evident in increased graphic content of homework and projects. Many samples can be found in students' capstone thesis projects, including: preliminary construction schedules developed with simple drawing tools in MS Office Excel; business organization charts and project timelines drawn in MS Visio; building structural analysis and temporary structures design demonstrated through 3d sketching models (see Figure 11); construction site utilization plans designed in MS Visio or AutoCAD, etc. According to a survey of the latest graduating classes from this program in Fall 2006 and Spring 2007, 100% of the graduates indicated they had made use of digital graphics applications in their capstone thesis project. Furthermore, the best measurement of effectiveness of the course may be evidence of graduates incorporating the skills learned in this course in their work while introducing graphic applications to their companies. Several of these examples are reviewed in the Successful Applications section of this paper.

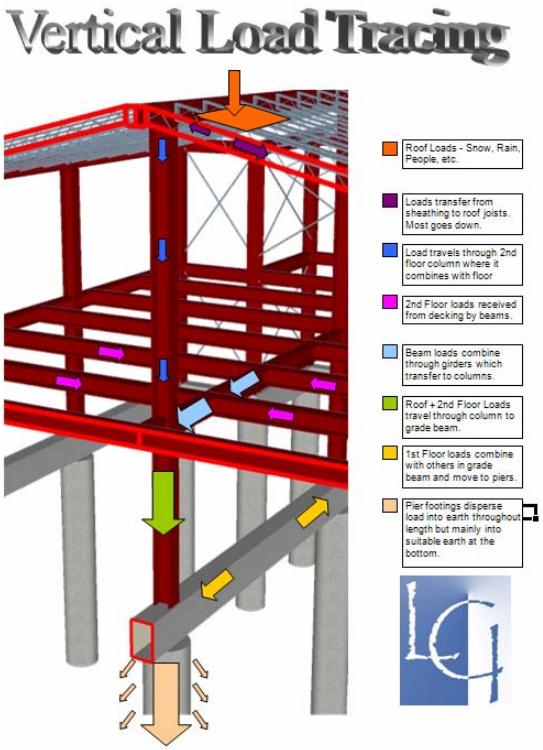

Figure 11: A 3D model created by a student illustrating a building's structure and vertical load tracing

5. Conclusions

Advances in hardware and software have made sophisticated digital graphic tools available for anyone to use. A recent survey of construction companies in the Southeast U.S. indicates widespread adoption of several significant digital graphics applications to enhance the communication of construction problems and solutions. These include digital image acquisition and editing, basic drawing tools provided in typical office software suites, 2D and 3D CADD applications, 4d, 5d and BIM applications, and on-screen takeoff and portable document creation and editing. The education of future constructors already includes training in the appropriate use of many of these applications for construction. It is clear that many recent construction graduates are joining the ranks of established firms with a new set of valuable skills. These graduates bring a new dimension of communication clarity to their companies, who are seeking such skills. This new visual skill set enhances the conventional analytical and management skills traditionally taught to students of construction management. As in any language digital graphics will undoubtedly continue to evolve, however at the beginning of the twenty first century, the skills identified in this paper represent essential elements of digital visual literacy for constructors.

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