CSCE Annual Conference
Growing with youth – Croître avec les jeunes

Laval (Greater Montreal)
June 12 - 15, 2019

A STATISTICAL ANALYSIS OF THE EFFECTIVENESS OF USING 3D MODELS IN TEACHING QUANTITY SURVEYING TECHNIQUES

Namhun Lee[1], Seong-Jin Kim[2], and Krishna Kisi[3]
[1] Associate Professor, Central Connecticut State University, USA, e-mail: leen@ccsu.edu
[2] Assistant Professor, Minnesota State University at Mankato, USA, email: seong-jin.kim@mnsu.edu
[3] Assistant Professor, Central Connecticut State University, USA, e-mail: kkisi@ccsu.edu

Abstract: The AEC industry is shifting from 2D CAD to 3D model use. In the coming years, every design project will be modeled using BIM. Nonetheless, BIM is merely used as a tool to produce 2D drawing sets from 3D models. BIM for construction is to promote collaboration through consistent information models with greater standardization. BIM will help project managers not only streamline the design and construction processes but also add new capabilities to better serve their clients. Quantity takeoff is one of the most critical subjects in construction engineering and management (CEM) education. To perform a detailed quantity takeoff, it is required to review a set of drawings, create mental images of building elements, and calculate quantities of building materials. It is often exasperating for students to convert the 2D design information into 3D mentally. Using 3D models designated as LOD 300 or higher supports the quantity takeoff process since they address building element geometry. The objective of this study is to investigate the effectiveness of using 3D models to teach quantity surveying techniques in education settings. To accomplish this objective, a pilot study was carried out. Students' performance data were collected from four different sections of a construction quantity takeoff course. To analyze the data statistically, an independent sample t-test was used. After analyzing the results, some pedagogical strategies for effective use of 3D models to teach quantity surveying techniques were discussed. The results of this study present a stepping stone towards the future of CEM education.

1 INTRODUCTION

Building information modeling (BIM) has seen rapid adoption over the past decade. According to the 2014 McGraw-Hill BIM report (McGraw-Hill Construction, 2014), project participants including architects, engineers, contractors, consultants, and suppliers not only realize the value of BIM technology, but also widely use BIM technology in their businesses. In some cases, owners require architects and contractors to provide BIM services at every stage of a project, from concept to completion (AIA, 2007). Without doubt, BIM is fundamentally changing the architecture, engineering, and construction (AEC) industry.

Nowadays, the way the architect designs has been markedly changed. As a result of BIM technology, the AEC industry is rapidly shifting from 2D computer-aided design (CAD) to 3D model use. According to the 2018 American Institute of Architects (AIA) firm survey (AIA, 2018), BIM is universally used at larger firms and is increasing its saturation at smaller and midsize firms. Cheshire (2017) states that every design project will be modeled using BIM in the coming years. Despite this transformation, BIM is merely used as a tool to produce 2D drawing sets from 3D models (Kilkelly, 2015).

One of the main reasons the architect is adopting BIM despite delivering 2D drawings is increased job efficiency (Cadnetics, 2018). Using BIM software, the architect creates one 3D model, rather than multiple

2D drawings, for the design development. In 3D environments, there is no need to create floor plans, sections, or elevations because they can be produced easily by changing the view. In addition, any modifications to the building design will be automatically updated in each view. In 2D environments, drawings are not connected to each other. If a measurement on a floor plan is changed, then all the other drawings affected by the change must be manually revised. This revision is time-consuming but mandatory, and often results in errors, omissions, or inconsistencies in design documents. Therefore, the architect can create and revise design documents faster using BIM software. At the same time, stringent quality assurance of the design documents can be provided by automatic coordination of the different views (Sharafutdinova, 2015).

Unlike CAD, BIM can modify the collaborative nature of a construction project. One of the ultimate goals of using BIM for construction is to promote collaboration through consistent information models with greater standardization (Thomassen, 2011). Project managers need to see various perspectives to identify potential issues or problems associated with the construction project. BIM will help them not only streamline the design and construction processes but also add new capabilities to better serve their clients.

The architect creates 3D models following the Level of Development (LOD) specification to specify and articulate with a high level of clarity the content and reliability of the models (NATSPEC, 2013). 3D models designated as LOD 300 or higher can be used for quantity takeoff. Using these detailed models supports the quantity takeoff process since they address building element geometry (Cerqueiro, 2014).

2 ISSUES ON TEACHING QUANTITY TAKEOFF

Quantity takeoff is one of the most critical subjects in construction engineering and management (CEM) education. Since quantities of building materials are determined from 2D drawings, plan reading is a fundamental skill required for the quantity takeoff process. To perform a detailed quantity takeoff, it is required to review a set of drawings, create mental images of building elements, and calculate quantities of building materials (Lee and Park, 2016). However, students in a CEM program have difficulty in building mental models of object configuration from 2D drawings on several sheets representing different views such as floor plans, elevations, sections, and details (Lee and Park, 2015). Branoff and Dobelis (2012) advocate that it is often exasperating for students to convert the 2D design information into 3D mentally. For example, students are expected to create the 3D object mentally in Figure 1(b) from the 2D drawings in Figure 1(a) of the same object part but from different angles.

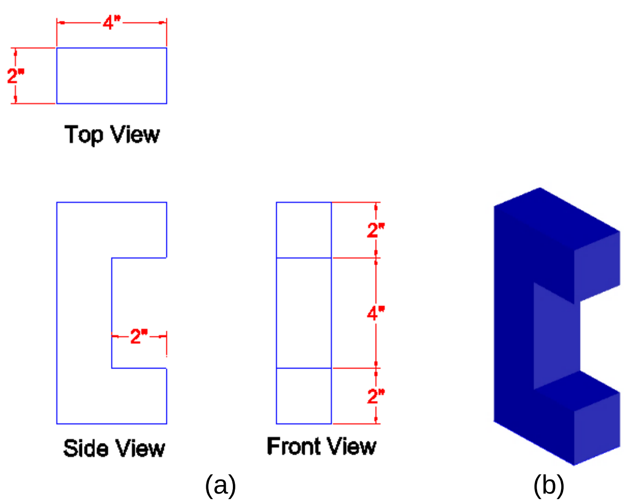

Figure 1: Conversion from 2D design information to a 3D object

To cope with this issue, CEM programs have at least one class topic to teach students how to systematically relate multiple orthographic 2D views to a corresponding 3D model. Nevertheless, students are still facing the challenge and spend a large amount of time in relating 2D drawing information to a 3D mental image when they perform a quantity takeoff with actual construction drawings.

3 BACKGROUND OF THIS STUDY

The objective of this study is to investigate the effectiveness of using 3D models to teach quantity surveying techniques in education settings. To accomplish this objective, a pilot study was carried out to examine if 3D models facilitate learning and instruction and improve students' performance of quantity takeoff.

For this study, an individual assignment was given to students with all the necessary information such as construction drawings and specifications to perform quantity takeoff for concrete. Students were asked to create 3D models for building parts only related to the project before they began taking quantities off. Refer to Figure 2 for a sample of student 3D models.

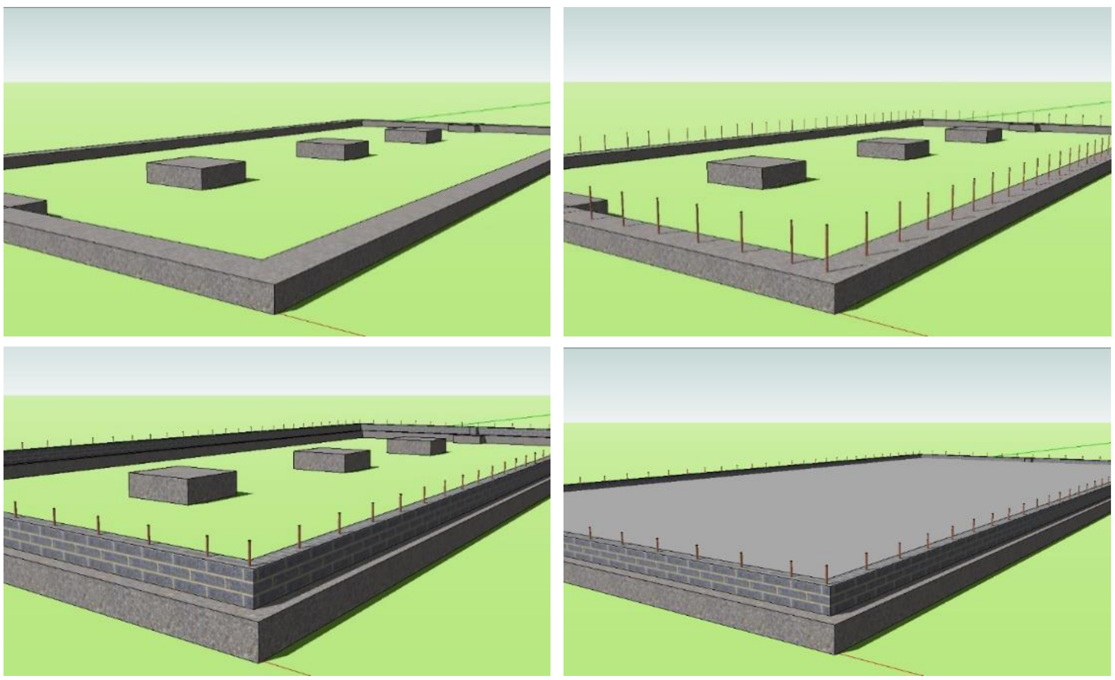

Figure 2: A sample of student 3D models

Regardless of whether the student developed 3D models, every student had to take a pre- and post-test on the related subject. Students' performance data on the pre- and post-tests were collected from four different sections of a construction quantity takeoff course. To analyze the data statistically, an independent sample t-test was used to check the effectiveness of 3D models. After analyzing the results of the pilot study, some pedagogical strategies for effective use of 3D models to teach quantity surveying techniques were discussed.

4 DESIGN OF THE PILOT STUDY

Two pedagogical methods were devised to teach quantity surveying techniques for concrete, formwork, reinforcing, and finishes: one method used both 2D drawings and 3D models and the other method used only 2D drawings. To examine the effect of the two pedagogical methods to teaching quantity surveying techniques, seventy-six undergraduate students from four sections of the course were assigned to two groups: experimental group (#2) used 3D models and control group (#1) did not use 3D model. Participants included sixty-nine males and seven females, primarily freshmen (N=29) and sophomore (N=23), juniors (N=18), and seniors (N=6). 88.16% (N=67) of the participants were majoring in construction management. 11.84% (N=9) of them have different majors or were undeclared (Refer to Table 1).

Table 1: Information for the participants who were not majoring in construction management

	N	Percentage
Non-matriculated	1	1.32%
Undeclared	2	2.63%
Industrial Technology	2	2.63%
Civil Engineering	1	1.32%
Management	1	1.32%
Mechanical Engineering Technology	1	1.32%
Technology & Engineering Education	1	1.32%
Total	**9**	**11.84%**

In this study, the groups being compared were not assumed to be equivalent at the beginning of the study. Any differences observed at the end of the study might not be caused by the intervention but were due to pre-existing differences. Therefore, this study included the non-equivalent control group design, where both control and experimental groups are pre-tested and post-tested (Refer to Table 2). All the participants in each group were required to take both the pre-test and the post-test. The scores on each test ranged from 0 to 15.

Table 2: Non-equivalent control group design

Control Group (#1)	P_1	--	P_2
Experimental Group (#2)	P_1	I	P_2

'P_1' represents the pre-test measure; 'P_2' represents the post-test measure; and, 'I' represents an intervention (using 3D models), which means that students in the experimental group used 3D models. On the other hand, students in the control group did not use 3D models.

This research design involved measuring the dependent variable (i.e., students' understanding level of design information and students' ability in quantity takeoff) both before and after the intervention. The frequency distributions of the 'change' score (also called a 'gain' score) of each group, which is the difference between the post-test score and the pre-test score, were compared. In addition, a t-test was used to compare the means of the change scores of two independent samples and to test whether the difference between the change scores is statistically significant. Using this way, the error level can be kept at or below 5%.

In this study, the independent variable is the use of 3D models since it defines the groups to be compared. The dependent variable, as mentioned above, is students' change scores whose means of the two groups are being compared. At the end of this study, the change scores of the students who were taught the course topic of concrete quantity takeoff using the two pedagogical methods were measured and compared to each other using t-test. The ratio of the variance between groups to the variance within groups (also known as the 't-value') was used to assess if there is any significant difference in the mean scores of the two groups of students.

With the two groups, the null hypothesis (H_o) was stated as follows:

> H_0: $\mu_1 = \mu_2$, *which means the means of the change scores of the two groups are statistically equal regardless of the two types of pedagogical methods.*

This null hypothesis can be rejected if there is a statistically significant difference between the two means. Therefore, the alternative hypothesis (H_a) was:

> H_a: $\mu_1 \neq \mu_2$, *which means there is a significant difference between the two means.*

5 DATA ANALYSIS AND RESULTS

To determine the pre-existing differences, pre-test scores in each group were first measured. Then, post-test scores were measured to identify the effect of the independent variable (i.e., the use of 3D models). Table 3 shows descriptive statics for both pre-test and post-test scores of the two groups. From this data, it appears that the use of 3D models produced some changes in test scores.

Table 3: Descriptive statistics for the pre-test and post-test scores

	Group #1		*Group #2*	
	Pre-test	*Post-test*	*Pre-test*	*Post-test*
Minimum	1	4	1	5
Maximum	8	13	9	15
Mean	3.98	8.07	4.15	9.24
Standard Deviation	1.77	2.06	1.96	2.47

Table 4 lists the descriptive statistics for the change scores in each group. As shown in Table 4, the difference between the pre-test means and post-test means of each group is 4.1 in control group (#1) and 5.09 in experimental group (#2) using 3D models.

Table 4: Descriptive statistics for the change scores

	Group #1	*Group #2*
Minimum	-1	3
Maximum	8	8
Mean	4.10	5.09
Standard Deviation	2.16	1.22

Figure 3 illustrates frequency distributions in percentages, compared to the change scores, which represent the effect of using 3D models. All the students (N=34) in group #2 had a change score of 3 or more whereas 21% (N=9) of the students in group #1 could not have the same.

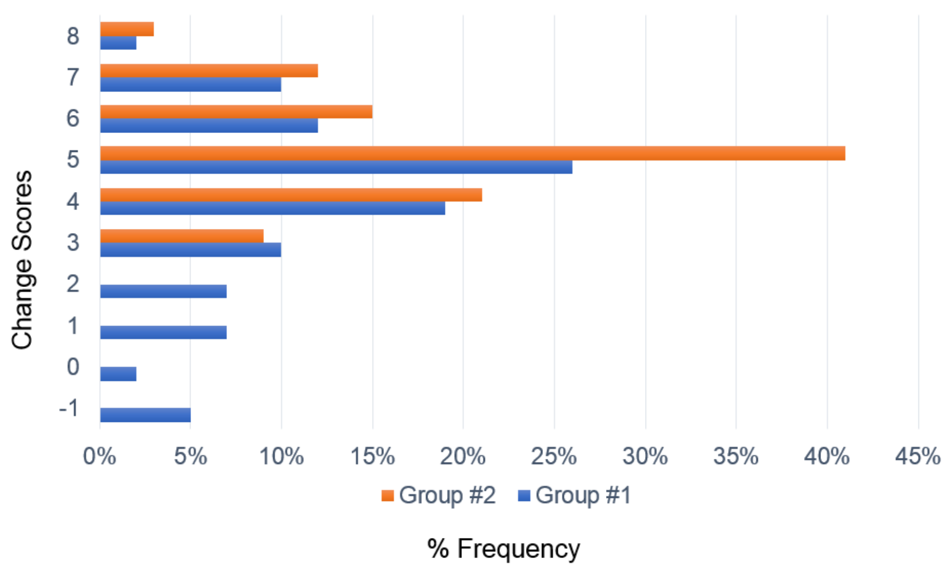

Figure 3: Frequency distributions of the change scores

An independent-sample t-test was used to check the effectiveness of 3D models since it tests whether this difference is statistically significant or if it happened purely by chance. The numerical results of the t-test are summarized in Table 5.

Table 5: Numerical results of the t-test

df	:	67
t Stat	:	-2.52
P(T<=t) two-tail	:	0.01
t Critical two-tail	:	2.00

The absolute value of the test statistic for this study is 2.52, which is greater than the corresponding critical value of 2.00. This result infers that there is statistically significant difference between the mean scores of the two groups of students at the $p<0.05$ significance level. Therefore, the null hypothesis (H0) should be rejected in favor of the alternative hypothesis (Ha). This indicates that the use of 3D models does make a difference in the students' test performance.

6 DISCUSSION AND RECOMMANDATIONS

This study investigated the effectiveness of using 3D models to teach quantity surveying techniques in education settings. Using an independent sample t-test, this study identified which pedagogical method is more effective than the other in terms of teaching quantity surveying techniques with students' pre- and post-test scores. Based on the results of this pilot study, it is concluded that 3D models can serve as an instructional tool for students to build mental models of building components and better perform material quantity takeoff from 2D drawings.

The use of 3D models can support both teaching and learning processes. Without doubt, instructors and students can take benefits from the instructional tool. The effective use of 3D models will also create more educational opportunities in CEM education. Furthermore, it can increase student's engagement and motivation towards learning. However, for the successful use of 3D models as an instructional tool, the following three conditions must be satisfied:

1. *There must be an explicit learning objective of using 3D models, aligned with course learning objectives.* The main problem of using 3D models is their efficiency, which usually results from unclear objectives. Also, detailed instructions and rules must be provided to reflect an intended pedagogical process.

2. *Instructors must have technological knowledge in using BIM software* (e.g., Revit, SketchUp, AutoCAD 3D, etc.) to assist students in creating, using, and manipulating 3D models properly. Otherwise, the pedagogical process will be easily interrupted by a variety of difficulties and obstacles to the utilization of 3D models.

3. *Most importantly, Instructors must know how to utilize instructional tools.* Using 3D models is not mandatory for instructors to teach quantity surveying techniques. When instructors decide using 3D models as an instructional tool, they must understand how the instructional tool can be properly used to enhance, supplement, support teaching and learning processes. Without this understanding, the use of 3D models will only waste students' time and increase their workload.

In conclusion, the successful use of 3D models may be able to make quantity takeoff processes faster, more accurate, and easier than the conventional method of material quantity takeoff. This is because the mental conversion of 2D design information to 3D can be supplemented by 3D models. Due to this fact, model-based quantity takeoff will become a common practice in the construction industry if the LOD and accuracy of detailed design models become standardized more strictly and the design models are more often shared with contractors. Therefore, the authors believe that the results of this study present a stepping stone towards the future of CEM education.

References

AIA (2007). *Integrated Project Delivery: A Guide*. Washington, D.C.: The American Institute of Architects

AIA (2018). *The 2018 AIA Firm Survey Report*. Washington, D.C.: The American Institute of Architects

Branoff, T. J. and Dobelis, M. (2012). The relationship between spatial visualization ability and students' ability to model 3D objects from engineering assembly drawings. *Engineering Design Graphics Journal*, **76**(3), 37-43, ASEE.

Cadnetics. (2018). *Architects benefiting from BIM.* [online] Available at:

Cerqueiro, D. C. (2014). *BIM Quantity Takeoff: Assessment of the Quantity Takeoff Accuracy as An Automatic Process. The Special Case of Revit and Vico Office*, Master Thesis, VIA University College, Aarhus, Denmark.

Cheshire, T. (2017). *BIM's 'Google Docs for buildings' is transforming architecture – but could it kill creativity?.* Wired. [online] Available at: https://www.wired.co.uk/article/architecture-software-creativity [Accessed 3 Feb. 2019].

Kilkelly, M. (2015). *Seven Steps to BIM Better*. Architect Magazine. [online] Available at: https://www.architectmagazine.com/technology/seven-steps-to-bim-better_o [Accessed 3 Feb. 2019].

Lee, N. and Park, S. (2016). Using Stereoscopic Visualization to Support and Facilitate Student Spatial Skills in Construction Education. In: *Proceedings of the ASEE NE 2016 Conference*. ASEE. Kingston, RI, USA.

Lee, N. and Park, S. (2015). Using Stereoscopic Visualization for Improving Student Spatial Skills in Construction Engineering and Management Education. In: *Proceedings of the 2015 ASEE Annual Conference & Exposition*. ASEE. Seattle, WA, USA.

McGraw-Hill Construction (2014). *The Business Value of BIM for Construction in Major Global Markets: How Contractors Around the World Are Driving Innovation with Building Information Modeling*. SmartMarket Report. Bedford, MA: McGraw Hill.

NATSPEC. (2013). *Building Information and Modelling and Level of Development*. NATSPEC BIM Paper NBP 001, Construction Information Systems.

Sharafutdinova, A. (2015). *BIM in practice*, Bachelor's Thesis, Saimaa University of Applied Sciences Technology, Lappeenranta, Finland.

Thomassen, M. (2011). *BIM and Collaboration in the AEC Industry*. Master of Science Thesis, Aalborg University, Denmark.