

Student Experiences with Virtual Design and Construction Applications for Quantity Takeoff: A Case Study

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The objective of this case study was to explore student experiences with, and perceptions of, the utility, strengths and weaknesses of various Virtual Design and Construction (VDC) applications for performing estimating tasks in an upper-level undergraduate course. A model-based estimating assignment utilizing VDC software platforms was implemented. A group of four students utilized an architect-created Autodesk Revit model in conjunction with 2D and VDC-based applications to perform quantity takeoff (QTO) tasks. Students elected to create their own model in Autodesk Revit for QTO and comparison to the architect-created model produced QTO. A description of the VDC-based estimating project and student-noted strengths and weaknesses (e.g. VDC QTO lessons learned) observed when using these VDC applications to complete QTO are provided. Implications of teaching VDC-based QTO concepts in undergraduate curricula are discussed. The paper concludes with discourse of study limitations and areas of future research.

Key Words: Student Perceptions, VDC, Model-based Estimating, Navisworks

Introduction and Literature Review

The proliferation of personal computers and computer aided design (CAD) in the 1980's (Cohn, 2010), introduced the use of computer technology to the construction industry in such a way as to revolutionize methods for construction management (Khanzode, Fischer, Reed, & Ballard, 2006) (Heesom & Mahdjoubi, 2004). By extension, the education of construction managers has similarly been influenced (Clevenger, Ozbek, Glick, & Porter, 2010). Construction management programs traditionally teach the principles of plan reading, estimating, scheduling, contracts, and cost controls (ACCE, 2014). Furthermore, the students are expected to learn these principles within the parameters of computer program applications which are specific to construction management, i.e. REVIT, AutoCAD, Primavera, Microsoft Excel, Microsoft Project, Navisworks, Bluebeam, etc. Research suggests that construction management education that provides a foundation of marketable CAD and BIM (Building Information Modeling) skill sets proves an advantage for the student (Russell, Cho, & Cylwik, 2014). As a result, many programs have found creative methods for integrating the use of CAD into the curriculum (Martin, Plugge, & Socha, 2015). As students and industry work toward literacy in these multiple applications, the capabilities and limitations of such applications becomes evident. Keeping up with the changing landscape of computer applications and working with its limitations is often in itself the challenge for most users (Murphy, 1993). Each user, therefore, much strive to find efficiencies within the system of computer-aided applications in an attempt to ultimately manage a construction project more competitively.

As computer applications have advanced, a number of programs have evolved which are specific to estimating a construction project, i.e. On-Screen Take-Off, Primavera, etc. Virtual Design and Construction (VDC) applications have naturally evolved from BIM applications in an attempt to more accurately and effectively pair the design with a quantity takeoff. Software developers, such as REVIT by AutoDESK, have design capabilities that allow the user to associate quantities of materials and are marketed as such. "Revit is a database driven 3D modeling software that encompasses information in every element. Using this information rich model (BIM) we can leverage the data in these elements for a great number of goals. We will be looking at how you can use schedules to create cost estimates of elements in a building (AutoDESK, 2017)." Case studies have been performed to determine the accuracy and effectiveness of REVIT as an estimating tool (Liu & Hu, 2016) (Tang, Chen, Dong, Wei, & Yang, 2013) (Guo, Chiang, Chong, & Chen, 2017). Guo et.al. found that BIM software overestimates the budget (Guo, Chiang, Chong, & Chen, 2017). Tang et.al., similarly found a number of errors in the quantity take off generated by the BIM application. A successful case study in estimating (Cheung, Rihan, Tah, Duce, & Kurul, 2012) used free-

form models rather than embedded material quantities in the application. Traditional quantity takeoffs were performed after and independent of the designed free-forms in BIM.

These case studies suggest that the estimating tools embedded in BIM, or VDC applications have significant limitations, and such limitations may be related to the user, or designer of the model. As such, this research group considered the potential efficiencies of BIM-based estimate. The question considered in the development of this case study was whether an accurate estimate can be efficiently produced using a VDC tool. To determine empirically the accuracy and efficiency of a BIM-based estimate, both would need to be measured comparatively based on current methods of performing a quantity takeoff (QTO). In teaching, and in industry, qualitative experience can be incredibly informative to curriculum development. As such, the objective of this case study was to explore student experiences with, and perceptions of, the utility, strengths and weaknesses of various Virtual Design and Construction applications for performing estimating tasks in an upper-level undergraduate course. A model-based estimating assignment, utilizing multiple software platforms was implemented. A group of four students utilized an architectural Autodesk Revit model in conjunction with several 2D and VDC-based applications to perform quantity takeoff tasks. Students were also required to compile a detailed cost proposal as part of the estimating project. The following describes the student's prior construction-related work and construction management competition experiences as well as their prior experience with VDC software packages. A description of the VDC-based estimating project and student-noted strengths and weaknesses (e.g. VDC QTO lessons learned) observed when using these VDC applications to complete QTO are provided. The paper concludes with a discussion of study limitations and the implications of teaching VDC-based QTO concepts in undergraduate curricula.

The Student Team

The group of students completing the VDC-based estimating project described in this case study were selected based on their commercial construction internship work experiences and participation in numerous construction management competitions. In total, the team had competed fifteen construction management competitions that focused on preconstruction and constructability practices. Of these, team members participated on the same competition team in three instances. Each of the students also had several work experiences on their resume comprising 11 total internship experience in the commercial construction industry. Two of the students had residential custom home building experience through family-owned businesses. All of the students completing the project had taken a 100-level graphic communication course that focused on Autodesk Revit. However, these students had no experience with performing QTO task in any VDC application prior to the start on the project.

Given the combined experience of the student project team, it should be noted that these students were familiar with Work Breakdown Structure (WBS) concepts as well as the Construction Specifications Institute's (CSI) MasterFormat and Uniformat breakdowns. In addition, the student group members were proficient in the use of Microsoft Excel. In should be noted that the student group had completed several traditional 2D QTO-based estimates as part of construction management competitions prior to completing this VDC-based estimating project. The VDC-based estimating project case study presented below reflects the experience of the team of students. Discussion of practical applications of VDC-based estimating concepts for students with less exposure to industry work experiences and construction management competitions is provided below.

Description of the Estimating Project

The estimating project described herein was offered to the group of students as an alternate to a traditional 2D estimating final project during the spring 2017 semester. The model-based estimating assignment comprised the final project for the selected students in a 300-level construction estimating course at a large university in the Mid-West United States. The students received the estimating project in the form of a Request for Proposal (RFP). The RFP required that a full detailed estimate be provided following the CSI 50-division MasterFormat and Uniformat numbering systems. The building used in the project comprised a 1-story, 6,300 square foot commercial office building. The building's interior was divided into a 3,150 square foot medical office building fit out and a 3,150 square foot core and shell for future tenant occupancy. Students were provided a set of 2D construction documents in PDF format and a, design-team created, architectural Revit model. The intent of the project was that students used the model and 2D documents for the initial investigation of the project's scope of work and to perform and compare material takeoff quantities.

In addition to creating a complete detailed estimate for the building project, students were tasked with comparing and contrasting the strengths and weaknesses of the VDC applications and digital 2D methods (i.e. Bluebeam and/or On Screen Takeoff) to complete material QTO tasks. The students were given autonomy when choosing the "best" VDC application to perform QTO. While students had a multitude of software programs at their disposal, they chose to use Autodesk Revit and Navisworks Manage in conjunction with Microsoft Excel and Bluebeam eXtreme to complete the project.

Student Experiences and Perceptions

The following section provides student's perceptions resultant upon several in-person debriefs during the study and after its conclusion. The commentary herein provides information about student experiences with VDC tools for QTO given the estimating project case. The perceptions and lessons learned presented are useful to educators intending to incorporate VDC applications within construction estimating curricula. This paper will limit remarks specific to student experience with two software applications; namely AutoDesk Revit and Navisworks.

AutoDesk Revit:

Students received and reviewed the architectural Revit model (figure 1) that was created by a regionally prominent architecture firm. The team noted that "When the team received the architectural AutoDesk Revit model, we were impressed. After digging deeper, we realized that there were no structural elements [within] the model. It was strictly architectural component". Given their understanding of the model components (e.g. the Revit selection tree naming structure, etc.) students portrayed a perception that "the model may not be suitable for estimating". The team of students further solidified a negative perception of Revit's usefulness for QTO as follows; "Performing quantity takeoffs within Autodesk Revit is typically not for an estimator's use. The process is essentially creating schedules, as Architect's would typically do (e.g. Window and Door Schedules)." Student's identified that Revit did provide some helpful information in their statement; "However, [Revit] will gather all the information that is in the model and create a master schedule. This can be helpful because, it can provide a live quantity takeoff while modeling."

Figure 1 – Architect-Generated Revit Model

Further discussion with the students revealed that some 3D elements were not modeled in the correct component families. This led to a group decision to build their own model using Revit (figure 2); "We then decided to build our own model that encompassed all construction elements required to construct the medical office building." Students

noted that "It was rather simple to draw some concrete, put up walls, and cap it off with a roof….but regarding estimating purposes that produced little help". Students noted that "Estimating based on modeling requires that every component is within the model." One major takeaway from the student team was noted in the following statement; "a crucial lesson the group learned, was proper naming of the components. Exporting raw modeled data will provide the name, quantity specified, and unit of measure. If little care is taken into naming each separate component, then the user will have no logical way of tracking it throughout the quantity takeoff process." In light of industry recognized terminology, this statement is closely in line with the topic of building model trust (Kiesel, 2017) prior to using the model for project management tasks.

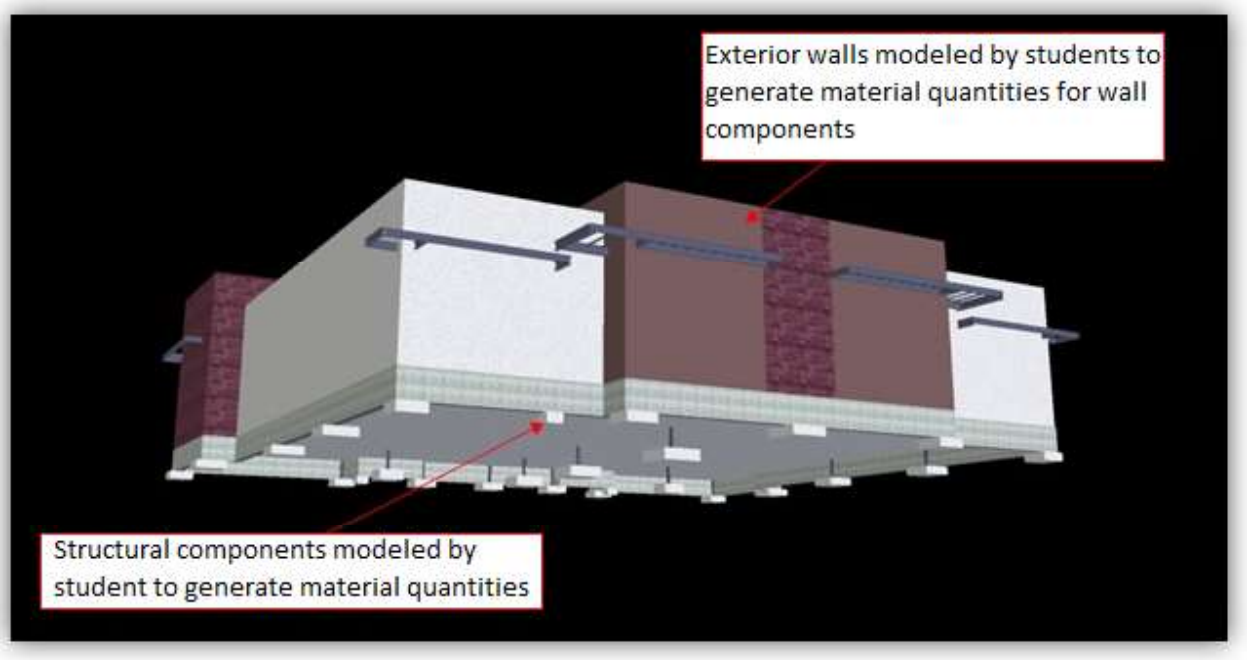

Figure 2 – Student-Generated Revit Model

Students reflected that building their own Revit model provided advantages; "A strength of the [Revit model creation] process was that we learned every detail about the 6,000 square foot medical center". However, with regard to the value gained by completing a separate student-built model for QTO, the team commented that "the time put into creating every component was detrimental compared to the information produced". This may imply that the time investment was larger than the value gained from personally completing a Revit model that produced trust-worthy quantities. Students indicated that the time spent modeling may have been more time consuming than preforming a full QTO using traditional 2D methods. This perception should be considered in light of the student project team's previously discussed construction competition, internship and work experience.

AutoDesk Navisworks:

As previously mentioned, the student team was given autonomy in choosing the VDC application(s) utilized for QTO. Students chose to use Autodesk's Navisworks Manage as the primary tool for determining the quantity of construction materials. Prior to completing the project, the students did not mention estimating or QTO when describing their perception of how Navisworks is used with in the construction industry: "Autodesk Navisworks is primarily a 3D design software that allows construction professionals to communicate multi-trade integrated models. The project outcomes that it provides have changed the construction industry in a substantial way. It is currently being used to facilitate mechanical, electrical, and plumbing clash detection...Multi-trade collaboration in conjunction with BIM 360 glue, which is another Autodesk product, and simulating models to depict desired sequencing throughout the life of the project."

The groups performed QTO using Navisworks on the provided architect-created model as well as their student-created model. The Autodesk Revit models were exported as Navisworks Cache (nwc) files for QTO. The students reported that "The quantification feature [in Navisworks] showed strengths and weaknesses that stood out in both of the models used". One reported strength of Navisworks was the automatic organization structure of information; "When creating the workbook, an option for CSI-16, CSI-48, or UniFormat II is provided, this will ultimately determine how the model quantities are stored". The ability to choose a CSI estimate format "proved to be very useful, as one of the assignment deliverables was to provide two estimate summaries, one organized in MasterFormat and one in UniFormat II". Figure 1 shows a screen shot of the Navisworks QTO tool with the automatically generated CSI 48-division MasterFormat and UniFormat.

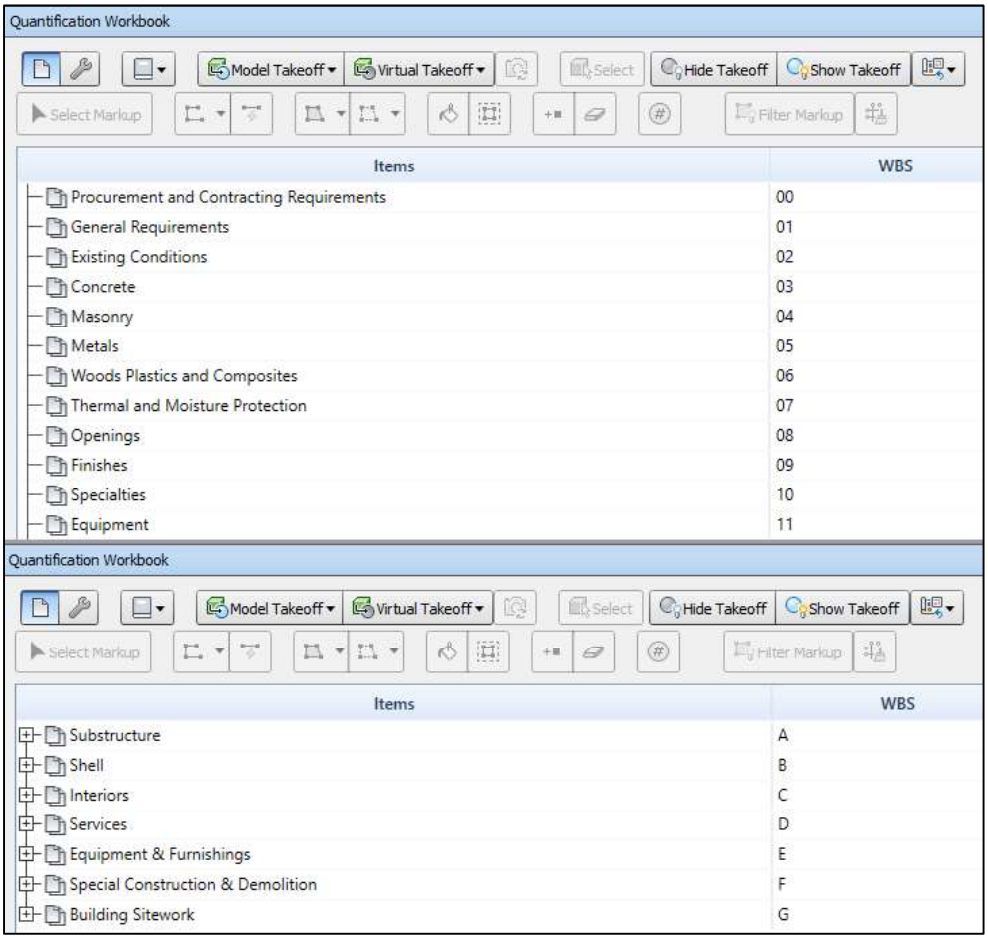

Figure 3 – Navisworks Quantification Workbook: 48-Divison MasterFormat and UniFormat Example

In order to properly use Navisworks for QTO, students reported that further manipulation of the Revit selection tree and model component naming was required to produce trustworthy material quantities; "Once the model components were allocated to the proper line item [Navisworks] can then export quantities, in whichever [CSI] format, to an excel spreadsheet that automatically creates PivotTables…This allows the user to extract the quantities of the modeled components that are generated in an excel report in CSI 16-Division MasterFormat, CSI 48-Division MasterFormat, or UniFormat Level 1-4 summary breakdowns" (Figure 3).

During the estimating project the students reported that Navisworks was limited by the quality of the Revit model; "The quantification tool works best when the model is properly put together in Revit". Students reported additional limitations of Navisworks QTO is follows; "a couple things about the [Navisworks] export that were particularly challenging were a lack of model detail for trade specific model components and organizing the data in a manner that would be easily communicated." Student summarized that the Navisworks application "is very useful when the

model allows for it" but also noted "that the modeler must do their due diligence regarding constructability and proper model components" in order for the model to create trustworthy material quantities for estimating".

The group reiterated that the provided "architectural model was not built to depict proper materials, methods or sequencing…It was built for marketing purposes, a pretty picture". With regard to the student-generated Revit model students reported the "even though techniques were developed when creating the model to be more accurate for material takeoff, not all items could be modeled to make the takeoffs effortless". The student cited the following example for the above statement: "The interior partition walls have steel studs with gypsum board attached. Revit allows the user to draw the wall component with these items and provide a proper naming tag. However, this will not provide every element within that wall….Navisworks will not be able to quantify the studs, rather this produces an export of linear footage or square footage for that wall. By drawing every stud, an accurate takeoff could be extracted using Navisworks, however the group found that this would be too time consuming to gain any benefit".

Discussion and Conclusions

Students completing the model-based estimating project in this case study provided first-hand insight regarding their experiences with, and perceptions of, the utility of Autodesk Revit and Navisworks for performing QTO tasks. The strengths and weaknesses of each software package mirrored those found in the literature (Guo, Chiang, Chong, & Chen, 2017). The students perceived that the quality of the material quantities produced from the VDC applications were highly dependent on the model's quality, the level of detail embedded in the model, the organization of the elements and components, and the accuracy of components selected for inclusion in the model. Students decided to create their own model for comparison with the architectural model. Building a separate 3D model with contractor-specific outputs in mind is common practice in the construction industry. These re-designs have been used to identify potential tradecraft conflict (Clayton, Warden, & Parker, 2002). Contractors have used 3D modeling as a visualization tool, both for internal and marketing purposes (Koo & Fischer, 2000). 3D models have also been used as an organizational tool, to simulate site logistics (Christiansen & Levitt, 1992). In this case study, students found that the details provided in the architect-generated design was insufficient to develop a detailed quantity takeoff; as such, a redesign was required.

The student insights noted in this case-study, while applicable and important for quantity takeoff and estimating, highlight a broader and more important part of the critical thinking and learning process. Specifically, the students completing this model-based estimating project demonstrated a first-hand understanding of several critical project management concepts; 1) that virtually all project management application outputs, including VDC, are limited by the value of inputted information, 2) VDC tools used for information extraction can be highly powerful but the outputs need to be critically evaluated and verified before use in project management tasks and 3) that the benefits of advanced tools and applications for completing project management tasks may not justify the time investment required. This is not to say that the model-based estimating project discouraged students from using VDC applications, but rather that they have the foundational understanding that project variables including the quality of the model, project size, scope of work, etc. can determine the most efficient method used to perform project management tasks like QTO. As educators, the initial intent of a VDC-based estimating project may be to teach student the key-strokes required in a given application to produce material quantities. However, the student's first-hand insights in this case study indicated an understanding of a broader, higher-level, critical thinking about the efficient use of construction technologies given project and situational variables. This may have occurred since students were given the autonomy to evaluate and select a VDC application and utilize it to meet the deliverable and a request for proposal. Exploring this question may be a logical and fruitful next step for construction education.

Limitations and Future Research

While the discussion above provides several points of practical application for educators interested in implementing VDC applications in construction estimating curricula, the findings are limited by several case-specific constraints. First, as noted above, the group of students participating in the VDC-based estimating project had a much higher than average level of construction competition participation and construction work experience than their CM

program peers. This produced a student group with exceptional foundational knowledge of estimating concepts, work breakdown structures, and Microsoft Excel. Second, the students had limited experience with Revit and no experience with Navisworks prior to the project. Therefore, a group of students with more knowledge of 3D modeling and VDC applications may have reported different perceptions of the ratio on time invested to value produced when modeling a building for QTO purposes. Third, student chose to use Navisworks as the primary tool for QTO. If other VDC applications were utilized student perceptions and experiences with QTO for estimating may have been different. Lastly, while the Revit model was created by a regionally prominent architecture firm, this may not guarantee the model would be of high-enough quality to produce accurate quantities.

In light of these limitations, future research should focus on a larger sample of students with varied backgrounds and levels of construction competition participation and construction work experience. Additional case studies utilizing models that have been vetted for accuracy and usefulness for QTO would also shed light on students understanding and perception of VDC for estimating purposes. While the project size (6,000 SF) and scope (1-story, medical office building) was appropriate given student's level of experience and course time limitations, a larger project may receive more modeling attention from a design team and, therefore, produce better quantities. A study focusing on a larger, more diverse sample of students and building models would continue to inform educators on appropriate means and methods when implementing VDC applications in construction estimating curricula.

Considering the oft-found limitations of architectural models for estimating purposes, the same principles may be applied between the relationship between an estimate and other project documents, i.e. schedules, cost controls, etc. An estimate alone may not sufficiently articulate the assumptions made by the estimator. As such, upon execution of a contract, the project management staff in a construction firm may often be required to rebuild an operational budget for a project. A future case study might consider the design of an estimating tool which allows the estimator to embed assumptions and communicate details within the application. Thus, providing an effective communication tool from estimating to operations. By extension, the development of such estimating applications within the design software may, in turn, improve the communicative nature from design to project performance.

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