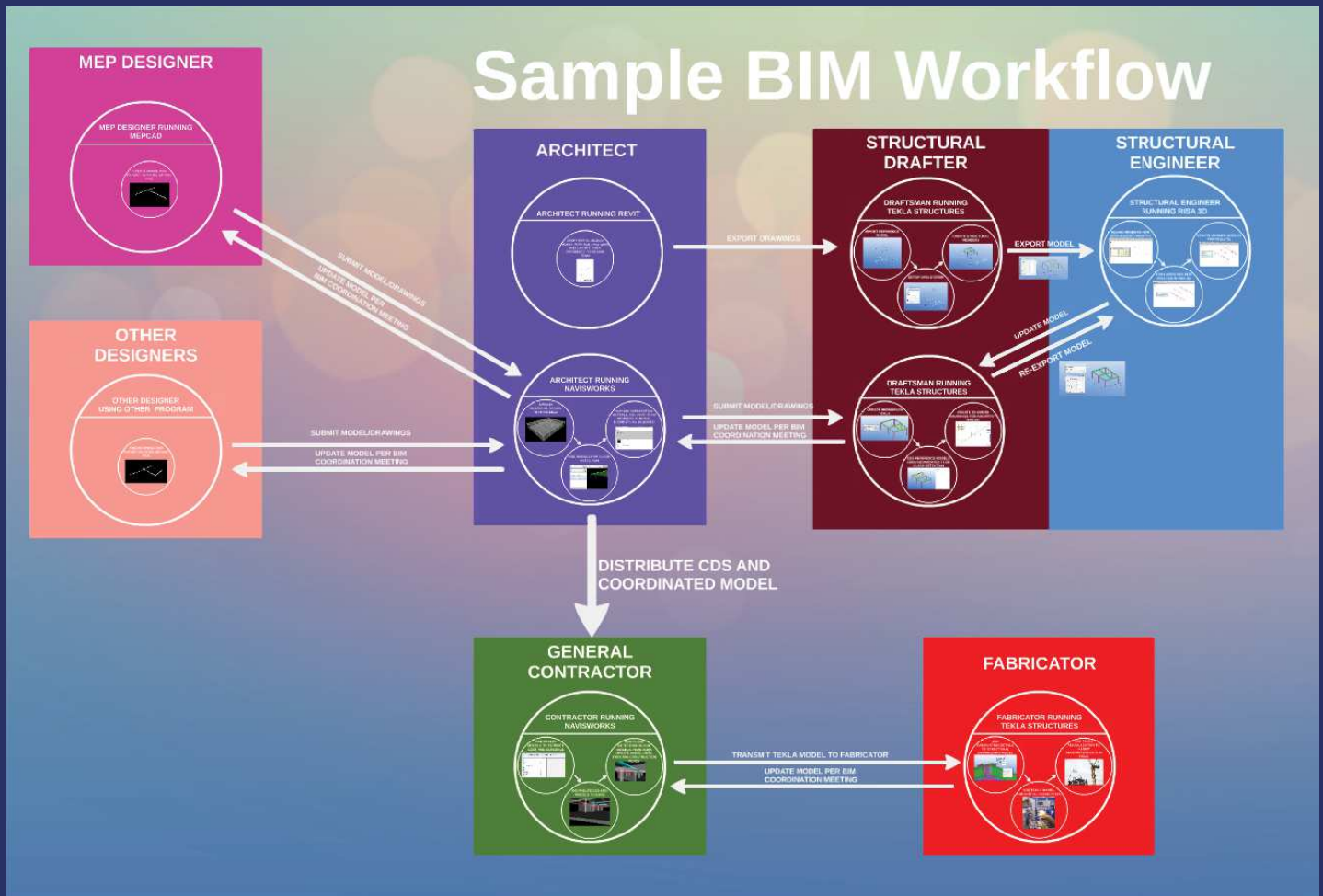


# EXPLORING EMERGING TECHNOLOGIES FOR THE BUILT ENVIRONMENT CIRCA 2015 FOR USE IN ARCHITECTURAL ENGINEERING AND RELATED MAJORS



BY: CONNOR J HANLON  
IN PARTIAL COMPLETION FOR B.S. IN  
ARCHITECTURAL ENGINEERING  
ADVISOR: ALLEN ESTES

# *Special Thanks To:*

*My Senior Project Advisor Allen Estes*

*CM 421 Advisor Elbert Speidel*

*DNA Consulting*

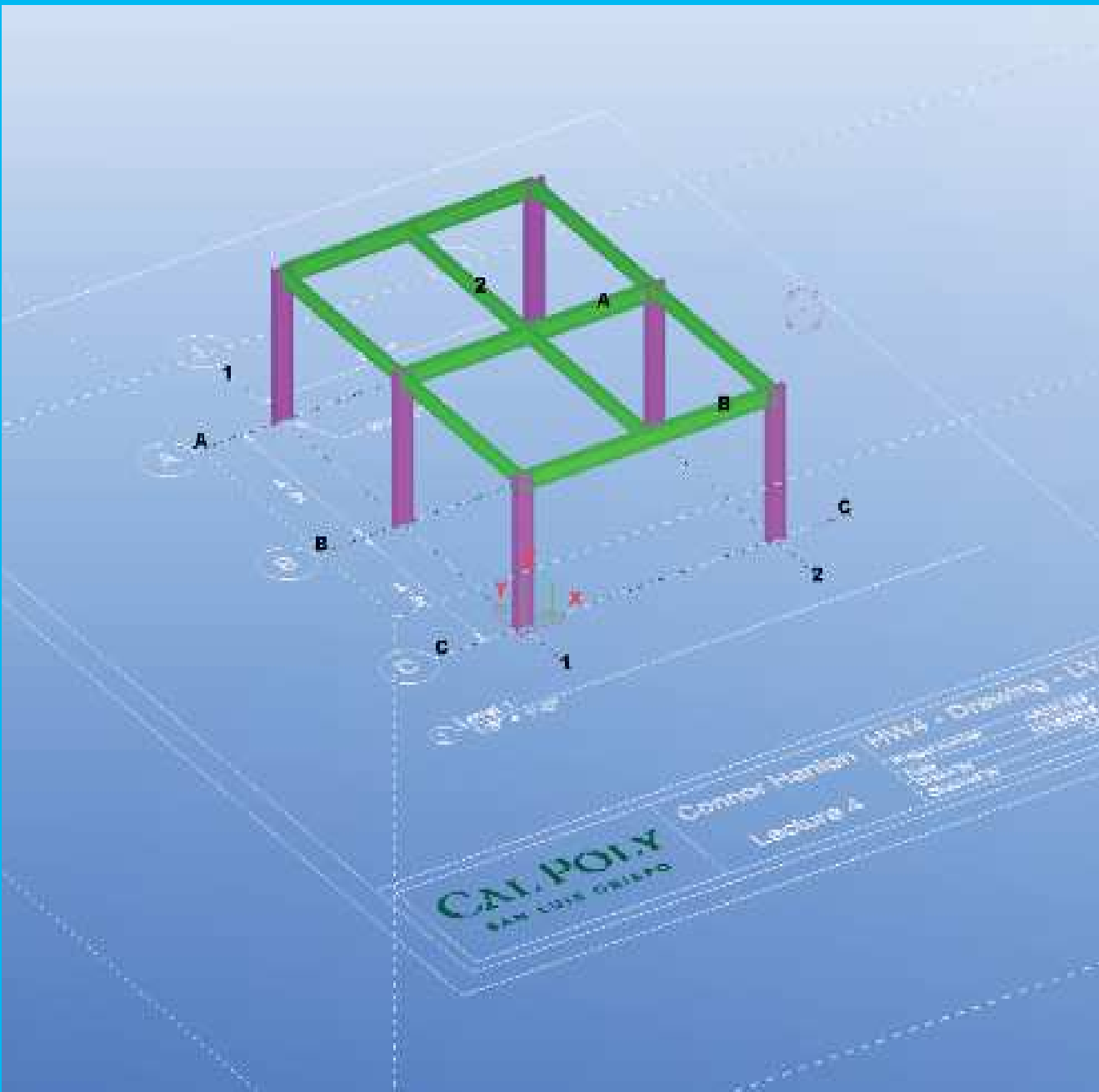
*Trimble*

*Matt Construction*

*The Co-Teachers of CM 421*

*Matty Reed*

# SECTION 1 - INTRODUCTION



A RENDERING OF A TEKLA MODEL BEING BUILT WITH A REFERENCE DRAWING. SEE LECTURE 4 FOR MORE INFORMATION ON THIS PROCESS.

Thank you for taking the time to read this Senior Project report. This section of my report seeks to explain the purpose and goals of this project. The Table of Contents shows the location of all the project elements. The executive summary give a succinct description of the project materials. The proposal lays out these goals in further details, and outlines the materials that are presented in the preceding sections of this project.

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## EXECUTIVE SUMMARY

For this senior project I am seeking to combine my knowledge of Structural Engineering with Construction Management. For this task, I have decided to look at Building Information Modeling (BIM). In this project I investigate the BIM tools Trimble Tekla Structures and Autodesk Navisworks Manage. Tekla is a modeling, fabrication, and design program. Navisworks is a visualization and Clash Detection tool. For this project I have identified two main goals relating to Navisworks and Tekla:

1. Create content to allow students and professors learn how to use Tekla and Navisworks
2. Determine the capabilities of these softwares, and figure out why these softwares matter to Architectural Engineering (ARCE) students.

After reading through this report, and accessing additional on-line resources including homework assignments and tutorial videos, students should have a solid understanding of how these programs work and why they matter to the Design and Construction process.

## **SENIOR PROJECT PROPOSAL**

*By: Connor Hanlon*

### **TITLE**

*Exploring Emerging Technologies for the Built Environment Circa 2015 for Use in Architectural Engineering and Related Majors*

### **INTRODUCTION**

Architectural Engineering (ARCE), as taught by the venerable professors at Cal Poly, is a program that is steeped in excellence and tradition. Many of the classes taught in this program have remained unchanged for decades, as many students have seen when talking to older alumni. This is a great thing, for the ARCE program instills a level of excellence that is fundamentally ageless. However the nature of the construction industry has changed over the past few years. Paper has been replaced by PDFs, two dimensional drawings are being replaced by five (or seven depending on your point of view) dimensional models, and a significant portion of engineering work is now being done overseas. In addition to this, more and more projects are moving from a Design/Bid/Build process to a Design/Build or Integrated Project Delivery (IPD) process. While the ARCE program at Cal Poly embraces some of these tools such as Autodesk Revit, there are always new tools to be explored.

In light of all of these things it is imperative that today's ARCEs be up-to-date on today's newest technologies in-order to stay ahead of a changing marketplace. By accessing the same technologies as the contractor and architect, the structural engineer will be able to offer compressive and cheaper solutions in a shorter amount of time. My senior project seeks to explore what technologies are used in the industry, and to make these technologies accessible to ARCE students. I will provide a variety of materials that can be either incorporated into current ARCE classes, or could be turned into a standalone class. Lastly, in order to foster communication with their peers, I will create content that is relevant to both ARCE and students in related majors. I will specifically focus on the relationship between ARCE and Construction Management (CM) students, due to my experience in CM. In my proposal below I will outline my goals, deliverables, resources, alternative ideas, and a schedule.

### **DETAILS**

#### 1. Goals

- a. To develop content that gives both ARCE and CM students a basic understanding of Trimble Tekla Structures. Students should be able to create basic structural models of concrete and steel buildings that show foundations, gravity systems, lateral force resisting systems, and basic connections. Students should be able to produce both 3D models and 2D drawings from this program. Please note I will refer to Trimble Tekla Structures as "Tekla" for simplicity.
- b. To develop content that gives both ARCE and CM students a basic understanding of Navisworks. Students should be able to create a Navisworks File (NWF), learn how to navigate and manipulate multiple models in a NWF, learn how to run clash detection, and learn how to create reports in Navisworks.
- c. To develop content that gives ARCE students an advanced understanding of Tekla. This will involve creating complex connections, rebar modeling, and the creation of details.
- d. To develop content that gives ARCE students a understanding of how to coordinate models between Risa 3D and Tekla, which is a structural analysis program. Students will be able to apply this plug in for basic steel construction.

#### 2. Deliverables

- a. Lesson Plans - The bulk of this project will include lesson plans for the items mentioned in "Goals" and "Alternative Goals". These lesson plans will include step by step instructions

for instructors as well as power points that will explain the process to students.

- b. Assignments - For the “Goals” stated above, student assignments will also be created. These assignments will include worksheets, drawings, and completed models/drawings for instructor use.
- c. Models and PDFs - A collection of relevant models, PDFs, and example projects will also be included. These files will come from projects Connor has already worked on, and also projects files donated to Cal Poly by professional firms (see “Resources” below).
- d. Final Report - At the conclusion of this project a final compressive report will be created. This report will contain the content created, outline the process to create content, and contain any additional resources. In addition to this a final evaluation will be created. This evaluation will outline the best method to include emerging technologies in ARCE class, or if a new class should be created. This report will include a thumb drive with all applicable models and PDFs. In addition, this report will be stored for future reference on Cal Poly’s Digital Commons website. Part of this report will include a direct comparison report between Tekla and Revit, as well as an explanation on why ARCE students should
- e. Final Presentation - A final presentation will be created for this project. The form of this presentation is to be determined by the faculty advisor and students. This presentation could be a summary of the lesson plans created, or it could be a lesson that is given to a combination of students and faculty.

### 3. Resources

- a. Faculty - The advisor for this project will be ARCE department head and professor Al Estes.
- b. Professional Firms - I has developed a network of contacts through his time at Cal Poly. Connor will reach out to these contacts for advice, sample models and projects, and potentially funding. See below for a list of contacts.
  - i. Matt Construction - Kevin Williams - kwilliams@mattconstruction.com
  - ii. DNA Consulting - Alyssa Schorer & Daniella Castro - alyssa@dnadetailing.com
  - iii. Trimble Tekla - Michael Evans - Michael.Evans@tekla.com
- c. Technology - I will use both the ARCE and CM computer labs in researching this project because the CM lab contains Tekla. In addition Connor will look into obtaining a version of Tekla, Fastrak, and Risa 3D for at least one of the ARCE Computers.

### COLLABORATION

This project has been designed to be accessible to both ARCE and CM students. Matty Reed, a 5th year CM student taking his final quarter at Cal Poly, is also looking at trying to incorporate emerging technologies in the CM department as a senior project. For this project, I will work with Matty to develop some content that both students can use. Matty and myself will be working on separate projects with separate advisors (Phil Barlow is Matty’s advisor). The exact scale of their collaboration will be determined at a later date (see schedule).

**SCHEDULE****Senior Project Schedule\*\***

	Administration	Tekla	Tekla/Risa 3D	Navisworks	Background	Conclusion	Video
WEEK 1	1.) Project Proposal						
WEEK 2	1.) Amended Project Proposal Due 2.) Reach out to industry 3.) Determine extent of collaboration with Mattv Reed	1.) Tekla demonstration for Al on 9/29/2015	1.) Obtain a version of Fastrack	1.) Navisworks demonstration for Al			
WEEK 3		1.) Tekla Basic modeling lesson Plan Created					
WEEK 4			1.) Become acquainted with Risa 3D				
WEEK 5		1.) Tekla Connections Plan Created					
WEEK 6			1.) Develop Risa 3D Plan		1.) Capabilities of Tekla and Navisworks Report		
WEEK 7		1.) Tekla, advanced lesson plan created		1.) Start Navisworks Lesson Plan			
WEEK 8	1.) Determine makeup of final presentation		1.) Create Risa 3D Lesson Plan			1.) Reflections on CM 421 report	1.) Lesson Plan 1 Video Created
WEEK 9		1.) Finalize Tekla Lesson Plans	1.) Finalize Risa 3D Lesson Plan	1.) Create Navisworks Lesson Plan	1.) Tekla to Revit Comparison Report		1.) Lesson Plan 2 & 3 Video Created
WEEK 10	1.) Finalize Lesson Plans by 11/25/2015 2.) Have working Final Presentaion created by 11/25/2015			1.) Finalize Navisworks Lesson Plan		1.) Recommendation to the Department report	1.) Lesson Plan 4 & 5 Video Created
WEEK 11	1.) Final Presentation					1.) Final Reflections on Teaching Methods Report	1.) Final Editing of Viedo
FIN	1.) Turn in Final Report 2.) Upload Project to Digital Commons						

\* Amended Proposal will be turned in if Alex Lohr is able to be added on to the project.

\*\* Unless stated otherwise, all items in this schedule are due at 6 PM on Friday.

**CONCLUSION**

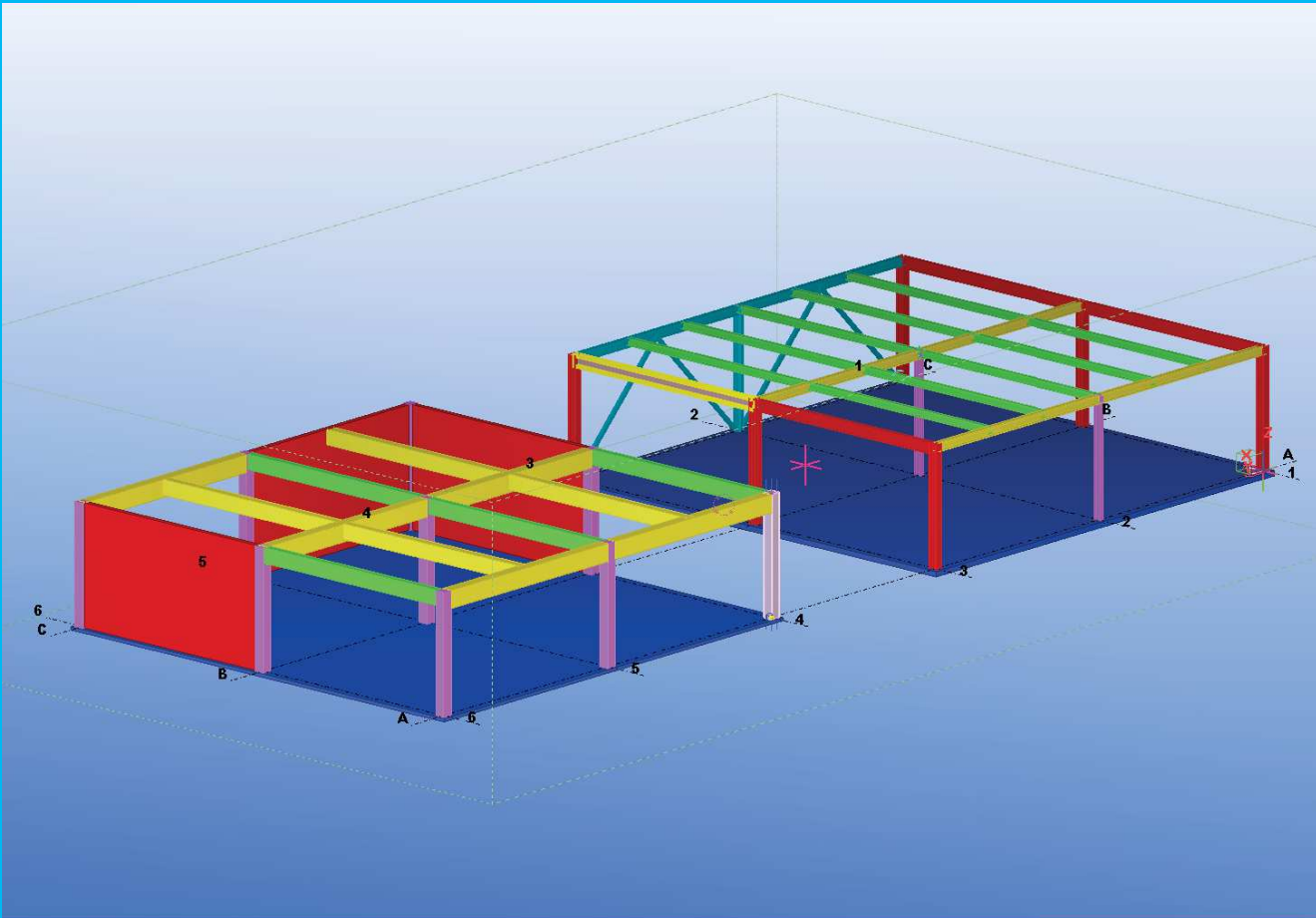
I have included the phrase “Circa 2015” in my project title because this project will be obsolete in a few years due to changing technologies. While this project should remain relevant for the next few years, it will be imperative that someone updates the curriculum for this project sometime down the road. Updating the content of this project could be a great future endeavor for future ARCE students.

It might come as a surprise that I have not mentioned Building Information Modeling (BIM) up to this point in my proposal. I have purposefully done this to move away from the boring image associated BIM, which is viewed as something too simple for Structural Engineering and too complex for Construction Management. I prefer the term “Emerging Technologies” because it is a more accurate description. Structural analysis programs such as Risa 3D and document control programs such as Bluebeam are not considered “BIM” programs. However they are as useful, sometimes more useful, than traditional “BIM” programs such as Revit, Tekla, and Navisworks.

My goal with this project is to broaden the horizons of Cal Poly ARCE students, and to share my unique experiences with the department. I hope the content that I create for this course will be useful to for both students and instructors. Although I realize that this project is unorthodox by normal ARCE standards, I believe that this project can potentially touch all ARCE students.



# SECTION 2 - BACKGROUND



A SCREEN-SHOT FROM LECTURE 2, IN WHICH CONNECTIONS AND REBAR IS ADDED TO THE EXISTING BUILDINGS SHOWN ABOVE.

One of the reasons that a significant amount of people struggle with engineering and applied sciences is that these disciplines are expressed in an abstract matter. On the other side of this equation, many people have an understanding of the abstract but struggle to pictorially communicate their ideas. In the venerable practice of structural engineering, a series of rigorous conventions have been created to communicate engineer's ideas. These conventions, while useful, do not fully convey the ideas that engineers wish to convey. With the rise of ever improving software, structural engineers are now able to fully convey the nature of their models. Every member, every bolt, every weld, every single detail can now be modeled efficiently and accurately. These models can then be analyzed or designed in a multitude of programs. In addition, these digital tools can be used to communicate more efficiently with the general contractor and the architect, and eliminate constructibility concerns in the beginning. These tools will make engineering more approachable for more people. Visual learners will be able to get an understanding of their projects while textually based learners will be able to easily display their ideas to everyone. With all the above in place the Structural Engineer will be able to design more efficient, integrated, and safe buildings.

## SECTION 2.1 – BACKGROUND – CAPABILITIES OF TEKLA AND NAVISWORKS

### TEKLA - DEVELOPMENT HISTORY AND CAPABILITIES OF PROGRAM

#### *Tekla - History*

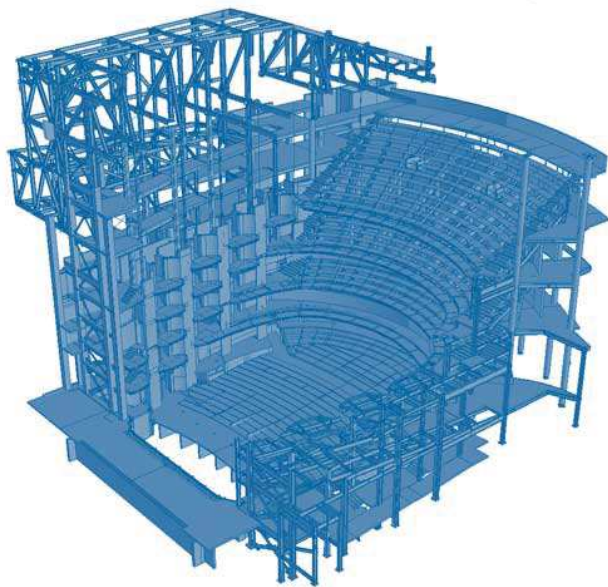


Tekla is an older company, it originally started out in 1960s Finland. At this point of time, engineering work moved the “the rate of postal”. Six firms decided to change this by pooling their resource into what was then a prohibitively expensive machine, a punch card computer. Originally called “Teknillinen laskenta Oy” (Finnish for Technical Computing), the trade name Tekla was chosen for the firm in Helsinki Finland in 1966. The company, originally focused on a broad range of engineering disciplines, focused on several markets including structural engineering, road building, and earth moving.

As the 70s came around, Tekla moved from punch cards to digital computers. While Tekla originally outsourced its computing in the early 70s, Tekla acquires its first central computer in 1979. This allowed all programmers and engineers to get their own “alphanumeric terminals” in order to write more efficient computer code. An interesting note of this time is the development of Tekla’s plotter and graphical software. The early to mid-70s were a time of recession caused by the end of the post-war boom and the 1973 oil crisis. While most of the world was in an economic recession, and building ground to a halt, Tekla developed graphical and plotter capabilities that made it more competitive. Lastly in 1973 Tekla began offering Finite Element Analysis services to



AN EARLY TEKLA ENGINEER SITTING AT AN ALPHA NUMERIC TERMINAL.



MODEL OF AN AMPITHERTER BUILT IN TEKLA XSTEELV

its clients. This analysis method has been built into Tekla's structural analysis software to the present day.

The 1980s was a time of continuous software development for Tekla. While there were no large milestones at this time, the software developed at this time was used for Tekla's dramatic rise in the early 1990s. In the 1990s the X series of programs were developed for PCs. This included Xpower (used for Electrical utilities to manage power systems), Xcity (for urban planning), and Xsteel (for steel construction). At this point Tekla was based on a Unix operating system, although by 1996 Tekla began transitioning to the Windows Operating system. With this expansion of technical expertise also began a geographic expansion. Tekla began opening offices in the US, UK, Germany, Japan, and other parts of Scandinavia by 1999.

The 2000s brought a period of continued expansion and change to Tekla. At this time Tekla as we know today began to take shape. Several of the non-structural software's that were developed by Tekla including Xcity and others were sold off to various companies. At this time Xsteel was replaced by Tekla Structures in 2004. This software was able to create models of steel, timber, and concrete buildings. Tekla's Structures also heralded Tekla's full progression from being a Finnish company to an international company; At this point of time 80% of Tekla's sales came from outside Finland. Tekla also became more widely used in the industry, 18,000 licenses of Tekla Structures were sold by 2010.

By the 2010s the international recognition of Tekla was so great that it was inevitable that it would be bought by a larger company. Trimble Navigation, decided to make just this offer on May 9, 2015 for €337 million or \$498 million ("Trimble Navigation"). This is just part of a wide series of our purchases by Trimble in the Construction industry. Other recent purchases by Trimble include Sketchup (which was originally owned by Google), Gehry Technology's Digital Projects, Vico Office, and many other software. This purchase has increased Tekla's ability to interact with other programs, and has helped to increase Tekla's visibility across the industry.

### *Tekla Today*

Today Tekla has 5 products geared towards construction. These products are:

- 1.) Tekla Structures - BIM software that is used for creating accurate models of almost any structure. This is the program that is being investigated in this project. Tekla Structures Version 21.1 will be used for this project. As stated earlier in the project proposal, Tekla Structures will be referred to simply as "Tekla" unless otherwise stated.



2.) Tekla Structural Designer - An engineering tool that is used for structural analysis and design. This program will not be investigated, although it is an excellent program for analysis.

3.) Tekla Bimsight - A program for construction coordination similar to Navisworks. This program has the ability to run clash detection and scheduling functions. I have chosen to explore Navisworks over Bimsight because of my professional experience with this software, and Navisworks wide implementation by General Contractors in California.

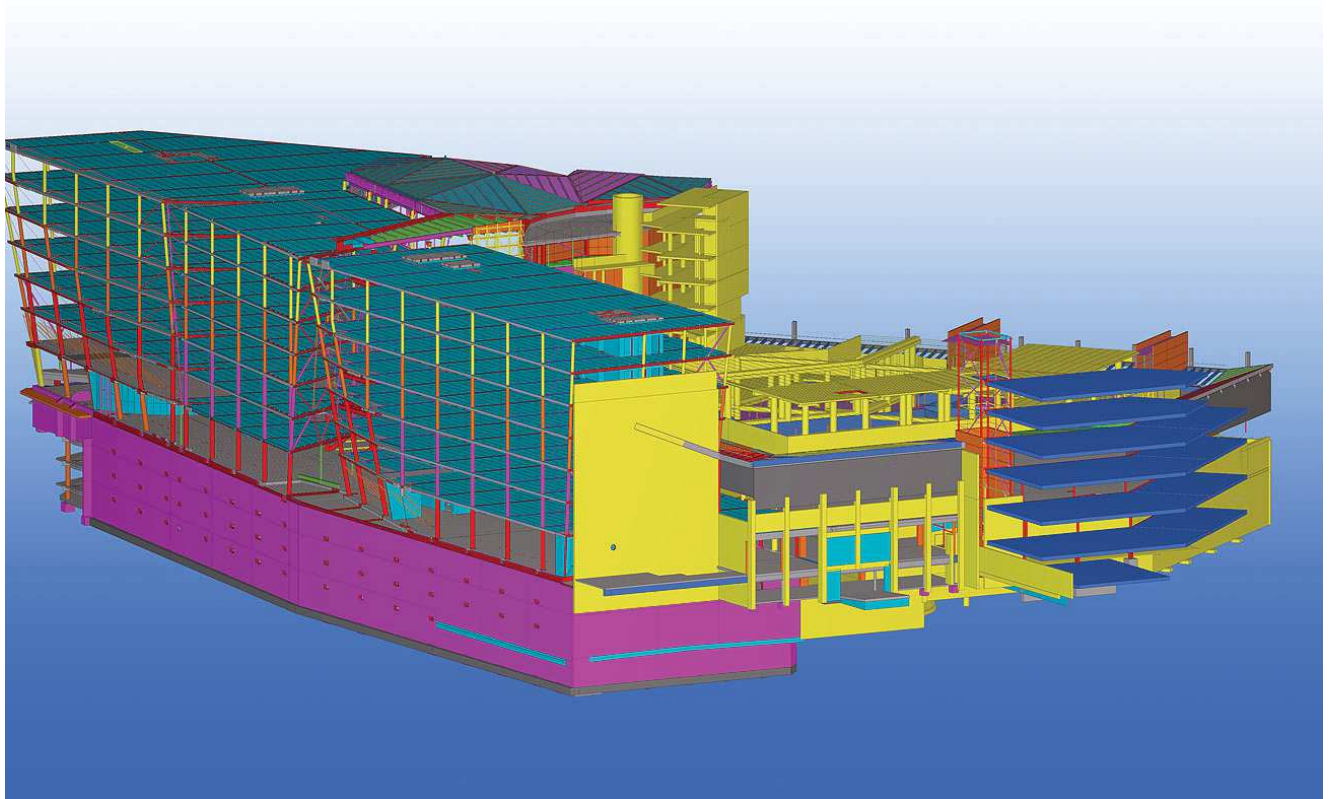
4.) Tekla TEDDS - A suite of programs meant to eliminate repetitive structural calculation tasks.

5.) Tekla Field3D - A tablet based program similar to Tekla Bimsight that is geared for construction coordination.

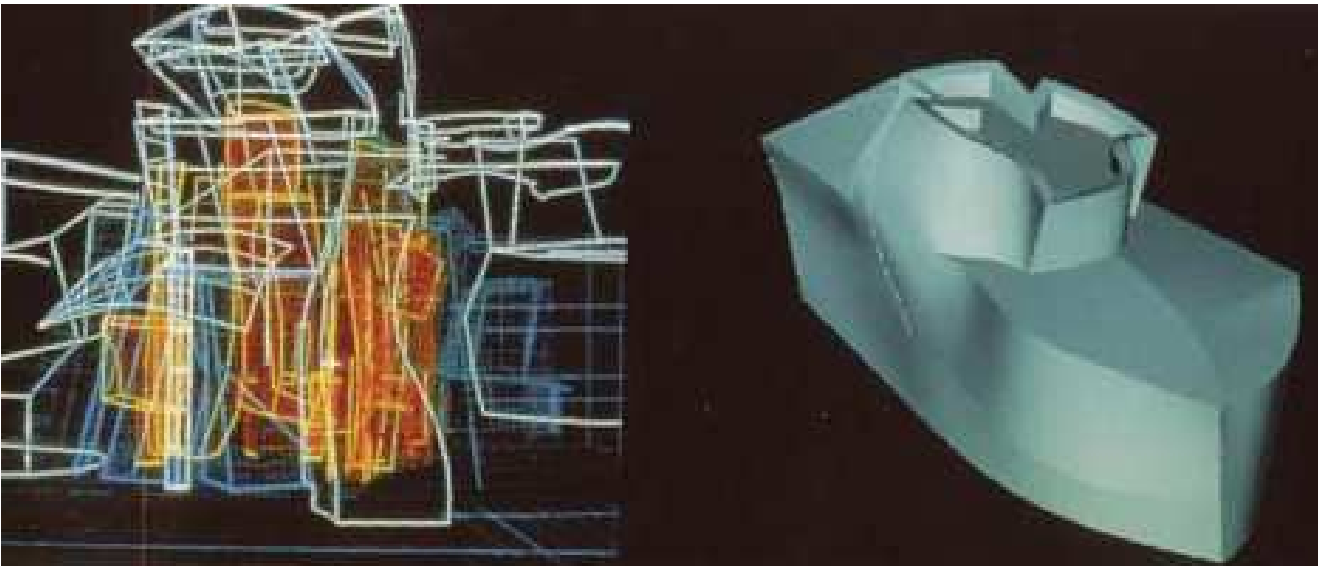
### *Overall Program Classification and Description*

Now that the history of Tekla has been established, the mechanics of the program will be discussed in a general sense. Specific tools and procedures will not be discussed, please read about this items in these lesson plans in the preceding pages of this report. This section will cover parametric modeling, file based projects, and Tekla's 3D interface.

Tekla at its core is an "Object Based Parametric Modeling" (Eastman 29) modeling program. Parametric Modeling is a way of digitally representing a shape that goes beyond traditional computer aided drawing (CAD). Parametric modeling has been in development since the 1980s, and has been incorporated in Tekla since the Tekla XSteel series. Unlike a traditional CAD model, a parametric model is not governed by a series of lines drawn on a page. For this type of digital



TEKLA 2014 BIM AWARDS WINNER OP-POHOJAL HEAD-  
QUARTERS IN HELSINKI, FINLAND BY SWECO

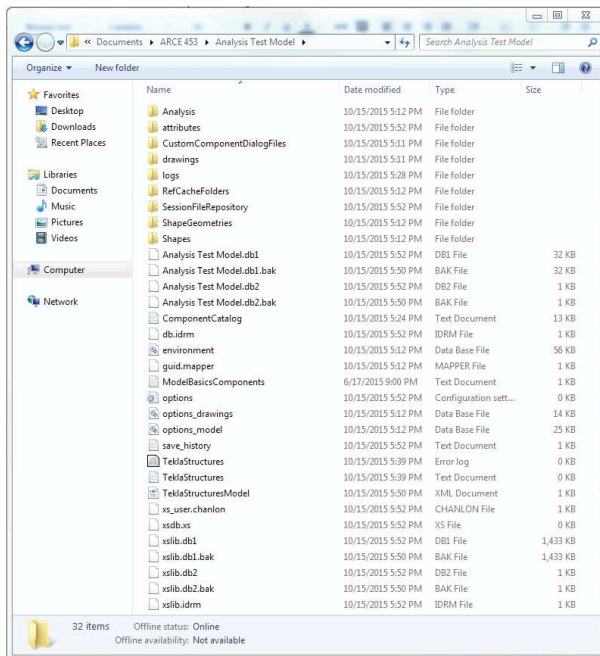


AN EARLY EXAMPLE OF PARAMETRIC MODELING FOR COMMERCIAL USE. PICTURED ABOVE ARE RENDERINGS OF THE GUGGENHIEM MUSEAM USING THE PROGRAM CATIA IN THE EARLY 90s (DAVIS).

modeling one will place objects in digital space that are governed by a series of rules. This includes rules can cover anything from the profile of an object, how an object changes when placed adjacent to a different objects, what happens with penetrations to the object, and many others things. This means that every single aspect of an object does not need to be modeled, unlike a conventional CAD drawing.

Usually, Object Based Parametric Modeling programs contain a large series of predefined objects based off of their application. Tekla includes a large library of objects geared towards structural engineering including many different member profiles, assemblies such as stairs and railings, rebar and hooks, and many other components. Objects in Tekla can be changed via the “properties” menu, which is usually accessed by double clicking an object. This menu contains all of the “rules” that define a parametric modeling object. This includes profile shape, material properties, connection to other objects, and many more options. This menu will also apply for non-structural objects including grid lines and annotations. It is also important to note that not all properties in the “properties” menu are not geometric attributes. Certain information such as material quality, end conditions for analysis, and other information can be used in engineering analysis programs.

In addition to being an Object Based Parametric Modeling program, Tekla is also a file based program and not a memory based program. Most programs that the average person will interact with are memory based programs. This means that one project, such as a CAD drawings, Word document, or photo will have one file associated with it. The benefit of this system is that it is easy to store and transfer files. However this means that the entire project needs to be open when one wants to work on it. File based programs work in the opposite way, one project is



A LOOK AT WHAT THE FILE STRUCTURE OF A TYPICAL TEKLA PROJECT

split into many different files and folders. This means that a small number of small files need to be open at one time to work on a project. A file based project will initially be much larger than a memory based program. However as the projects get larger, a file based project will be smaller than a memory based project. In a larger memory based project, one will encounter more problems with virtual memory. More virtual memory is used on a memory based project since the entire project is open; this results in significant waiting times as the computer “swaps” (Eastman 59) virtual memory. File based programs help to eliminate this slow-down.

Another important component is that Tekla fully embraces a 3D interface. Many other modeling programs such as Revit and ArchiCAD use a 2D interface in-order to create 3D objects. In Tekla starts and primarily works in a 3D interface. Even elevation and plan views in Tekla are 3D views that can easily be rotated or manipulated. For drafters with more experienced in traditional

drafting, this can make the learning curve a lot higher. However, this improves the visualization of complex shapes and allows engineers to get a much easier view of connections.

### *Modeling Capabilities and Terminology*

With the general characteristics of Tekla discussed, the exact capabilities of the program will now be investigated. This section of the report will talk about Tekla’s terminology, modeling capabilities, and analysis capabilities.

Two important terms when working in Tekla are parts and assemblies. Parts in Tekla are individual objects that can be edited. For example, framing members in Tekla are almost always considered to be parts. One will work primarily with parts in the early design process until connections are considered. Assemblies in Tekla are groups of parts. Assemblies in Tekla generally are connections that require multiple parts such as a shear plate connection. One can also create a nested assembly when an object has multiple assemblies. For example if one created an object that included a column with two endplate connections, this would constitute as a nested assembly. In addition to the above, Tekla also has many pre-made assemblies called components. Components are useful assemblies such as structural steel connections, concrete reinforcement, and prefabricated items such as stairs or railings that can be easily added into a working model.

Below is a list of the different structural objects and capabilities that can be modeled in Tekla:

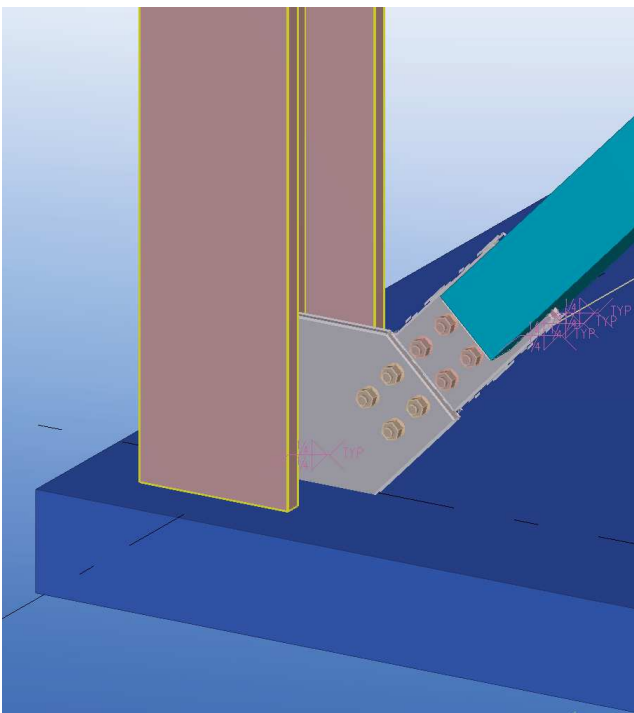
#### 1.) Reinforced Concrete Objects and Components

- a.) Volumes of walls, slabs, beams, columns, and other items can be shown.

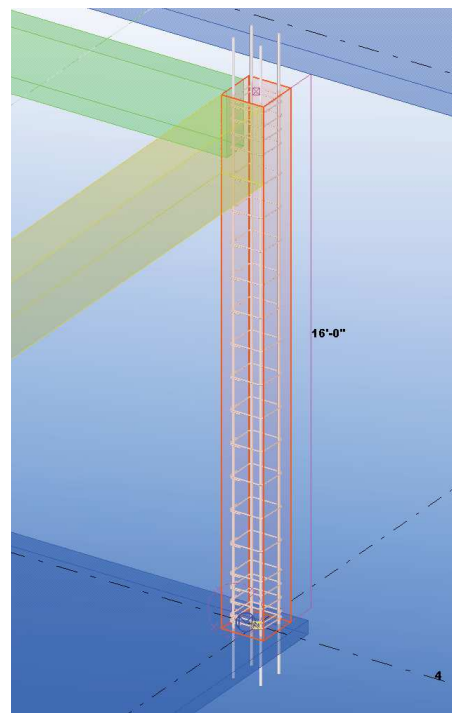
- b.) Rebar, hooks, ties, couplers and other reinforcing items.
  - c.) Slab pours can also be shown in Tekla.
  - d.) Material strengths of concrete and steel can also be specified for analysis and material takeoffs.
- 2.) Steel Parts and Components
- a.) A larger variety of members can be shown including wide flanges, channels, angles, etc.
  - b.) Connections can be accurately modeled with plates, welds, bolts, and other components.
  - c.) Material strengths of members, bolts, welds, and other items can be specified for analysis material takeoffs.

While Tekla Structures is not capable of undertaking actual analysis, Tekla models can be set up to do analysis in other programs. Programs that Tekla can easily communicate with include ETabs, SAP2000, and Risa 3D. Models from Tekla can either be sent to these programs for analysis, or design models in these programs can be sent directly to Tekla. Thus, a simple line drawing in a program such as Risa3D can be transformed into a flushed out model in Tekla with no wasted time on transcribing the information. Lecture 4 covers this topic in more depth.

I have decided to investigate Tekla's interoperability with Risa 3D over investigating Tekla Structural Designer for a few reasons. First, I wanted to use an analysis program that engineering students are already familiar with. Secondly, I was unfamiliar with Tekla Structural Designer at the begging of this project. This program however should be explored by future ARCE students.



STEEL BRACE FRAME CONNECTION IN TEKLA



COLUMN RIENFORCMENT IN TEKLA



## NAVISWORKS - DEVELOPMENT HISTORY AND CAPABILITIES OF PROGRAM



### *Navisworks - History*

Navisworks, when compared to Tekla, is a much younger and specialized software. Navisworks grew out of the desire for a person to be able to view multiple computer models from multiple programs at the same time. This idea came to a Cambridge University student in 1995, and was developed to a fully-fledged program. At this time this functionality was unheard of. Seeing the marketability of this idea, Lightworks Inc. licensed the software in 1997 and developed what would eventually become Navisworks. Lightworks Inc. is a computer rendering Software Company based in England.

Navisworks was further developed in the 2000s, and became widely used in England. Because this software became so widely used by the construction industry, Navisworks split off from Lightworks in 2000 to form Navisworks Ltd. Another mark of this software's widespread use was seen in receiving the Queen's Award for Enterprise from the British Monarchy in 2005. This award was given to Navisworks due to the huge volume of sales the company had overseas. A further vindication of Navisworks value came from its use on London's Heathrow Airport. Using Navisworks the designers of this building were able to save £375 million in construction costs through coordination, clash detection, and other tools in this software.



LONDON'S HEATHROW AIRPORT

Like any good company that was not a large conglomerate, Navisworks was bought out by Autodesk in 2007 for \$25 Million (Stachoni). While this software is one of the (relative to other programs) additions to Autodesk, it became one of the widest used software in a short period of time. Autodesk expanded the reach of this program and made it more interactive with other software such as Revit and AutoCAD.

### *Navisworks - Navisworks Today*

At this time Autodesk has created several different iterations of Navisworks based off of the needs of the client which can include the General Contractor, Engineer, Architect or Fabricator. These Products include:

- 1.) Navisworks Freedom - The greatest strength of this program is as the name implies, it is free. Navisworks Freedom allows one to view multiple models, view model hierarchy, view-points, and other information. This software can



be downloaded at: <http://www.autodesk.com/products/navisworks/autodesk-navisworks-freedom>

2.) Navisworks Simulate - Simulate offers a suite of products that go beyond the basic model viewing properties of Freedom. Simulate has additional tools for the model review process, the ability to create model takeoffs and schedules, and the ability to create photorealistic renderings.

3.) Navisworks Manage - The main difference between this program and Simulate is that Manage has the ability to run clash detection. This aspect of the program makes it invaluable to General Contractors and MEP sub contractors. For Lecture 5 Navisworks Manage will be used for this project in order to demonstrate the clash detection tool.

4.) BIM 360 Glue - Although this is not a “Navisworks” program it deserves mention. BIM 360 Glue is a stripped down version of Navisworks that is hosted online. This software also directly ties into Revit, AutoCAD, and other Autodesk programs. This program was created to make the coordination process easier for novices.

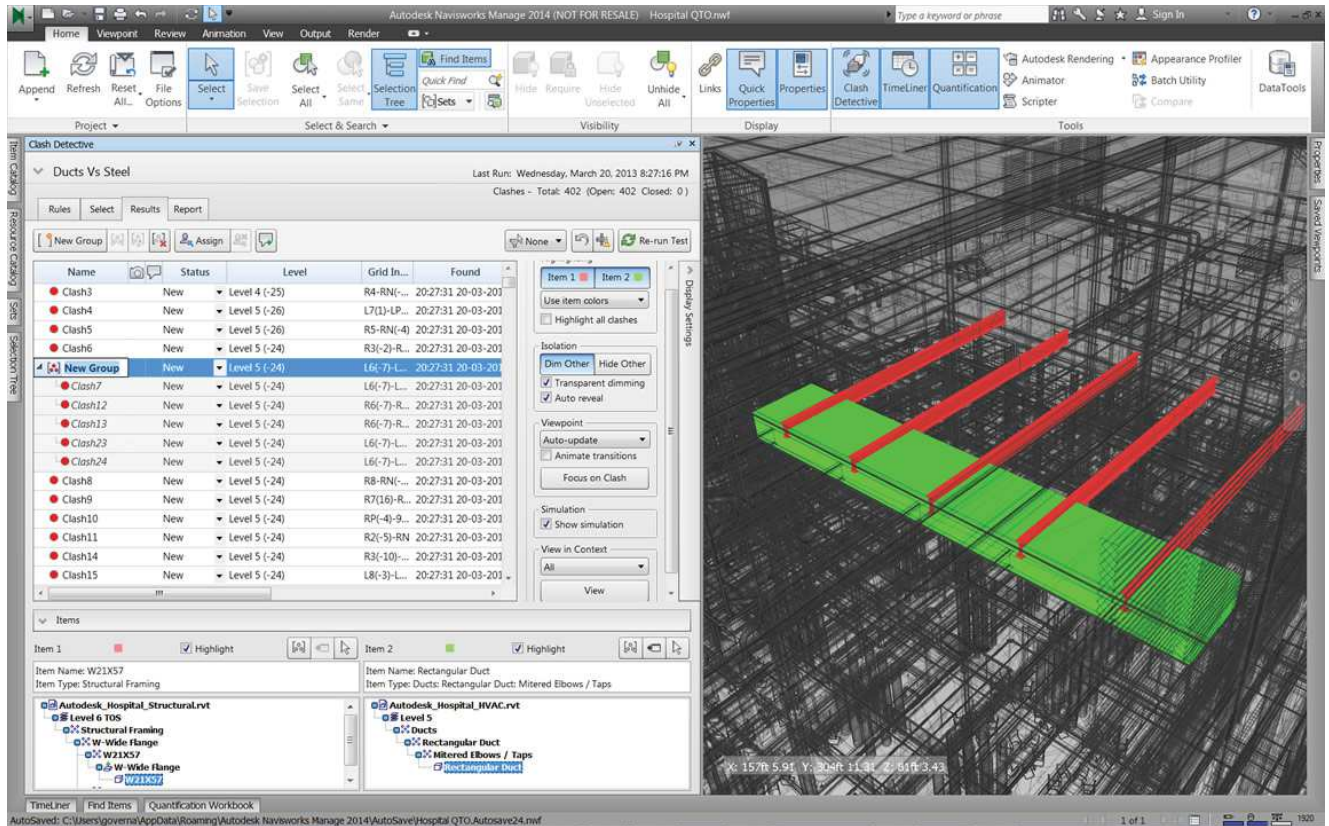
### *Navisworks - Features and Capabilities*

Below is a list of the some of the tools contained in Navisworks Manage:

1.) Visualization of Multiple Models - While this seems like a no-brainer, the ability to open multiple models in the same space to a high degree of accuracy is not something seen in many other programs. Navisworks is able to do this, and not require an absurd amount of RAM, through its ability to aggregate information. When a Navisworks File (NWF) is created models



EXAMPLE NAVISWORKS FROM AUTODESK'S WEBSITE ILLUSTRATING HOW ONE CAN COMBINE STRUCTURAL, ARCHITECTURAL, MEP, AND OTHER SYSTEMS IN NAVISWORKS



AN ILLUSTRATION OF THE CLASH DETECTION TOOL FROM AUTODESK'S WEBSITE

are “appended” to the file, Navisworks does not actually contain the model itself. Instead Navisworks references the individual files on the computer and creates an image of the original model. This process is analogous to how one will “place” images and other media in an Adobe InDesign file. Navisworks also has the ability to read more than 30 different parametric modeling or point cloud file types. Because of this ability to read so many file types, Navisworks is a huge program that is larger than other Autodesk programs including Revit.

2.) Clash Detection - This tool is why Navisworks is such a widely used program. The General Contractor is able to combine multiple files in one space, create clash “tests” based on their retirements, and rerun tests as models are updated with new information. From Navisworks the contractor is able to assign responsibility of individual clashes to individual subcontractors or design partners.

3.) Timeliner - This tool is used to tie multiple models to a schedule. This can be used to show a client the progression of a building over time. This tool is also useful for planning the layout a construction site over time.

4.) Rendering - Navisworks comes with a suite of rendering tools in order to make photo-realistic renderings of a model.

## REVIT TO TEKLA COMPARISON REPORT

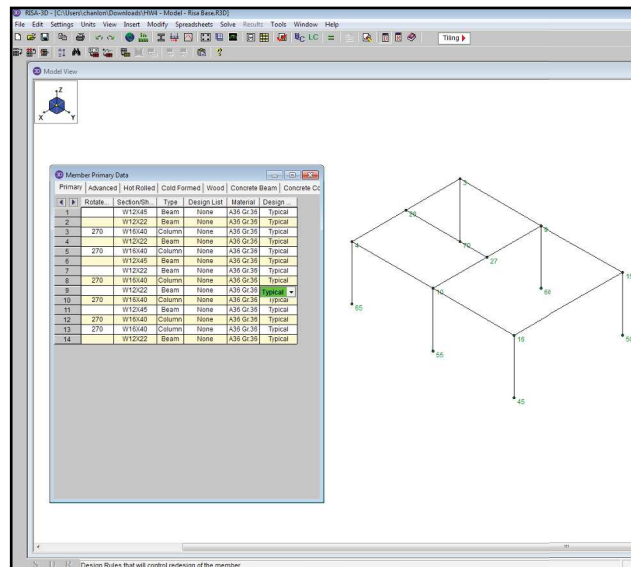
### Introduction

Since the advent of complex modern building systems such as reinforced concrete and structural steel the structural engineering field has risen to take on the complex task of understanding and designing these systems. These systems required an advanced level of understanding that could only be acquired through years of intense training at the university level. As a result of this, the structural engineer became more and more removed from the physical construction process in order to be able to understand the theoretical complexity of these systems. The main method in which the structural engineer could communicate with the rest of the building design and construction team was through drawings. Structural drawings are great tools, they present a macro level of detail that is required for analysis and design. While details can be shown in drawings, it is not possible to convey the complexity of the structural system in its entirety. The creation of BIM software has allowed the structural engineer to show a level of detail that is not possible in conventional drawings. This makes it possible for the engineer to close the gap between themselves and the construction team. While both Trimble Tekla and Autodesk Revit are great tools for the creation of design drawings and models, Tekla can function as both a design and fabrication tool. This report will focus on how this higher level of detail makes Tekla the best tool overall for structural modeling. This report will look at the structural analysis, reinforced concrete modeling, and structural steel modeling capabilities of Tekla and how they compare to Revit. This report is based on personal experience, case studies, interviews with industry representatives, and other research.

In addition to the research sources stated above, Autodesk University courses are used to show the capabilities of Revit. These courses, which are 1-2 hour lectures given by international professionals at the annual Autodesk University convention in Las Vegas, Nevada. These lectures are included in this report because they represent some of the most innovative minds at BIM, and show the full capabilities of Revit. The two lectures in the preceding report come from courses at Autodesk University 2014, which I feel most accurately demonstrates the current capabilities of Revit. These courses can be viewed for free on-line at <http://au.autodesk.com/>.

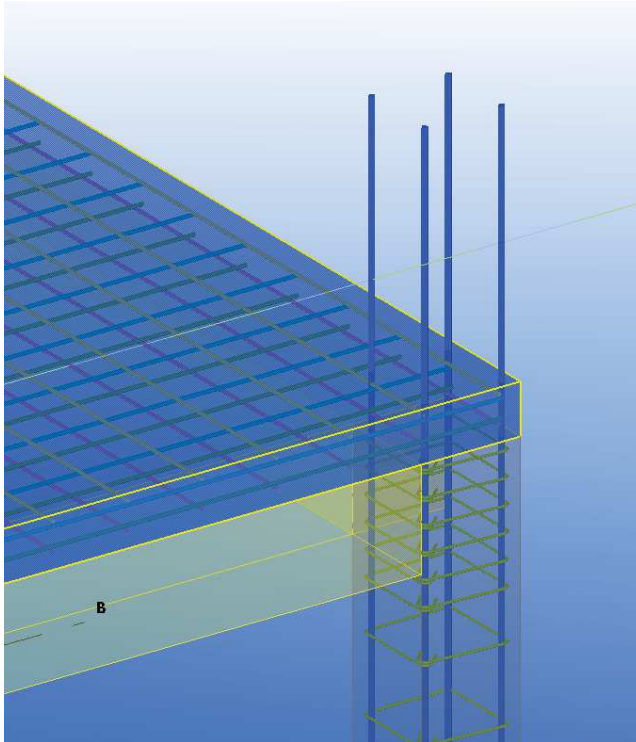
### *Tekla vs Revit: Structural Analysis*

Both Revit Structure and Tekla Structure are not analysis programs. These programs are meant to illustrate the intent of the designer through structural drawings and models. However both



A SCREEN SHOT FROM LECTURE 4 OF THIS PROJECT SHOWING WHAT AN TEKLA MODEL LOOKS LIKE ONCE EXPORTED TO RISA 3D.





SCREEN SHOT FROM TEKLA SHOWING LONGITUDINAL COLUMN REBAR INTERSECTING SLAB REBAR. BEAM REINFORCEMENT TURNED OFF FOR SIMPLICITY.

programs can be incorporated directly into the design process. In Tekla one can add geometric information, members and materials, loading information, and load combinations based on national or international code books. This information can then be sent to the analysis program, and the results then translated back into Tekla to create a more accurate model. This concept was demonstrated in lecture 4 of this project with the analysis program Risa 3D. In addition Tekla can also communicate with other analysis programs such as ETABs and SAP2000. This process helps to eliminate miscommunication between designers and drafters, as well as eliminating time wasted on creating two separate models in design and analysis programs. Revit also has the ability to communicate with the analysis programs Risa 3D, ETABs, and SAP2000 in a similar way to Tekla. While both of these programs are relatively equal in this context, Tekla has the ability to create more accurate structural models which will be explored in the preceding paragraphs.

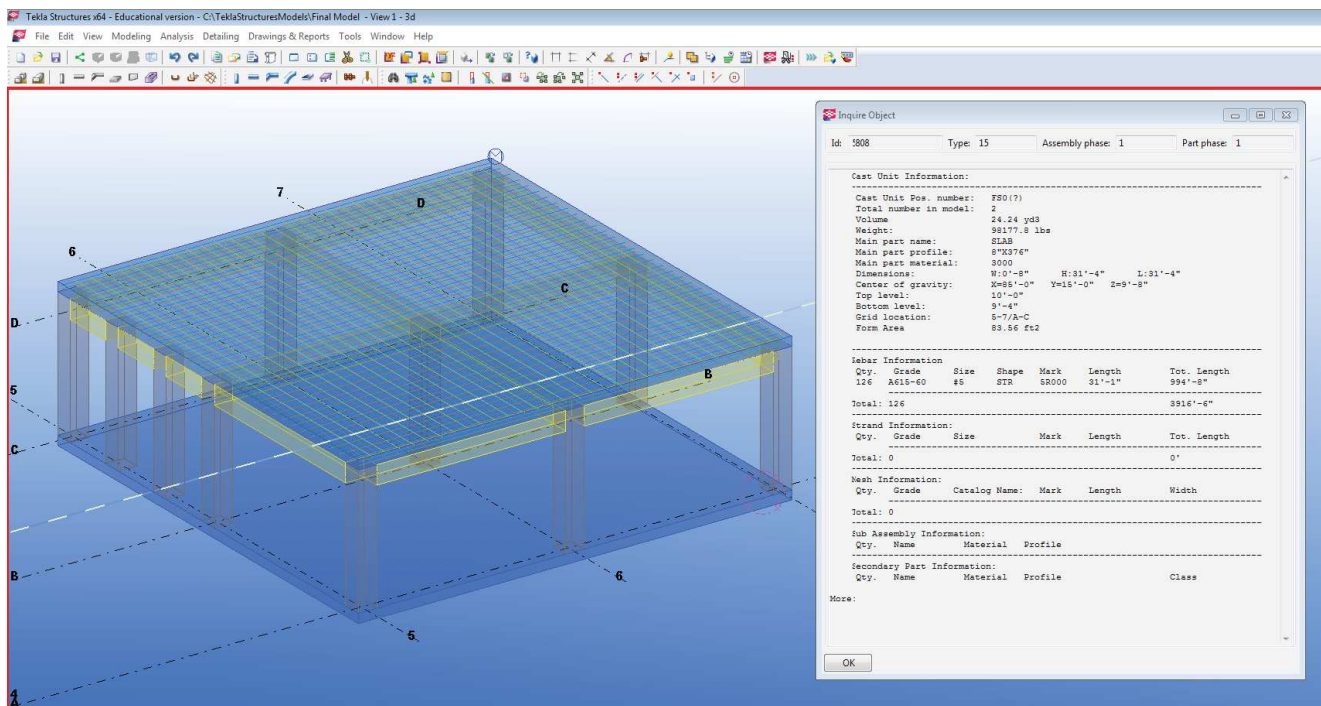
### *Tekla vs Revit: Reinforced Concrete Modeling*

The first thing that one will notice when opening Tekla is colorful objects that look more like legos than building components. When working with a reinforced concrete model, this is certainly the case. When one switches to a half-shaded rendering however, every single piece of rebar is exposed. As I show in Lecture 2 of this project, Tekla will model longitudinal reinforcement, ties, hooks, and any other reinforcement component imaginable. This allows the engineer to get a better understanding of constructibility that is not available in 2D line drawings. For example, one is able to see development length for beams in 3D space. This allows the engineer to see their design will clash with other rebar elements before the structure is built in the field.

Tekla's high level of detail is especially useful for complex elements such as precast rebar cages, as explained by firm DNA Detailing & BIM LLC. DNA LLC works with structural engineers and contractors to make fabrication level Tekla models. In my interview with this firm, they explained how they used Tekla to create complex prefabricated rebar cages for a new complex San Jose area corporate campus. On this project, the structural engineer specified rebar couplers for this cage. However, the structural engineering firm only created a symbolic 2D representation of this detail in their submittal. DNA detailing used Tekla to show how this component made the proposed design impossible, and helped to facilitate a constructible design. With Tekla, DNA was able to help solve this issue before it was discovered in the field which was able to save time and money on this project.

Along with the 3D model, Tekla will also create a suite of information that can be used for concrete construction. The easiest way to see this is by using the “Inquire Object” command in Tekla. This can be done on any object in Tekla, whether it be a beam, bolt, weld, etc. In the inquiry menu, one will find a host of information on this object including the name, material, weight, and dimensional information. All of this information can be synthesized into reports such as bar lists, materials lists, and other reports that can be used for estimation and fabrication. In my interview with DNA construction, they discussed how they have created their own custom reports that are submitted to the general contractor. These reports can be used to create more accurate cost plans and schedules. This information can be used for more than just cost plans and schedules. For this report I also interviewed Michael Evans, who is Director of Education and Key Accounts at Tekla. In this interview we discussed how Tekla can be used to accurately determine the weights of objects. For example, when creating a precast panel in Tekla, the weight of the concrete, reinforcement, and all other components will be included in the weight of this component. This level of detail can be used to help contractors determine the types of cranes that should be used at the job site. In addition, individual components can be given different phases. With this information the contractor can use Tekla to determine the layout of cranes, job trailers and other infrastructure for the entire job-site.

In comparison to Tekla, Revit also has the ability to model reinforcement in 3D. One now has the ability to create parametric beams, columns, and slabs that populate with rebar in a similar manner as Tekla. Revit also has the ability to create detailed bar lists and other schedules using modeling information. In Revit the ability to create detailed 2D plan and elevation views exists as well. While all of this can be done, it is important to note that this capability has only been avail-

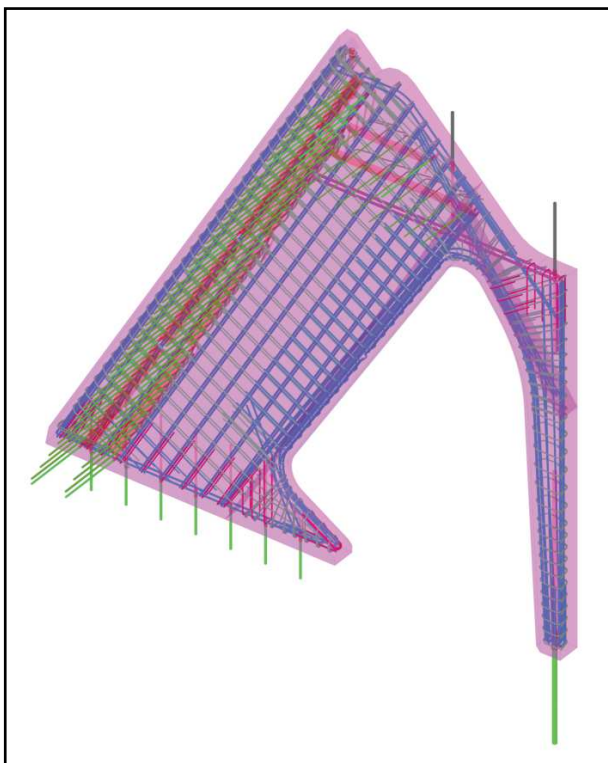


“INQUIRE” REPORT SHOWN FOR A SLAB WITH REBAR. NOTE THAT THE SLAB WEIGHT (WITH REBAR WEIGHT INCLUDED), VOLUME, FORM-WORK AREA, AND REBAR INFORMATION IS INCLUDED.

able in Revit within the past few years. According to the Autodesk University Course “SE6926: Revit as a Tool for Modeling Concrete Reinforcement” by structural engineer Håvard Vasshaug of the Norwegian firm DARK, some of these capabilities have only been available since 2014 (when viewing this course access section “Revit Software as an Efficient Modeling Tool for Concrete Reinforcement”). As early as 2012, Revit had problems translating model information into shop drawings and dealing with wall penetrations. Tekla has been working on these capabilities since the release of Tekla Structure in 2004, while Autodesk has been trying to catch up in the past few years. In addition Revit struggles with non-orthogonal shapes, this includes curved masses and any item with double curvature. From my interview with DNA consulting I learned that Tekla can handle these shapes easily. While one might be able to work with these objects using convoluted “workarounds” in Revit, Tekla is able to handle complex shapes that are widely used in contemporary buildings.

### *Tekla vs. Revit: Structural Steel Modeling*

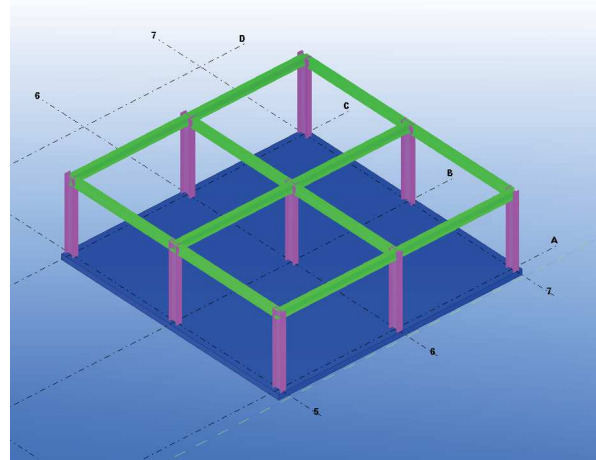
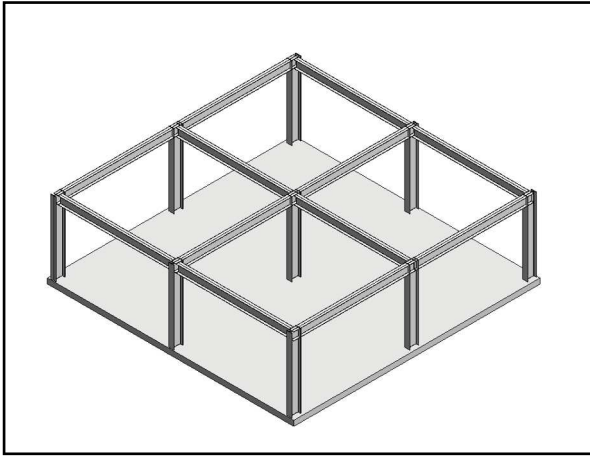
While Tekla and Revit have similar capabilities for reinforced concrete modeling, the level of detail that can be shown in structural steel modeling surpasses what can be shown in Revit. This can impart come from the rich history of Tekla in steel construction. Tekla Structures is originally based on Tekla XSteel, which was a steel fabrication software that came out in 1993. By comparison, Revit Structure first hit the market in 2005 (Conant). Even in the late 90s and early 2000s, Tekla XSteel was known as a fabrication level software. Tekla Structures includes this high level of detail, but is easy enough for inexperienced students to learn.



AN EXAMPLE OF COMPLEX CONCRETE MODELING IN TEKLA. THIS EXAMPLE COMES FROM THE MONS RAILWAY STATION IN BELGIUM. THIS MODEL CREATED BY THE FIRMS HURKS DELPHI ENGINEERING AND HURKS PREFABRICATION WAS FEATURED AS A WINNER OF TEKLA'S 2014 BIM AWARDS.

Both programs have similar capabilities for inputting structural members. In Tekla, one can add full 3D steel columns, beams, girders, and shear walls. These members have a high degree of accuracy, and member sections are based off of common sizes found in the American Institute of Steel Construction, and other code books. In addition, custom member sizes can be imported into the program. This model can then be incorporated into highly detailed 2D drawings for submittal purposes. Revit can accomplish all of these tasks to a similar degree of precision.

Tekla shows its strength when it comes to connections. As I have demonstrated in Lecture 2 of this project, using components in Tekla allows for the easy creation of highly detailed structural steel connections. Every part of the connection is detailed including bolts, bolt holes, coping, welds, member penetrations etc. Tekla will use parametric rules to create the connection, so the designer does not have to waste time manually inputting different parts of the connection.

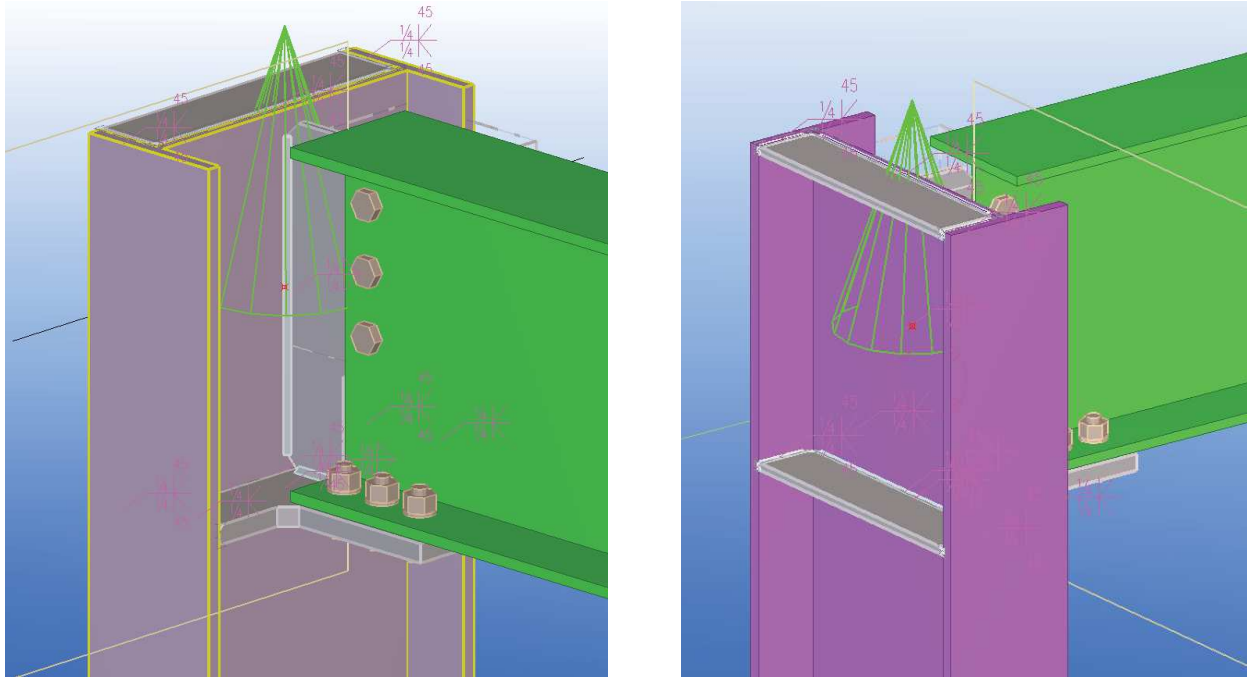


THE SAME STRUCTURE SHOWN IN A SHADED RENDERING IN REVIT (LEFT) AND TEKLA (RIGHT).

Once a connection has been created, it can then be easily copied and pasted to similar conditions throughout the model. In addition these connections can be rotated, sectioned, and rendered in 3D. Lecture 3 of this project showed how connections can be converted into a conventional shop drawing in Tekla. One is able use information directly from the model such as dimensions, material, weld type, etc. and apply it directly to the drawing.

While it is possible to create full 3D steel connections in Revit, it is not the optimal program for this task. Components, as they are defined in Tekla, do not really exist in Revit. Instead steel connection components, such as plates and bolts, have to be individually and manually inserted into a Revit model. This is often an inefficient way to model connections, and because of this steel connections are usually shown in a 2D drafting view in Revit. While these drafting views can display a significant amount of information, they cannot be used for tasks beyond detailing itself. For example, a steel connection in Tekla can be used for clash detection (because it is a full 3D representation) and cost planning (Tekla can export quantities of materials such as plates, welds, bolts, and other material into a cost plan). Even experts of Revit have shown that while it can create fabrication models on the small scale, Revit is not a great software for large scale fabrication models. Please see the Autodesk University Course “FB5474: Create Structural Shop Drawings and Fabrication Models Using Autodesk Revit” by Dan McCloskey of MB BIM Solutions which explains this concept in further detail (when viewing this course go to section “Import Steel Framing into Advance Steel Software”). Instead of using Revit as a tool for fabrication drawings, Autodesk recommends transferring the entire model to other programs such as Autodesk RoboCAD. Tekla eliminates the need for this extra step, and the possibility of a translation error, by being able to handle fabrication drawings within the program.





A BOLTED MOMENT FRAME CONNECTION SHOWN IN TEKLA. NOTICE THAT THE BOLTS, COPING, PLATES, WELDS, WELD SYMBOLS AND MEMBERS ARE FULLY RENDERED. THE GREEN CONE IS A SYMBOL THAT SIGNIFIES THAT THE BOLTED MOMENT CONNECTION COMPONENT HAS SUCCESSFULLY BEEN ADDED TO THE MODEL

A final thing to keep in mind with Tekla is its ability to work with digital fabrication technology such as computer numeric control (CNC) machines. A common file format for cut data to a CNC machine is a .dstv file. This file format can store information such the locations and dimensions for a bolt hole on a wide flange beam. A steel fabricator can extract this information directly from a Tekla model, and use it to create this feature in the shop. A thorough search of Revit finds that this capability does not exist in this software. Although not fully investigated in this report, Tekla also has the ability to communicate with rebar bending and other digital fabrication equipment.

### *Conclusion*

Tekla and Revit are both great tools for the creation of design level drawings. Both software also have the ability to work in tandem with professional structural analysis software to create more accurate models that eliminate waste. However when it comes to fabrication detailing and constructibility, Tekla and Revit do not have the same abilities. While Revit can accurately model concrete reinforcement and structural steel connections, it is not nearly as easy or accurate as with Tekla. This can be seen with steel connections in general and working with curved concrete object specifically. This level of detail allows the structural engineer to become closer to the construction process, and work closer with the fabricator. For a more detailed discussion of why this matters, and how it applies to the ARCE and CM curriculum at Cal Poly please see Section 4.2 of this project, "Recommendation to the Department on Tekla and Navisworks".



# SECTION 3 - LESSON PLANS

The screenshot shows the Navisworks software interface. The top menu bar includes Home, Viewpoint, Review, Animation, View, Output, BIM 360, and Render. The toolbar contains various navigation and rendering tools such as Pan, Look Around, Walk, Orbit, and Realism. The central 3D model displays a building structure with a red beam highlighted. On the left, the Clash Detective window is open, showing a table of clashes and a list of detected clashes.

Name	Status	Clashes	New	Active	Reviewed	Approved	Resolved
STR vs DATA	Done	3	3	0	0	0	0

Name	Status	Found	Approve...	Approved	Desc
Clash1	New	20:23:39 03-12-2015			Hard
Clash2	New	20:23:39 03-12-2015			Hard
Clash3	New	20:23:39 03-12-2015			Hard

A SCREEN SHOT FROM NAVISWORKS LESSON PLAN SHOWING HOW TO USE THE CLASH DETECTION TOOL.

In the Lesson Plan section of this report, I will provide material that should take novice users from a basic level of understanding of Tekla and Navisworks to an advanced level. These lesson plans are meant to be used by the instructor to teach the program. Please use the hyperlinks in the report to access additional resources on Google Drive and Youtube. Please feel free to leave comments on the Youtube videos if you have any questions.

## LESSON PLAN 1 - TEKLA - INTERFACE AND CREATION OF BASIC STRUCTURAL ELEMENTS

1. Introduction to this Lesson Plan:
  - a. Introduction: This Lesson Plan is being created in a way that can be used by instructors both teaching and trying to learn Tekla for themselves. This Lesson Plan is based off of a homework assignment also developed for this class, this homework assignment will be referred to as “HW1”. Below you will find a list of conventions for this document. A video of this lecture has also been created for reference. All relevant reference documents and files can be found on google drive. Please also note that this lesson plan uses Tekla 21.1.
  - b. Miscellaneous notes:
    - i. Please note that when I use the term “toolbar” I refer to the menus at the top of the screen.
    - ii. Please note that when I use the term “ribbon” I refer to the collection of buttons at the top and bottom of the screen.
    - iii. Rebar placement and material properties will not be considered during this lecture.
    - iv. Connections will not be considered during this lecture
    - v. Drawings will not be considered during this lecture.
    - vi. Tekla contains advanced tools to create section planes and renderings, these will not be considered in this lecture and default views will be used.
  - c. Document Conventions:
    - i. Notes to the instructor will be underlined
    - ii. *Things that the instructor should say directly to the students will be italicized.*
    - iii. **Actions that the instructor should perform will be in bold.**
  - d. Link to support files
    - i. Digital copies for the HW1 prompt, HW1 drawings, HW1 complete model, and a video demonstration of this lecture can be accessed for free by clicking on the google drive link below.
    - ii. <https://drive.google.com/open?id=0ByVv8FtY7QE-VGo2OHcwRXZ3UUE>
    - iii. For Youtube video on this Lecture, see link in “Section 5.1 - Work Cited”.
2. Introduction to Tekla:
  - a. *Tekla is a program that is created with the structural Engineer, the General Contractor, and Fabricator in mind. While this program has great depth, it is also easy enough for the average student to learn. Today we will focus on the creation of a basic model, this includes going over how to set up a grid, create basic structural elements, and to create relevant views of your model.*
  - b. For this lecture please make sure you are using Tekla 21.1 with the U.S. Imperial Environment.
  - c. *Tekla has been around for over 50 years, and is now used by design and construction professionals in many different countries. Due to this widespread use, Tekla has created different “Environments” for each country. An “Environment” contains the default unit type and typical member profiles that are used in a particular country. Please be aware that there is a “U.S. Metric” and “U.S. Imperial” environments available for use, we will use the “U.S. Imperial” environment.*
  - d. **Instructor will open Tekla, create a new project using the “U.S. Imperial” environment, and will save this project in a new folder.**
  - e. *Please note that when you create a new file in Tekla, it does create 1 file such as Revit or Word. When a Tekla model is created a whole series of folders and smaller files will also be created, this is why it is important for you to save your Tekla project to*

*the right place.*

3. Setting up your Project
  - a. Setting up a Grid in Tekla / Explaining Tekla file structure
    - i. *The first thing to consider before modeling is the creation of your grid system. Unlike other modeling programs such as Revit or AutoCAD, Tekla creates a grid through the use of a dialog box as opposed to dragging and dropping grid lines. To set up a grid system in Tekla, one can simply enter the distance between grids the x,y, and z grid lines, and adds the labels.*
    - ii. **Instructor will select the grid dialog box by double clicking the grids, and entering in the correct grid data per “HW1”.**
    - iii. *A benefit to this approach, as opposed to manually placing grids, is that one can save a grid as a GRD file and easily distribute this file to others. This GRD file can be found in the attributes of your project file. We will discuss Tekla file structure in more depth next lecture.*
    - iv. **Instructor will show the location of the grid system, which will be found in “project file/Attributes” folder and will be labeled “standard”.**
  - b. Basic interface in Tekla
    - i. *Tekla operates from an entirely 3D interface, so moving around a model in this program requires different skills than other programs.*
    - ii. **Instructor please go over the following commands below with students**
      1. Zoom in and out - Use the scroll wheel
      2. Pan - Hold down the scroll wheel
      3. Orbit around point - Hold Control and scroll lock
      4. Change orbit point - Press V and click on a grid intersection or object
  - c. Creating multiple views with Tekla
    - i. *While Tekla constantly operates from a 3D viewpoint, it is also possible to create plan and elevation views. We will be creating views along grid lines.*
    - ii. **Instructor will access the view creation tool by clicking from the toolbar “View/Create View of Model/Along Grid Line”. Use default settings and click “create”. Add views for “Plan at EL. LV1” and “Plan at EL. LV2” to the “Visible Views” portion of the “View” dialog box once it pops up.**
    - iii. *It is also possible to set up multiple views on your screen at once. One way to optimize work flow is to set up a full 3d axonometric and a plan view.*
    - iv. **Instructor will create a multi paneled interface by access on the top toolbar “window/tile vertically”.**
    - v. Please note that a quick shortcut to change between visible views is “Ctrl + Tab”
4. Creating Foundation elements in Tekla
  - a. Creating Column Footings
    - i. *Now that we have spent time setting up our model, we can finally add in structural elements. We will start off by adding column footings.*
    - ii. **Instructor will demonstrate adding in a column footing by selecting from the “Pad Footing” button from the foundation ribbon. Place a footing by selecting a grid intersection point. Instructor will add a single footing.**
    - iii. *Before we add in the additional column footings we will want to change the default settings to match “HW1”. When you double click the footing you will bring up the “Properties” menu. This menu is similar for all objects in Tekla. Once you decide on the settings of your footing, you can save these setting and pull them up later. Please note that when you save the settings of your footing file, it is saved in the “attributes” folder of your project.*

- iv. **Change the profile to match “HW1”. To change the depth and thickness of the footing, access the “position” tab. Please give your footing a title, click save as, and then click modify.**
  - v. Please note you must click “modify” to change an object’s settings. Clicking “OK” doesn’t actually change the object, it saves what is currently entered in the dialog box and closes the dialog box.
  - b. Copying and pasting elements in Tekla
    - i. *The next thing to consider in Tekla is creating the additional column footings. You can either continue to use the “Pad Footing Tool”, or use one of the tools below.*
    - ii. **Instructor to demonstrate the following tools below**
      1. Copy Paste
      2. Copy Linear - Right click object, select copy special/Linear. Use the dialog box to specify the number of copies and the spacing and direction between copies.
  - c. Creating a foundation slab in Tekla
    - i. *For the sake of simplicity of this homework assignment. You will create a 6” concrete slab for each level of this building. We will not consider rebar placement during this homework assignment.*
    - ii. **Instructor will create a slab using the slab button in the concrete ribbon. Instructor will then double click on the slab to access the property menu to adjust the slab to the proper depth.**
    - iii. *You will notice that the property window for the slab is virtually the same as that of the footing. This is true for almost all components of Tekla.*
5. Creating Structural Framing in Tekla
- a. Creating columns in Tekla
    - i. *Now that our Grid and foundation is set up, it will be relatively painless to create columns.*
    - ii. **Instructor will create a steel column using the column buttons from the steel ribbon. Instructor will then double click on the column, and apply the correct properties. For the position tab chose the top as 20’ and the bottom as -1’.**
    - iii. *Tekla has a database of column profiles that can be accessed from the properties menu. The profile menu contains a list of profiles optimized for the U.S. Imperial environment. New profiles can be added as necessary.*
    - iv. **Once the correct column profiles are selected, copy and paste the column at the appropriate locations throughout the model.**
  - b. Creating Beams and Girders in Tekla
    - i. *Once your columns are in place, add your 2nd floor beams and girders.*
    - ii. **Access your LV2 plan, or create a level 2 plan if it is not open using the steps in “3.d.ii”. Create the girders using the create beam button in the steel ribbon. Create one girder, and then access the property window and chose the correct girder profile per “HW1”. Make sure that the beams are offset 6” below the slab as well.**
    - iii. *Once you have created the girders, add in the beams using the same process as girders. Please note that the property window for beams and girders is virtually the same.*
    - iv. **Follow the steps in “5.b.ii” to create the beams.**
    - v. *You will notice that when you beams in Tekla, your cursor will automatically snap to grid intersections or girder midpoints. These snaps can be turned off and on using the snap ribbon.*
    - vi. **Instructor will explain what snap buttons to turn on or off including**

**snap to grid intersections, snap to endpoints, etc.**

## 6. Conclusion

- a. *This concludes the first Tekla lecture. You now have enough knowledge to model the simple building outlined in "HW1". Please note that in the 3D view of the model, the beams and columns will intersect. This is because we have not added connections, we will add connections next class.*
- b. *Please note that because Tekla is based on a collection of files, so it is important that you zip your files before turning it in.*

## LESSON PLAN 2 - TEKLA - STRUCTURAL STEEL CONNECTIONS AND CONCRETE REBAR PLACEMENT

1. Introduction to this Lesson Plan:
  - a. Introduction: This Lesson Plan is being created in a way that can be used by instructors both teaching and trying to learn Tekla for themselves. This Lesson Plan is based off of a homework assignment also developed for this class, this homework assignment will be referred to as “HW2”. Below you will find a list of conventions for this document. A video of this lecture has also been created for reference. All relevant reference documents and files can be found on google drive. Please also note that this lesson plan uses Tekla 21.1.
  - b. Miscellaneous notes:
    - i. Please note that when I use the term “toolbar” I refer to the menus at the top of the screen.
    - ii. Please note that when I use the term “ribbon” I refer to the collection of buttons at the top and bottom of the screen.
    - iii. Drawings will not be considered during this lecture.
  - c. Document Conventions:
    - i. Notes to the instructor will be underlined
    - ii. *Things that the instructor should say directly to the students will be italicized.*
    - iii. **Actions that the instructor should perform will be in bold.**
  - d. Link to Support Files
    - i. Digital copies for the HW2 prompt, HW2 drawings, HW2 complete model, and a video demonstration of this lecture can be accessed for free by clicking on the google drive link below.
    - ii. <https://drive.google.com/open?id=0ByVv8FtY7QE-LUFGNHZUVHpOMk0>
    - iii. For Youtube video on this Lecture, see link in “Section 5.1 - Work Cited”.
2. Introduction to lecture 2:
  - a. Downloading Model
    - i. *For this lecture we will be working off of a pre-constructed model instead of starting from scratch. The purpose of this lecture is to introduce you to detailing both steel and concrete structures in Tekla. For this lecture we will approach things from the perspective of a detailer; the engineer has given you a model with the correct member sizes, now it is up to you to add appropriate connections. Before we can go further move forward, we need to spend some time talking about downloading a Tekla model from somewhere else.*
    - ii. **Instructor will download the “Lecture 2 Base” model. Instructor will then unzip the folder, and place it in an appropriate spot on their computer.**
    - iii. *As we mentioned last class, Tekla models do not come as individual files. Instead, Tekla models come in a series of folders and must be zipped before distribution. Make sure you unzip the file and save it in an appropriate place before continuing.*
    - iv. Please note, this is a two story structure without a roof. The roof has been removed for ease of instruction.
  - b. Class Colors
    - i. *In Tekla, members colors are determined by their “class”. Beams and girders are usually green, columns are pink, and slabs are usually blue. While this color scheme works well, you might find you want to apply your own class system based on your needs as an engineer. Before we move onto applying connections, we will classify each object based on its structural use. Please note, every color has a number associated with a class. Google “Tekla Class*



- numbers” or see HW2 prompt for a list of these numbers*
- ii. **Instructor will classify objects based off the “HW2” prompt.**
3. Structural Steel Connections in Tekla
- a. Component Menu
    - i. *In Tekla connections are not something you generally create from scratch. Instead connections are essentially prefabricated and are referred to as “components”. Components can be found in the component catalog. This catalog contains structural steel connections, CIP concrete reinforcement, prefabricated components, and many other items. While it is possible to add your own custom connections in Tekla, we will use prefabricated connections because they are easy to use and apply in many different situations.*
    - ii. **Instructor will open the component catalog, select the thumbnail view, and show a variety of different connections that are possible.**
  - b. Base Plate Connection
    - i. *To begin this process we will start with a relatively simple connection, a base plate connection. This connection can be found under the details submenu in the component catalog. By entering “End Plate Connection” into the search menu. In addition most connections in Tekla are given a number, if you search for just this number you will also be able to find a connection you were looking for. Specifically we will be using the “End Plate Detail 1002”. Once you have the connection selected follow the dialogue on the bottom left hand corner of your screen.*
    - ii. **Instructor will access “End Plate Detail 1002” in the component catalog and will add this connection to the center column. Once this is done the instructor will double click the connection to show the property menu.**
    - iii. *Tekla will apply automatic settings to your connection once it is created based on the size of your members. However as an engineer, you should fully understand what is going on in your connection, and make changes based on your calculations. In the properties menu you can change the physical size and materials of the base plate as well as the composition of your welds. To add in your own settings, type in the correct plate size in the appropriate box based off of the “HW3” prompt, and then click modify.*
    - iv. **Instructor will go through the properties menu, and update the connection based off of “HW2” prompt.**
  - c. Connection Conventions and Visualization
    - i. *Before we move on to the next convention it is important to note some of the conventions around connections. When a connection has been created successfully a green arrow will appear around the connection. If there is an error with the connection, and it cannot be created (like if you tried to splice a steel column to a concrete slab) a red arrow would appear to indicate the failure. Please note that connections can be copied and pasted in the same way that framing members can be copied and pasted.*
    - ii. **Instructor will point out the location of the green arrow. Instructor will then display the copy and paste features of connections by using the copy especial tool to apply the base plate connection to all columns.**
    - iii. *Please note that it might be necessary to change the viewing options of the model in order to better view connections. Please see menu below for Visualization options and shortcuts. Please note that it might make sense to use transparent objects when placing connections or rebar, but it might make more sense to have fully shaded objects when placing members.*

- iv. Instructor will cycle through these options
  - 1. Wireframe (control-1)
  - 2. Shaded Wireframe (control-2)
  - 3. Hidden line (control-3)
  - 4. Shaded (control-4)
  - 5. Show only selected (control-5)
- d. Shear Plate Connection (Beam to Column)
  - i. *Now that we have added in the base plate connection, we will follow the same process for a basic shear plate connection. This connection can be found in the beam-to-beam sub menu. The connection is called "Shear PL Simple 35".*
  - ii. Please note that this connection can be used for both a beam to beam connection and a beam to column connection. When placing this connection the dialogue in the bottom left-hand of your screen ask you to choose the "main" part. The main part is the member that receives the welded shear plate. The secondary part receives the bolted connection.
  - iii. **Instructor will install the shear plate connection at the location specified by the "HW3". Instructor will then access the properties menu, and insure that the settings match the details shown in "HW3".**
- e. Moment Frame Connection
  - i. *For the moment frame connection will be using the default components settings in order to save time. From the US recommended submenu please select "Moment Connection 181".*
  - ii. **Instructor to demonstrate placing the Moment connection.**
- f. Brace Frame connection
  - i. *Like the Moment Frame connection, we will use default settings for the Braced frame connection. For the braced frame connection please access the bracing connection sub menu and select connection "HSS brace special 66". Please note that when you apply this connection to wear the braces meet the beam you will need to select two secondary parts.*
  - ii. **Instructor to demonstrate placing the Brace Frame connection.**
- 4. Concrete Detailing in Tekla
  - a. Introduction
    - i. *Because concrete detailing is such a complex art, we will only cover the how to fully concrete a beam and then we will show the default settings when modeling a slab or wall.*
  - b. Concrete Beam Detailing
    - i. *To fully detail a beam in Tekla is very simple; select the "Beam Reinforcement 63" component from the cast in place reinforcement submenu. Simply click on a beam to add reinforcement.*
    - ii. **Instructor add reinforcement to a beam.**
    - iii. *Once you have added your reinforcement, you will want to be in the shaded wireframe view (cntr-2). While this was easy, you will now want to access the properties menu to insure that the rebar you have added meets the required specifications.*
    - iv. **Instructor open the properties menu, access the parameters tab.**
    - v. *The parameters tab is where one can specify the concrete cover distances and bar details. The drawing shown in this menu is more complex than we are modeling, so only fill in the details for the top and bottom of this beam.*
    - vi. **Instructor will fill in cover distances to match "HW3" details.**
    - vii. *The stirrups tab is where one enters in there stirrup information. One extremely nice part about Tekla is that it sets up stirrup zones for you, no need to enter these stirrup groups individually. You can enter in either the number*



*in spacing of stirrups, stirrup sizes, and the distance between the beam ends and the initial stirrups.*

- viii. **Instructor will fill in stirrup details to match “HW3” prompt.**
- ix. *The final tab, advanced, is where one determines the class, material, and other identifying information for the reinforcing. For this assignment we will insure that we are using grade 60 steel.*
- x. **Instructor will fill in advanced information to match “HW3” prompt.**
- c. Other Rebar Modeling
  - i. **To add rebar to the girders, use the same “Beam Reinforcement 63” component. To add rebar to the columns use the “rectangular column reinforcement 83” component. To add rebar to the slab use the “Slab Bars 18” component.**
  - ii. *Please note that while we have not explored connections between beams and columns, Tekla components help to set up these connections. For example, notice that the column rebar cage extends outside the column. If you look at where the column meets the slab we can begin to see where different types of rebar overlap may overlap in order to eliminate this issue in the field.*
  - iii. *Please also note that there are similar components to accomplish similar tasks in Tekla. For example, for a more options when modeling beams please consider using the “Rectangular Beam - automated reinforcement layout 54” component.*

**LESSON PLAN 3 – TEKLA – STRUCTURAL DRAWINGS IN TEKLA**

1. Introduction to this Lesson Plan:
  - a. Introduction: This Lesson Plan is being created in a way that can be used by instructors both teaching and trying to learn Tekla for themselves. This Lesson Plan is based off of a homework assignment also developed for this class, this homework assignment will be referred to as “HW3”. Below you will find a list of conventions for this document. A video of this lecture has also been created for reference. All relevant reference documents and files can be found on google drive. Please also note that this lesson plan uses Tekla 21.1.
  - b. Miscellaneous notes:
    - i. Please note that when I use the term “toolbar” I refer to the menus at the top of the screen.
    - ii. Please note that when I use the term “ribbon” I refer to the collection of buttons at the top and bottom of the screen.
    - iii. Drawings will not be considered during this lecture.
  - c. Document Conventions:
    - i. Notes to the instructor will be underlined
    - ii. *Things that the instructor should say directly to the students will be italicized.*
    - iii. **Actions that the instructor should perform will be in bold.**
  - d. Link to Support Files
    - i. Digital copies for the HW3 prompt, HW3 drawings, HW3 complete model, and a video demonstration of this lecture can be accessed for free by clicking on the google drive link below.
    - ii. <https://drive.google.com/open?id=0ByVv8FtY7QE-VIEySGpUWDITRG8>
    - i. For Youtube video on this Lecture, see link in “Section 5.1 - Work Cited”.
1. Creating a Drafting View
  - a. *Tekla has automated the drafting process so that once a model full 3D model is created, it is a simple matter to create a drawing. Tekla drawings will automatically populate with what is shown in the model. To create a drawing, we will open the applicable view first, and then have Tekla create a drafting view of the drawing.*
  - b. **Instructor will open the “HW3 - Base” model. Instructor will then open the “Plan at Level 2” view. For instructions on how to create a plan view, please see instructions in Lecture 1.**
  - c. *Once the correct drawing view is open, the instructor will need to select a template to use. Templates contain a title block and default settings for various types of drawings including framing plans, foundation plans, schedules, etc. We will use the “Framing\_Plan (G)” template to create our drawing. Tekla also likes to group drawings with a letter after the template name, (G) stands for “General” drawings. Other abbreviations include (A) for Assembly, (C) for Cast unit, and (W) for single part Drawings.*
  - d. *Please note we will not review the creation of Templates in this lecture due to the amount of time it takes to create these items.*
  - e. **Instructor will then open the “Create Drawing” menu from the “Drawings & Reports” toolbar while the “Plan at Level 2” view is open. Click the create drawing button while the “Framing Plan (G)” template is selected.**
  - f. *Please note that after you create the 2nd floor framing drawing that a list of available views also comes up. You can use this list to create other drawings with the same template if you want to.*
2. The Drawing List
  - a. *All drawings in Tekla are stored in the “Drawing List” menu. From this menu one can see drawing metadata and select drawings to be open. Please note that when one opens a drawing in Tekla that the workspace, ribbon, and toolbar will change to*

- show tools associated with drawing.*
  - b. Please also note that drawings are stored in the project folder in automatically in a folder called "drawings". These files can be exchanged between Tekla Projects.*
  - c. Instructor will open the Drawings List menu and show the location of the created drawing. Instructor will also show the location of drawings in the project folder.**
  - d. Please note that when one updates a model, drawings are not automatically updated. To update a drawing one must select the drawing in the drawing list, and click the update button.*
- 3. The Metadata, Title Block, and Exiting a drawing
  - a. Metadata refers to information that is part of a model, but isn't a physical characteristic. This includes information such as the project name, project address, and other information that can identify the project.*
  - b. One of the first things to consider when creating a drawings is making sure the title block is correct. In Tekla one cannot change the Title Block by directly clicking on it, the title block is changed by accessing the properties menu. To do this, double click anywhere outside the model. We will use this menu later to change things such as the line and fill characteristics of the framing plan.*
  - c. To change the Sheet number and Drawing name, please fill in the appropriate information in the properties menu. To change other information please access the "user-defined attributes". This metadata includes things such as who the drawings was completed by, and who checked the drawing. Please note that all this information is considered metadata.*
  - d. Instructor will access the drawing properties menu and enter information per instructions above.**
  - e. Please note that your drawing will not update automatically once it is modified. One must save, exit and return to the drawing to see these project changes. This will be explained below.*
  - f. Please note that some information such as the project name and project address is not available in the drawing properties menu. To access this metadata, one must exist the drawing view, and enter the model view. To do this make sure to save the drawing, then select the "Close (Back to Model)" button from the Drawing File Toolbar. Once in model view one can access the Project Metadata through the "Project Properties" button under the file toolbar.*
  - g. Instructor will save and close drawing. Instructor will access the Project Properties menu and enter information through HW3 drawings instructions.**
  - h. Instructor to update drawing before opening it the second time.**
- 4. Changing the area visible in a drawing
  - a. When the Drawing is open one will see a framing plan view showing the steel and concrete building. The first thing that should be confirmed is that the drawing shown includes the entire scope of the project. It is apparent that the entire scope is not shown in the default drawings, the upper half of the concrete building (the beams north of grid line 5) are not shown. To do this one will expand the bounding box around the view. This can be done by clicking on the grey box around the drawing, then electing the corners of the pink box that appears, and then expanding this box.*
  - b. Instructor will expand bounding box to include the entire model, this might take an extended amount of time for Tekla to execute. Instructor can easily move the updated view by dragging the view within the titleblock**
- 5. Gridlines, Dimensions, Labels and Text
  - a. Tekla populates the your drawing with information directly from the model this includes dimensions, labels, and gridlines. The first thing we want to do is to eliminate unnecessary dimensions and text, and add the correct dimensions. Please note that*

when adding dimensions use either the “add horizontal” or “add vertical” buttons. This distinction helps to eliminate incorrect dimensions that are off by a few degrees. Please also note that dimensions cannot be added

- b. **Instructor will add and eliminate dimensions to match “HW3” drawings.**
  - c. Now that redundant dimensions have been eliminated, it might be desirable to change the size and shape of the grid system. To do this double click on the grid, and change the spacing of the grid head from the structure to  $\frac{1}{4}$ ”.
  - d. **Instructor will access the grid preference menu, change spacing to  $\frac{1}{4}$ ” and change the grid frame to a hexagon shape.**
  - e. Another nice feature about these drawings is that the text that appears is not just static text, it is a dynamic label. When one double clicks on the labels, a list of available elements pops up. One can add a whole list entities such as name, camber, size, material, etc. We will change the labels on the CIP elements to show their name as opposed to size, as is appropriate in CIP structural drawings.
  - f. **Instructor will go through the CIP structure and change labels in order to show the element names names.**
6. Automatic Revision Clouds
    - a. Another useful feature about drawings in Tekla is that revision clouds are automatically created when an element is changed in the model. To demonstrate this, we will change the name of the girders in the CIP concrete structure along grid line B from “Beam” to “FG1”.
    - b. **Instructor will exit the drawings view (remember to save!), change the name of the girders, and then reopen the framing plan drawing.**
    - c. You will now notice that a red revision cloud appears over the the girder labels.
  7. Creating a Detail and Section View
    - a. In Tekla you can create section and detail views to showcase the connections, CIP Reinforcement, and other parts of a project.
    - b. Creating a detail view is straightforward in Tekla, simply access the “Detail View” button from the View/Creating Drawing View toolbar. Once this tool is selected, follow the instructions that appear in the lower left toolbar to create the view.
    - c. Creating a section view is a similar process. Access the “Section View” button from the View/Creating Drawing View toolbar.
    - d. **Follow the directions above to create details to match the ones shown in “HW3” drawings.**
  8. Line thickness and Printing Drawings
    - a. Up to this point line thickness has not been colored. In reality drawings will be printed in monochrome black and white. Line thickness is determined based on the color of the line, which is similar to creating drawings in AutoCAD. The actual thickness of the lines are determined in the Printing menu.
    - b. To change the color of lines in the drawings, double click anywhere outside the drawing to bring up the drawing properties menu. From this menu one can change the appearance components such as Parts, Bolts, Welds, and other items individually.
    - c. **Instructor will then open the document properties menu and show the appearance sub menu within parts and the welds subcategory.**
    - d. One can save the drawing properties by clicking the “save” and “load” properties in the top of the drawing properties menu. Please note that these settings will be saved in the “attributes” folder in the project folder.
    - e. Once you have chosen a color scheme that suits you, you can change the line thickness associated with a color by accessing the printing menu. Once in the “Print Drawings” menu (which can be accessed in the “Drawing File” toolbar), select the “line thickness tab”.
    - f. **Instructor will show the location of the menu above.**

- g. Once the line thickness are chosen, it is recommended that one print initially to PDF. This way imperfections can be seen before a large piece of paper is wasted. To print to PDF simply chose "PDF file" from the options menu, enter in folder location, make sure the paper size is correct, and click "print." Please note that printing takes a significant amount of RAM, please make sure that all background programs are stored before printing.*
  - h. Instructor will run through the printing process, and make sure that the final product looks correct.**
  - i. Please note that after printing that the color scheme used in the drawing view will still apply, however line thicknesses have now been added.*
9. Exporting to DWG
- a. The final thing to be discussed today is exporting to PDF. Sometimes a DWG file will be required for the creation of shop drawings or details from 3rd parties.*
  - b. Instructor will create a DWG file from the open view by selection Export Drawing button from the "Drawing File" toolbar. Make sure a DWG file is being exported, and give it a name that matches drawing name.**
  - c. DWG files will be stored in the "Plotfiles" folder in the main project folder.*
  - d. Instructor will open the DWG file in AutoCAD or similar program to demonstrate the final product.**

## LESSON PLAN 4 - TEKLA - REFERENCE MODELS AND STRUCTURAL ANALYSIS

1. Introduction to this Lesson Plan:
  - a. Introduction: This Lesson Plan is being created in away that can be used by instructors both teaching and trying to learn Tekla for themselves. This Lesson Plan is based off of a homework assignment also developed for this class, this homework assignment will be referred to as “HW3”. Below you will find a list of conventions for this document. A video of this lecture has also been created for reference. All relevant reference documents and files can be found on google drive. Please also note that this lesson plan uses Tekla 21.1.
  - b. Miscellaneous notes:
    - i. Please note that when I use the term “toolbar” I refer to the menus at the top of the screen.
    - ii. Please note that when I use the term “ribbon” I refer to the collection of buttons at the top and bottom of the screen.
  - c. Document Conventions:
    - i. Notes to the instructor will be underlined
    - ii. *Things that the instructor should say directly to the students will be italicized.*
    - iii. **Actions that the instructor should perform will be in bold.**
  - d. Link to Support Files
    - i. Digital copies for the HW4 prompt, HW4 drawings, HW4 complete model, and a video demonstration of this lecture can be accessed for free by clicking on the google drive link below.
    - ii. <https://drive.google.com/open?id=0ByVv8FtY7QE-THJHWW5zLVNPTUk>
    - iii. For Youtube video on this Lecture, see link in “Section 5.1 - Work Cited”.
  - e. *This lecture will cover the use of reference files in Tekla and using 3rd party Structural Analysis software to confirm that a building will meet gravity, seismic, and other loads. We will simulate MEP coordination by bringing in a simple MEP coordination model into our structural model. For this lecture the analysis program Risa 3D will be used. This program has been chosen because it is commonly used by ARCE 2nd and 3rd year students, unlike other more sophisticated programs such as SAP2000 or ETags. Please note that the actual analysis process in Risa 3D will not be discussed. Instead the focus will be on sending model information between Tekla Structures and Risa 3D.*
1. Using Reference Drawings
  - a. **Instructor will create a new project in Tekla Structures using the US Imperial template.**
  - b. *When working on a new project, it can be helpful to use existing drawings to create the a Tekla model. In Tekla to add a reference PDF, select file/Insert Reference PDF from the Toolbar. In the menu that comes up, please select the correct PDF and make sure that the scale is correct. When choosing a scale use the formula: Scale = 12” / Drawing scale.*
  - c. **Instructor will open a Level 1 view in Tekla (for instructions on how to do this, please see instruction in lecture 1). Instructor will follow the instructions above to add “HW4 - Drawings - LV1” to the model.**
  - d. *One will need to move the reference drawing to the correct part of the model. When*



*clicking on the model, make sure that the “reference model” button is selected in the bottom ribbon.*

- e. For more explanation on selection options please see Lecture 1.
- f. *If one wants to turn the reference drawings or models on or off, or wishes to change options in the models such as scale, select the cube icon on the right hand corner of your screen. From the use the eyelid buttons to turn reference models on or off. fyyfy*

## 2. Using Reference Models

- a. **Instructor will open the “HW4 - Model - Base” model in Tekla Structures.**
- b. *Although Tekla is not a dedicated clash detection program such as Navisworks, it is possible to use reference models to run basic clash detection in Tekla. To do this we will import a reference IFC file. To do this access the reference model menu, click on the “add model” button, and select the “HW4 - Model - MEP Coordination model” (do not change any other settings).*
- c. **Instructor will append the “HW4 - Model - MEP Coordination” model to Tekla. There will be an obvious clash between the MEP system and one of the beams. Eliminate the beam from your model.**

## 3. Explanation of CIS/2 protocol

- a. *This lecture will focus on using Steel buildings as opposed to concrete buildings. One important concept before we begin is something called electronic data interchange (EDI). EDI refers to the protocol that computer programs used to transfer data between each other. There are many great programs on the market for design, analysis, detailing, and fabrication. However these programs do not always talk with each other. Therefore a EDI for analysis (Risa 3D) and detailing (Tekla Structures) was investigated in the late 90s by Leeds University. This protocol was called CIMSteel Integration Standards (CIM), although today it is called CIM/2 due to updates within the past decade. The American Institute of Steel Construction (AISC), recognized the potential of CIM in the mid 2000s and have advocated for its use since then. The main impetus for this was a National Institute of Standards and Technology study that claimed, “the US Capital Construction Industry wastes over 15.8 billion dollars per year through lack of interoperability” (CIS/2). For more information on this subject please search CIS/2 on AISC’s website.*
- b. **Instructor will show the “Scope of Integration” chart which can be found in the Lecture 4 Google Drive folder.**
- c. *Seeing the potential of this protocol, Tekla included the ability to export models with CIS/2. The chart shown demonstrates what properties can be exported from Tekla into Risa 3D. Unfortunately certain features in structural steel cannot be communicated between the two programs including camber and most connection details. Because of this, it is important to bring in Risa 3D early in the design process, as opposed to using Risa 3D after much of the building has already been designed.*

## 4. Exporting a Tekla Model as a .STP file

- a. *The export process works in 2 parts, first one will need to export the Tekla file using the CIS/2 protocol. The actual file that is created is called a .stp file. Then the .stp file will be converted to a Risa 3D file (.r3d) using a plugin from Risa. To begin the export process, select the entire model, and then select file/export/CIMSteel from the toolbar.*
- b. **Instructor will use the edited “HW4 - Model - Base” model and follow instructions above and open the export properties window.**





- d. Open the “Members” menu in Risa 3D, you will now notice that a “Detailing” menu appears. From here you can change the cardinal points, as well as adding an end offset to the member.*
- e. Instructor will show the “detailing” layer per instructions above.**
- 8. Exporting a Model from Risa 3D into Tekla
  - a. Once one has completed their analysis in Risa 3D, it is possible to update the existing Tekla file. This can be done multiple times for every design iteration.*
  - b. Instructor will open the “RISA CIS/2 Translator”.**
  - c. To bring the model back into Tekla, the Translator will be used again. This time a Risa 3D (.r3d) file will be inputted and a .stp file will be exported. Before running the Translator, make sure that the “Use Cardinal Points” option is selected in the Detailing Choice window. This will insure that all selections made in the Risa 3D window are incorporated in the Tekla model.*
  - d. Instructor will follow the instructions above, and export the “HW4 - Risa Complete” model using the “RISA CIS/2 Translator”.**
  - e. Instructor will open the original “HW4 - Base Model” in Tekla.**
  - f. Once the file has been translated, one will need to import the model into Tekla. To do this open Tekla, and select file/import/CMISteel from the toolbar. This will automatically open a new dialog window called “Inport New Model”. In this menu you are effectively creating a script for model conversion. Because one can export more up-to-date versions of a Risa file in the design process, you can create a script for a repetitive process. For example, if you know your Risa .stp file will always be called “Lecture 4”, you can set up an import script to update your tekla model.*
  - g. Instructor will open the import window per instructions above and import the “HW4 - Model - Risa Export” .stp file**
  - h. Now that you have imported the data, you have the ability to reject or accept the updated design. One can accept all changes, or accept changes to members individually. Refer to the color key on the import window. Once you click “accept” Tekla will update the sizes of your members and delete old members.*

## LESSON PLAN 5 - NAVISWORKS - VISUALIZATION AND CLASH DETECTION

1. Introduction to this Lesson Plan:
  - a. Introduction: This Lesson Plan is being created in away that can be used by instructors both teaching and trying to learn Navisworks for themselves. This Lesson Plan is based off of a homework assignment also developed for this class, this homework assignment will be referred to as “HW5”. Below you will find a list of conventions for this document. A video of this lecture has also been created for reference. All relevant reference documents and files can be found on google drive. Please also note that this lesson plan uses Navisworks Manage.
  - b. Miscellaneous notes:
    - i. Please note that when I use the term “ribbon” I refer to the collection of buttons at the top and bottom of the screen.
  - c. Document Conventions:
    - i. Notes to the instructor will be underlined
    - ii. *Things that the instructor should say directly to the students will be italicized.*
    - iii. **Actions that the instructor should perform will be in bold.**
  - d. Link to Support Files
    - i. Digital copies for the HW5 prompt, HW5 drawings, HW5 complete model, and a video demonstration of this lecture can be accessed for free by clicking on the google drive link below.
    - ii. <https://drive.google.com/open?id=0ByVv8FtY7QE-OF9HMxc1bXJGTFk>
    - iii. For Youtube video on this Lecture, see link in “Section 5.1 - Work Cited”.
1. Introduction to Navisworks and File Structure
  - a. *Unlike Tekla, Navisworks is not a modeling software at all. Instead Navisworks is a tool for model visualization and analysis. It has a suite of tools that can be used by the entire Architecture, Engineering, and Construction team. These tools include being able to visualize models from almost any program, the ability to run clash detection, the ability to obtain quantities from models, the ability to create architectural renderings, and the ability to create schedule visualizations. Today we will be focusing on the visualization and clash detection elements of this program. These are tools that are most applicable to the structural engineer and the contractor.*
  - b. Instructor will open Navisworks Manage, a create a new blank project.**
  - c. *Before we begin, it is important to spend a minute talking about file structure in Navisworks. Navisworks has three different file types which are explained below:*
    - i. *Navisworks Files (NWF) - This is the type of file that is automatically created when one opens Navisworks. This file does not actually contain any internal model data. Instead a NWF will reference models that are stored on a computer or network. It works in the same way that Adobe Indesign will reference “placed” images, while the images appear in the document the actual model is not in there. This makes it possible for a normal computer to view what would normally be a gigantic model that would crash most computers. Please note that items such as annotations, viewpoints, and clash detection tests are saved in the NWF (more on this later). Another final note, if one creates a new version of a file referenced by a NWF, this new model will appear in Navisworks*
    - ii. *Navisworks Cache (NWC) - When a program such as Revit or AutoCAD ex-*

ports model data to be imported into Navisworks, a NWC is created. When Navisworks reads models from other programs, NWC files are also created. NWC files contain model data, they do not include any annotations or other information.

- iii. *Navisworks Document (NWD) - NWDs are the same things as NWFs with one exception, NWDs contain model data. NWDs are created when one wants to not deal with all of the links that are created in a NWF. NWDs are usually large files, and only should be created when one needs to export a large amount of information.*

	NWF	NWC	NWD
Model Data		x	x
Annotations, etc.	x		x

#### Appending Models and the Selection Tree

- d. *The Navisworks interface is broken into three main parts:
 
    - i. *Workspace: This is the blank space in the center of your screen. When we load in the model it will appear here.*
    - ii. *Ribbon: this contains most of the global commands in Navisworks.*
    - iii. *Submenus: These contain other tools that can be used in Navisworks including measure tools and the clash detection test. Currently all menus are set to auto-hide. If you would like keep these menus on your screen, click on the pin icon. If you accidentally delete a submenu, these can be accessed by under ribbon.**
  - e. **Instructor will go through and demonstrate some of the submenus and other features in Navisworks. Specifically the instructor will point out the location of the “Selection Tree”, “Find Item”, and “Clash Detection” menu.**
  - f. *We will now want to append models to the NWF. A note on this, it is important that your models are stored in a logical place and given a logical naming convention. If your models are moved, or if the name of the model is changed, these models will not show up in Navisworks. In addition, if your model is updated when Navisworks is closed and you reopen the program, the Navisworks file will also update.*
  - g. **Instructor will append the “HW5 - reference - structural” NWD file.**
  - h. *Now that your first model is appended, you will notice that it also shows up in the selection tree. The selection tree contains a list of all appended models. In addition you can break down your model into different parts. If the draftsman has created a model with a logical naming scheme in their native program, it should be easy to find the component that your are looking for.*
  - i. **Instructor will go through the selection tree and showcase the different parts of the model.**
2. Model Navigation
- a. *Before we move further it is important that navigation in Navisworks be discussed. Several different modes exist to move about the model these include:
 
    - i. *Walk Mode: This mode is akin to moving around a video game. You have the option to move backwards, forwards, and to strafe in all directions when holding down the middle mouse button. This mode, and the others below, can be accessed through the mini menu on the right side of your screen.**

- ii. *Look Around Mode: This mode allows you to move the camera directly, it is as if you were moving your head around in virtual space.*
  - iii. *Navigation Wheel: The scroll wheel contains a variety of features including zoom, pan, walk, rotate, set center of rotation, and rewind. There are several different Navigation wheels in Navisworks, these can be accessed through the arrow underneath the navigation icon on the right side of your screen.*
- b. Instructor will go through and demonstrate these model navigation modes.**
- 3. Section Plans
  - a. *Another powerful tool for Visualization is section planes. In Navisworks up to six section planes can be added.*
  - b. Instructor will activate the section plans function by clicking on the section planes button in the viewpoint menu.**
  - c. *The active section plan is shown in the viewport menu. will Use the “move” button to see the location of the section plan. In addition the exact location of the section plane is shown under the move button.*
  - d. Instructor will show how to use the move tool to manipulate section planes. Instructor will then go through and turn several section planes on and off.**
- 4. Viewpoints
  - a. *We will now look at saving viewpoints in Navisworks. Viewpoints are useful for automatically moving to a part of the model that is often accessed. In addition, annotations can be added to viewpoints can be used to illustrate issues in the model.*
  - b. Instructor will exit the section view mode by clicking on the section view button in the ribbon.**
  - c. *To create a viewpoint, pin the “saved viewpoints” submenu to the left side of your screen. When you find a viewpoint you want to save, right click the “saved viewpoints” and select “save viewpoint”. You can then create folders to organize your viewpoints.*
  - d. Instructor will go demonstrate how to save a viewpoint.**
  - e. *Once you have gone through and saved a viewpoint, you can add annotations. This can include adding text, revision clouds and other linework to the viewpoint. All of these tools can be found in the “Review” ribbon. In addition, you can add “tags” to viewpoints to save longer comments. After creating a tag in a viewpoint, the associated comment can be found in the “saved comments” submenu at the bottom of your screen.*
  - f. *If we want to distribute these viewpoints as images we will create a “viewpoint report”. When Navisworks creates a viewpoint report it will export a JPG image for each viewpoint that contains the location of the camera and any comments associated with this viewpoint. Navisworks will then create an HTML file that can be opened in your default internet browser. Navisworks uses this format because it cuts down on memory, if Navisworks create one PDF with all this information it could be hundreds of Megabytes large. You will want to make sure to save each report in a dedicated folder, because each viewpoint will be saved as an individual image.*
  - g. Instructor will demonstrate exporting a viewpoint report.**
- 5. Measurement Tools
  - a. *You might wish to double check dimensions of in Navisworks using the measurement tools. Measurement tools are found in the “review” ribbon. You can measure linear distances, angles, cumulative distances, and areas. You will notice when creating*

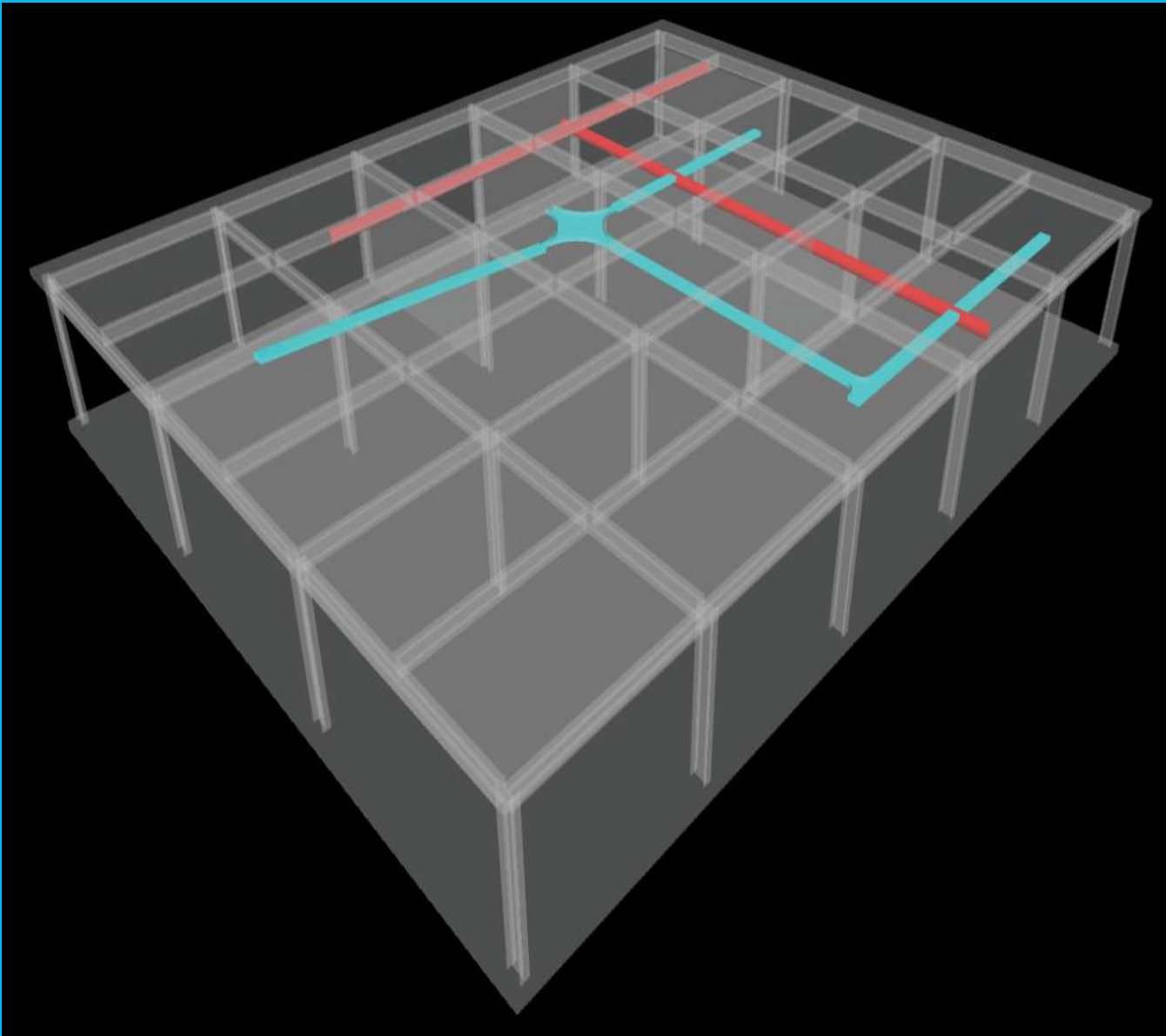
a simple measurement that Navisworks will also give you the dedicated x, y, and z distances as well.

- b. **Instructor will take a linear measurement in the model, and show the other tools such as the area, angle, and accumulative distance tools.**
  - c. *An important topic to discuss here is making sure that one is using both the correct units and tolerance. Navisworks will default to using a tolerance of 1/256" when measuring. You will almost never encounter tolerances this small in a building, so we will want to change the tolerance to something higher to reflect a realistic tolerance. For this model will set the tolerance to 1/32", and make sure that we are using "feet and inch fractions" for units.*
  - d. **Instructor will access the "display units" menu in options and ensure that units are set to "feet and inch fractions" and that the tolerance is 1/32".**
  - e. To access the options menu, click on the large Navisworks logo on the top hand of the screen, then click on the "options" box. The "display units" submenu is under the "display" menu.
  - f. *The final topic to discuss is locking the measure tool to a certain access. This can be useful if we are just trying to get heights. The measure tools can be locked onto the X, Y, and Z axis. In addition we can lock the measure tool so that it is perpendicular to an object's surface. We do this by clicking on the "perpendicular" lock, choosing a surface to be perpendicular to, and then taking a measurement.*
  - g. **Instructor will use the perpendicular lock and take a measurement in the model.**
6. Clash Detection
- a. *We now come to the heart of Navisworks functionality, Clash Detection. To start this process we will pin the clash detection tool to our workspace. After this we will want to create our first test. "Tests" contain a series of rules for the clash detection. For each test we will want to look at whether two different models clash.*
  - b. **Instructor will pin the clash detection tool to the workspace and create a new test. Call this test "STR vs DATA".**
  - c. *We will now want to assign the rules for this test. For this first test we will want to see if there are any clashes between the "HW5 - Reference - Structural", and "HW5 - Reference - Data". You will make sure that the structural model is selected in the first window and the data model is selected in the second window. Once we do this, we will want to specify the type of clash we are looking for. We can chose between a hard clash or clearance. A hard clash will require the two objects to physically intersect each other. If we chose clearance, we can specify a distance that the two models need to be separated by.*
  - d. *For this model we will use a hard clash for this type of clash we can specify a tolerance. If two objects intersect each other by a distance less than the tolerance, Navisworks won't consider this a clash. We will not want to use a tolerance of 0". Setting the tolerance to 0 will create clash that don't actually exist. For example if two object are right next to each other, Navisworks may consider this a clash. It is best to set the tolerance to something small like 1/64" - 1/32".*
  - e. **Instructor will go through and update the rules to match the description above and then run the clash detection test.**
  - f. *Once the clash detection test has been run, we can filter through the results in the result tab. This contains a list of the locations of all the clashes. We can go through and*

*assign a viewpoint for each of these clashes that most accurately shows the issue. In addition we can assign these clashes statuses such as “reviewed”, “resolved”, etc. We can come back to Navisworks at a later time and update these results as the models are corrected. In addition we can go ahead and assign responsibility of this clash to an individual or firm.*



# SECTION 4 - CONCLUSION



A SCREEN-SHOT SHOWING HOW A STRUCTURAL, MEP, AND DATA MODEL CAN BE USED AT THE SAME TIME FOR COORDINATION AND CLASH-DETECTION.

Now that the teaching material of this project have been established, the final part of this report will expand on why this all matters for ARCE students. I will first expand on my experiences in teaching CM 421. I will then show how this experience, as well as the lesson plans I have created for this project, can be incorporated into the ARCE curriculum. For this second report, I collaborated with CM student Matty Reed, who is pursuing a similar project for the CM Department. I will conclude this project with my final reflections on teaching methods and materials.

## REFLECTIONS IN TEACHING CM 421

### *Introduction*

For the past two quarters, I have worked as an Instructional Student Assistant (ISA) for Construction Management (CM) 421 “Emerging Technologies”. This experience has been the inspiration for me to pursue this Senior Project. The report below is a reflection on how I obtained the ISA position. Through this report, I also expand on how my experiences as an Architectural Engineering (ARCE) student helped me create content and teach this course. I will also explain what this course is, how I became involved with this course, what I contributed this course, and what I learned through this experience.

### *CM 421 Course Description*

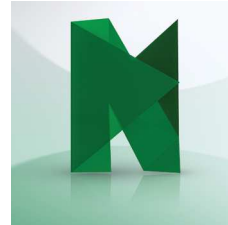
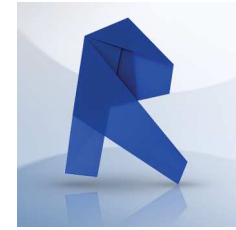
CM 421 provides an overview of several different software packages in the construction industry that can be used for a wide variety of purposes. The main focus of this course is on Building Information Modeling (BIM) software, although other non-BIM related products are discussed. This course was developed originally by Elbert Spidel in 2007 to help educate students on the growing use of BIM software in the CM industry. Since its inception, CM 421 has been a student run class. A group of 2-4 students will take turns teaching different software. These Instructional Student Assistants (ISAs) will also spend time creating homework assignments, projects, and tests for class. This is considered a standalone two unit elective course in the CM curriculum, which does not provide a large amount of instruction time. Because of this, the approach to CM 421 is to give a topical overview to as many software packages as possible. While the students in this course will not become masters of these software from this class alone, the hope is to give students enough information to pick up these software when working and to be able to talk about the capability of these products intelligently. While this is a CM course, Civil Engineering, Architecture and Architectural Engineering students have taken this course for elective credit.

Below are the descriptions to the main software taught in CM 421, please note that additional programs have been used in the past as well:

- 1.) Bluebeam Revu: While not necessarily a BIM software (although the capability to use it with 3D PDFs does exist) this software is taught because it so widely used in the construction industry. Revu’s main purpose is a PDF reader, however this software can be used create drawings, annotate PDFs, perform 2D drawing takeoffs, and create comparisons of drawings. In addition, students are shown how to use Bluebeam Studio, which allows for the easy distribution of information between a large team.
- 2.) Autodesk Revit: See Section 2.2 of this Project.
- 3.) Trimble Tekla: See Section 2.1 of this Project.
- 4.) Trimble Vico: This program can takes in models from a wide variety of programs to create cost plans and schedules. Firms can use historical cost data saved in Excel format and apply it to the 3D models.
- 5.) Autodesk Navisworks: See Section 2.1 of this project.
- 6.) Syncro: This program can be used to demonstrate a construction site as it changes over time by linking a schedule with a 3D model. This software is great for making videos of construction sites and showing how they change over time.

## *My Background in Building Information Modeling*

I have had several experiences with BIM software to prepare for my position as ISA for CM 421. All ARCE students begin their college career by taking freshman architecture studio. While the focus of this series of classes is focused on creativity and design, students are given a strong background in hand drafting, computer modeling, and graphic design. Although I no longer use Form Z, which was the main modeling program used in studio, my experiences with Form Z helped me to easily learn other programs. These initial experiences were reinforced by taking ARCE 257, Structural Computer Aided Drafting (CAD) for Building Design. This course gave me a solid background in creating structural modeling with Autodesk Revit that I use on a daily basis. In addition to this, once ARCE students get into the design lab series, best practices for structural drafting are enforced within the first few weeks. In addition to Revit, students are also taught analysis programs such as Risa 3D and ETabs. While these are not traditionally considered BIM programs, I have demonstrated with lecture 4 that they can be implemented with more conventional BIM programs such as Tekla Structures.



LOGOS OF SOME OF THE PROGRAMS TAUGHT IN CM 421

While my experiences as a student helped to peak my interest in BIM, the real experience that sparked my interest was my internship as a Project Engineer Intern with Isec in the summer of 2014. Isec is a national architectural woodwork, millwork, and ornamental metals sub-contractor. I was hired to assist an operations team with Facebook's new corporate campus in Menlo Park, CA. My job responsibilities evolved from project engineering to BIM coordination. The architect on this project, Gehry Partners LLC, required that all components in a project be modeled, even architectural components. My job at Isec was to work with an outsourced drafting team in Kraków, Poland to develop 2D shop drawings and 3D models. I used Autodesk Navisworks for quality control and to run clash detection test with architectural and structural reference models. In addition to learning Navisworks, I also learned how to use Gehry Technologies Digital Project (now owned by Trimble as of late 2014).

## *CM 421 and its Relation to the ASC Reno Competition VDC Team*

My experience as an ARCE student piqued my interest in construction management, which led me to the Associated Students of Construction (ASC) competition in Reno, Nevada which occurs every winter. The ASC competition is the yearly highlight for CM students. This competition requires students to solve real world problem in construction. Categories for this competition in-

cluding Commercial, Heavy Civil, Concrete, Integrated Project Delivery (IPD), Virtual Design and Construction (VDC), and other categories. The skills taught in CM 421, especially the ability to take off quantities from a model, can apply to all of these competitions. However CM 421 applies directly to the VDC competition.

Virtual Design and Construction (VDC) and Building Information Modeling (BIM) are both broad terms that cover a large range of software, management practices, and modeling procedures. VDC recognizes the potential and need for BIM software to incorporate the entire Architect, Engineer, and Contractor (AEC) team, this is why VDC stands for “Design” and “Construction”. While both terms are essentially interchangeable, VDC tends to emphasis software that go beyond traditional basic modeling programs. The VDC contains several components including creating a model, creating cost plans and schedules from an existing model, running clash detection between models, creating site layout plans using BIM software, and questions relating to general construction knowledge. The models used for this competition, which for the past 5 years has been sponsored by Webcor Builders, comes from the sponsor’s real world projects.

I participated in the 2015 ASC Reno competition on the Cal Poly VDC team. Most of the models encountered in this competition where structural in nature. For our practice sessions and the competition we would use Revit and Tekla to create models of large buildings including high-rises, museums, and other structures. During these sessions my team would encounter large structural plans for both Structural Steel and Reinforced Concrete buildings. I used my background in ARCE to help my team model these structures. There were times where my team did not know how to read certain plans, especially when it came to structural steel plans. Through my ARCE



A PICTURE OF MY MY CO-INSTRUCTOR MATTY REED  
TEACHING CM 421

design lab experiences I was able to decipher the plans, details, and general notes for my team. I was also able to help explain certain structural systems to my teammates. For example, several of my teammates were unaware of the exact function of braced frame in a lateral force resisting system. I was able to explain the components of a braced frame and what they are used for. This helped us to not only create more accurate cost plans and schedules, but helped us in our final presentation to the competition judges.

### *Content Created for CM 421 Based on ARCE and Professional Experience*

After the 2015 ASC Reno competition I was asked to become a CM 421 ISA for the spring 2015 quarter by Elbert Spidel. I decided to pursue this job in order to expand my knowledge of BIM software and to improve my resume. For this I job did not start from the ground up, content had been developed by previous students. However it was apparent when I started the course that content could constantly be improved. My main focus has been to develop and expand lesson plans for Bluebeam, Revit, Tekla and Navisworks.

The lesson plans for Revit had been very straightforward, the instructor would lead the class through the creation of a basic reinforced concrete building. The plans for this building were for a small apartment structure and parking garage. From my ARCE classes I was able to bring my knowledge of structural systems drawings to the class. While the main focus of the class was on the creation of the model, I introduced a short exercise in which the students would create and export structural drawings. I spent time going over how line weights worked in drawings, how to create and use section views, and how to use title blocks in Revit. While the drawings we created did not contain the amount of information required by an ARCE design lab, it introduced CM students to this process and gave them a deeper appreciation of the time and energy it takes to create drawings.

In regards to Tekla, I did not learn this program until CM 421 was taught in spring 2015. The CM student Matty Reed introduced me to this program, and taught Tekla that quarter. I was able to pick up this program as the quarter progressed, and was able to even assist Matty in the spring. Matty had a great understanding of the basics of Tekla's mechanics, but did not understand the detailing side for Tekla. In spring 2015 I created several 2D details of cast in place concrete reinforcement that were used to demonstrate Tekla's advanced capabilities to the class. My knowledge of these details came directly from my ARCE concrete design lab that I had recently taken. This design lab not only showed me how to draw to the detail, but gave me a decent understanding of the typical sizes and dimensions used. When I began to teach Tekla in fall 2015, I explored Tekla's detailing components further, and I looked adding structural steel connections to the curriculum. Specifically I showed the class how to create base plate and shear plate connections in Tekla, and how to edit these connections to accommodate different sized members. I used details I developed from my ARCE steel design lab in developing this curriculum.

While not every person will create structural or architectural models, it is important that all construction and engineering professionals know how to use and visualize them. Before I became a CM 421 ISA, Navisworks was not taught as part of the curriculum. I felt that Navisworks needed to be added due to its widespread use by general contractors, as well as my personal experience as an Isec Project Engineering Intern. The content I developed for CM 421 is similar to Lecture 5 of this project; I introduced the class to model visualization, editing models, and clash detection.



The concepts I taught in these lectures came directly from my experiences in the field.

In addition to the above, I also was able to spend time teaching Bluebeam to Revu software. For spring 2015 I worked with Matty Reed to develop content to help students learn the basis of this program. We elected to use structural drawings with Bluebeam, since most of the models we built were structural. We showed students how to edit PDFs, create annotations, how to overlay different and compare different sets of drawings. The assignments created for this class came from my experience working with and creating red lined structural drawings in ARCE Design labs. In addition to Bluebeam basics, we also showed students how to use Bluebeam studio to easily distribute large groups of drawings over the internet.

### *New Content Learned for CM 421*

While I helped to create new course content based off of my academic and professional experiences, my peers in the CM department introduced me to new programs that I would have never encountered in the ARCE department. My experiences with BIM software had focused mostly on the modeling aspect of BIM, even Naviswork's main focus was on the use of space by 3D models. However I discovered that programs existed that embraced the I of BIM, which is information. The program used in CM 421 that most represents this is Trimble Vico. With Vico, one is able to create a cost plan and schedule using a 3D model. Vico can use models from a wide variety of programs including Tekla Structures, Revit, and many others. Using a 3D model, and historical cost data which can be saved in an excel sheet, one is able to create cost plan and schedule that can update as a model becomes more and more defined. This makes Vico a great product to use for a IPD project; it allows the design team to work with the construction team in real time. I first began using Vico as a member of the 2015 ASC competition. I taught myself the program, and used it during the competition. I found the program so fascinating afterwards, I helped to expand content created from previous instructors.

### *Conclusion*

Becoming an ISA for CM 421 has been one of the most rewarding and challenging components of my Cal Poly education. I have been able to take my back bone of Architectural Engineering knowledge and apply it in new ways I did not even think about in my freshman year. The best component of this experience has been the ability to work with students across different departments that are as interested in buildings as myself. Through my experiences I have tried to make CM 421 a course that applies to any student in engineering or construction. I hope that this course will be improved in time by the next generation of CM and ARCE students.



## RECOMMENDATION TO THE ARCE DEPARTMENT ON THE INCLUSION OF TEKLA STRUCTURES AND AUTODESK NAVISWORKS IN THE CURRICULUM

{ Written in Collaboration with CM Student Matty Reed }

### *Introduction*

The previous conclusion in this report sought to establish two things. The first was to establish the capabilities of Tekla and Navisworks. The second was to determine how this affects ARCE students. This report wrap up how these programs affect ARCE students, and then go a step further by determining why these programs can and should be included in the Curriculum. In addition, I will also explain how ARCE students could benefit from learning this content in tandem with CM, ARCH, and other disciplines. In looking at implementation of these programs, I will be referencing my college Matty Reed's senior project, in which he looks at implementing BIM in Cal Poly's CM department.

### *Tekla*

The differences between Tekla and Autodesk Revit were discussed in "Section 2.2" of this report. For this report I began by asking the question "Is Tekla a better program better than Tekla?" What I found is that this question was vague and unhelpful. Instead the question I chose to focus on in this report is "How do Tekla and Revit differ?" The answer to this question I feel is in the level of detail that these two programs provide. Both Tekla and Revit are great programs for design level drawings. Both can create accurate models of members, communicate with analysis programs, create construction documents, and create basic connections. Both of these programs are also relatively easy to use, and can be introduced to either freshmen or sophomore college students. However Tekla has a greater level of detail. Every single piece of rebar, every single bolt, every single weld can be modeled in this program. These highly accurate models are also easy to navigate and will not crash one's computer. While Revit can create detailed models, even experienced users admit that Revit should not be used for fabrication level drawings for large projects.

While this level is great the next question that should be asked is, "Why does this matter to the ARCE students?" Revit can create wonderful design level drawings for submittal purposes. The structural engineer is also not a detailer, they do not need to know the location of every single bolt, weld, and bar. Why then should this



A SLIDE FROM MY PRESENTATION REGARDING THE QUESTIONS I ASKED WHEN COMPARING TEKLA TO REVIT

program be used? The answer to this problem is waste. The Institutes of Standards of Standards and Technology found that the US construction industry wasted “\$15.8 Billion” due to a lack of interoperability (CIS/2. AISC). For most structural engineering practices, the client is not the owner, contractor, or fabricator. Instead the client is usually the architect. This removes the structural engineer from the construction process, and the building has to be modeled multiple times by fabricators once the project gets to the Construction Document (CD) phase. Not only does provide a channel to miscommunication, but it creates paper and human productivity waste. Tekla helps to close this gap because it can be used by both engineers and fabricators, closing a crucial information gap. In addition, the structural engineer does not need to use Revit because the architect uses Revit. As I demonstrated in Lecture 4 of this project, reference models from other programs can easily be imported into Tekla for use. When combined with other benefits of Tekla including the ability to create complex connections and rebar cages easily, the ease of creating useful visualization, and its other features, Tekla becomes a program that needs to be explored by Cal Poly’s ARCE department.

### *Navisworks*

When the great recession happened in 2007 and 2008, new technologies were developed as the construction market slowed to a halt. One of these software that became fully developed was Navisworks. As I clarified in “Section 2.1 - Capabilities of Tekla and Navisworks”, Navisworks was bought out by and fully developed by Autodesk in 2007. Since then, smart general contractors have realized the importance of this software. As mentioned in my earlier report, Navisworks was shown to save millions of pounds on London’s Heathrow Airport. For this project I also interviewed with



LONDON'S HEATHROW AIRPORT

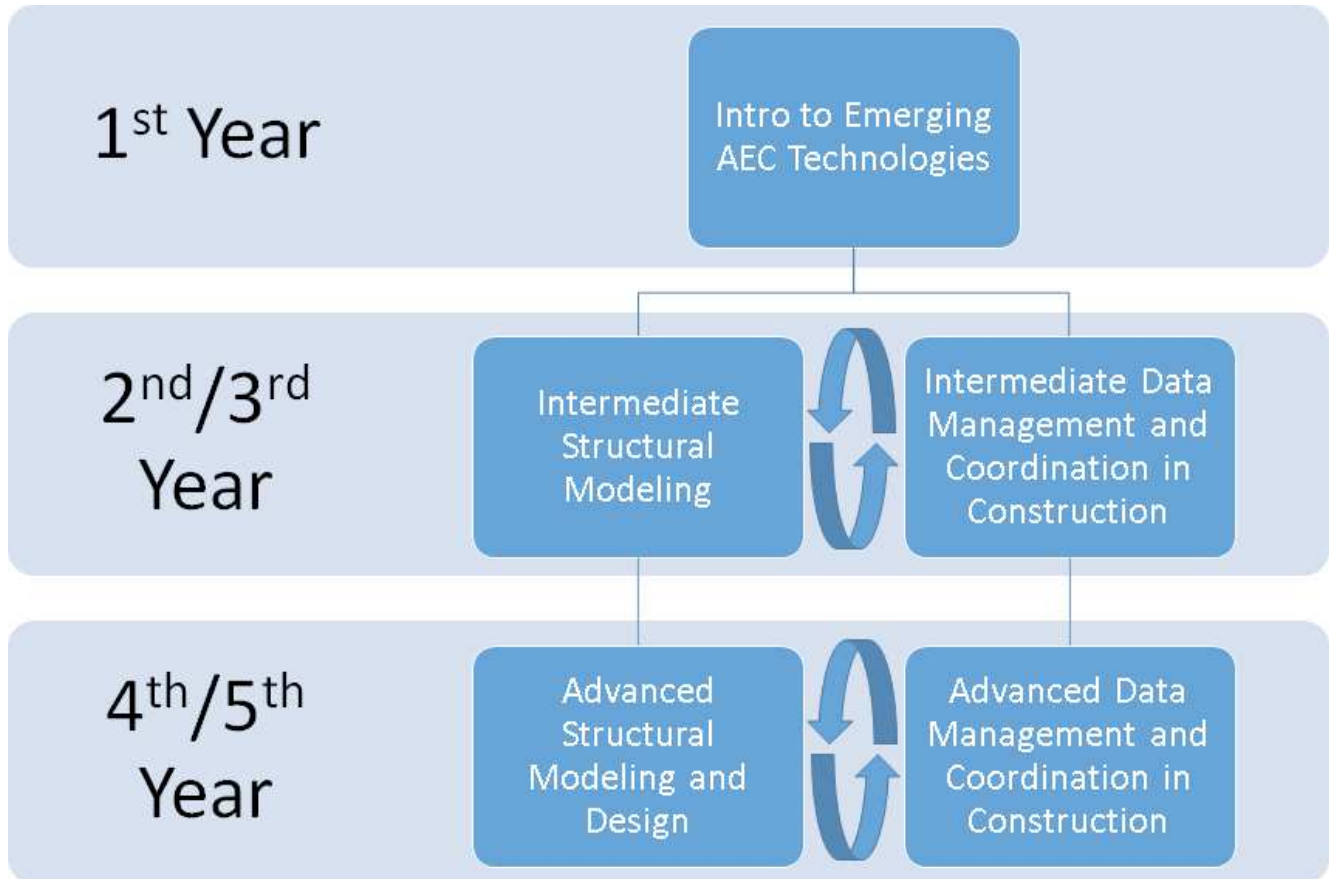
interviewed Tekla's head of education Michael Evans. From my interview with Michael I found that all building in the UK will need to have a design level of BIM modeling will be required on all new buildings by. In the next few years a fabrication level of BIM will be required.

In the US, BIM coordination has been required on large scale projects. In my own experience on Facebook's West Campus, which is the flagship corporate campus for one of the largest tech companies in the US. For this project every single component needed to be BIM modeled, whether structural steel, curtain walls, architectural woodwork, or even the surrounding landscape and topography. Navisworks was used in this project to facilitate communication between both the design and construction team. Although there were many different companies working on this project using many different software, all of the models could easily be accessed and manipulated in Navisworks. From my own experience I know that many other large general contractors and ar-

chitects require BIM modeling on some or all of their jobs. Some of these names include Webcor Builders, Level 10, Gehry Partners Architects, Hathaway-Dinwiddie, Matt Construction, etc. The ARCE department should look into including this software in the curriculum because it allows the structural engineer to communicate easier with other disciplines. This allows the structural engineer to become more competitive in a changing marketplace.

### *Implementation*

In terms of implementation of these software into the ARCE curriculum, I believe it is important to consider other disciplines as well. Because of this, I have decided to work with CM student Matty Reed on this aspect of this project. Matty Reed, like myself, is an Instructional Student Assistant (ISA) for CM 421 Emerging Technologies. We believe that BIM software should be implemented throughout the curriculum. Our discussions can be simplified into the graphic on the next page. The ideas behind each of these graphics will be explained in the course outline below. Please note the descriptions from "Intro to Emerging Architecture, Engineering, and Construction Technologies", "Intermediate Data Management & Coordination in Construction", and "Advanced Data Management & Coordination in Construction" come from Matty Reed's Senior Project "Integration of Emerging Technologies into the Cal Poly Construction Management Curriculum".



1. Intro to Emerging AEC Technologies
  - a. Prerequisites: None
  - b. Required by: All ARCH, ARCE, and CM Majors/Minors, and possibly all of the CAED
  - c. Topics:
    - i. Introduce students to emerging technologies in the AEC industry.
    - ii. Using Bluebeam to manage and coordinate 2D drawings.
    - iii. Basic Modeling with Sketchup and Revit.
    - iv. Basic Coordination with Navisworks.
  - d. Detail: The AEC industry is bubbling with new and exciting technologies. It is important to expose students to the emerging trends in the industry early in their college careers in order to stir their imagination and spark their interests. BIM Technologies are now pervasive in the AEC industry and they are being used to bring all design and construction professionals together. The main goal of this class is to open students' eyes to new and exciting possibilities, but it is also important to teach the students about practical tools such as Bluebeam, Sketchup, Revit, and Navisworks. These computer programs are practical tools used throughout the fields of architecture, engineering, and construction. Students will learn how to manage their 2D documents in Bluebeam. They will learn the basics of 3D modeling in Sketchup and Revit as well as the basics of model coordination in Navisworks. Exposing students to these programs early in their college careers will make it easier for them to use other programs during the rest of college. This course curriculum should be a combination of tutorials, guest lectures, and demon-



strations.

- e. Implementation: *Intro to Emerging AEC Technologies* could be structured as an add-on to EDES 101 or it could be a 2 unit standalone course required in the 1st year of college.

#### 1. Intermediate Data Management and Coordination in Construction

- a. Prerequisites: CM 102, CM 115, and *Intro to Emerging AEC Technologies*.
- b. Required by: All CM Majors, an elective course for ARCE Majors, and an elective course for CM Minors.
- c. Topics:
  - i. Using advanced functions of Bluebeam to manage and Coordinate 2D drawings.
  - ii. Using advanced functions of Excel to organize and manipulate data.
  - iii. Extracting information from Revit/Tekla models.
  - iv. Coordinating and clashing models in Navisworks.
- d. Detail: This class will be geared towards Construction Management Majors in that it will not teach students how to design and create a model, but rather it will teach the valuable skill of how to manage data. The information age is upon us and the professionals in the construction industry are required to know how to handle large amounts of information with the help of a computer. Utilizing BIM, students will develop the ability to manage and coordinate construction data. In the first half of this course, students will learn how to manage 2D drawings using Bluebeam. They will also develop valuable skills in using Excel to organize and manipulate large amounts of data. During the second half of this course, students will work closely with their peers in *Intermediate Structural Modeling* to extract data from the models created in the other class. They will be taught how to use programs like Dynamo in order to manipulate Revit models and extract useful information as well as programs like Assemble in order to extract quantities and create accurate cost plans. Students in this course will also learn how to combine and clash multiple models in Navisworks.
- e. Implementation: This 2-4 unit course should be taught twice a year and in tandem with *Intermediate Structural Modeling*. This will require extra steps in coordination with the ARCE department as students in both classes will need to communicate and use each other's data.

#### 2. Intermediate Structural Modeling :

- a. Prerequisites: EDES 101, CM 115, and *Intro to Emerging AEC Technologies*.
- b. Required by: All ARCE Majors, an elective course for CM/CE Majors, and an elective course for ARCE Minors.
- c. Topics
  - i. Creation of Structural drawings with Revit
  - ii. Creation of Revit models from 2D drawings
  - iii. Creation of Tekla models from 2D drawings
  - iv. Creation of Structural drawings with Tekla
  - v. Revit modeling tricks using Dynamo
- d. Detail: Intermediate Structural Modeling already exists in the ARCE department as ARCE 257, Structural CAD. The focus of this class is to be able to create structural drawings. Although having a BIM model is useful, it cannot reach its full functionality without an understanding of how drawings work. Students would learn about



how the drawings work, and then would move onto the creation of models. Revit and Tekla should both be used for this course. I advocate the use of both programs in this course for two reasons:

- i. Revit is, and will remain to be, a widely used program by engineers and contractors for the foreseeable future. ARCE students should know how to use this program to remain competitive.
  - ii. Learning these two programs will allow young engineers obtain a better understanding of how to model. The engineer will be able to compare and contrast these programs and determine for themselves which program they prefer.
- e. Detail (II): In addition other advanced topics could be included. For example the Revit plug-in Dynamo, which automates Revit modeling, could be explored and contrasted with similar Tekla functions.
  - f. Implementation: This class could be an updated version of the existing ARCE 257 Structural CAD or an additional elective course. This class one of the most important ARCE classes in the curriculum because it provides essential skills that all ARCEs will use in design labs and projects. If we include both Revit and Tekla in ARCE 257, it should be expanded from a 2 unit to a 4 unit class. If intermediate structural modeling is taught as a separate course, the prerequisite should not include ARCE 257 in order to allow ARCE minor students to take this course.
3. Advanced Data Management and Coordination in Construction
    - a. Prerequisites: *Intermediate Data Management and Coordination in Construction*
    - b. Required by: Elective course for CM Majors and CM Minors.
    - c. Topics:
      - i. Understanding a complete BIM work-flow.
      - ii. Using Vico and Synchro to create cost loaded schedules.
    - d. Detail: CM students who are interested in learning more advanced uses of BIM should take this course. The entire course is based on the idea that we can use accurate 3D models to generate 4D schedules and 5D cost plans in order to reduce risk and increase quality throughout the entire life-cycle of a project. The first half of this course will focus on the BIM work-flow. This includes an in-depth understanding of each stage in the BIM process from conceptualization, to modeling, to estimation, to scheduling, to construction tracking, and finally to facilities management. Students will also learn about the purpose of writing BIM execution plans and the structure and content of the documents. The second half of this course will require students to work with their peers in *Advanced Structural Modeling and Design* to create a project in Vico and/or Synchro based on a fully detailed Tekla model. It may also benefit students to learn how to run an advanced model check using Solibri. This project will require the students to work through a BIM work-flow in order to generate a cost loaded schedule.
    - e. Implementation: This 2-4 unit course should be taught once a year and in tandem with *Advanced Structural Modeling and Design*. This will require extra steps in coordination with the ARCE department as students in both classes will need to communicate and use each other's data. This should be the final course in a BIM Minor or BIM Concentration if the department decides to add these avenues to the CM curriculum.
  4. Advanced Structural Modeling and Design:

- a. Prerequisites: : ARCE 257, ARCE 412, At least 1 ARCE Design lab and Intermediate Structural Modeling
- b. Required by: Elective course for ARCE/CE Majors and ARCE Minors
- c. Topics:
  - i. Using Tekla with Structural Analysis programs
  - ii. Using Tekla models for Fabrication
  - iii. Using Tekla models for Cost Planning
- d. Detail: Not all ARCE Majors will be interested in BIM coordination; there are already so many different topics for ARCEs to explore. One could spend their entire college career studying reinforced concrete and not understand all of its attributes. This class would be designed for the ARCE Majors and ARCE Minors interested in making BIM Coordination part of his/her skill set. The focus of this class will be on interoperability. The first part would combine the computer analysis skills learned in the ARCE 350 series with the modeling knowledge learned in ARCE 257 and *Intermediate Structural Modeling*. For the second part of this class, the ARCE department would reach out to a steel fabricator that uses Tekla. The students would then look at creating designs that could be sent to Digital Fabrication machines. For the final part of this course, ARCE students would combine with students in “Advanced Data Management & Coordination in construction” to create Tekla models for cost estimation and scheduling. ARCE and CM students would finish off the quarter with a combined project that used a fully detailed Tekla model to create an accurate cost loaded schedule.
- e. Implementation: This course should be a 2-4 unit Advanced Structural Elective. The scale of this course also could be large enough to become a new Senior Project course.

### Conclusion

Implementing Tekla and Navisworks into the curriculum is something that should be considered for future catalog cycles. I believe that by using classes that already exist, such as EDES 101 and ARCE 257, these programs could be implemented without adding on many excess additional units. In addition, not all students are going to be interested in these programs, but some students will be. This is why I believe that an advanced structural elective should be created for these courses. The implementation of these programs will not only make Cal Poly ARCEs more competitive on the market, but it will enhance our relationship with other departments, especially the CM department. Another thing to note here is that the content created here focuses primarily on construction management and structural engineering. Although not discussed in this paper, future faculty should look at BIM implementation for other disciplines such as mechanical, electrical, and miscellaneous architectural components. Incorporating these other disciplines in these classes could give ARCE and related major students a better understanding of how to communicate with others and finish projects in the real world. While BIM is only part of the wide range of skills that ARCEs need to know in the modern workplace, it is becoming something that all design and construction professionals should be familiar with to remain competitive and relevant in today's competitive environment.

## CONCLUSION ON TEACHING METHODS

The first conclusion for this project covered my experiences with CM 421. The second conclusion covered how I believe Tekla and Navisworks should be incorporated into the ARCE. This conclusion will cover my final thoughts and reflections on this project. I plan on speaking about the teaching materials and methods that when covered in this project. In addition I hope to cover ideas that could be incorporated into future projects.

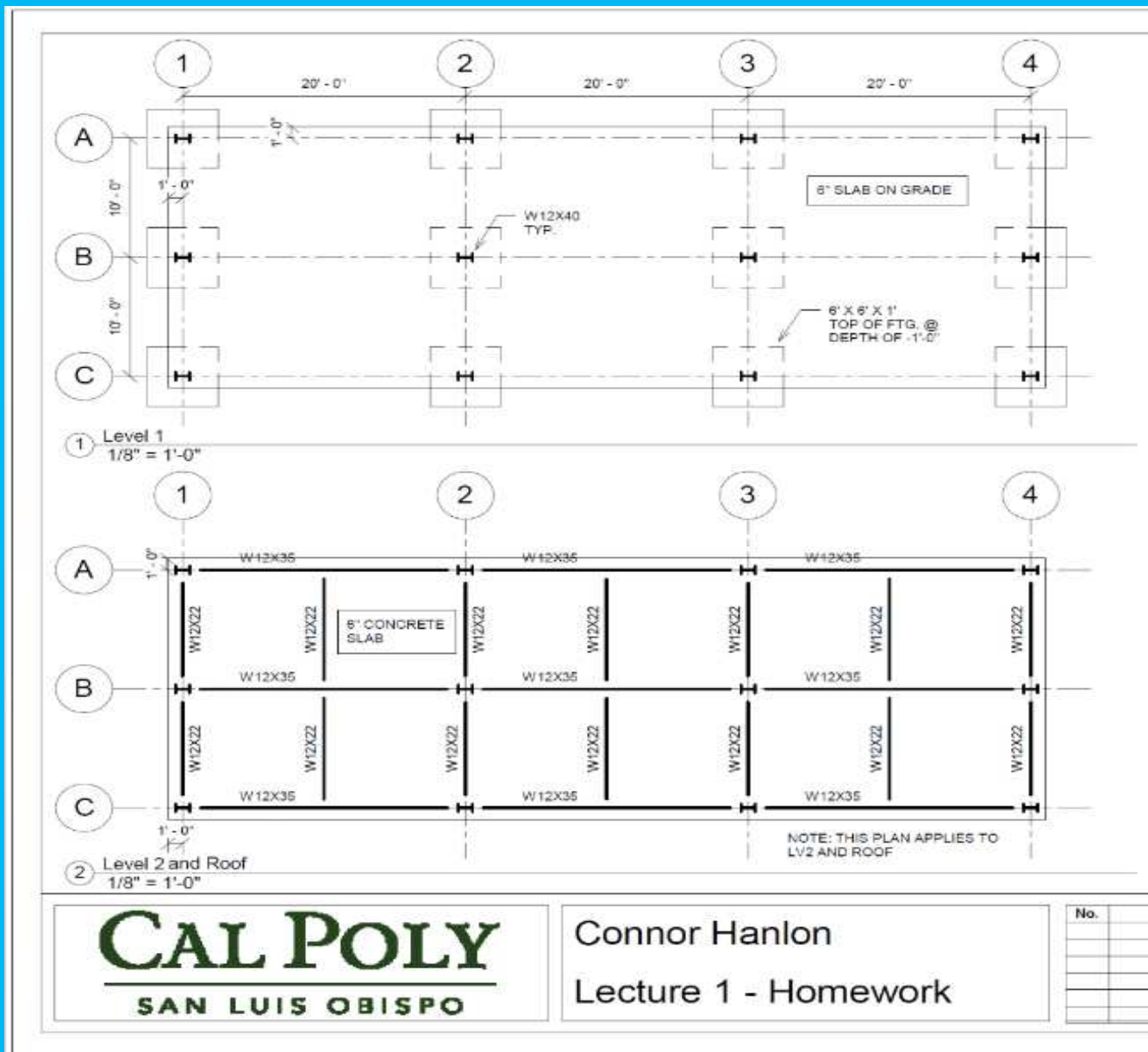
Teaching is not an easy job. It requires one to learn about a subject far more than the student. This is very true for the technical coursework I have created here. In creating these lesson plans I found that I always had to be a step ahead of what I was teaching. It was not enough to know how to do something, I needed to know why this was happening. I have tried to include this information in the instructor notes and in the tutorial videos. Another particular note about this project is the amount of time spent on organizing information. I spent a significant amount of time determining how to format lesson plans, how to split up my lesson plans into sensible chunks, and how to put all of this information in a final report.

Tekla and Navisworks are just two programs that are helping to improve construction and design. Other software should be investigated by engineers in addition to the ones investigated in this report. The list below details future potential ARCE senior projects in other software as well as more advanced functions in Tekla and Navisworks:

1. **Bluebeam:** To develop content that gives ARCE and CM students a basic understanding of Bluebeam Revu. Students should be able to understand how to create annotations, create documents and stamps, create Bluebeam studio sessions and projects, how to compare documents, and understand advanced features such as Scripting and Optical Character Recognition (OCR).
2. **Autodesk BIM 360 Glue:** To develop content that gives ARCE and CM students a basic understanding of BIM 360 Glue. Students should be able to append models to a glue session, run clash detection, and to create reports. If this goal is pursued, students will spend time evaluating the benefits and disadvantages of BIM 360 Glue when compared to Navisworks.
3. **Structural Analysis with Revit:** To develop content that give ARCE students the ability to run structural analysis in Revit. Plug-ins for this process have yet to be determined. If this goal is pursued, students will spend time evaluating the benefits and disadvantages of Revit Analysis when compared to Tekla analysis.
4. **Advanced Tekla Analysis:** To develop content that gives ARCE students an advanced understanding of how to use Tekla Structures with other sophisticated analysis tools such as SAP2000 and ETABS.
5. **Tekla Interoperability with DFab:** To develop content for ARCE, CM, and ME students on how to use Tekla with digital fabrication machines. This could be done in collaboration with a fabrication shop.

Another important thing I have learned from this experience is that BIM is not the answers to all of the issues in design and construction. There are many parts of the construction process that I do not fully know or understand. BIM however is an important part of the solution to these issues. The largest problem in construction that I can see is intellectual and physical waste. The softwares I have investigated for this project help bridge the gap between design, construction, and fabrication teams. More needs to be done to make sure these emerging technologies work, they need to be embraced by firms and best practices need to be taught. The technology in this project can be used to make efficient, cheaper, and even more sustainable and elegant buildings.

# SECTION 5 - APPENDIX



A SCREEN-SHOT OF ONE OF THE DRAWINGS CREATED FOR THIS PROJECT THAT WAS USED AS A PART OF AN HOMEWORK ASSIGNMENT.

In this appendix one will find the work cited page, and a collection of meeting minutes between my advisor and myself. For this project I meet on a weekly basis with my project Advisor Allen Estes, who is the ARCE department head. In these meeting minutes one will see how my project progressed from the begging to the end. Additional resources such as the homework assignments I created for this project can be found on either Youtube or Google Drive. Please see the links in the Lesson Plans. The Youtube video link is also found in the work cited page.

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Evans, Michael. Personal Interview. 19 November 2015

Daniella Castro and Alyssa Schorer. Personal Interview. 19 November 2015

Kevin Williams. Personal Interview. 8 December 2015.

### Senior Project Record of Meeting

Date/Time/Location: ARCE Cont Room Tues 29 Sept 2:00pm

Participants: Al / Connor

What was worked on – activities:

Demostration of software: Tekla / Footrak  
Konsult

Meeting on Thurs 4-5

What was discussed

Overview of project  
Collaboration with CM  
Senior project schedule  
Requirement to present senior project  
Seeking support & examples from professional firms

What should be completed prior to next meeting

Sample lesson so that I get a feel for  
what one looks like

Time spent on project since last meeting:

10 hours

### Senior Project Record of Meeting

Date/Time/Location: ARCE Cont Room Fri 10/9/15 10:00

Participants: Al / Connor

What was worked on – activities:

Presented sample lesson

What was discussed

Meeting time Friday 10:00 - 11:00

Use google drive - send me email for access

Built a simple 2 story model

Lesson: lecture notes / video / final example models <sup>homework problem</sup>

Completed project: 1 lesson per week

Intro / 3 Techs / 1 Foot Trak / 1 Navis Work  
1 drawing  
connection/rebar

What should be completed prior to next meeting

Progress update on Foot Trak - Quick demo  
Structure of project report

Time spent on project since last meeting:

10 hours

### Senior Project Record of Meeting

Date/Time/Location: ARCE Cost Room 10/16/15 10:00

Participants: AI / Connor

What was worked on – activities:

Table of Contents for Report Structure  
 How Tekla does analysis ↔ RISA 3D  
 Connection overview

What was discussed

Thorough introduction that sets stage  
 Conclusions as to why this is better for ARCE

Milestones as production of report

Still concerned about interdisciplinary aspect  
 Maddie @ Campbell this week

What should be completed prior to next meeting

Comments of project report structure  
 List of report milestones -- elements of report

Time spent on project since last meeting:

5 hours

### Senior Project Record of Meeting

Date/Time/Location: *NRCC East Room 10/23/15 10:40*

Participants: *Al Connor*

What was worked on – activities:

*Lesson on connections*

What was discussed

*Quick demo of program  
milestone list or report*

*Content of introduction*

*Tekla competition -- entry due 23 Nov.*

What should be completed prior to next meeting

- *First part of report (proposal / lesson plans  
table of contents / exec summary)*
- *Update on 3-D Risa transfer buck & fork  
between RISA & Tekla*

Time spent on project since last meeting:

*8 hrs*



### Senior Project Record of Meeting

Date/Time/Location: 10/30/15 10:20

Participants: Al / Connor

What was worked on – activities:

Background sections of report

What was discussed

Report found  
- Background sections

Using CH421 to clarify interdisciplinary connection  
Tekla/RISA 3-D lesson in 2 weeks  
Conduct interviews w/ industry on Tekla vs REVIT  
in industry

What should be completed prior to next meeting

Al reads & reviews Background sections  
Drawing lesson plan for Tekla  
Update sources in report

Time spent on project since last meeting:

12 hrs.

### Senior Project Record of Meeting

Date/Time/Location: 16 Nov 2:00

Participants: Al/Connor

What was worked on – activities:

What was discussed

Sample presentation - structural analysis (RISA 3D)  
 & tekla  
 Loads  
 Fixity of connection } don't transfer over

Book 11-15-15 recent version

Final presentation

- Explain roles / capabilities of Program (BIM workflow)
- tekla v. REVIT
- interdisciplinary
- products produced

What should be completed prior to next meeting

Keep Friday meeting

Tekla to Revit comparison

Feedback on report

Time spent on project since last meeting:

12 hrs

### Senior Project Record of Meeting

Date/Time/Location: 11/23/15 2:00 pm

Participants:

What was worked on – activities:

Navis works video  
Industry interviews OMA Consulting

What was discussed

Presentations ~~not~~ used of final week  
Video taking much longer than expected  
Advisory board presentation  
Final paper due on Fri of final weeks

What should be completed prior to next meeting

Monday 1 Dec 2:00 pm  
Finish all content  
Go over presentations

Friday 4 Dec  
Anytime after 12  
for Adv. Board

Sr. Proj Presentation  
Wed 8 Dec  
anytime after noon  
preferable 3-4

Time spent on project since last meeting:

9 hrs.

## Senior Project Record of Meeting

Date/Time/Location: 11/23/15 2:00 PM

Participants:

What was worked on – activities:

Navis works video  
 Industry interviews DNA Consulting

What was discussed

Presentation ~~not~~ used of final week  
 Video taking much longer than expected  
 Advisory board presentation  
 Final paper due on Fri of final weeks

What should be completed prior to next meeting

Monday 1 Dec 2:00 PM  
 Finish all content  
 Go over presentation

Friday 4 Dec  
 Anytime after 12  
 for Adv. Board  
 Sr. Proj Presentation  
 Wed 3 Dec  
 anytime after noon  
 preferable 3-4

Time spent on project since last meeting:

9 hrs.

