Fundamentals of Framing Construction in Architectural Engineering: A Hands-on Learning Experience

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Abstract

Education of framing construction is a component of the undergraduate architectural engineering curriculum. Besides the traditional lecture learning environment, problem-based learning (PBL) is an alternative to support teaching fundamentals of framing construction. PBL can be described as a learning environment where the problem drives learning or as "learning by doing". It has been implemented at different levels of education in the world since first introduced in 1960's. For a university curriculum it may be recommended that using multiple educational models together as traditional lecture learning environment and PBL may be beneficial. PBL activity can be supported by preparatory blocks / sections such as mock-up assembly as PBL exercise in this case study. This approach was accepted in Missouri S&T Architectural Engineering Program ArchE 103 course during spring 2014 term to maintain a hands-on learning experience on framing construction. The PBL activity was narrowed through "the task project" as completion of scaled model study of timber frame house by the help of user / design guide. The PBL activity was formulated by the help of prefabrication rules, open building concept and prescriptive codes. Framing construction was selected as timber framing system because of consistent demand at the construction industry and ease of availability and workability with balsa sticks to study scaled models. Other construction methods, such as; prefabricated reinforced concrete system or cold-formed steel framing system were discussed in lecture but not developed into a scale model PBL exercise due to cost. Evaluation criteria are important for the students to evaluate their work products more consciously. In order to determine the outcomes of the PBL activity in this case study, a survey was held two times before and after the hands-on learning experience. The survey results show that the PBL activity had positive impact on the traditional lecture learning environment.

Introduction

Demand for framing construction using either timber or cold-formed steel is widespread around the world. Therefore, engineers and architects need basic knowledge of these framing construction methods. In order to meet needs of future engineers and architects, education of framing construction methods has become an essential part of the undergraduate curriculum. Rules and possible outcomes of problem-based learning are incorporated with the thought learning environment to teach the fundamentals of framing construction instead of using traditional learning environment. Particularly in architectural engineering education, hands-on learning experience is crucial to improve design skills and longer retention of desired knowledge

received in the university. The pedagogical approach is being presented herein in order to focus on the case study in Missouri University of Science & Technology (Missouri S&T) Architectural Engineering Program.

1. Problem-based learning (PBL)

Traditional lecture learning environments have been criticized as being not suited to all students and not developing the prerequisites for professional expertise; the emphasis can be on giving information rather than learning [1] [2]. In practice, young professionals need the ability to analyze problems, to separate complex matters into sub-problems and to solve these problems without losing sight of the whole picture [3].

Problem-based learning (PBL) helps to bridge the gap between academia and practice [4]. PBL can be described as a learning environment where the problem drives the learning [5]. PBL is an approach to professional education that stresses the use of real-life problems as a stimulus for learning [4]. PBL is viewed as a model for classroom activity that shifts away from teacher-centered instruction and emphasizes student-centered projects [6]. This technique usually involves learning in small groups, which are supervised by tutors [5] [7]. PBL asks for an active learning attitude and students are in a constructive investigation [1] [8].

Project-based learning is still more often used in K-12 whereas in post-secondary education problem-based learning is more commonly used [9]. Many of the principles of project-based learning are common to problem-based learning as well [10] [11]. The difference between two terminologies is; problem-based learning is more often single-subject, project-based learning is often multi-disciplinary subject [9].

John Dewey, educational pragmatism, supported the *"learning by doing"* approach to education as far back as the early 1900's, which is the essential element of PBL [12] [13] [6]. Formalized PBL began in the late 1960's at Faculty of Medicine McMaster University in Canada by Howard Barrows and rapidly flourished as an educational technique in the health sciences [14] [4]. At first PBL was mostly applied in new schools in 1970's, starting fresh with the development of a completely new curriculum, like the University of Maastricht in the Netherlands, Newcastle University in Australia and the University of Aalborg in Demark. These were among the first medical schools to adopt PBL [15] [16]. Also, PBL has been formally adopted by some architectural schools in the world. The architectural faculties at Newcastle in Australia and Delft in the Netherlands, as two examples, made the transition to a formalized PBL curriculum in the 1990's [4]. Since then many different varieties of PBL have emerged and PBL is widely regarded as a successful and innovative method for engineering education [1] [17] [7].

Criticism leveled at US engineering schools include: they offer too few "practical" and "hands-on" courses in terms of freshman engineering design experiences [18]. As a field, PBL is still in the developmental stage. For example, there is not sufficient research or empirical data to state that PBL is a proven alternative to other forms of instruction in engineering schools [19]. PBL in beginning engineering design education still requires further study [4].

Possible PBL outcomes are; an intrinsic motivation to learn, effective problem-solving skills**,** self-directed, life-long learning skills, effective collaboration skills, improved understanding and retention of course content [5] [4]. It is a very common experience that students are more motivated and work much harder with the PBL model than with traditional teaching methods [7]. The tutor (teacher) is the facilitator of the learning process; the tutor does not have the role of transmitter of knowledge. She/he stimulates the group discussions and monitors the social group processes. The problems are used as a tool to identify the required knowledge to eventually solve the problem [1].

It is essential that architectural engineering students develop both quantitative and qualitative understanding of engineering concepts and principles. Small-scale modeling provides students with opportunities to discover that learning structural engineering principles can be an enjoyable experience that leaves a stronger impression for longer retention [20]. Three fundamental types of project work can be distinguished in PBL: *the task project, the discipline project and the problem project* [7]. The task project is characterized by a very high degree of planning and the choices are made for students in advance. The problem project is a full scale project in which the course of action is not planned in detail by the instructor. In terms of analogy of a football game, this means that the students have the ball but lack the playing regulations and a marked playing field. The freedom on design or studied subject is increased and limitation on PBL is decreased through *problem project* [7].

1.1 The methodology of "the task project" studied in case study

The methodology of "the task project" studied in this case study consists of three crucial aspects. These are prefabrication rules, open building concept and prescriptive methods and presented to the students in a user / design guide;

- The modular coordination in *prefabrication rules* maintains designer and manufacturer ease of coordination between building components. Before introduction of open building concept, the focus was very much on "modulation" and "prefabrication" [21].
- *Open building concept* increases design diversity in prefabrication which was introduced in 1960's by John Habraken. Decision making process is distinguished in levels as "support (base building) level" and "in-fill (fit-out) level" and particularly "dimensional coordination" is focused [22]. Common conventions are required to implement open building concept in building industrialization to use limited number of members by dimensional coordination [23]. Common conventions refer user / design guide as it is in toy and furniture industry such as; meccano, lego, ikea, etc.
- *Prescriptive codes* [24] are being used during design education of framing construction system in this undergraduate architectural engineering course. The use of prescriptive codes and how they impact the design of construction system in addition to hands-on learning help the students to better understand design principles of framing construction. Design limitations of PBL activity can be described as within the limits of prescriptive codes such as; it is possible to cross longer span for floor joists than accepted dimension according to prescriptive codes.

1.2 PBL in architectural and engineering curriculum

The Faculties of Architecture in Newcastle University (Australia) and Delft University (Netherland) were among the first to embrace this new PBL educational methodology. Both faculties started to develop their problem based curriculum after the example of medical school education [16].

PBL Curriculum in Newcastle University; Integrated PBL was introduced in 1984 in Faculty of Architecture Newcastle University in Australia. The integration of subjects in a PBL curriculum is by no means an easy task. In the beginning, there was no formal lecturing. Between 1984 and 1995, the concept was gradually modified and now various educational formats are applied. In some areas, there are lectures supporting the 'phase problems' and tutorials to build up a theoretical base and model testing sessions to exercise technical skills, etc. [16]

PBL Curriculum in Delft University; By the end of the 1980's criticisms from outside the faculty of architecture at Delft University resulted in a proposal to develop a new curriculum. The PBL curriculum in Architecture was modelled in 1990 after the example of Maastricht, with thematic blocks, integration of theoretical knowledge and practice through cases discussion, supervised by a tutor. The implementation of the PBL curriculum in the faculty of Architecture in Delft University has to be characterized as a top down decision. As a consequence, the new PBL curriculum in Delft University faced some difficulties. Step by step elements of the PBL curriculum were altered or changed back into the old familiar format. A little more than fifteen years after the introduction of PBL, the last leftovers were removed [15].

In both cases, full integration of the technical disciplines proved not to be completely successful. Students may lack the necessary minimum of prior knowledge to be able to formulate productive learning goals. As a consequence, the continuance and sequencing in the curriculum is broken. Based on these experiences, an alternative is suggested in which various educational formats are employed to support the problem-based learning process. Prior to introducing the *PBL learning blocks*, a series of *preparatory learning blocks* are offered. This allows the students to master some subjects in which their prior knowledge is below a minimum level. Preparatory blocks should provide students with knowledge they can apply in PBL blocks, and the PBL blocks should motivate students to explore further in-depth study [16].

2. Case study at Missouri S&T

“ArchE 103 Architectural Materials and Methods of Building Construction” is an introductory undergraduate course at Missouri S&T Architectural Engineering Program. The course description can be summarized as a study of the origin and properties of construction materials, methods of building construction and installation. General outcomes of the course are;

- The student will develop a basic knowledge of the materials used in typical building construction, including their sources, manufacturing processes, and used area.
- The student will also gain an understanding of the basic testing methods used to evaluate material performance.

- The student will gain an understanding of methods of building construction. The course will expand the students understanding of a building as a system. Introduction of design parameters, material properties and technological facilities combine the idea of several sub system as a building system.

A variety topic are covered in the lectures such as; building codes and standards, thermal properties of materials, masonry, wood light frame construction, structural steel and cold-formed steel construction, etc. The course is distinguished as lecture and lab sections. Lab section is also divided in three parts as material test activity, mock up assembly activity and scaled model activity. PBL is in use in lab sessions and hands–on learning is experienced by the students in order to achieve better understanding and longer retention of the fundamentals of framing construction. Both traditional lectures and construction site visit activities were included in the preparatory block prior to the PBL activity (Table 1).

Table 1. Scope of PBL activity in ArchE 103 course

Preparatory block / section	PBL block / section
traditional lectures	mock up activity (PBL exercise)
construction site visit	scaled model study (main PBL activity)

Teaching the fundamentals of framing construction is an essential part of architectural engineering since it covers both material properties (strength, thermal properties, connection type, etc.) and installation principles.

3. PBL activity in ArchE 103 course

The framing system in ArchE 103 course was selected as timber framing due to consistent demand of construction industry and availability and workability of balsa sticks during scaled model study activity by the students. A hands-on learning activity such as PBL is strictly dependent on the material which the students work with. Prefabricated reinforced concrete (r.c.) system, timber and cold-formed steel framing systems were previously studied as scaled models. Results of scaled models (1/20 scale) using a prefabricated r.c. system produced by foam board was not satisfactory and a 3D printer result was costly for the students. On the other hand, it was difficult to find small members symbolizing galvanized C and U cold-formed steel profiles and it was not easy to work in 1/20 or 1/10 scale by the students. Whereas, balsa sticks are widely available and workable while erecting a timber frame scaled model by the students [25] [26]. After being introduced to the basic framing knowledge from the lectures and a timber frame construction site visit, the students were ready for doing a PBL mock -up exercise activity.

3.1 Construction site visit (preparatory block / section)

After introducing the basic principles of timber framing in the lectures, the students had a visit to a construction site to observe a timber frame building installation (Figure 1). They observed and obtained knowledge from the instructor and builder regarding the fundamentals of framing construction during their site visit. This provided a good learning environment with actual construction and materials before starting their scaled model study.

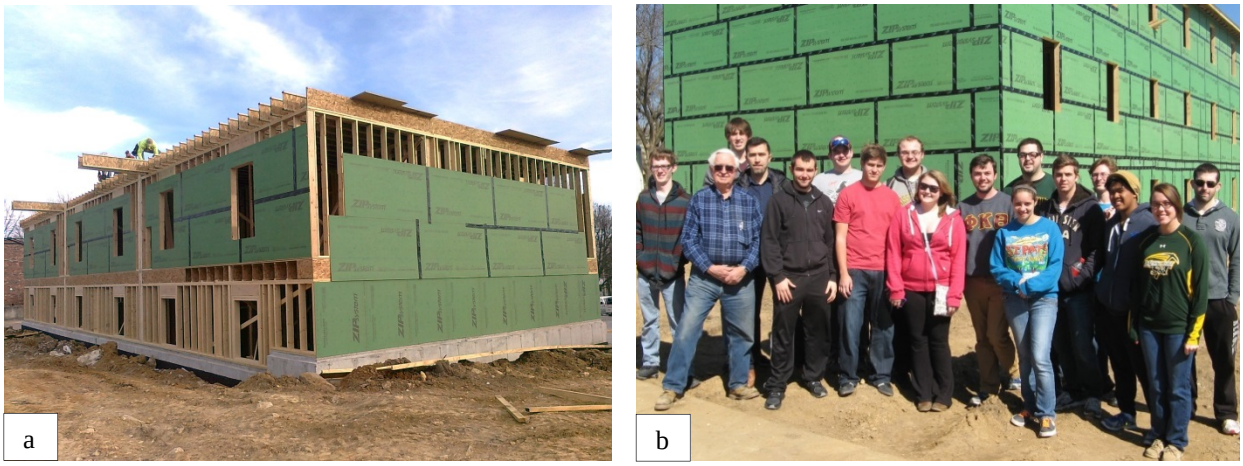


Figure 1. Visiting of timber frame construction site in Rolla, Missouri by ArchE 103 students in spring 2014 term

3.2 Mock-up study phase as PBL exercise (PBL block / section)

The mock-up study phase of the PBL activity was an exercise for the students before starting their timber frame scaled model activity. Framing construction has some specific principles to assembly. The students had been introduced to basic principles of framing construction such as; in-line framing, on-center stud location, principles of platform framing, building envelope, etc.

Two mock-ups were chosen and the size of the materials was scaled in order to better handle and enable completion during the available laboratory time. As illustrated by Figure 2, the study was not a full building study but it was a partial building mock-up of the corner of a two-story house. The roles of instructor were; monitoring the student's performance on the learning activity and helping in critical details to a better understanding of the framing.

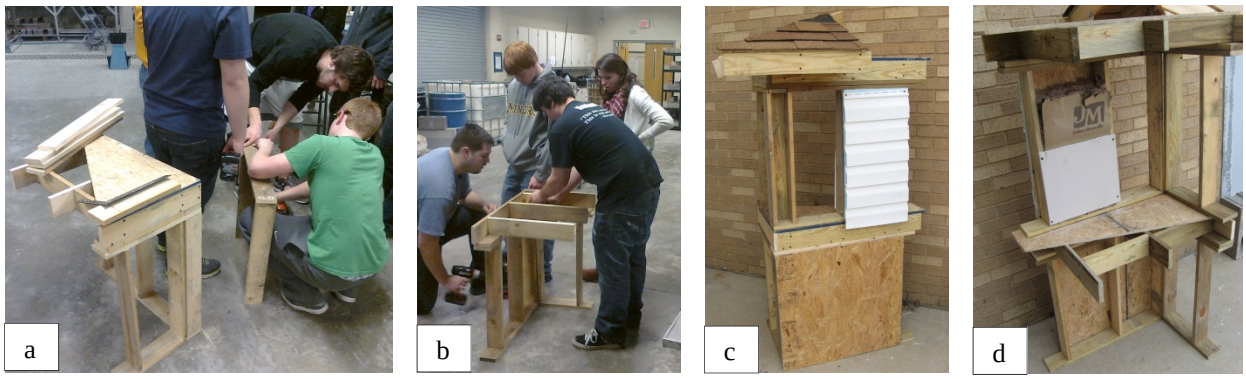


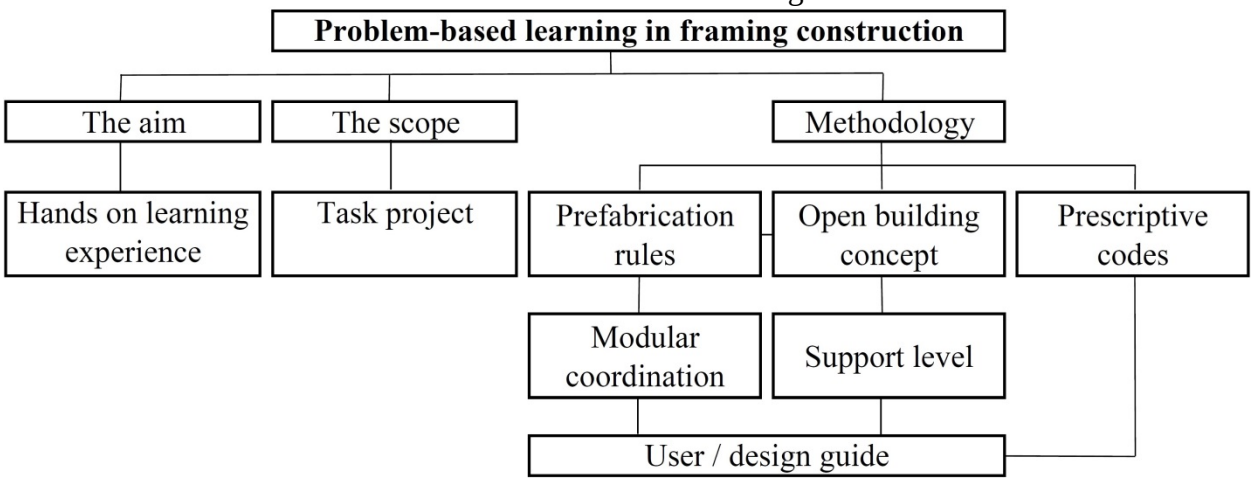
Figure 2. Mock-up assembly of timber framing

3.3 Timber frame scaled model study as main PBL activity (PBL block / section)

The educational model used for teaching fundamentals of framing construction is accepted as PBL in terms of the pedagogical approach. Possible outcomes of PBL described in 'Section 1' are exactly matching with the aim of the course as hands-on learning experience. The PBL activity was introduced at the latter part of the course after, basic knowledge of framing

construction provided to the students during traditional lectures. Problem-based learning activity for framing construction in ArchE 103 course is formulated in Table 2.

Table 2. Formulation of PBL in framing construction



The scope of the study in terms of PBL activity is described as "task project" by determining details in depth. Also the main goal of the activity was that the students better understand the fundamentals of framing construction and be exposed to team-based learning by working together in teams. A building consists of a variety of subsystems and requires different kind of expertise during design and construction phases. Therefore, team work between the variety architectural and engineering disciplines is an essential part of a success building construction. That is why team work as a learning activity was selected in this PBL activity instead of individual effort.

The enrollment in ArchE 103 course during spring 2014 term was 52. The students formed 13 teams with 4 team members each for the main PBL activity. The PBL activity was introduced to the students in first related laboratory section by supplying information as shown in Table 3. The duration of the study was 5 weeks at the end of the term. It is crucial that the students totally understand the project, possible outcomes, scope and methodology in order to complete "the task project" on time and successfully. So, before starting the scaled model study, students must have basic knowledge of framing construction and all related data of "the task project". This information was provided to the students by using hand-outs.

The role of instructor was to monitor the process of the study and supervise the students regarding how they use the supplied documents. The hand-outs served as a user / design guide. This material was provided to help to solve the project and it included written and visual documents (Table 4). A sample of the written documents is shown in Tables 5. Figure 3 illustrates several of the 13 building types as visual document that the students could consider for their scale model.

Four different modules are accepted and the variations of these modules create the building types as variety shape and number of story (Figure 3).

Table 3. Introduction of PBL activity to the students

1. Introduction of the problem	2. Duration of the study	3. Used material
4. Learning method and outcomes	5. Selection of team members	6. Lab safety rules
7. Distribution of building types	8. Hand-outs (user/design guide)	

Table 4. Types of hand-outs (user / design guide)

written documents	visual documents	
* design limitations * lab safety rules * definition of used materials * evaluation method (rubric)	* building types & used modules * header (lintel) types and details * images of previous studies	* building floor layout * a set of project sample * perspectives showing steps of learning activity

Table 5. Part of limits and definitions of "task project" as a sample of written documents

	Definitions	Attributes		Definitions	Attributes
General	Education Model	PBL	**Wall**	Load bearing wall thickness	6 "
	Type of Project	Task Project		Wall height	9 ' 3 "
	Level of decision making	Support		Stud height	8 ' 9 "
	Structural system	Timber Frame		Opening in loadbearing wall	max. 8 '
	Load distribution type	Platform system	**Floor**	Span for floor joist	max. 16 '
	Industrialization level	Stick system		Height of floor joist	10 "
	Building types applied	1 or 2 story		Stair well dimension	8 ' x 10 '
	Building geometry	Rectangular		Cantilever dimension	24 "
	Grid (basic module)	24 "	**Roof**	Roof style	Gable, hip
	Sub module	12 "		Ceiling joist height	10 "
	Position of member on grid	on-center		Roof rafter height	6 "

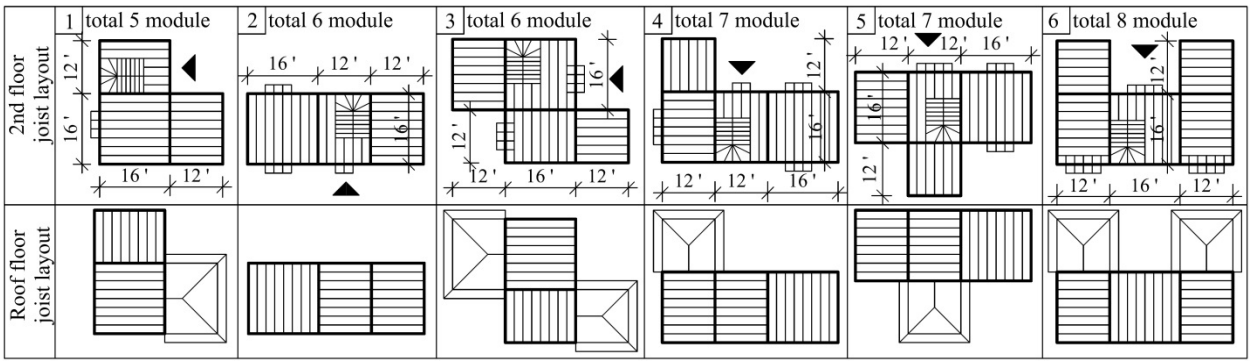


Figure 3. Modules defining braced wall footprint and building configuration as a sample of visual documents

The students were informed that there are two methods to install the 1/20 scale model of the framing construction, i.e. stick-built system and panelized system (Figure 4). The choice of system was a team decision and so, they learnt the pros and cons of working with both methods

during the course of the study. The panelized system was more preferred by the students and resulted in good communication between team members and it was observed that the distribution of responsibility between team members was well determined. Foam board was used as base board for the scaled model and 24 inch grid was drawn on it as the starting point of the study.



Figure 4. Scaled model assembly as stick system (a) and panelized system (b)

Building types with one and two story options helped the students to understand the variety of wall and floor combinations. A typical staircase compatible with all building types was preferred in order to maintain standardization. Roof slope was applied as 4/12 in all building types (Figure 5).

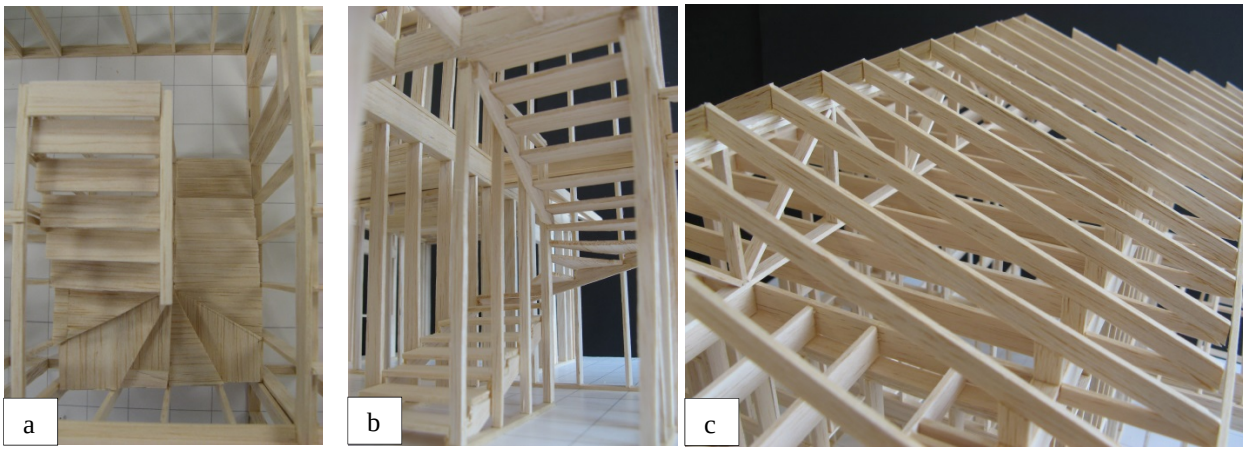


Figure 5. Staircase (a) (b) and roof (c) assembly

The typical balcony dimension was applied in all building types as 24 inch cantilever. Structural sheathing was implemented by the students partially with insulation layers in wall cavity (Figure 6). Hip roof style was applied to experience basic roofing knowledge as installation principles of roof ridge and rafters (Figure 7).

Students had the opportunity by hands-on experience, to practice the knowledge of fundamentals of framing construction received during the traditional lecture learning environment as PBL preparatory blocks / sections. The “task project” as hands-on learning experience was completed

on schedule. The scope of “the task project” covers completion of a 1/20 scaled model of a two-story house as shown in Figure 7.

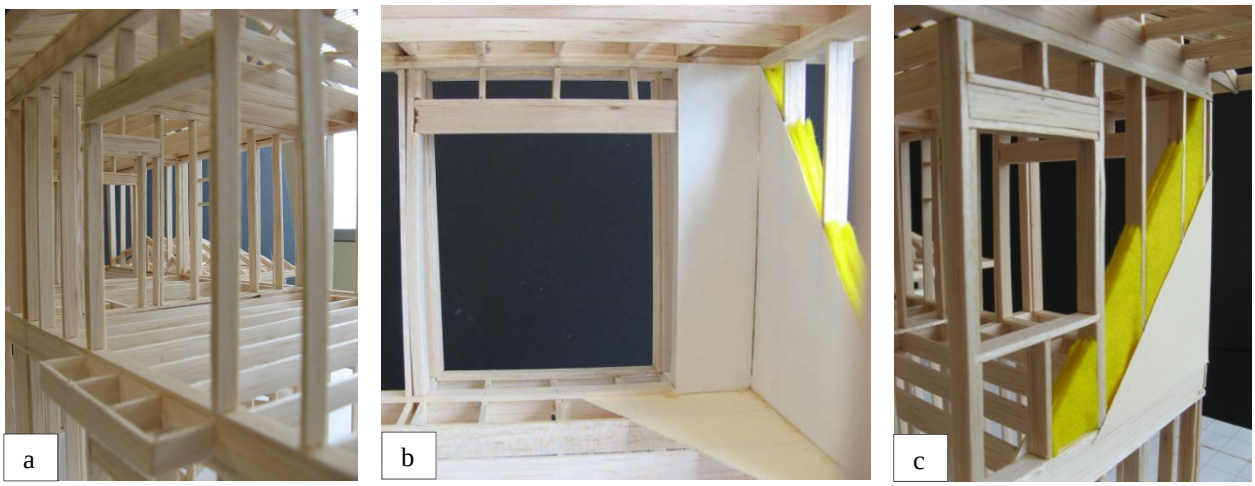


Figure 6. Balcony detail (a), structural sheathing and thermal insulation (b) (c)

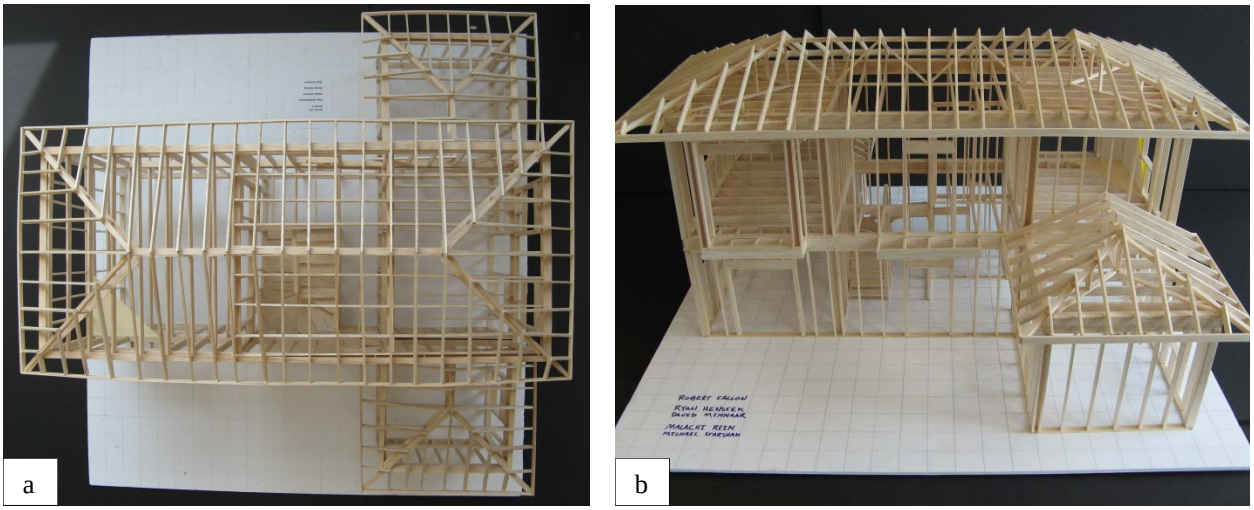


Figure 7. General overview of completed 1/20 scale models of timber framing system

4. Assessment and grading (rubric)

A peer assessment was performed by the students to assess the participation of team members during the study [27]. The peer assessment had a 20% value in whole PBL activity and the remaining 80% value was assessed by the instructor according to evaluation criterion mentioned in Table 6.

The evaluation criteria can be named as a rubric. A rubric is an easily applicable form [28] of authentic assessment. A rubric simply lists a set of criteria, which defines and describes the important components of the work being planned or evaluated [29]. Each criterion was graded using a scale of 1 through 10 (with 1 meaning unsuccessful and 10 meaning successful). The overall grade was the sum up of all criterions.

Table 6. Evaluation criteria and grades (rubric)

Group number	Evaluation criteria										**Overall grade**
	Grid bottom plate relation	Horizontal & vertical alignments	In-line framing	Floor joists parallel to each other	Header detail	Cantilever / overhang details	Staircase details	Roof details	Workmanship	General appearance	

5. Survey

In order to assess the results of PBL activity in ArchE 103 course, a survey was completed by the students two times per term. An initial survey was performed before the PBL activity and the second survey was performed after completion of the scaled models. The survey questions shown in Table 7 focused on the educational value of the different blocks / sections of the course [30].

Table 7. Survey questions

1	Please indicate your academic level.
a. Freshmen b. Sophomore c. Junior d. Senior	
2	Please indicate your level of construction experience?
a. None b. Some, intern etc. c. 1 – 2 years' work experience d. 3 – 5 years' work experience	
For questions 3 through 9 please rate the statement using a scale of 1 through 10 (with 1 meaning unimportant ……. and 10 meaning very important)	
3	Rate the importance of performance testing of constructional materials in the lab for this course
4	Rate the significance of visiting a building construction site for this course.
5	Rate the educational value of having lab exercises on partial construction methods (like mock-ups)
6	Rate the educational value of the scaled model study on wood framing systems
7	Rate the educational value of the building types used in scaled model study
8	Rate the team work effectiveness for the scaled model study
9	Rate the educational value for building a scaled model out of cold formed steel framing

There were 42 participants in the first survey and 49 participants in the second survey. The major academic standing of the students was sophomore with 55% and 67.34% of the students had no construction experience (Table 8).

The students rated the statements in the survey using a scale of 1 through 10 (with 1 meaning unimportant and 10 meaning very important) and average rate of significance of each question is shown in Table 9. The PBL activity affected the outcome of the traditional learning environment positively as shown in Table 9 question 3 with 6.02% difference and question 4 with 11.47% difference. There was no remarkable change in the result of question 5 as a result of the PBL exercise. The highest improvement was observed in main PBL activity in question 6 by the difference of two survey 17.12%. The results of the question 7 and 8 are almost same with the difference of 4.65% and 5.2%. The survey results showed that there was positive impact on educational value of the hand-outs.

Table 8. Percentage of academic standing (a) and construction experience (b)

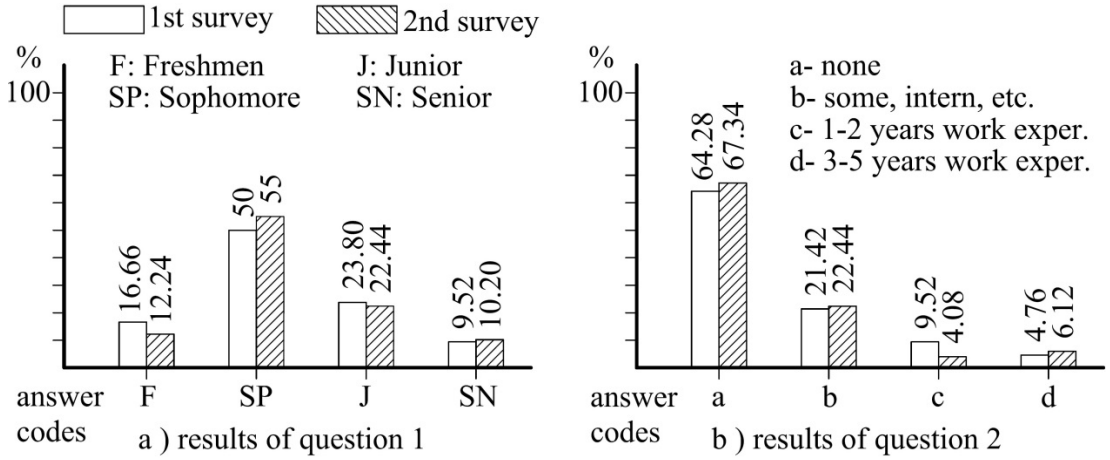
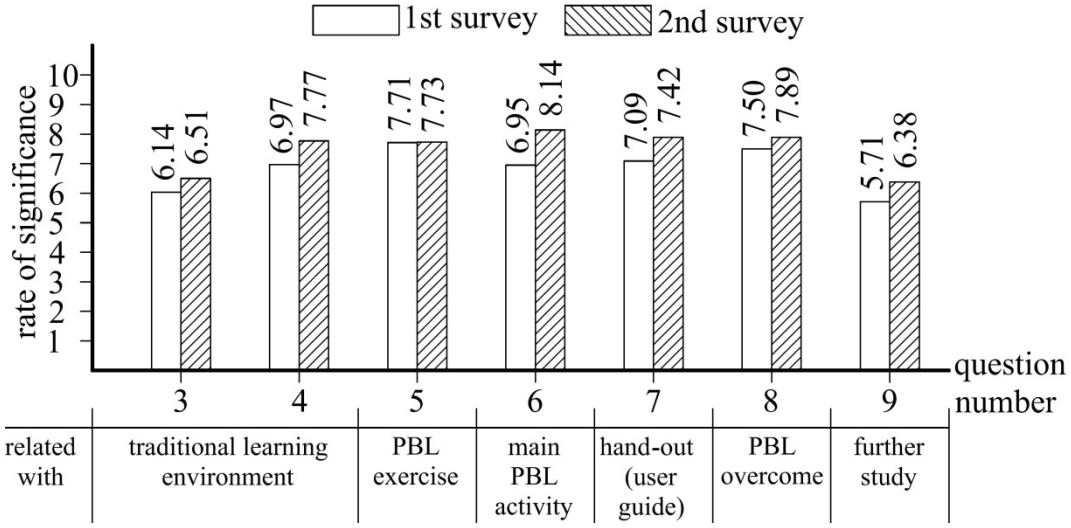


Table 9. Average rate of significance of each question



Considering the survey results in terms of educational value; question 6 had the highest value with 8.14 and question 8 was second rank with 7.89 as illustrated by Table 9. The traditional learning environment, question 3, had the lowest value with 6.51.

6. Conclusion

This research provided an initial first step as to prove whether or not PBL is a proven alternative to other forms of instruction in architectural engineering education. On the other hand, the application of PBL as a standalone curriculum caused difficulties in some universities in the world, because of not being completely successful of full integration of technical disciplines and lack of necessary minimum of prior knowledge to be formulated in PBL environment. Therefore, it is recommended to use a combination of the educational methods, the traditional lecture learning environment and PBL together. The recommended education model is distinguished as a preparatory series of lessons supplemented with a series of PBL blocks. The effectiveness of a

PBL activity was measured by a survey in this case study. The survey results showed that the PBL activity had positive impact over the traditional lecture learning environment.

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