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Improving Visualization Capability in Construction Education (Plan Reading)

Boong Y. Ryoo, Ph.D. and Mi Sun An
Texas A&M University
College Station, TX

COVID-19 dominant academic year witnessed unprecedented educational environments. Enforced transitions to online commenced with concerns for lower quality education. This involuntary shift ironically provided grounds for bold approaches to overcome expected educational weaknesses. Addressing unfavorable circumstances of an online construction plan reading course, 3D modeling using Revit was adopted. This course initiated with low cognitive tasks, understanding construction drawings and memorizing associated terminology, which culminated in a high cognitive task, applying what is learned to building a 3D model, for both of which flipping the class, a proven educational strategy in face-to-face classrooms, was implemented. This experimental course implementation was proven successful in the survey performed after the course completion (n=99, response rate = 13%). Students understood how 2D drawings are created showing the ability to illustrate details: what materials the wall is made of, which is expected to remove the need for shop drawings and to reduce the number of RFIs. Based on the proof that Revit and flipped class helped students learn better, this study suggests a more developed course design for construction the plan reading course which is a prerequisite for higher-level construction education courses.

Key Words: Revit, BIM, Plan Reading, Flipped Class, Construction Education, Visualization

Introduction

The outbreak of the pandemic, COVID-19 has enforced abrupt transitions toward online education (Gallagher & Palmer, 2020). This shift had its concerning commencement due to the possibility of limited learning (Ślaski, Grzelak, & Rykała, 2020). However, this enforced transition toward remote learning whether it is synchronized or not brought about a mass implementation of long-standing online education (Gallagher & Palmer, 2020), which provided educators with the opportunity to devise and try a variety of approaches to achieve intended learning outcomes.

A plan reading course is fundamental in construction education. All bachelor's degree programs accredited by American Council for Construction Education (ACCE) have a plan reading course. The plan reading course was not an exception; the course was decided to be delivered online. Students before the pandemic opened drawings on the table mostly as a group, and they located information turning pages of drawings along with instant feedback from peers and lecturers. Reflecting how the plan reading course was taught in the face-to-face setting, it is natural to conclude that teaching reading drawings online is challenging.

There has been a strong demand to go online in any discipline even before the pandemic, and teaching plan reading can't be an exception from this education trend. To accommodate this trend, the goal of this research is to propose a course design for an online plan reading course. The objectives are to design a plan reading course which (1) facilitates visualizing buildings in 3D from 2D drawings; (2) facilitates defining locations and orientations of space and facility of the building, (3) facilitates extracting numerical information from drawings, (4) facilitates to identify materials along with their properties matching to building codes, and (5) builds BIM model understanding governing relationships, which helps students ready for construction methods and construction order. Ultimately, this research will help to develop a course framework that facilitates online teaching and learning using computer tools.

Literature Review

When moving online, the plan reading course is expected to suffer as students are required to read drawings on the screen in class. However, getting accustomed to reading construction drawings on paper is recommended before moving to using electronic devices such as tablets (Reyes, Ghosh, Perrenoud, & Goldman, 2015). To make it worse, online education harbors concerns about instructional feedback (Bonnel, 2008).

Improving 3D visualization is critical in construction education. The fact that research on construction place values on 3D visualization (Han, Hasan, Bouferguène, Al-Hussein, & Kosa, 2015; V. R. Kamat & Martinez, 2000; Vineet R. Kamat & Martinez, 2007) suggests the importance of building 3D visualization ability in construction education. In addition to practical benefits to the industry-related education, having students able to visualize spatially is known beneficial to their academic works (Astuti, Sugiyarto, & Ikhsan, 2020; Šafhalter, Glodež, Šorgo, & Ploj Virtič, 2020). However, teaching students to visualize objects in 3D is challenging because acquiring the spatial visualization ability relies on individual capability (Batra, Richardson, & Webb, 2020).

To facilitate education delivered in the new environment, the course was executed holding the concept of the flipped class. Flipping the class is a proven approach in face-to-face classrooms in terms of effectiveness (Doo & Bonk, 2020; He, Holton, Farkas, & Warschauer, 2016; Zheng, Bhagat Kaushal, Zhen, & Zhang, 2020). Flipping the class can be defined as students doing homework or individual work before in-class learning (Touchton, 2015). Using online resources for flipping the class in the face-to-face setting is effective in learning (Liranti, Fadil, Ilham Tri, Hesty, & Jufriadif, 2019). Applying the flipped class for a synchronous and asynchronous blended learning using online communication tools during the pandemic was proved successful in higher education (Rehman & Fatima, 2021).

Methodology

This study takes design-based research (DBR) as its core methodology. DBR seeks to transfer educational research into improved practice and takes interventions to make differences (Anderson & Shattuck, 2012). Teaching 3D visualization using Revit was implemented as a modified design-based intervention. In order to determine whether or not specific objectives have been met and to establish baselines against which future comparisons can be made (Isaac & Michael, 1995), the survey was implemented. The mean of each survey question was used for the evaluation. Empirical analysis on survey results and term project was performed.

Course Design

Conventional Face to Face Plan Reading Course

To help obtain an understanding of construction drawings, specifications, and associated terminology, plan reading courses consist of learning fundamental concepts (construction drawing organization, construction math, measuring, line and symbols, specification and building codes, and materials) and their application to construction drawings (site, architectural drawing, foundation, structural prints, residential framing, plumbing, HVAC, and electrical prints), whose student learning outcome is to have learners analyze construction documents for planning and management of construction process.

Class activities consist of lecturing fundamental concepts and finding given elements or reading numbers from drawings. Actual reading drawing parts after fundamental concept learning ask students to open a number of pages of drawing sets and locate the required information turning multiple pages back and forth trying to find the matching drawings; for example, students have to find a matching section drawing or details with a floor plan or an elevation to locate the CMU size. The instructor should help students trace the flow of information on the drawings (from a floor plan, a matching sectional view to the detail holding required information), and instant feedback from the instructor is necessary. The assessment aims to evaluate whether students understand basic knowledge in each unit.

Plan Reading Course Adopting Revit in Fall 2020

Along with a textbook, Revit was added as part of the course as a department requirement. To facilitate added workload to students (only plan reading was covered in previous semesters, but Revit was added to the plan reading), the course was executed with the concept of flipping classes. The main goal of having Revit is to help students learn better in the plan reading course; that is to say, to facilitate 3D visualization of buildings along with consolidating the basic contents while simulating the tasks that are to be done in construction sites; how 2D drawings including floor plans, elevations, sections, details are generated from a 3D model.

Plan reading textbook consists of two parts broadly; the first part covers basics, and the second part covers the actual drawing reading part. The second part follows the construction sequence in large. Contents in Autodesk Revit 2021 Tutorial follow the governing relationship of Revit; that is to say, “Create Walls” comes right after creating a project and adding levels before other tasks as the location of walls makes it convenient to perform other tasks such as creating a building pad, a floor or a roof – the governing relationship or data dependency of Revit.

Two tactics were executed to help students learn better in this plan reading course; one tactic is having Revit, and the other is flipping the class. This 3D visualization through constructing a model using Revit is expected to facilitate students’ understanding of construction sequence and governing relationships in construction. Beyond simply retaining information, Revit adoption is also expected to enable students to perform high-order cognitive tasks such as connecting what they learned in the concept learning part with a 3D model building.

Every class was implemented through a live Zoom and recorded, and the recording was posted on Canvas. The plan reading course that was executed consisted of two parts: fundamental concept parts and the Revit application part. To help students catch the fundamental concepts, basic understanding of drawings and associated terminology, legends, lines, and symbols, Revit was adopted in the second

part of the course (Model 1 in Table 2). Both the concept part and Revit application part comprised pre-class activities and in-class activities holding the concept of flipping the class. For pre-class activity (flipping the class), students were provided with unit summaries and a couple of associated videos for the first concept learning part, and they were given text tutorials and accompanying videos created by Autodesk for the second Revit part on Fridays before the week of instruction.

16 units from the textbook and 13 parts from Revit tutorials were divided into 4 groups, each of which became 4 homework respectively. Besides, students were required to submit a Revit file which showed completion of the work of the day after each class. For the evaluation, one exam was administered assessing the fundamental concepts from the textbook and one term project, building a Revit model from 2D drawings, which assessed whether students were able to visualize in 3D fulfilling the requirements such as placing walls, openings, and roofs at the right location.

Evaluation of the Course

This research conducted the survey after completing the course through email distribution (n=99, response rate=13%). Students in the survey were asked to mark the items that they believe competent; the items are matched with the research objectives. In the data processing, each item was differentiated using 1 (marked) and 0 (unmarked). The survey score was defined as the mean of each survey question (see Table 1).

Table 1.

Evaluation of the course

Objectives: to create teaching and learning steps which	Items to assess: I am competently able to	Survey score
(1) facilitate visualizing buildings in 3D from 2D drawings	visualize the building in 3D from 2D drawings	1.00
(2) define locations and orientations of space and facility of the building	match sections and floor plans; floor plans to elevation views; floor plans/sections to details	0.94
	trace the connection/flows of plumbing, electrical, and HVAC	0.67
	tell the true north from plan north and read bearing	0.78
(3) facilitate having numerical information	read elevations	1.00
	determine missing dimensions	0.89
	locate related sections of building codes	0.83
(4) identify materials along with their properties matching with building codes	read materials	1.00
	determine material properties such as types and thickness	0.94
(5) construct BIM model understanding data dependency	construct BIM model using Revit without support	0.67

All the items assessed were covered in the textbook; the only difference is whether each item is covered in Revit or not. The survey findings show that students better learned the items that are covered in Revit; reading elevation and material, and 3D visualization achieved 1.0, determining missing dimensions, 0.89, reading material property, 0.94, and finding building codes, 0.83. However, distinguishing plan north and true north and reading bearing, 0.78, and tracing the flows of plumbing, electrical, and HVAC showed 0.67, which are not covered in the Revit (see Table 1). From the survey

score in Table 1, it is concluded that having Revit in the plan reading course helped students acquire important components of plan reading; reading drawings got improved through developed visualization using Revit. Although materials are not covered in the Revit part, the survey showed a high score; 1.0 for reading materials and 0.94 for determining material properties such as types and thickness. The reason for these high survey scores is that materials are not directly related to visualization; they are text information. It is also noticeable that 3D visualization achieved 1.0 considering that teaching to have 3D visualization ability is notoriously challenging (Batra et al., 2020). Constructing a 3D model using Revit without support scored 0.67, which is one of the lowest. Although they completed the required tasks of constructing a 3D model from reading 2D drawings, they feel less competent. Developing the full range of Revit skills is not the focus of this course, which is understood to have contributed to the low score. It is also assumed that the score discrepancy between 3D visualization ability and constructing a 3D model without support suggests that improving competence in Revit skills is not directly related to improving 3D visualization.

Although the survey suggests that having Revit in the plan reading course improved the visualization capability and helped learn better in the course (6 out of 10 scored over 0.8 in Table 1), the term project analysis showed a lack of logical thinking. For the term project, students were required to construct a Revit model from 2D drawings of an office building. Due to the limited understanding of dependency between parts like walls and openings, some Revit models of the term project were devoid of foundations under the openings; other models have walls that are extended down through the slab because the walls are placed on the wrong level; other models have a stair to the rooftop which does not have the opening for the stair; other models have multiple slabs on the ground floor; some first floor walls were placed on the foundation level instead of the first-floor level.

Proposed Plan Reading Course

Table 2

Disposition of Revit parts in the course

	Description	Strengths	Concerns
Model 1	Teaching Revit part can be placed after teaching plan reading.	Knowledge acquired in the plan reading consolidates visualizing in 3D acquired from Revit.	Unretained knowledge from plan reading hinders achieving the intended goal or should be taught again.
Model 2	Teaching Revit part can be placed before teaching plan reading	Visualizing ability in 3D helps visualize and understand building components in the plan reading.	Unretained skills from Revit hinder achieving the intended goal, or Revit should be taught again.
Model 3	Teaching Revit part and plan reading part will be juxtaposed with each other.	3D visualization from Revit part and associated knowledge from plan reading can be directly matched.	The sequence of teaching Revit is different from that of teaching plan reading; this difference might make learners confused.

Having Revit in a plan reading course is proven to help students learn to read construction drawings in fall 2020, in which the Revit part came after the plan reading content part. Therefore, reorganizing the sequence of the Revit part is possible to maximize the effect of having Revit in the plan reading course and to address the limitations that are found through the analysis of the term project.

What is critical is that this course is a plan reading course, not a Revit course. A regular Revit course being executed in the department is more sophisticated having the component of controlling the construction project rather than just constructing a 3D model. Reading construction drawings is facilitated if students can spatially visualize, and reading drawings such as matching sections and floor plans; floor plans to elevation views; floor plans/sections to details and tracing the connection/flows of plumbing, electrical, and HVAC especially requires visualization. Therefore, incorporating Revit in the plan reading course is intended to learn better plan reading course with the help of developed visualization ability through constructing a 3D model using Revit.

Each model holds strengths and concerns respectively. Model 1 placing Revit after the plan reading enables students to review the knowledge acquired in the plan reading, and the knowledge from the plan reading will be consolidated while constructing a 3D model. However, if learners do not retain what they are supposed to hold, Revit modeling becomes a meaningless activity without background information on construction and construction drawings. Therefore, for the intended benefits, plan reading should be repeated during the 3D model building part, which is a waste of time (see Table 2).

Model 2 places the Revit parts before the plan reading. The 3D visualization ability may help students learn reading plans as they can visualize the components in 3D from 2D drawings. However, learners construct a 3D model without proper knowledge for construction and construction drawings. Therefore, students might not maintain the intended skills for plan reading, in which case having Revit in the plan reading class loses the ground.

Model 3 positions plan reading and Revit side by side. The merit for this model is applying instantly what they learn to 3D modeling, which could maximize the benefits of incorporating Revit in the plan reading course by designing content learning and practice together (Downing, 2017). However, due to the different dependencies, the sequence of teaching plan reading and teaching Revit should be modified. For example, foundation plans come before structural plans in the textbook following the construction sequence, but placing foundations for convenient reasons comes after placing walls in Revit as the location of the foundation is governed by that of walls. The differences in teaching might make students confused, which hampers the learning experience.

Despite the expected hardships, Model 3 has the highest potential to maximize having Revit in the class as it executes a learn and practice model(Downing, 2017), and it is possible to overcome the expected difficulties using the flipped class. With the possibility to maximize the effect of having Revit and minimizing the danger using the flipped class, Model 3 is worthwhile to be implemented in the class with careful course design.

Table 3 describes the sequence the textbook and Revit tutorials will be covered. References are the units from the textbook that could be referred to for each Revit part. The plan reading course that is designed to incorporate Revit juxtaposing the Revit part with the content part consists of 3 groups. The first group, Units 1 to 7 cover the basics which are to help learn the contents in later units, so these units will be addressed in succession without the intervention of Revit. The second group, Unit 8 to 16 are the main contents which are directly related to reading construction drawings, so each unit takes 2 classes, and Revit does 1 class. The last, Unit 17 represents the application of what is learned in the course. Students will create door/window schedules and take quantities using an automated estimating function in the Revit. They will also create 2D drawings such as sectional views and/or details, which make sheets of construction drawings.

Table 3

Proposed course design incorporating Revit

Plan Reading TOC		Autodesk Revit 2021 Tutorial TOC	References
Unit 1	Construction Drawing Organization		
Unit 2	Construction Math and Application		
Unit 3	Reading Measuring Tools and Using Scales		
Unit 4	Lines and Symbols		
Unit 5	Fundamental Drawing Practices		
Unit 6	Specification and Building Codes		
Unit 7	Construction Material		
Unit 8	Site Plan	Introduction to Revit	
Unit 9	Architectural Drawings	Create a Project and Add Levels	Unit 2, 8
		Create Grids*	Unit 2, 8
		Create Wall Families/Types*	Unit 6, 7
Unit 12-1	Residential Framing Prints	Create Walls	Unit 11,12
		Create a Terrain and a Building Pad	Unit 8
Unit 10	Foundation Prints	Create Foundations	Unit 5, 6, 10
Unit 11	Structural Prints	Create a Floor (Pad, Slab)	Unit 5, 11,12
		Create a Roof & a Ceiling*	Unit 5, 11,12
Unit 12-2	Residential Framing Prints	Place Doors	Unit 12
		Place Windows	Unit 12
		Place a Curtain Wall	Unit 12
		Create Stairs and Railings	Unit 12
Unit 13	Plumbing Prints	Place Plumbing*	Unit 4, 13
Unit 14	HVAC Prints	Place HVAC*	Unit 4, 6, 14
Unit 15	Electrical Prints	Place Electrical*	Unit 4, 6, 15
Unit 16	Welding Prints	Add Welding, Add Notes*	Unit 4, 6, 16
Unit 17	Estimating	Add Dimensions	Unit 3, 4
		Creating Schedules, QTO*	Unit 1, 17
		Create Views - Sections, Details, Note	Unit 1, 5
		Create Sheets	Unit 1, 9

* Autodesk Revit 2021 Tutorial does not include the items, but the designed course includes them.

Some are added to the Autodesk Revit tutorial; they are marked by asterisks (see Table 3). Creating a wall family belongs to a higher-level Revit course, but creating a wall family which consists of multiple layers of material and placing the created wall family is taught to teach that drawings are referred to each other; that is to say, walls in the floor plan do not show the materials, but details of the wall section show material and detailed dimensions. Moreover, students will learn mechanical parts of construction as well, which will enable students to trace connections or flows of them to supplement the low scorings in the Fall 2020 execution (see Table 2).

Basically, flipping the class will be executed; as did in the Fall 2020 execution, unit summaries and accompanying videos will be provided for the contents part, and Autodesk Revit 2021 tutorials will be distributed before classes. Missing tutorials in Autodesk Revit 2021 tutorials will be created and given

along with relevant videos. Having known that adopting Revit to the plan reading course helps students learn better, incorporating the Revit positioning each Revit part according to the contents in the textbook is to maximize the effect of having Revit in the plan reading courses in construction education and to address the lack of the logical thinking, the limitation that is found in the analysis of the term project.

Construction sequence should be considered in the designed course execution. The purpose of improving visualization in the plan reading course is to develop a better understanding of construction. Unfortunately, neither plan reading textbook nor Revit tutorial covers construction sequences. Although textbooks deal with each discretely, construction activities such as framing, drywall installation, MEP installation are not discrete; rather they are overlapping. For example, to make a drywall, framing is followed by one side installation of drywall panel, after which MEP work is done. After the other side install of drywall panel, MEP fixture works follow. In order to address the non-discontinuity of construction work, multimedia resources showing construction sequences will be added to each unit.

Findings and Suggestions

The survey scores were divided into 2 competence levels, high and low. High scores in competence are composed of two groups – getting information from reading texts (reading materials and determining material properties) and from reading drawings (spatial visualization, locating drawings that show matching information, reading elevations which are covered in Revit parts). Items showing low scores are commonly those that are not covered in Revit parts (tracing flows of plumbing, electrical, and HVAC). The low score in constructing the BIM model without support is attributed to the fact that this plan reading course covered a limited range of Revit skills. Term project analysis suggests that students lack logical thinking, which is shown in the models; voids in the foundations under the wall openings, extended walls under the slab, a stair without the opening on the floor to pass through, more than one slab for the ground floor, and having walls on the wrong level.

Empirical analysis suggests that applying the concept of flipped class facilitates students' learning. Out of 8 sections that were executed altogether, students in the 2 sections who consist of the research population met the course requirement of completion without profound difficulties; the only difference is having flipped class or not.

In order to maximize the effectiveness of incorporating Revit and to address the limitations found in the study, it is necessary to study how to incorporate Revit into the plan reading course. Careful course designing is required to maximize the effects of having Revit on the plan reading course as a governing relationship is different between construction sequence and constructing Revit model. The differences should be severely considered when designing and delivering the course.

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