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The Use of Parametric Modeling to Enhance the Understanding of Concrete Formwork Structures

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Over the past twelve years, I have worked as an architect/ planner on various residential, commercial, and retail mixed-use projects in the hospitality and public development sectors. I have managed projects from the initial design stage to completion. Throughout my profession, I have become increasingly involved in project management roles. In addition to my hands-on experience, other areas that interest me in my future research are improved techniques and sustainable construction methods. These are a couple of projects I plan to continue and grow with the Kennesaw State University's support. One of the studies that I have started is the development of performance certification techniques for sustainable sites, water efficiency, energy & atmosphere, materials & resources, indoor environmental quality, innovation, and design. I have also analyzed the cost and schedule for a specific sustainable construction project. Through my capability, I have become well versed in conducting research, writing reports, analyzing and presenting data, and scheduling programs. Currently, I am a graduate student of Kennesaw State University to pursue my Master's degree in Construction Management program.

The use of parametric modeling to enhance the understanding of concrete formwork structures

Abstract

Teaching construction management (CM) courses are often challenging due to students' different learning styles. Students may be required to develop three-dimensional (3D) models by mentally visualizing other project components. Students with little or no practical experience often seem to find such exercises challenging, spending unnecessary amounts of time developing 3D digital models. One example is temporary structures for concrete slab formwork, comprised of four parts: sheathing, joists, stringers, and shores. It indicates the relationship between these parts and the concrete slab, their sizes, and quantity takeoffs. This research introduces an automated parametric tool to foster and encourage learning, allowing students to develop digital models at their own pace through provided, interactive, and easy-to-understand 3D models of a temporary structure.

In this study, parametric modeling tools represent a temporary structure for concrete slab placement applications. The approach helps students to visualize the design of loads and formwork in different configurations through 3D models. Beyond this course exercise, such models could be used to analyze material quantity takeoffs, assess alternative designs, study constructability, and automate shop drawing production. The parametric tools used in this study were Revit and Dynamo. This study aims to determine if and how parametric tools can aid students enrolled in the CM program to better understand 3D models, specifically for representing temporary structures in concrete applications.

To evaluate this study's results, an online survey was designed and distributed among CM students, capturing student learning experience during parametric modeling, and assessing time-efficiency and student engagement. The survey results are analyzed, and data is presented to compare challenges faced with or without using parametric modeling on teaching and learning activities. Results show how this approach increased students' motivation and ability to learn structures with satisfactory results for both instructors and students.

Keywords: parametric modeling, concrete slab formwork, construction management curriculum, building information modeling (BIM), 3D model, Revit, Dynamo.

Introduction

Computer models with 3D visualization help increase student understanding of complex course material, providing an opportunity to enhance visual-spatial skills. Glick et. al [1] conducted a survey using 3D visualization, indicating that curriculum benefits from the use of 3D models [1]. Building Information Modeling (BIM) in Construction Management (CM) education has not only the potential to be a graphic representation tool, but also a means to enhance student learning [2]. Irrizarry et. al [2] explored how new digital tools help students overcome challenges and measure their effectiveness, concluding that students face a challenge in grasping certain concepts because of difficulty visualizing the concepts being taught.

Further research discusses student perceptions of BIM application, knowledge and skill development, and possible career success attributed to CM courses. Suwal and Singh [3] focused on students' perception of BIM courses, BIM learning platforms, and BIM tools, suggesting that online BIM learning platforms are highly rated by students as a positive learning experience and noting the need for greater integration tools in other AEC courses. Student perceptions of BIM were studied by Adhikari et al [4] on CM students. The result indicated that 90% of the respondents had heard of BIM. There were 71% of the respondents who knew of BIM heard it at University. On the other hand, most students thought they had an average or low level of BIM familiarity and competency. Ku et. al [5] explored the status of BIM implementation, organizational structures, training requirements, and construction companies' strategies and examined CM graduates' expectations. Their findings suggest that BIM is growing as an essential component of the construction industry.

Joannides et al [6] evaluated the implementation of BIM in architecture and construction academic programs. Many of the schools expected their students to have basic knowledge of BIM upon graduation. However, implementing BIM into undergraduate programs has some challenges due to available class time, student knowledge retention, and the curriculum's flexibility to adapt to the fast-developing technology [7].

Ahn and Kim [8] examined the degree of awareness and acceptance of BIM among architecture students in Asia. The results showed that students have recognition, interest, and experience with BIM and IFC (Industry Foundation Classes). Clevenger et al [9] proposed BIM-enabled educational modules designed to support and enhance spatial understanding, interoperability, and communication within construction education and training, presenting three different modules: development, implementation, and assessment. Lu et al [10] measured the benefits of BIM as a learning tool in real-life construction tasks with and without BIM, suggesting that BIM provides a less-expensive virtual environment for learning by doing and for project-management of construction activities.

Design and visualization, specifically concrete formwork, have been more comfortable using BIM; tasks' productivity, including formwork selection, design, and material quantity estimation is increased. Barak et al [11] carried-out research to establish detailed functional requirements for future BIM tools that will enable engineering, production detailing, and construction management of Cast in Place (CIP) RC (Reinforced Concrete) structures, derived from a process model used to understand the processes surrounding reinforced concrete design and production. Meadati et al [12] defined the learning styles of construction engineering and management (CEM) students in a concrete formwork course, describing how BIM was used to facilitate visual learning in teaching formwork concepts to CEM students. Meadati et al [13] discussed various applications of a concrete formwork repository developed through BIM, which can be used for different applications during various concrete formwork lifecycle phases. Since formwork systems layout is significantly impacted by site characteristics and factors such as storage, transportation, assembly, and erection, there is a need for an efficient method of managing such phases. Uwimana [14] analyzed BIM application in the ergo-technical design of the formwork phase and its advantages.

Jin et al [15] proposed a BIM-based tool to help to design concrete formwork. The Revit API (Application Programming Interface) tool integrates information associated with individual elements in BIM models and design processes, developing a tool that provides contractors in planning concrete operations. Revit API was used by Sing et al [16] to automate iterative production-oriented activities for the formwork of concrete walls, providing automation of formwork design, production, layout, and 4D simulation. Jin and Gambatese's [17] investigation found that temporary structures have a greater potential for construction innovations as compared to permanent structures. Typically, the AEC industry pays less attention to temporary structures and more attention to improving temporary structures' safety performance. Collins [18] explored the process of incorporating Revit into the architectural precast concrete manufacturer's workflow, tracking a real-world project from a design intent model by incorporating industry-specific fabrication details to generate digital models. This research also assists in the production of shop drawings and shop tickets using that model. Collins [18] described three approaches to creating custom Revit models: using parametric Revit families, through Dynamo scripting, and via Excel spreadsheet input.

Although research shows the positive impact of the introduction of BIM platforms on students' learning experiences, more data is needed on methodologies for introducing practical BIM techniques in the classroom and course work. This research aims to begin addressing this gap, focusing on introducing temporary structures slab concrete formwork using BIM parametric software. There are five critical aspects of this process: 1) Defining design of concrete slab formwork; 2) Development of Revit model families; 3) Dynamo script generation; 4) Modeling of slab formwork structure using Revit and Dynamo; 5) Student perception of generating BIM models. A learning objective is associated with each step, making the use of the software a powerful tool to introduce new concepts.

Objectives

This paper presents a study conducted to understand whether the introduction of parametric design software can improve CM students' understanding of temporary formwork structures. One strategy used in this study to incorporate spatial and visual aspects of the project was to bridge CM's expertise to the architectural realm, bringing faculty with an architectural background into the classroom. This study's motivation is in response to previous students' course feedback and to address the lack of understanding of the design of temporary formwork structures.

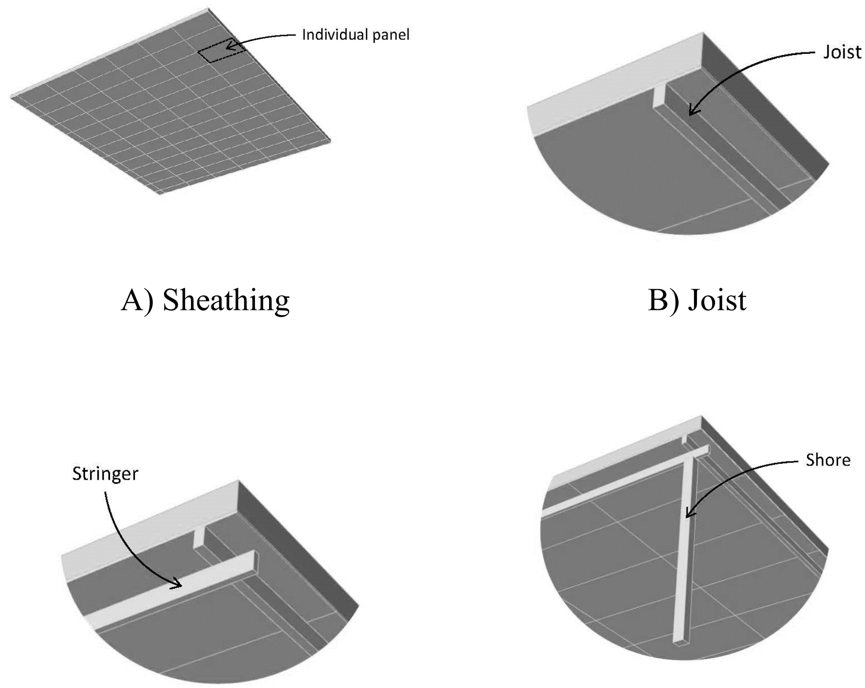
Parametric modeling – specifically the use of Revit and Dynamo – was chosen as a tool for this study because it allows flexible configurations and optimization of formwork designs while keeping other conditions constant, namely the concrete slab's size. It capitalizes on a key advantage of parametric modeling; that once a model is defined, the shape of model geometry can be adjusted without remodeling. Students will therefore be able to customize the provided model for themselves.

Model elements are initially developed using Revit. Then, Dynamo – a visual scripting interface embedded in Revit – is used to automate model elements' distribution. A key benefit of Dynamo is the ability to customize standard Revit components. This research aims to examine the role of parametric tools in the classroom and their effect on student learning. Further analysis could extend this investigation to look at other variables such as cost, schedule, structural member sizing, etc.

Methodology

There was a total of 30 students in the temporary structure class. For a specific assignment was prepared to introduce parametric software, students were tasked with designing the formwork for a slab. For this project, the thickness of the concrete slab was given 6 inches, the slab's length (L) 292.33ft, and the width of the slab (W) 123.33 ft. For designing concrete formwork, students needed to make some assumptions such as temperature, rate of placement, and other concrete properties. Four components were considered as part of the slab formwork design as shown in Figure 1: A) SJ- sheathing (plywood panel); B) Joist – horizontal structural member supporting sheathing; C) Stringer – horizontal structural member supporting joists; and D) Shore – vertical structural member supporting stringers. Joists are perpendicular to slab length, stringers to slab width, and shores are along the slab's length and width.

The assignment focused on developing concrete slab temporary formwork structure and was introduced in steps according to the five key aspects of this study: 1) Defining design of concrete slab formwork; 2) development of Revit model families; 3) Dynamo script generation; 4) Modeling of slab formwork structure using Revit and Dynamo; 5) Student perception of generating parametric models. Specifically, during step 1, students determined the appropriate size of sheathing, the size of joists, the size of stringers, and the shores' size. They also determined the spacing of joists, stringers, and shores. A sample calculation of the size and spacing of slab formwork is shown in Table 1. To determine the size and spacing of formwork components, students followed the ACI 347 guidelines [19], Formwork for concrete. During step 2, based on the calculation of size and spacing of formwork components, students developed a parametric Revit family defining relationships between slab formwork, sheathing, and a single joist, stringer, and shore (shown in Figure 2a). Each student may have different size components. In steps 3 and 4, students implement the provided Dynamo script, placing components across the concrete slab pouring areas (shown in Figure 2b). After students developed a full model of the slab formwork and completed the assignment, during step 5, a survey was distributed to gather feedback and examine experience while developing parametric models.



A) Sheathing B) Joist

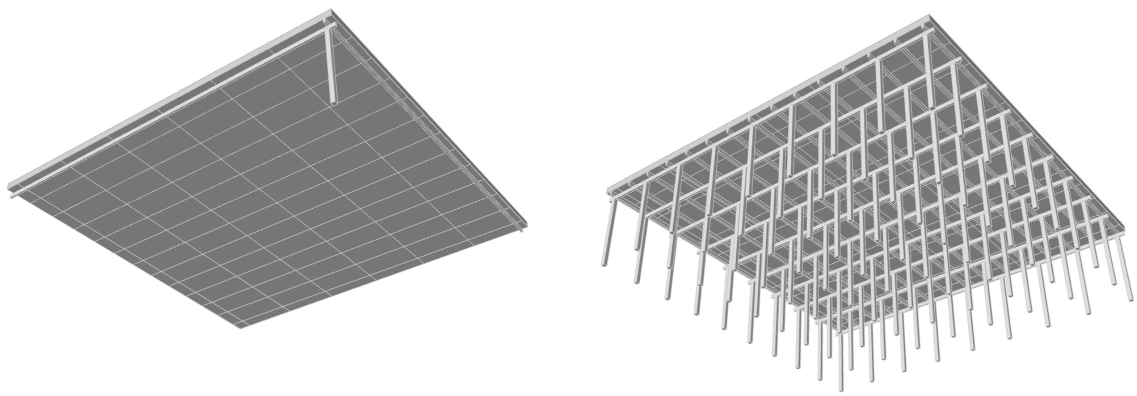
C) Stringer D) Shore

Figure 1: Components of concrete formwork structure

Table 1: A sample calculation of the size and spacing of slab formwork

Slab formwork components	Size, in	Spacing (in)	Number
Plywood Sheathing thickness (Size 8'x4') inches	0.75		1109 Pcs
Joists	S4S 2x4	21	160 x 121.33 = 19,412 LF
Stringer	S4S 2x4	41	36 x 292.33 = 10,524 LF
Shores	S4S 4x4	45	78 x 36 = 2,808 Pcs

The number of joists along slab width = 160; The number of stringers along slab length = 36
The number of shores per stringer line = 78 and shore height =12 ft.



A) Initial assembly model B) Model after arraying model elements

Figure 2: Modelling in Revit and Dynamo

The survey investigated four major aspects of students' perceptions of the parametric model, (A) Duration; (B) Ease of Learning; (C) Level of Satisfaction Accomplishment; and (D) Level of Challenge. The survey consisted of multiple-choice questions designed in such a manner that the respondents could complete the study within 3 minutes. Questions included:

1. How long you took to finish each activities activity of BIM courses?
2. On a scale of 1 (lowest) – 5 (highest), please rate Ease of learning commands to complete each activities activity of BIM courses.
3. On a scale of 1 (lowest) – 5 (highest), please rate the level of satisfaction of your accomplishment of each activities activity of BIM courses.
4. On a scale of 1 (lowest) – 5 (highest), please rate the level of challenge of each activities activity of BIM courses.
5. On a scale of 1 (lowest) – 5 (highest), please rate your Confidence level to complete a similar project related to each activities activity of the BIM course.

Development of parametric formwork model

The introduction of temporary formwork was done through parametric modeling. Consequently, the large number of variables with complex interactions among them had to be addressed and defined ahead of time. The list of parameters and methods used to generate the parametric models in Revit and Dynamo by instructors to prepare, study, analyze and include all possible configurations for student designs are listed in Table 2 below.

A set of models were created for student use and customization within their temporary framing project from these variables. These models were created in Revit, specifically using *Generic Model Template Family* files. For each model, *Reference Planes* are used to define dimension strings and, thereby, *Instance Parameters* for each of the above variables and relationships. After the creation of joist, stringer, and shore models, an assembly model is created. This model includes the slab and sheathing and inserts and locates a single joist, stringer, and shore.

Table 2: Model variables and relationships

	Variable	Relationship
1	Slab width	
2	Slab length	
3	Slab thickness	
4	Sheathing thickness	
5	Joist width	
6	Joist height	
7	Joist length	same as slab width
8	Joist location	offset from end of slab to center of joist
9	Dimension between joints	nominal
10	Stringer width	
11	Stringer height	
12	Stringer length	same as slab length
13	Stringer location	offset from end of slab to center of stringer
14	Dimension between stringers	nominal
15	Shore width in X direction	
16	Shore width of Y direction	
17	Shore height	
18	Shore location	offset from end of slab to center of shore
19	Dimension between shores along length	nominal
20	Dimension between shores along width	same as dimension between stringers

Refer to the above Table 2, dimensions between joists, stringers, and shores along the length are described as "nominal" on items #9, #14, and #19. The reason for this nomenclature is to assure that these elements are distributed evenly across the slab. A predefined spacing and number of these elements may not necessarily be a factor of the slab width or length. To account for and remediate this scenario, in addition to arraying the models, the Dynamo script also calculates the actual dimension between these elements based on the provided quantities, slab dimensions, and spacing to ends of slabs and enters this new "actual" spacing figure into the array operation.

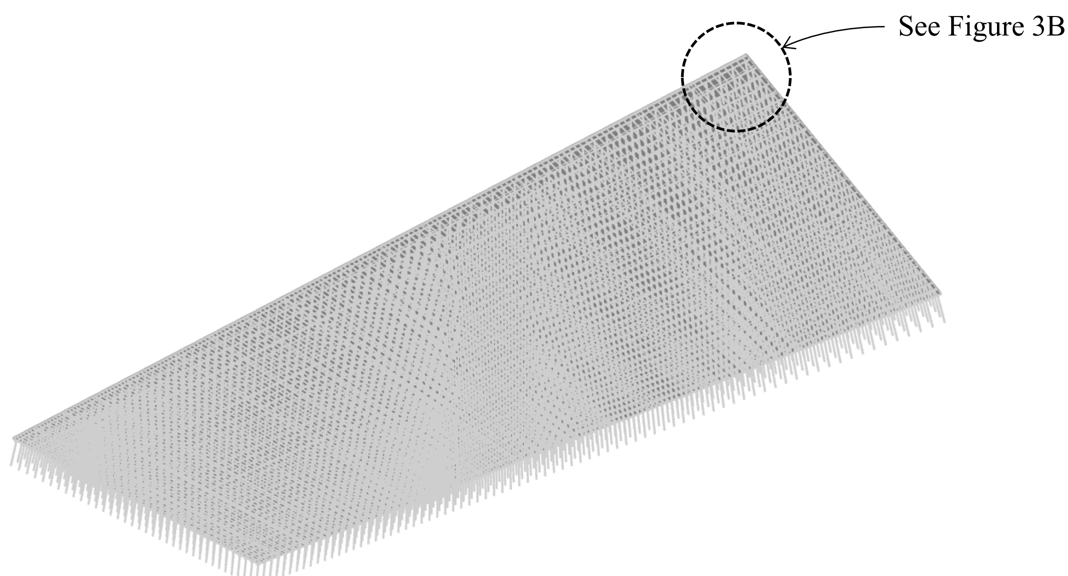
The following items were provided to students in the course:

- PowerPoint presentation
  - Part 1: Parametric modeling
  - Part 2: Visual scripting
- Revit Family models
  - Joist
  - Stringer
  - Shore
  - Initial assembly (includes slab, sheathing, and references above the joist, stringer, and shore)
- Dynamo file script
- Word document outlining steps for model creation

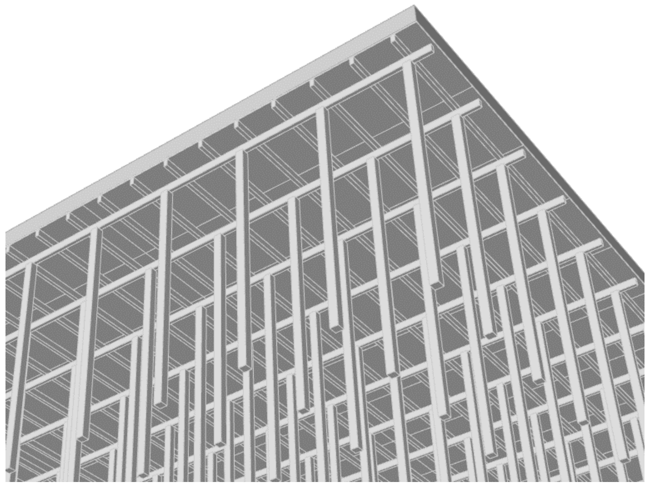
Three class sessions were used to get students introduced to the software and complete the assignment. Specifically:

- Class one introduced students to parametric modeling, demonstrating the creation and use of Revit models.
- Class two introduced students to visual scripting, demonstrating the creation and use of Dynamo models.
- Class three was used to check on students' progress, questions and answers.

Figure 3 shows sample views of student work from this project based on the component sizes listed in table 1 that mentioned sample calculation of the size and spacing of slab formwork.



A) The full model of slab formwork



B) Enlarged formwork detail

Figure 3: Sample student model

Course assessment and results

Data was collected from a Qualtrics survey, gathering responses to provide the instructors with feedback on student learning and experience. Questionnaires were issued to students at the end of the semester, after they finalized their BIM parametric models. There were 19 respondents for this study. For each question, students were asked to evaluate their experience with parametric modeling based on:

- Confidence level – evaluation of students' confidence in learning a new tool for visualization and simulation of the design and construction process.
- Level of challenge – evaluation of students' interest in learning the course material, the general attentiveness of a class, and the intellectual challenge of a course.
- Level of satisfaction – satisfaction delivers important information from students that may be important in defining what courses are successfully delivered and which may need improvement.
- Ease of learning – evaluates students' understanding of slab formwork concrete assignments with which they have been engaged.
- Time – the amount of time that a student use the new software and prepared their work for the class.

Confidence level, level of challenge, level of satisfaction, and ease of learning were evaluated on a scale of 1 to 5. The results are reported in Figures 4, 5 and 6.

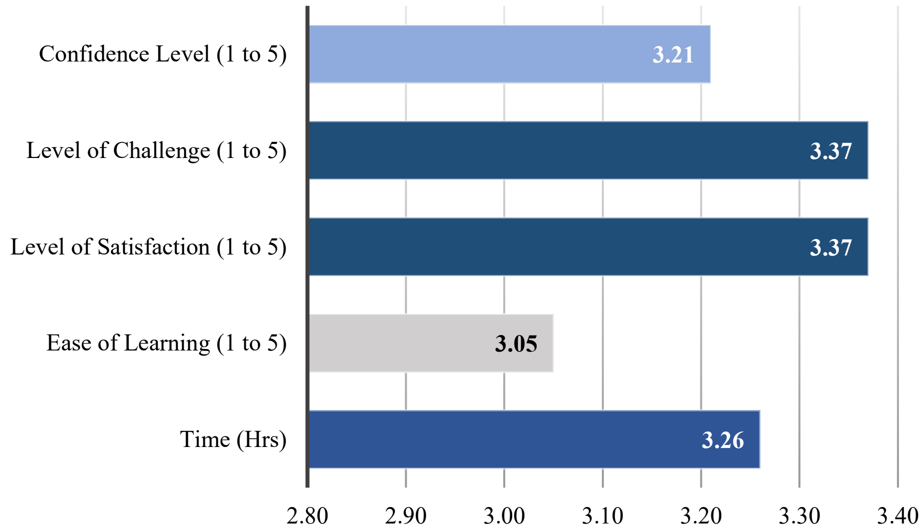


Figure 4: Students Response of Parametric Modelling of Concrete Formwork

As shown in Figure 4, students rated level of challenge and level of satisfaction an average of 3.37 out of 5; a good indicator that students perceived the assignment as moderately difficult but worthwhile. The chart also shows that students spent an average of 3.26 hours to finish their work. When asked about the parametric modelling techniques used, students responded: "*I found… [parametric modelling] useful with showing how the whole concept of plugging in our calculated numbers into the template to then create the model itself was,*" and *"Once I got used to it, I felt that it was a great tool that should be taught early on in the CM or CE curriculum."*

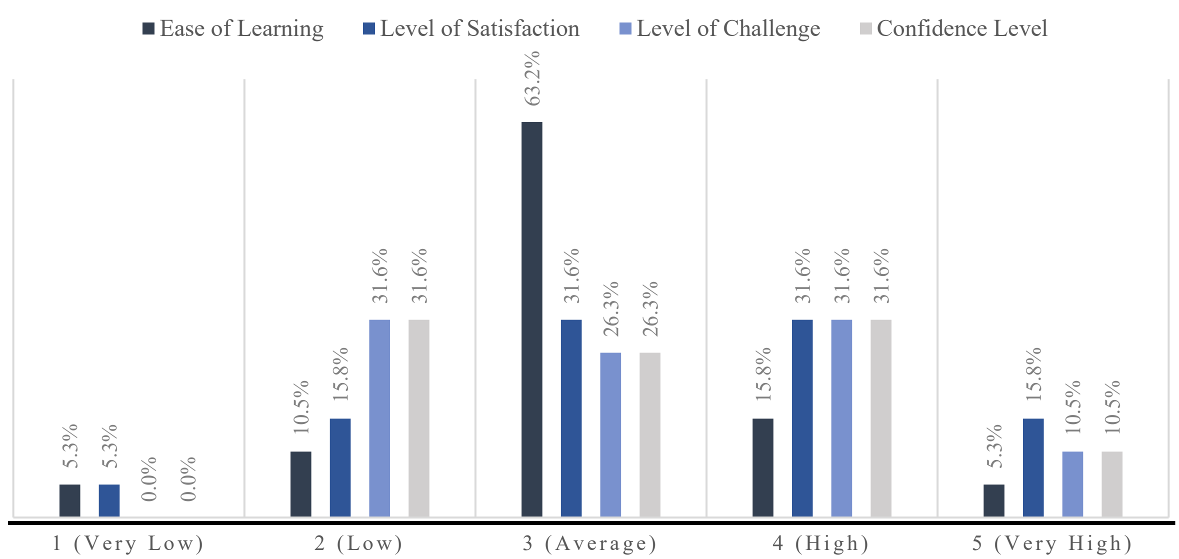


Figure 5: Students Response of Parametric Modelling of Concrete Formwork (5 Likert scales)

Beyond seeking information about the course content and the teaching methods, the survey also sought to evaluate the parametric modeling implementation and goal of enhancing understanding of concrete formwork structures. Data in Figure 5 shows that 63.2% of students scored ease of learning a 3 out of 5, indicating a majority of students grasped the concepts discussed and their applicability to the concrete formwork assignment. When asked about the most important concept they learned about parametric modelling, students noted, *"How to make the model of a building easier and more efficient,"* and *"That is easier to use, I never heard about the program before this class and it would be nice to learn more in other classes."*

Figure 5 also shows that ratings for level of challenge were dispersed; 31.6% rated 2 out of 5, 26.3% rated 3 out of 5, and 31.6% rated 4 out of 5. When asked which concepts were difficult to understand, students responded: *"I think initially the whole software seemed overwhelming and confusing because it was something brand new to me," and "Mainly how it all worked since I never used it before but the information provided by the instructor was very helpful."*

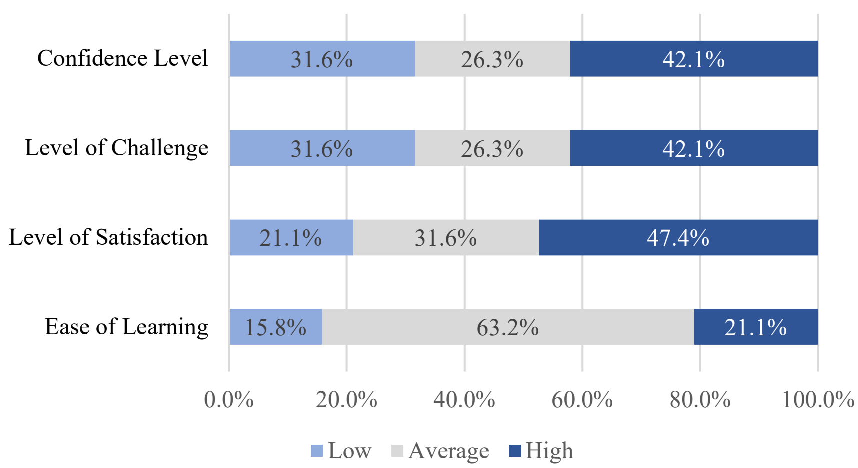


Figure 6: Overall students' perception of Parametric Modelling

Respondents to the survey seemed to find the parametric modelling exercises interesting, enjoyable, and intellectually challenging. Figure 6 shows a high percentage in confidence level (42.1%), level of challenge (42.1%), and level of satisfaction (47.4%). When asked for recommendations for improvements to the parametric modelling exercises, students suggested: *"Maybe [the assignment description could include] a little more information about the program and how it can be used for other models such as wall formwork and column formwork,"* and *"Go more in depth with making [Revit and Dynamo] templates on our own."*

Conclusions

This paper summarized a method for addressing CM student motivation and understanding of temporary structures through the use of BIM software. Assignment results and survey responses demonstrate a high level of satisfaction for both instructors and students and an eagerness on students' part to learn more about BIM software. In general, student motivation appeared to be improved with the use of parametric modeling, enabling them to learn CM strategies as well as a new analytical tool. The level of student involvement was increased through the practice of different sets of skills (i.e., problem-solving, analytical, software). Furthermore, students noted how the modeling exercises improved their visualization of temporary formwork structures.

Based on the course assessment results, the project will be further modified for future applications. Specifically, future assignments will incorporate further modelling by students in addition to provided model templates. Examples of parametric modelling use in real-world projects will also be presented, connecting classroom techniques to application in professional activities. The project schedule will also be adjusted to allow more time to practice modelling iterations.

In conclusion, the methodology presented in this study helped to improve students' understanding of temporary structures in concrete applications. The introduction of parametric BIM software allowed students improve technical skills while increasing coursework motivation. Future studies will continue to improve these methods while expanding benefits of 3D digital models to include, for example, structural analysis, quantity take-offs, and cost estimating.

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