



Integrating Building Information Modeling (BIM) into the Civil Engineering Curriculum

Dr. Edwin R. Schmeckpeper P.E., Norwich University

Edwin Schmeckpeper, P.E., Ph.D., is the chair of the Department of Civil and Environmental Engineering and Construction Management at Norwich University, the first private school in the United States to offer engineering courses. Norwich University was the model used by Senator Justin Morrill for the land-grant colleges created by the 1862 Morrill Land Grant Act. Prior to joining the faculty at Norwich University, Dr. Schmeckpeper taught at a land-grant college, the University of Idaho, and worked as an engineer in design offices and at construction sites.

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I. Introduction

This paper presents information from a work in progress on integrating Building Information Modeling (BIM) throughout the structural analysis and design portion of the ABET accredited Civil Engineering curriculum at Norwich University.

BIM is a model-based process that is used to plan, design, construct, operate, and maintain buildings and other infrastructure. It has a wide range of beneficial effects on construction project disciplines such as facilitating communication, improving the flow of information, delivering a constructible design, enhancing cost estimation and cost control, meeting schedule deadlines successfully, mitigating conflicts and disputes, increasing productivity and reducing safety incidents. Surveys of the engineering industry indicate within a short time-period market forces will relegate those Structural Engineering firms that do not use BIM to the low-rise residential market¹. All commercial, industrial, governmental, or multi-story residential projects will be done by firms that are proficient in BIM. If universities are to remain relevant in the education of Civil Engineers who are able to work in the Structural Engineering field, it is imperative that BIM be incorporated into the structural analysis and design courses.

In order to improve student knowledge in structural engineering, Norwich University's Civil Engineering department made changes to the content and format of the undergraduate Structural Analysis, Structural Steel Design, and Reinforced Concrete Design courses. These changes were intended to allow for the inclusion of experiential learning, to provide opportunities for increased use of industry standard structural analysis and design software, and to provide time for the students to begin to use Building Information Modeling (BIM) systems for analysis and design.

The research in this project focuses on the impacts of incorporating these changes into the Structural Engineering courses of the Civil Engineering curriculum, and assessing whether the potential benefits have been achieved. The primary research approach is based upon the assessments for the Civil Engineering Student Outcomes that are measured each school year as part of the accreditation process for the BS in Civil Engineering.

II. Status of the Work in the Field

Building Information Modeling (BIM) is a model-based process that is used to plan, design, construct, operate, and maintain buildings and other infrastructure. BIM is one of the tools that many clients, such as the General Services Administration², require on all infrastructure projects. It is essential that all Structural Engineering students have knowledge of BIM in order to be better prepared for their future careers and to be able to meet the expectations of the engineering profession.

Finite Element structural analysis programs such as Autodesk-RSA are capable of utilizing the BIM models as the basis for structural modeling for both analysis and design³. However, prominent structural engineer David Ruby, P.E.⁴, in his five-part series of articles

“But it worked in THE MODEL!,” describes the pitfalls that inexperienced engineering students encounter when using BIM and structural analysis programs, and cautions against students becoming too reliant on computer analysis.

James Hanson, in his book *Structural Analysis: Skills for Practice*⁵, describes some of the problems that engineering students encounter when they are introduced to computer based structural analysis and design. Based upon a 10-year study gathering experience from practicing engineers⁶, his solutions to deal with these problems involve helping students develop intuition about structural behavior, practicing concepts in structural analysis, and helping the students develop skills so that they can accurately evaluate results.

III. Description of the Project

The use of structural analysis, design, and BIM software for analyzing and designing structures are critical tools for Civil Engineers. The increase in efficiency gained through the appropriate use of computational tools is required for design firms to remain competitive in our international economy. Students of engineering need to be educated in both modern computational tools and the classical analysis methods, since the classical analysis methods may be used to verify and check the results of computational tools.

In order implement Hanson’s ideas into the Structural Analysis and design courses, a series of BIM structural models were developed to provide students with a progression of computerized structural modeling labs of increasing complexity. Through the use of these models the students could verify their results through checking fundamental principles and checking specific features of the computer generated solutions.⁷

Instead of adding a stand-alone BIM course, the Civil Engineering department focused on redesigning the existing structures courses to use BIM as one of the tools for presenting materials and student assignments. Integrating BIM into existing courses, rather than independently, has been shown to be the most practical way to offer BIM, since this strategy divides the BIM contents into smaller, more manageable components, which can improve the quality of education⁸. For example, one of the BIM modules in the Structural Analysis course is used for the determination of snow loads on buildings. This BIM model is then used for design assignments in both the Design of Steel Structures course and the Reinforced Concrete Design course. The use of BIM modules distributed throughout curriculum exposes students to material that is realistic, but not of overwhelming scope. The students are given assignments that are manageable, and that increase in scope and complexity over the course of a student’s academic career.

IV. Program Changes for the Structural Analysis and Design Courses

Structural Analysis is the prediction of the effects of loads and environmental factors on a building or other structure. Structural Analysis is a critical element of Structural Design, which involves the determination of structural configurations, selection of materials and members, and then analyzing the structure to ensure that the structure has adequate strength and stability.

The Civil Engineering department changed the format of the Structural Analysis course, to allow for the inclusion of experiential learning, increased use of industry standard structural analysis and design software, and the increased use of Building Information Modeling (BIM) systems for analysis and design. The University Curriculum Committee approved the request to change the contact hours for Structural Analysis from 3 hours of lecture per week to 2 hours of lecture plus 2 hours of laboratory per week to accommodate the experiential aspects of these proposed changes. After assessing the changes to the Structural Analysis course, we will decide whether to make similar changes in the class meeting times for the Structural Design courses.

The Structural Analysis course syllabus lists the following broad goals for the course:

- a) Students will develop technical skills in classical methods for analysis of determinate and indeterminate structures.
- b) Students will gain proficiency in analysis structures comprised of trusses, beams, frames, cables, and arches and will gain an appreciation of structural analysis as a necessary component of the design process.

The following goal has been added to the course:

- c) Students will gain familiarity with industry standard structural analysis and design tools, including 2-D and 3-D structural analysis and Building Information Modeling systems.

This last goal was also added to both the Structural Steel Design course and the Reinforced Concrete Design course.

The objectives of this project were to develop and implement BIM and other materials that would help students develop their structural analysis skills and the ability to evaluate the reasonableness of computer generated solution. To accomplish these objectives, a series of computation laboratory exercises were created that were intended to:

- 1) Provide realistic practice exercises which demonstrate structural concepts.
- 2) Help students develop an intuitive understanding of structures so that the students can predict the qualitative behavior of a structure.
- 3) Help students to develop the ability to accurately evaluate the results of a structural analysis problem.
- 4) Provide introductions and instruction in use of software tools.

Work was conducted on revising the Structural Analysis and Structural Design courses' lectures and preparing lab exercises to take advantage of the computational lab hours for the Structural Analysis course. The following software tools were incorporated into the Structural Analysis and Structural Design courses:

1. RISA-2D. 2-dimensional structural analysis program (Structural Analysis)
2. Autodesk REVIT. Industry standard Building Information Modeling (BIM) program (Structural Analysis, Structural Steel Design and Reinforced Concrete Design).
3. RISA-3D. 3-dimensional structural analysis and design program. (Structural Steel Design and Reinforced Concrete Design)
4. Autodesk RSA. Industry standard 3-D Finite Element analysis, advanced structural analysis, and structural design program. (Structural Steel Design and Reinforced Concrete Design)

V. Structural Lab Exercises

Example Model #1: Tributary Area and Load Tracing

One of the first Lab exercises developed was the BIM model of a simplified multi-story building. This model, shown in Figure 1, was used in the structural analysis course to demonstrate the concepts of tributary areas and load tracing. The students first determined beam and column loads manually, then used the results of the load analysis to determine the axial forces, shear forces, and bending moments in typical framing members, such as Girder 01 and Beam 01 in the floor framing plan shown in Figure 2. This BIM model is also used in the Structural Steel Design course and the Reinforced Concrete Design for column design and beam design problems.

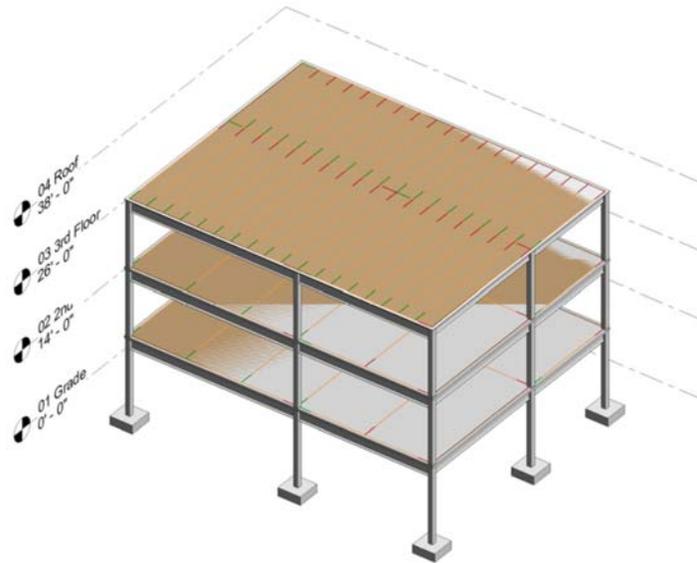


Figure 1: Tributary Area Example: Multi-Story Building 1: 3d-View

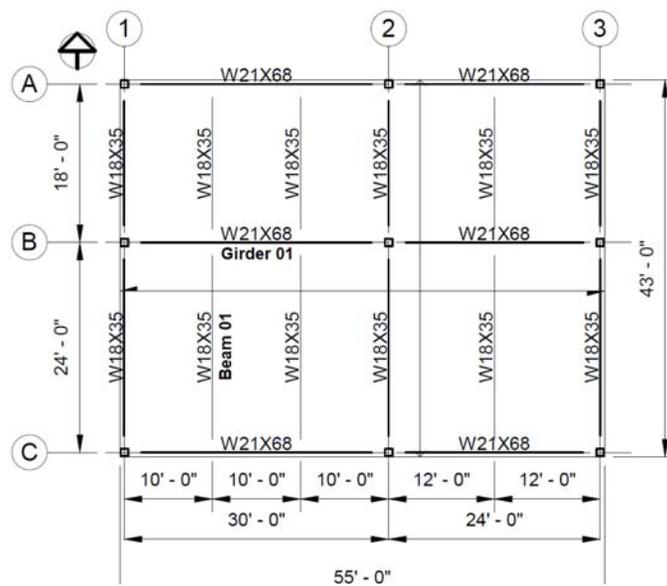


Figure 2: Tributary Area Example: Multi-Story Building 1: Floor Framing

Example Model #2: Snow Load on Buildings

This load analysis and design exercise used two BIM models. The first model, shown in Figure 3, was used in the Structural Analysis course to determine snow loads on flat roofs. The second model, shown in Figure 4, was used to determine snow loads on sloped roofs. Since both models have the same plan area, students are able to compare the differences between the two roof framing systems that result from the sloped roof. These two models are also used in the Structural Steel Design course to design roof framing members.

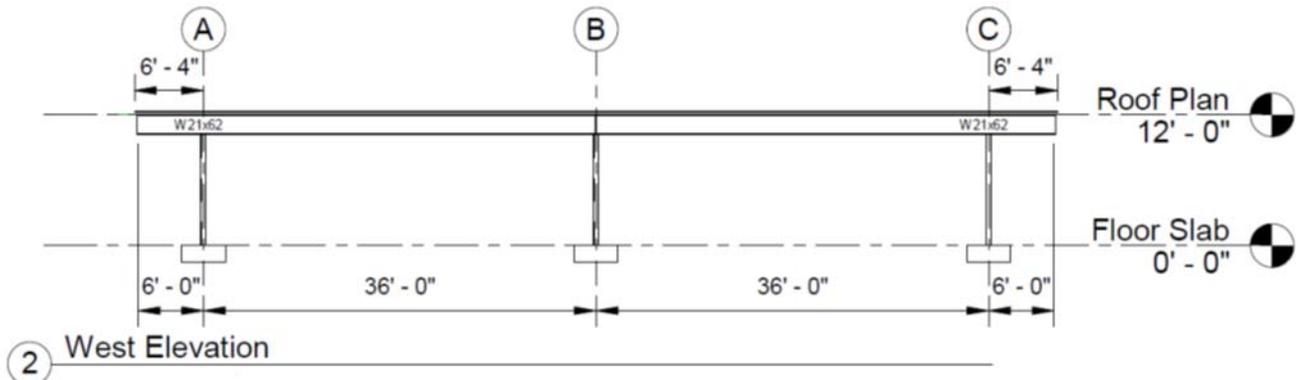


Figure 1: Snow Load Example: Flat Roof

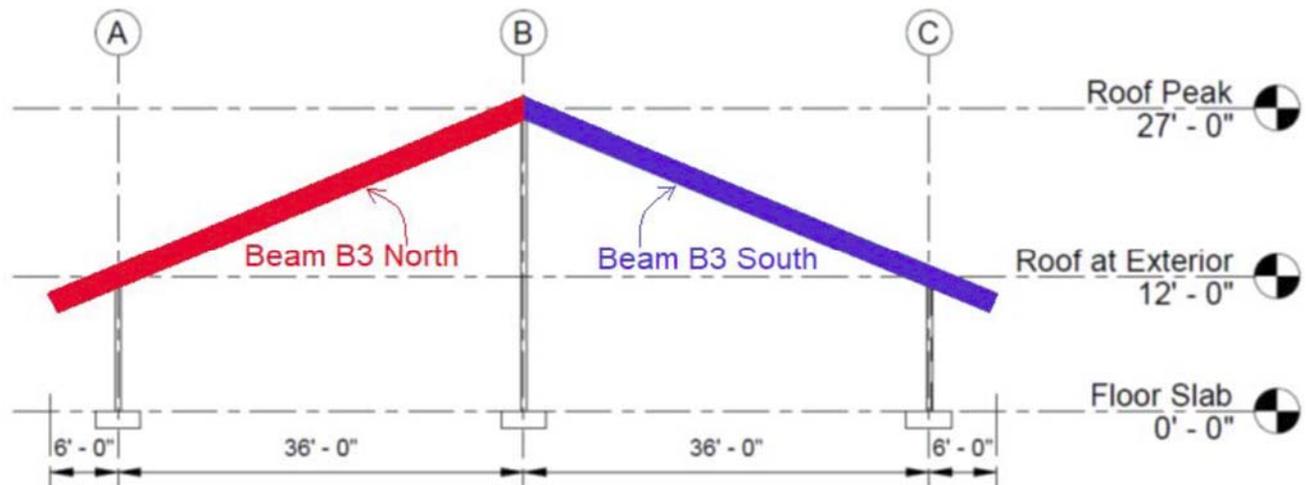


Figure 4: Snow Load Example: Sloped Roof

Example Model #3: AISC 3 Story Building

The third BIM model presented in this paper is based upon the 3 story steel framed building presented on the American Institute of Steel Construction's (AISC) Web-Enhanced Teaching of Structural Steel web page.⁹ AISC provides architectural and structural drawings for this building, along with loading and design information. The 3-d view of this building is shown in Figure 5 and the South elevation of the building is shown in Figure 6. The BIM model for this building is

used in the Structural Analysis course for tributary load and load path exercises, wind load analysis exercises, and snow load analysis exercises. The model is used in the Structural Steel design course for both the design of individual components and for framing system analysis.

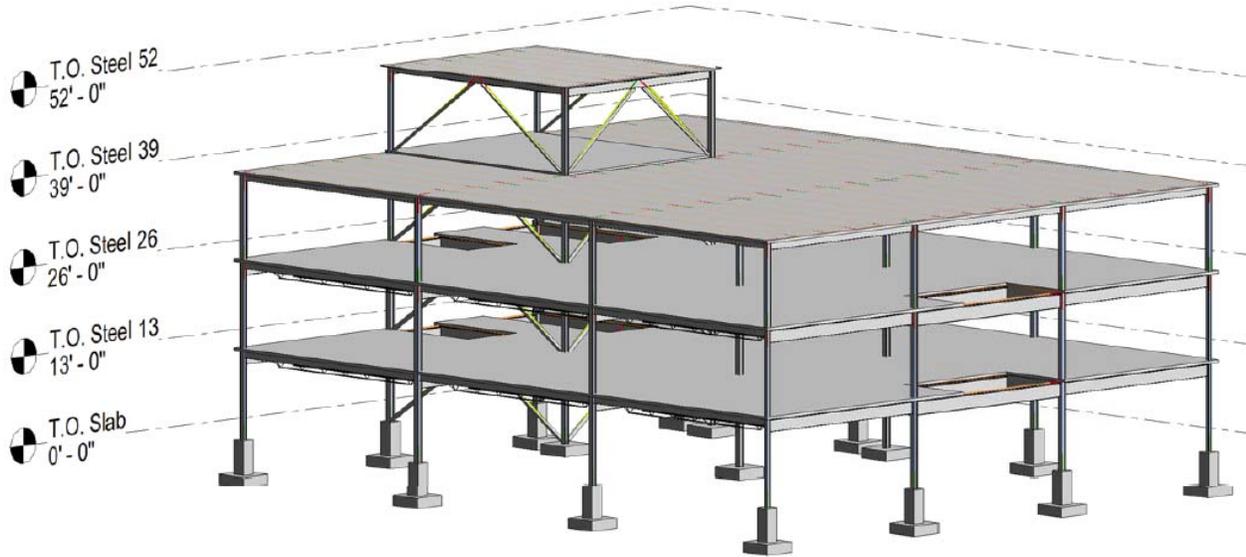


Figure 5: AISC 3 Story Building: 3d-View

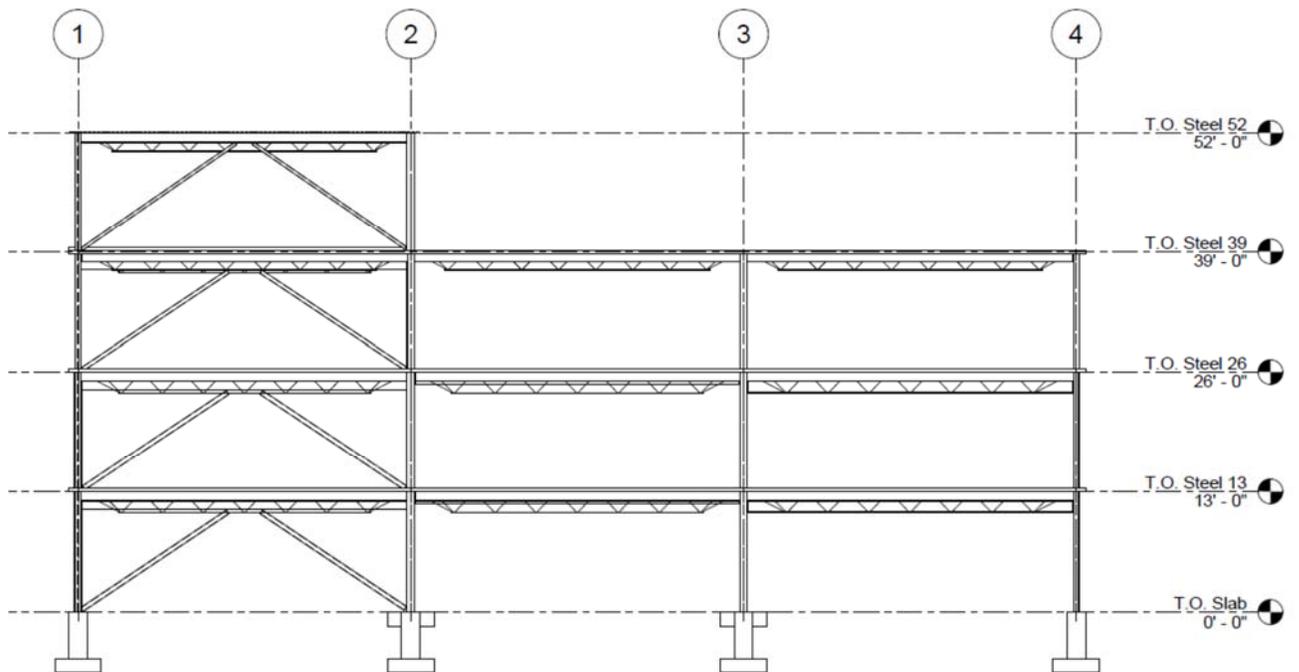


Figure 6: AISC 3 Story Building: South Elevation

The complete list of Structural Analysis and Design Exercises is continually being expanded. Currently, BIM models have been developed for the following exercises/design problems.

- Tributary Area, Load Tracing
 - Vertical loads – Multi-Story Building 1
 - Snow Load Analysis, Flat Roof, Sloped Roof
 - Wind Load Analysis - Multi-Story Building 1, AISC 3 Story Steel Building
- Truss Analysis: Richford VT Highway Bridge, US Forest Service Truss Bridge
 - Truss Deflections
- Influence Diagrams: Bridge Girders, Bridge Trusses
- Beam and Frame Deflections
- Braced Frame Analysis
 - Single Story Buildings: Grocery Store, Steel Warehouse
 - Multistory Buildings: AISC 3 Story Steel Building, 4 Story Building
 - Bracing Vs. Shear Wall Analysis
- Rigid Frame Analysis: 4 story Building – Unbraced Rigid Frame

VI. Assessment

Assessments of the changes in the Structural Analysis, Structural Steel Design, and Reinforced Concrete Design courses are being conducted using the Student Outcomes from the 2019-2020 ABET Engineering Programs Criterion 3.¹⁰

The student outcomes that are specifically assessed in the Structural Analysis course are as follows:

1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. The specific artifacts used for these assessments include homework assignments, exam problems, and analysis projects.
7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.¹⁰

The student outcomes that are specifically assessed in the Structural Steel Design course and the Reinforced Concrete Design course are as follows:

1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. (Note: not all of these factors are considered on all projects)
7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.¹⁰

The specific artifacts used for these assessments include homework assignments, exam problems, and design projects. One of the specific projects used for assessing ABET Student Outcomes 1 and 2 was the analysis and design of the roof and floor framing systems for either the AISC 3 Story Steel Building or the 4 Story Building. In these projects students had to identify constraints, determine loads, analyze different framing configurations, and apply engineering principles to produce an optimum design. The students had to consider economic, architectural, construction safety, environmental, and other considerations in the design process.

VII. Summary and Conclusion

This paper presented information on how Building Information Modeling (BIM) is being integrated throughout a program's structural analysis and design courses. Structural Analysis and Design courses have been modified to utilize BIM models to provide experiential learning opportunities for Civil Engineering students. Students were introduced to a range of BIM and Structural Analysis and Design tools. While assessment is ongoing, preliminary results indicate that the majority of the program's junior level students in the structural analysis class are excited about the opportunities to integrate BIM into their curriculum.

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