COLLABORATIVE BIM IN TEACHING ARCHITECTURAL STRUCTURES

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ABSTRACT

Structure is the main ingredient of architecture. In contemporary sphere, it has acquired an independent personality, so that its own intimate aesthetic quality is highly valued. At the same time structure must obey scientific and engineering laws to be correct. The separation between these aspects in practice continued since the beginning of the Industrial Revolution, when structural engineering has become a specialized field separate from architecture.

This article focuses on the experiences gained in introducing Building Information Modeling (BIM) beyond the traditional design studio courses. Using BIM as a framework for teaching architectural structures, BIM tools were implemented as the primary approach for advancing other types of structural knowledge that centers on how to engage the student's imagination and to use it no less creatively than a musician or artist producing ideas. On the other hand, structural correctness emphasizes the conceptual and quantitative engineering sciences of the structural design. The framework combines various threads of knowledge; some may seem contradictory and incompatible, to arrive at structural beauty and correctness. These threads arise from many origins - an understanding of space and human activities, engineering sciences, knowledge of the behavior of actual materials, and the construction process.

The proposed framework will allow architecture and engineering students to applaud the fusion of art and scientific laws, develop deep learning, promote collaborative thinking as a core activity, improve long-term knowledge retention and cultivate professional qualities to meet the demands of today's as well as tomorrow's integrated practice requirements.

Keywords: BIM tools, Revit Architecture, Revit Structure, structural melody, structural poetry, structural art.

1. INTRODUCTION

Architectural Structures is an essential component of building design and has always been. This is due to the roles and meanings of safety, economy and performance of buildings to the society at large. From early civilizations to the present, buildings have provided shelter, encouraged productivity, embodied cultural history, and definitely represent an important part of human civilization. In fact, the role of architectural structures is constantly changing in terms of shaping certain quantities of materials and makes them support the architectures against gravity and other environmental forces. Also, from earliest times a sense of beauty has been inherent in human nature; all buildings were conceived according to certain aesthetic views, which would often impose on structures far more stringent requirements than those of strength and performance. Thus, studying architectural structures is becoming deceptively complex as buildings today are also life support systems, communication and data terminals, centers of education, justice, health, and community, and so much more. They are incredibly expensive to build and maintain and must constantly be adjusted to function effectively over their life cycle. The safety and economics of building has become as complex as its design. Hence, for many, the subject is frequently marked by complexity.

Structural analysis is among undergraduate courses mainly focuses on computation and understanding the principal of statics and strength of materials, without stressing the importance of understanding conceptual behaviors of structural systems and their aesthetic implications. Addis (1991) noted that at all times in architectural engineering history there have been some types of knowledge which have been relatively easy to store and to communicate to other people, for instance by means of diagrams or models, quantitative rules or in mathematical form. At the same time, there are also other types of knowledge which, even today, still appear to be difficult to condense and pass on to others; they have to be learned afresh by each young engineer or architect-a feeling for the structural behavior and their aesthetic functions, for instance. Currently, in the education of young structural engineers and architects, educators have tended to concentrate particularly on that knowledge which is easy to store and communicate. Unfortunately, other types of knowledge have come to receive rather less than their fair share of attention.

Currently, architectural students in the design studios are concerned primarily with artistic expressions and philosophical description, independent of the building as an organism and how it is constructed. Structure is minimally discussed and presented in their work. They apparently are not motivated by the current way of conveying structural concepts and design processes. The purely mathematical approach of the classical engineering schools is not effective in architectural and building construction colleges. Thus, students of these schools are driven to consider themselves as artists with less interest in scientific and engineering principles. However, all artists must acquire mastery of the technology of their chosen medium, particularly those who choose buildings as their means of expression.

The structure of a building is the framework that preserves its integrity in response to external and internal excitations. It is a massive object that must somehow be incorporated into the architectural program. It must therefore be given a form that is compatible with other aspects of the building. Many fundamental issues associated with the function and appearance of a building including its overall form, the pattern of its fenestration, the general articulation of solid and void within it, and even, possibly, the range and combination of the textures of its visible skins are affected by the nature of its structure. The architectural structure also influences programmatic aspects of a building's design because of the ability of the structure to organize and determine the feasibility of pattern and shape of internal and external spaces. Furthermore, structures can be defined to control the inflow of natural light; improve ventilation or many other functions that are needed by the architectural spaces.

The relationship between structure and architecture is therefore a fundamental aspect of the art of building. It sets up conflicts between the technical, scientific, and artistic agendas that architects and engineers must resolve. The method in which the resolution is carried out is one of the most tested criteria of the success of a building design. This issue has been recognized by many engineers and architects such as Schueller (1995, 2010), Belington (2003), Schodek (2004), and Sandaker (2008). This work focuses on providing the fundamentals to help architects and engineers achieve a successful resolution to such conflict. It addresses other types of structural knowledge that centers on the conceptual and qualitative aspects of a structure and how to engage the student's imagination and to use it no less creatively than a musician or artist producing solution ideas.

With the recent technological advancements, students have more tools to create structural forms, analyze and demonstrate how load combinations affect the stability and behavior of a structure. Specifically, Building Information Modeling (BIM) has the potential to assist in achieving different types of structural knowledge learning objectives without compromising their distinct requirements. BIM is a process that fundamentally changes the role of computation in structural design by creating a database of the building objects to be used for all aspects of the structure from design to construction and beyond.

BIM has revolutionized the design and construction of buildings mainly due to its ability to specify the interaction of architectural form, stresses, section properties, material strength, and deformation based on different type of boundary conditions and connections. This research project centers on utilizing Revit Architecture and Structure and their extensions, including Robot Structural Analysis software, to understand the basics of structural art and how to conceptually analyze structural members and systems.

This knowledge of structural design is similar to the type of knowledge usually associated with craft skill, or the skill of knowing how to do something (e.g. swim, paint, make docks, play a musical instrument) and normally yields deep learning results.

2. VOCABOLARY AND METHODLOGY

The experimental research team includes two undergraduate architectural students (2^{nd}. & 3^{rd}.. year) and two undergraduate students (3^{rd}. year) from the College of Engineering, both at the University of Florida to investigate how BIM would improve learning and understanding of building structures. The research team was introduced to the basics of BIM and Revit Architecture and Structure. This introduction took about eight contact hours. The last phase of this introduction was an overview of Revit Architecture and Structure, emphasizing the comprehension of new concepts such as model element, categories, families, types and instances. Before starting the analysis, students are then assigned simple projects to practice using Revit Architecture and Structure in modeling simple 3D structures. Figure 1 below illustrates the process followed in this introduction (Sharag-Eldin & Nawari 2010).

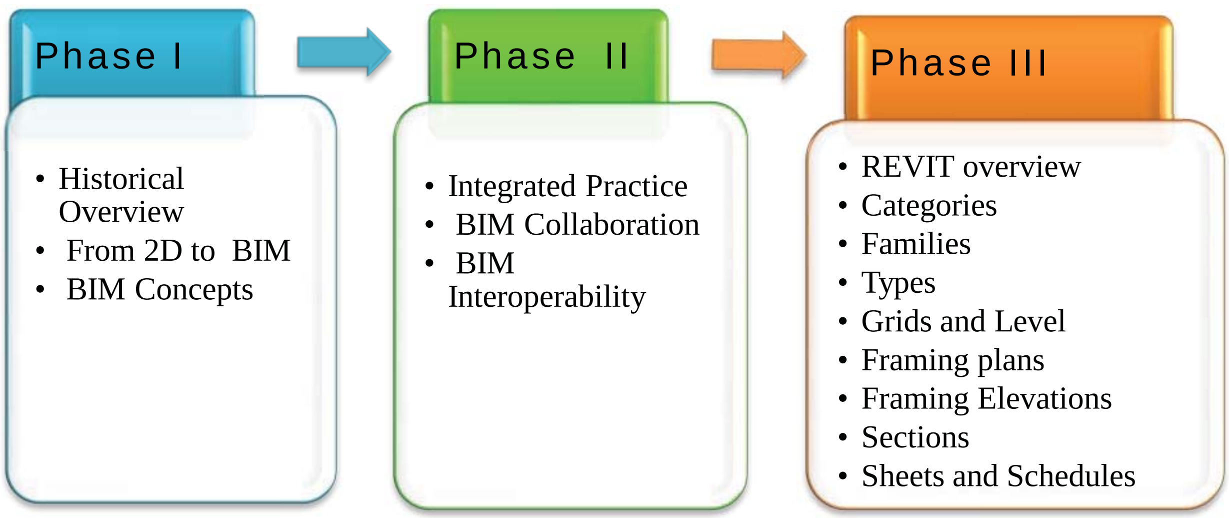


Figure1: BIM Introduction Blocks

Following the introduction, students start to learn about the analysis tools in Revit Architecture and Structure. These tools are available as extensions to the basic versions of Autodesk Revit.

Using BIM as a framework for learning architectural structures, BIM tools were implemented as the primary approach for promoting the understanding of the fundamental of building structures and the relationship between architectural and structural design. Examples include essential concepts such as human activities, spatial systems, forms, circulations, enclosure systems, structural systems and elements, load diagrams, lateral stability, force equilibrium, support reactions; shear force, and bending moment diagrams. It is also intended to develop this framework into a holistic vehicle to introduce architectural structures vocabulary, the hierarchy of structural members and the interplay between architectural concepts and structural systems to undergraduate architecture and engineering students. The framework is referred to as “Buildoid Framework”. This framework has three main components. Namely,
(i)Structural Melodies, (ii) Structural Poetry, and (iii) Structural Analysis.

To advance other types of structural knowledge, structural melodies and poetry focus on how to engage the student’s imagination and to use it no less creatively than a musician or artist producing ideas. On the other hand, structural analysis concentrates on the conceptual and quantitative aspects of the structural performance. In addition to the envisioning of a geometrical shape or type of material, which can be done largely from memory, there is also the possibility of carrying out structural analysis in the mind - what can be termed conceptual analysis. The Buildoid Framework aims to emphasize the value of these knowledge domains and specifically the interplay between architecture and structures as well as the qualitative understanding of structural behavior.

Furthermore, this Framework will elaborate on improving students ability in handling cross-disciplinary interests through use of Building Information Modeling knowledge and other digital tools. The Buildoid Framework will allow architecture and engineering students to develop deep learning about fundamental of architectural structures, promote collaborative thinking as a core activity, improve long-term knowledge retention and cultivate professional qualities to meet the demands of today's as well as tomorrow's integrated practice requirements By approaching the study of architectural structures in this manner, several objectives are realized.

- First, students get the chance to learn the fundamentals of BIM at an earlier stage of their current core curriculum which will help them in other advanced digital design courses and design studios.
- Second, the student will explore structure as an art and thereby gains an understanding of the influence structure can play in creating form and spatial order.
- Third, it introduces the student to the vocabulary and hierarchy of a structural system, enabling structural decision making to be integrated early in the design process.
- It establishes the notion that structural analysis computation is primarily a tool to verify structural decisions rather than a design strategy.
- Finally, it initiates an attitude of understanding the interplay between architecture and structural systems that should continue into the student's remaining education and forward into her or his professional career.

2.1 Structural Melody

After introducing the fundamentals of BIM and BIM platforms, the first phase goal is to help students understand how linear and planar structural elements can be orchestrated to understand spatial order in architecture using BIM tools. It is also the intention to develop this idea as a holistic vehicle to introduce structural vocabulary, the hierarchy of structural members and the interplay between architectural concepts and structural systems such as stratification, transition, hierarch and, heart of spaces.

In the structural melody phase, students learn about the structural vocabulary such as elements names and their order and hierarchy. The study starts incrementally from a simple 3D system and then evolving into whole one and two story buildings. The first assignment was a simple 3D system consisting of 4 wood columns, girders and beam system (joists) as well as single footings as depicted in Figure 2 below.

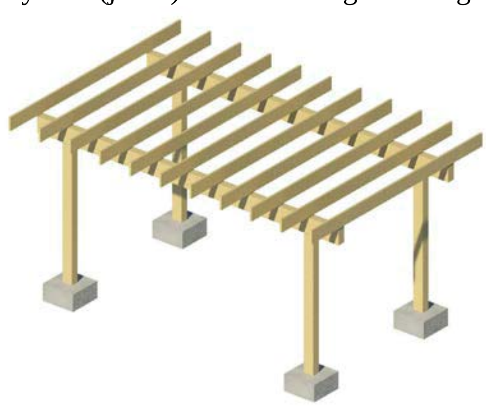


Figure 2: Simple 3D Structural Model.

Using Revit Architecture, students learnt about foundation and framing plans, as well as framing elevations. They were able to create a sheet showing all these elements. Some Examples of their results are depicted in Figure 3 below. Students started to understand much more about the underlying concepts and the relationships between elements and their tasks in transferring loads as well as their two dimensional representations.

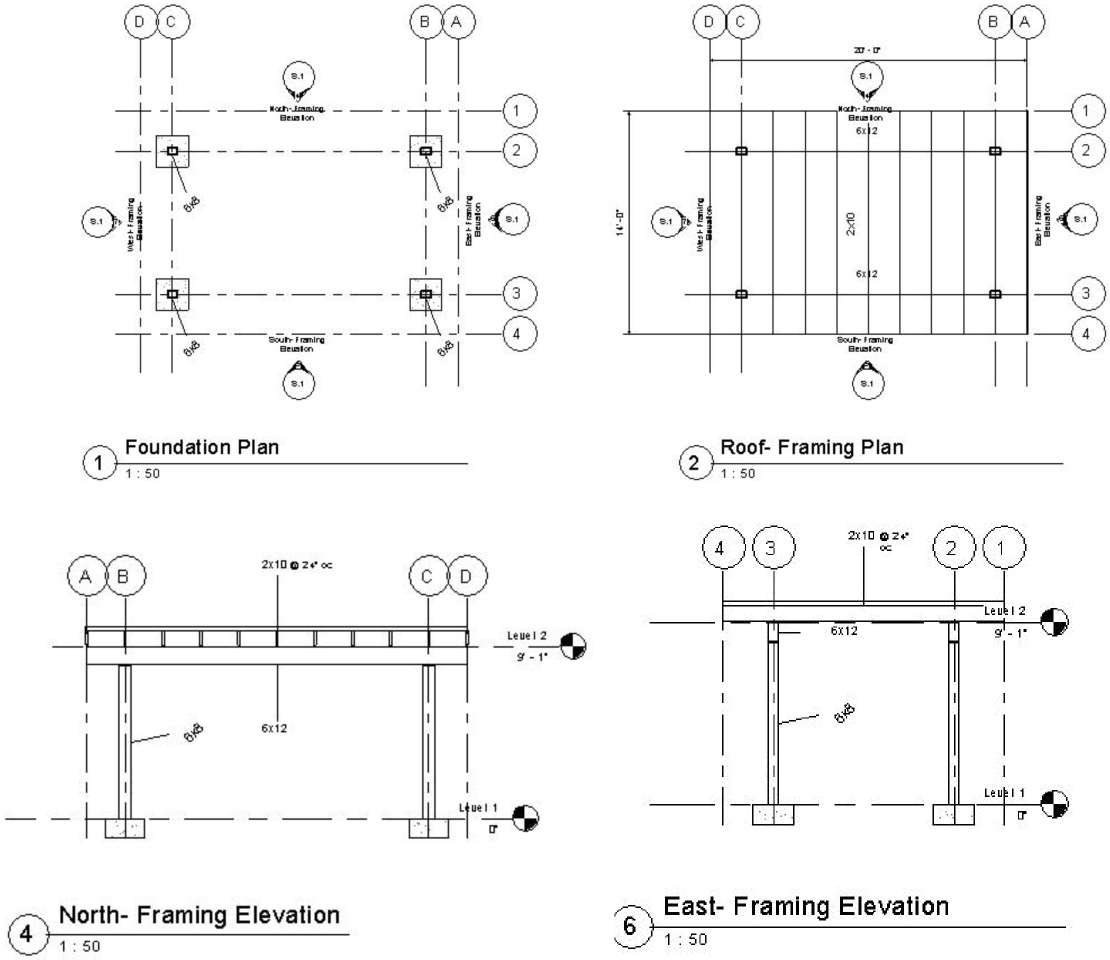
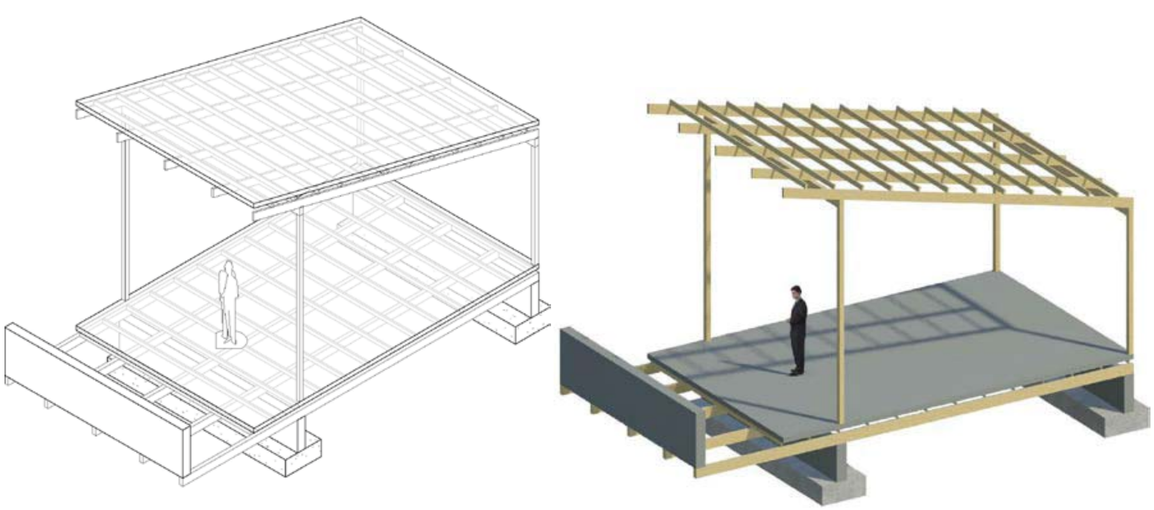
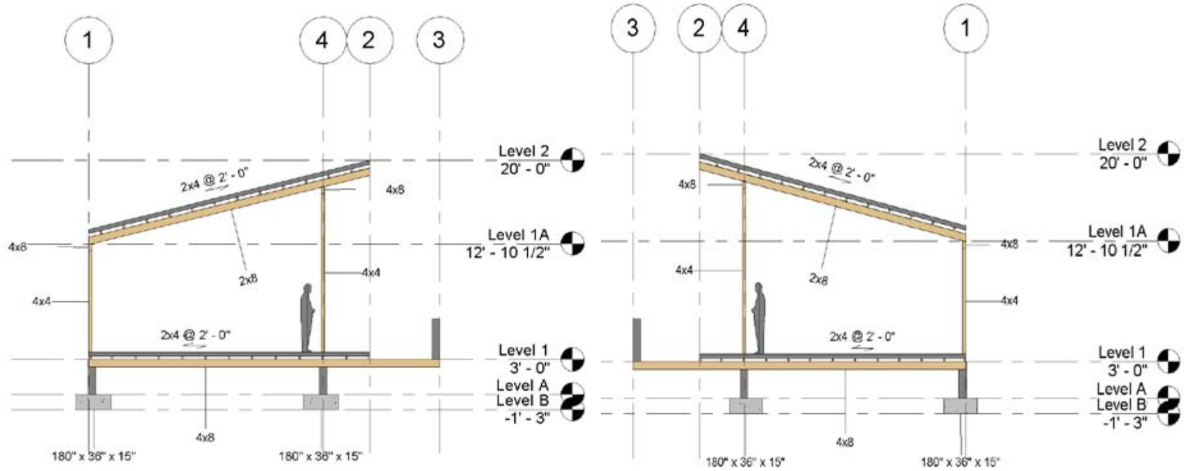


Figure.3a: Introducing “Structural Melody”- Example 1



(a) 3D Models



(b) North Framing Elevation (c) South Framing Elevation

Figure.3b: Introducing “Structural Melody”- Example 2

2.2 Structural Poetry

The word poetry has its origin in Greek and means a making: forming, creating or the art in which language is used for its aesthetic and evocative qualities in addition to, or instead of, its notional and semantic content. In other words, poetry is a fundamental creative act using language. Similarly, structural poetry is a creative exercise to provide structural form using structural vocabulary and melodies in order to organize and stabilize architectural spaces. Just like language poetry structural poetry has evolved over thousands of years and will continue to evolve now and in the future.

In more general sense, structural poetry strives to develop structural creativity and how to think three dimensionally and present architecural structures design solutions in a conceptual manner. This allows one to develop an imaginative complex architectural system without a thorough understanding of its individual components at the initial design stages. This holistic methodology can run concurrently with the design studio in architecture or pre-structural design course in engineering program. Without the traditional emphasis on first understanding beams, columns, bearing walls, etc., two dimensionally, using the laws of statics and strength of materials, structural poetry utilize the power of Building Information Modeling (BIM) tools to create a three dimensional structural forms (Buildoid) to satisfy spatial, aesthetic and other programmatic requirements.

The initial goal is to initiate an attitude of understanding the interplay between architecture and structural systems that should continue into the one’s remaining education and forward into her or his professional career.

In this phase a buildoid is required to create a space that is three feet elevated above the ground level and has a plan area of 17’ x 22.5’ and a volume of 1732.5 ft^3. Wood structural elements and reinforced concrete foundations are allowed to be used for this purpose. A solution is presented in figure 4 below. In this example, a simple space is created using linear wood structural elements. Most of the basic structural melodies discussed earlier are applied when creating this buildoid. More examples of basic buildoids are given in figure 5.

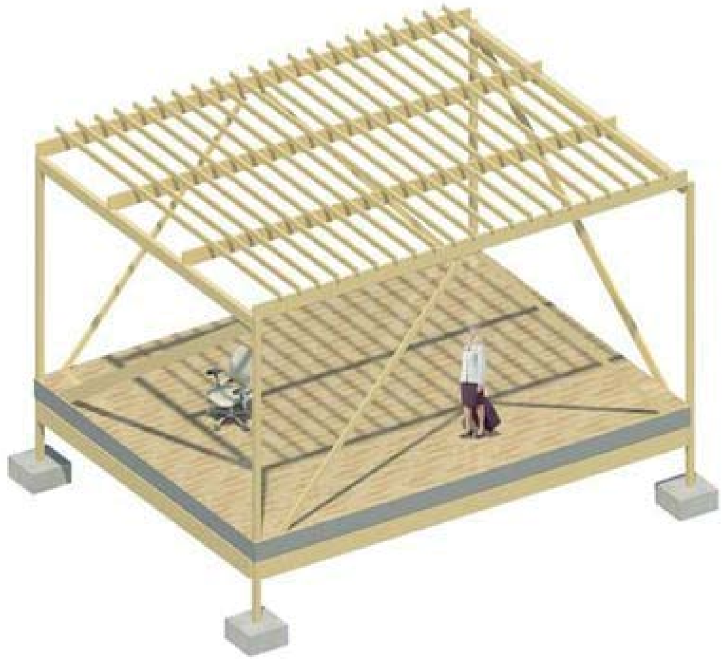


Figure 4: Starting Buildoid

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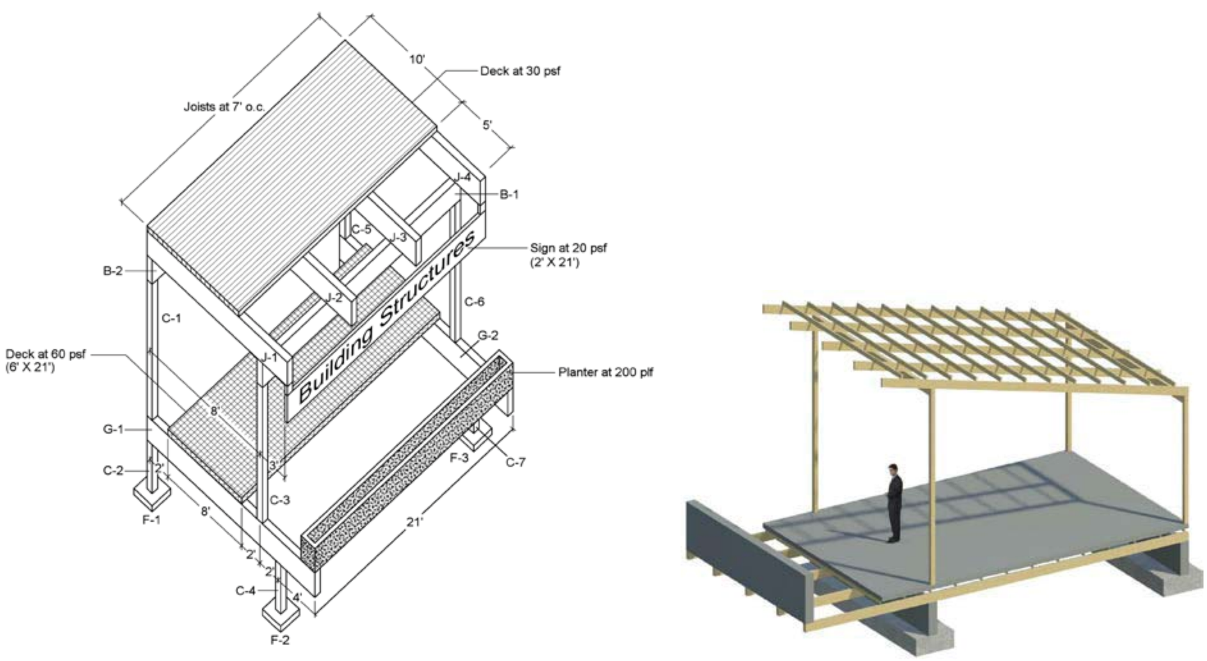
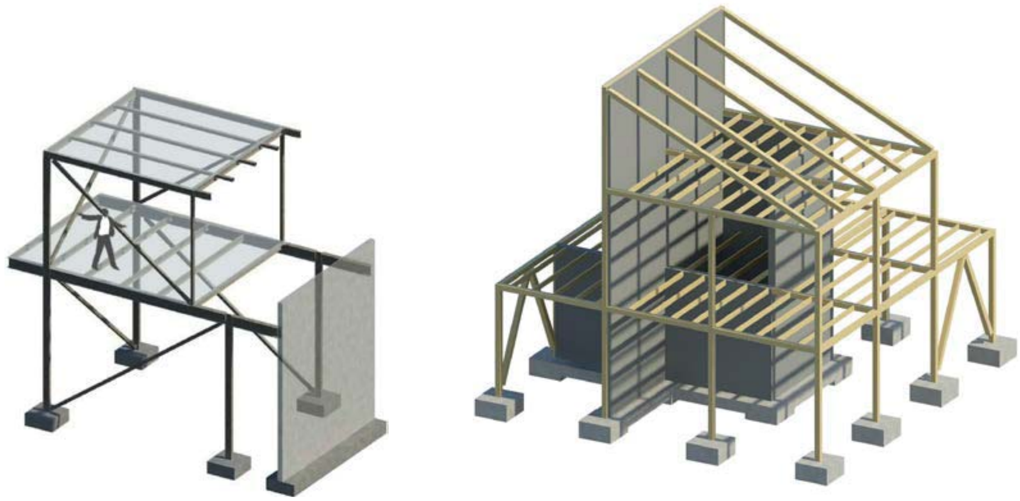
A critical part of the Structural Poetry is to experiment with the illusion of the three-dimensional depth on a two-dimensional computer screen. To experiment with the digital tool is more valuable at this stage than to produce, free try and play in the beginning develops courage and motivation: “If you have a space, something happens, the program then starts. It doesn’t start before you make the space”. In this manner, student should be able to simultaneously generate the “structure” and interpret the special implication of that structure.



(a) (b)



(c) (d)

Figure 5: Examples in Structural Poetry

Next it is required to increase the space requirements by four times as private space and additionally 210 ft^2 as semi-private space. Thus, attention must be given to spatial sequencing and composition. Materials should be the same as in the previous example. A student's solution is presented in figure 6 below.

Figure 6: Progression from the Original Buildoid.

In these examples a parallel is drawn with language poetry to enhance student's comprehension. For instance poetry may use condensed or compressed form to convey emotion or ideas to the reader's or listener's mind or ear; structures can be formed using a few members in different form to provide certain aesthetic and framework for spaces; it may also use devices such as assonance and repetition to achieve musical or incantatory effects, similarly structures can be orchestrated by repeating the same pattern of supports to achieve simplicity and elegance. Poems frequently rely for their effect on imagery, word association, and the musical qualities of the language used. Also, structures can use its form, orientation, type and quality of materials to impact the final design. The interactive layering of all these effects to generate meaning places is what marks structural poetry.

Further examples of buildoids are given in figure 7 illustrating different elements, structural hierarchy and organization, special order and aesthetic. The variations of the structural poetry shown in these buildoids demonstrates different concepts such as elevated floors, cantilevers, simple trusses, frames, shear walls, bracing, two-levels of framing for the elevated floor, three-levels of framing for the roof as well as the two spaces established (interior and exterior spaces), flat and sloped roofs.

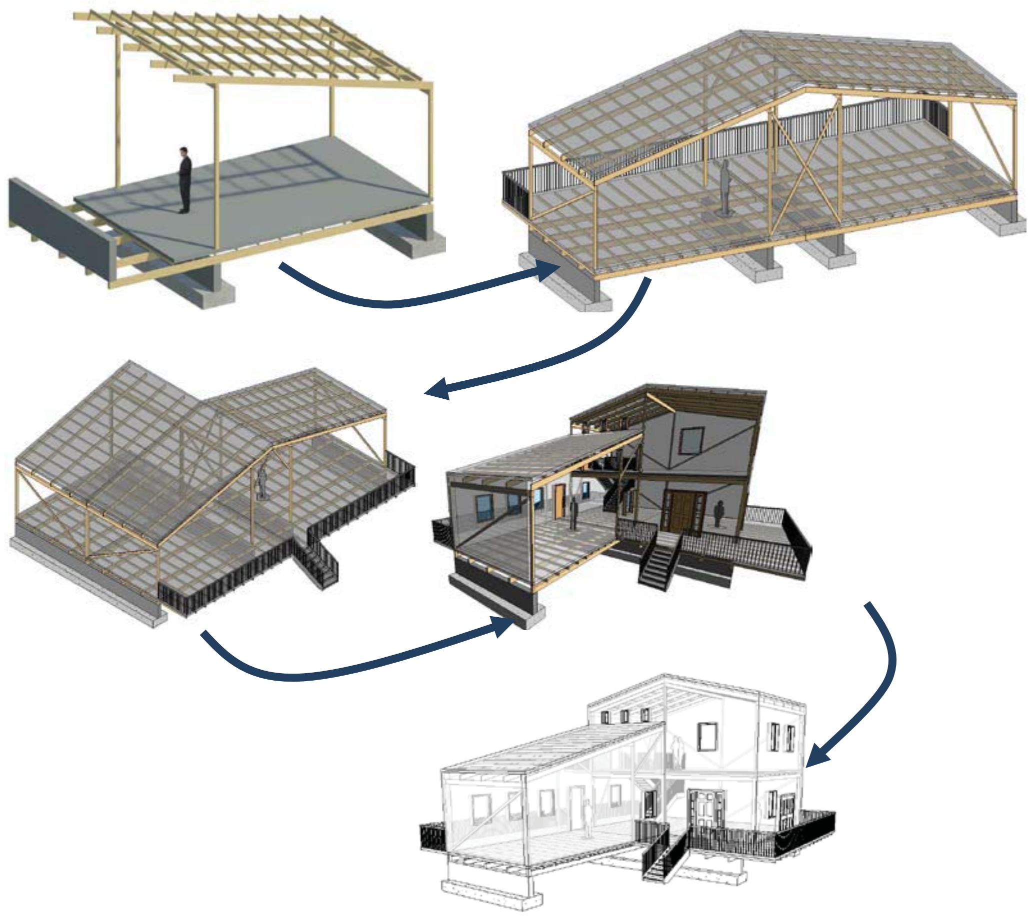


Figure 7: Progression in Structural Poetry

2.3 Structural Analysis

After completing structural melody and poetry phases the structural models are finalized. Then students are introduced to the various analysis tools within Revit Structure. BIM tools used in this phase are principally the beam, frame simulation, the load takedown, and the integration with Robot Structural Analysis. The load takedown played an important role in introducing load path, load tracing, reactions and constraints in building structures (see Figure 8 & 9). Students were able to understand concepts such as tributary areas for beams, girders and columns in visually interactive manner which greatly stimulated the interest and motivation to explore other analysis capabilities of the tool (Nawari et.al., 2011). The study was then centered on understanding the conceptual behavior of frames under gravity and lateral loads using these tools. Engineering students took the lead in this part and helped other architecture students in the team to follow through.

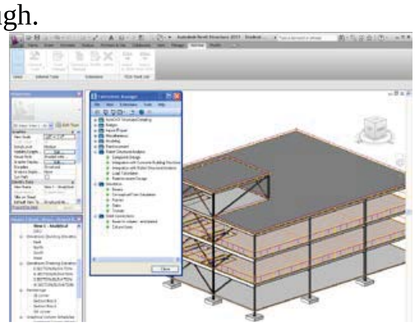


Figure 8: Structural Analysis Tools in Revit Structure

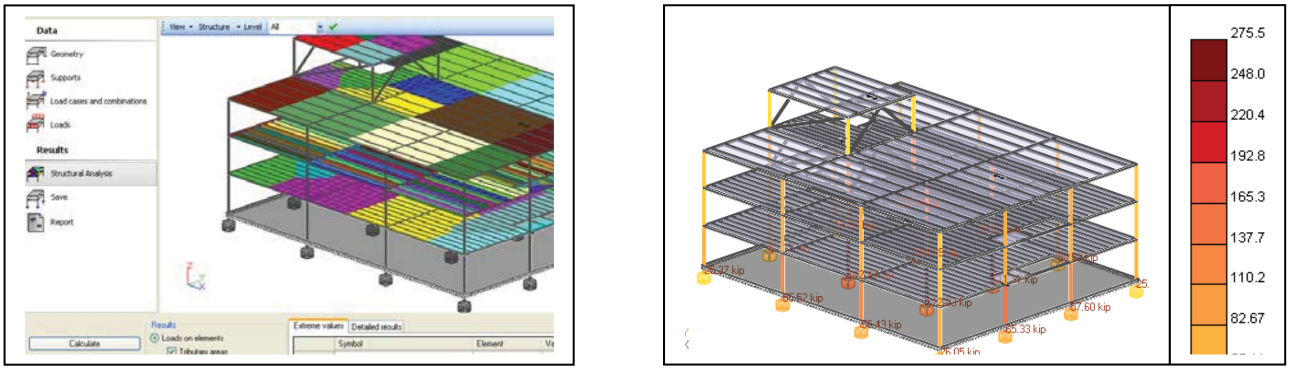


Figure 9: An Example of Load Takedown Results.

3. CONCLUSIONS

The research work was focused on the development of more effective ways in which architectural structures can be studied, judged, improved, communicated, learned, and taught. The investigation emphasized the development of more effective techniques by which structural and architectural knowledge, including the understanding of structural behavior, which is essential to the skill of design, can be educated and learned. Structural education in engineering, as well as in architecture, should incorporate an increased concentration upon structural melody, structural poetry and conceptual analysis as a central activity.

A direct approach to the understanding of structural behavior is to be emphasized, rather than relying on the assumption that such understanding necessarily follows from learning the mathematics of structural analysis. Ultimately, this type of knowledge is the only check on the legitimacy of using structural engineering theories in design procedures and computer aided design software.

BIM tools promoted focused and collaborative brainstorming activities among architecture and engineering students at all phases of the research project and thus, encouraged an exchange of ideas and information and allowed truly collaborative design solutions to take form. The use of BIM tools in such a reflective mode to enhance learning of the fundamentals of architectural structures concepts allowed students to appreciate the full behavior of the structure and hence this approach has promoted improved deep learning and understanding of architectural structures.

REFERENCES

Adis, W. (1991). “Structural Engineering – the nature of theory and design”. Ellis Harwood, New York.

Billington, D. (2003). “The Art of Structural Design – A Swiss Legacy”. Yale University Press.

Nawari, N. O., Itani, L., and Gonzalez, E. (2011). “Understanding Building Structures Using BIM Tools”, Proceedings of the 2011 ASCE International Workshop on Computing in Civil Engineering, pp. 478-485, June 19-22, 2011, Miami, FL.

Sandaker, B. N. (2008). “On Span and Space: exploring structures in architecture ”, Routledge, Taylor & Francis Group.

Schueller, W. (1995). “The Design of Building Structures”, Prentice-Hall.

Schueller, W. (2010). “Building Support Structures: Analysis and Design with SAP200 Software”, Computer and Structures Inc.

Sharag-Eldin, A., and Nawari, N.O. (2010):“ BIM in AEC Education” 2010 Structures Congress joint with the North American Steel Construction Conference in Orlando, Florida, May 12-15, 2010, pp.1676-1688.

Schodek, D. L. (2004). “Structures”, 5th. edition, Prentice-Hall.