CS226843

Drones, Reality Capture & BIM: A Construction quality control workflow

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Learning Objectives

- Understand work flows using point clouds obtained from multiple sources.
- Recognize the potential of various solutions using multiple Autodesk software platforms in the BIM coordination process.
- Understand the potential of Drones and Photogrammetry for point cloud creation.

Description

How do you build three 220 Ft tall concrete shear wall towers and then erect the building steel and know that it will align with all the steel attachment plates or that all wall penetration sleeves were installed correctly? This class illustrates a solution to this challenge by using point clouds created from traditional laser scanning methods and drone photogrammetry. Using this data along with Autodesk Recap, Revit, Dynamo, 360Glue and Navisworks, we will demonstrate a workflow used to coordinate wall openings and embeds, confirm this information as climbing formwork was used to pour concrete walls; and finally confirming the installation of wall penetrations and steel embed plates prior to final steel fabrication and erection in order to insure minimal rework.

This class will demonstrate the work flow process; from collecting and processing the point cloud data using a laser scanner and drone, to converting 2D subcontractor drawings into model objects with Dynamo and finally, incorporation with the steel fabrication model using Navisworks for analysis and confirmation prior to steel erection. In addition we will demonstrate the coordination process required to coordinate the shear walls while the overall building coordination was occurring while attempting to do this in an efficient manner.

Speaker(s)

Robert Judd, Skanska USA Building, Inc., VDC Manager
Robert has been in the architecture, engineering, and construction industry for more than 30 years and started down the VDC path in 2003 when first introduced to the power of Revit.   After obtaining bachelor's and master's degrees in Architecture and Construction Science, his career has spanned from working in small architecture firms, to VDC consultant, to working for large Engineering and Construction companies. His current role allows him to harness his interest in software and technology and its application to solving construction challenges in an efficient and productive manner.

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Seong Choi, Skanska USA Building, Inc., VDC Engineer
After graduating from NC State University with a B.S. Construction Engineering degree in 2014, Seong began his career as a construction project engineer before moving to a structural engineering firm and finally into his current role as VDC engineer on a $250 million Hospital Bed Tower Addition. He combines his job site "boots on the ground" experience and structural design background with his passion for technology by looking for and testing innovative solutions to day to day project challenges.

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Oliver Smith, Skanska USA Building, Inc., VDC Director
Oliver's 17-plus years of experience within the design and construction industry have focused on lean processes, sustainability, Building Information Modeling (BIM), emerging and advancing technologies and services, to name a few areas. At Skanska, Smith serves as the regional virtual design and construction director for the southeast region (Washington, DC; Maryland; Virginia; North and South Carolina; Georgia; Florida; Louisiana; and Puerto Rico). Over his career he has created and implemented many standards and workflows to help integrate a more streamlined and effective process, and in addition to recently becoming a certified pilot, he heads up Skanska's unmanned autonomous systems (drone) program.

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Objective

1. <u>Efficient</u> and <u>accurate</u> Trade Coordination process to support "Just in Time" concrete form and pour schedule

2. Using <u>Reality Capture</u>, confirm as-built condition of (3) +200 ft tall concrete shear wall towers prior to steel erection

3. Test the <u>potential use of point clouds generated with photogrammetry from drone imagery</u>, using laser scan data as baseline for confirmation of accuracy and detail.

Coordination Process

Two-fold BIM coordination occurring at same time:

1. **Traditional MEP/FP Building coordination done in Navisworks**
   a. All Subcontractor models hosted on BIM 360 Glue site and updated individually as changes occurred, ideally on a daily basis
   b. Navisworks 2018 used to append these files and then the Federated coordination model saved to the 360Glue site for use by all parties, thereby maintaining an up-to-date "live" coordination model. This file is opened from Navisworks on desktop for clash detection and subsequent saved viewpoints saved back to Glue for use by subcontractors in resolving clashes.
      i. Note: recently Glue was updated making the interace much easier to use to find and manage clashes. The project team has moved towards clash detection using Glue
   c. The concrete structural model used in this process was the Construction Manager (CM) "owned" structural model as defined in Part 2 shear wall coordination process.

2. **Shear wall coordination process**
   a. The CM took ownership of the Structural engineer Revit model and used the design engineers shear wall elevation views as a basis to coordinate against.
      i. Initial attempt was made to upgrade this file from Revit16 to Revit18 in order to try and allow linking of MEP/FP Navisworks coordination models, however there were issues viewing the linked geometry in all views, particularly elevation views
   b. This Revit model's wall elevation views of the Shear tower walls were used to link 2D elevations of Concrete subcontractors shop drawings into the Revit model to define "no-fly" zones for re-bar, anchor / lift points for climbing shoring system. (More detailed coordination required than typical concrete walls) In addition the MEP/FP subcontractor's provided 2D elevations of their respective wall openings that were also linked to these elevations.
   c. This approach of using the Revit model as a basis of wall coordination as opposed to Navisworks was based on having detailed formwork shop drawings in

2D that indicated not only anchor points for the climbing formwork but also concentrations of re-bar that did not lend itself to the 3D coordination process.
  d. Dynamo was used to model the anchor point "no-fly" zones by extracting 2D line work from Concrete Subcontractor shop drawings into model elements in the Structural concrete model that could be used in MEP/FP coordination of their respective openings during this coordination effort.
  e. The updated Concrete model was periodically reviewed in Navisworks to confirm the Revit elevations matched the 3D geometry in the MEP/FP coordination including reviewing the steel framing attachment embed plates incorporated from the Steel fabricators model.
  f. Shear wall Coordination drawings were created to indicate sleeves, embeds, openings, etc for the CM team to use to back check as forms, sleeves, etc were placed prior to pouring concrete. Shared Views were setup on 360Glue to use Ipads in the Field to assist in this confirmation process.

Point cloud Generation and Analysis using Drone Photogrammetry and Laser Scanner

1. **Initial Test**
    A first test run of the drone was done about mid-way through the shear tower construction to test the potential of the drone photogrammetry process and workflow. In addition preliminary laser scanner was done to determine best locations to scan from
    a. For this initial test we were limited to flying the drone at 350 feet due to tower crane activities so were only able to obtain straight down photos. We had hoped to be able to fly around perimeters of the towers and up and down the height to test the accuracy of these more detailed images.

B. **Point cloud generation**
    a. The drone images were uploaded through Recap Photo where they were converted through photogrammetry into a point cloud data file
    b. The laser scans were stitched together with Recap Pro
    c. The drone point cloud was then stitched into the laser scan point cloud in Recap Pro
    d. This combined point cloud (.RCS format) was the brought into Navisworks to review accuracy and detail

C. **Analysis of this preliminary point cloud to test proof of concept.**
    a. Drone point cloud was reasonably accurate with respect to scale. This was determined by looking at a section view in Navisworks of the largest tower and color coding the drone scan to visually analyze.
    b. The detail was unacceptable (not dense enough to provide needed detail)
    c. It was hoped a more detailed set of images taken closer to the walls would lead to more detailed point cloud.

D. **Additional laser scanning during construction**
   a. Exterior of towers were scanned as formwork removed.
   b. Interior of shafts were scanned prior to stair scaffolding removal by moving the scanner to multiple landing locations in order to completely capture the interior of the towers. The side affect of this approach is the scaffolding is captured in the scan and obscures some of the wall information.
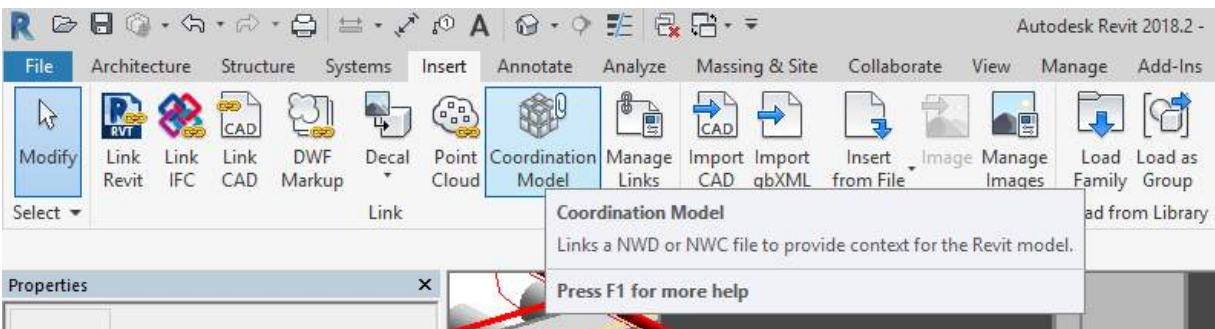
E. **Final Drone test at completion of towers**
   a. As the final formwork was removed from the towers a final test was performed with the intent to take up close images of the towers to test the photogrammetry process. Unfortunately we were unable to do so based on technical difficulties with calibrating the drone which we believe may have been due to interference from attempting to take off to close to the large concrete and steel masses of the towers. Due to the complexity of the coordination approval process to fly drones in the project environment, we determined we would not attempt any further flights.
   b. Mini Drone – during this final test we also tested a recently purchased DJI Spark mini-drone to test its potential. The drone is controlled from a mobile phone and obtains surprisingly good quality still images, showing potential for easy job-site inspections in the hands of project team members.
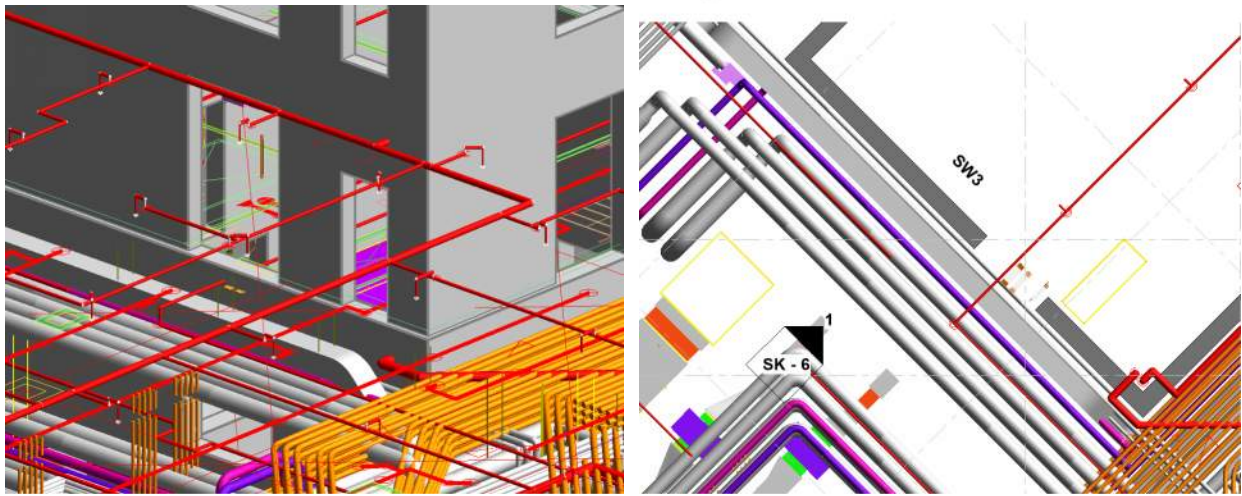
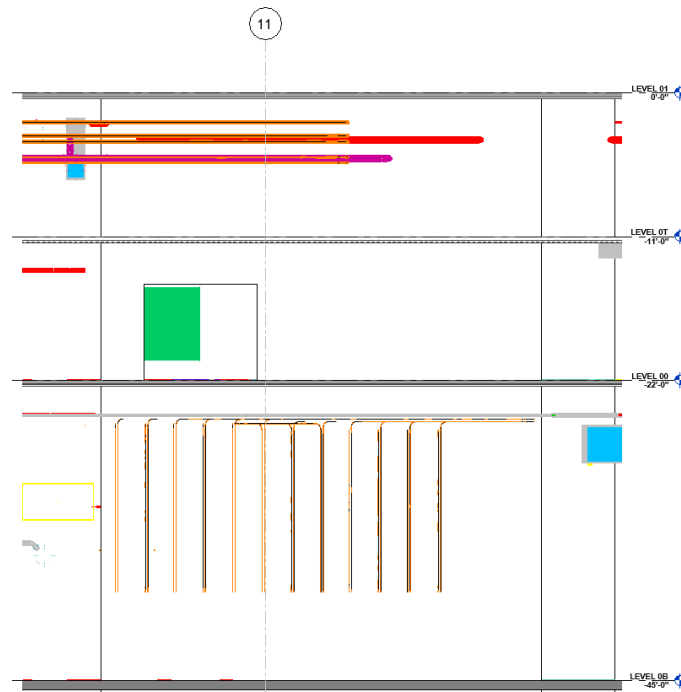## Tools Used in Coordination and Quality Control Analysis Process

Revit

Initially Revit was used to upgrade the design model from V16 to V18 in order to take advantage of the "linked coordination model" feature allowing linking of the Navisworks coordination models into Revit. Initial thoughts were this would allow us to easily see all wall penetrations required by the Mechanical, Electrical and Fire Protection trades. Unfortunately the graphics in the elevation views did not consistently show up even after significant time spent searching the Internet for solutions and multiple and various attempts at manipulating graphic display options with in Revit. We observed that the Navisworks models showed up well in 3D and plan views but did not display well enough in the shear tower elevations and were therefore unreliable.

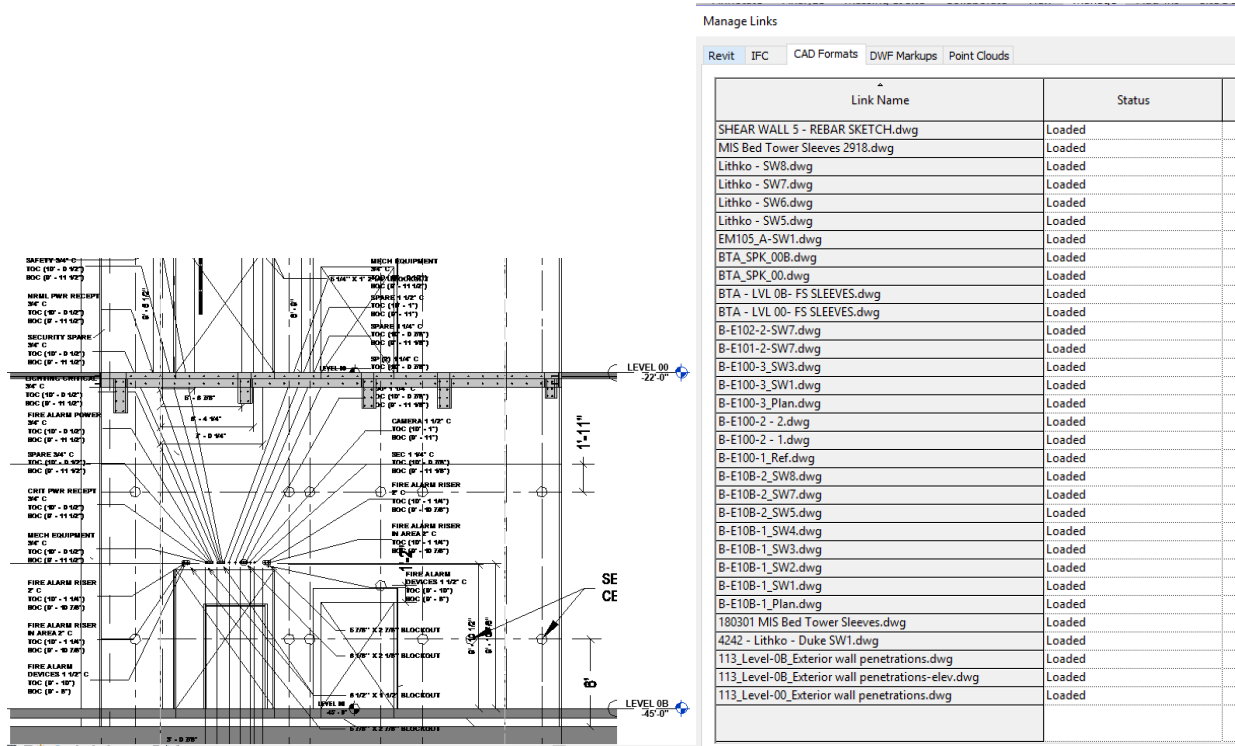View of linked coordination model feature of Revit 2018

Linked coordination model looks great in 3D and Plan views

Elevation views are not usable due to graphic control limitations

Another issue using Revit is the backwards incompatibility of versions which created challenges with model updates from the designers. Eventually the design models were upgraded to v17 and Revit 2017 was used to update and manipulate the Structural Revit model shear wall elevations by linking 2D Elevation DWG files into elevation Views. As this model was updated

through the concrete wall coordination process, a NWC file was exported and uploaded periodically to BIM360Glue for use in the overall trade coordination effort

Manage Links

Link Name	Status
SHEAR WALL 5 - REBAR SKETCH.dwg	Loaded
MIS Bed Tower Sleeves 2918.dwg	Loaded
Lithko - SW8.dwg	Loaded
Lithko - SW7.dwg	Loaded
Lithko - SW6.dwg	Loaded
Lithko - SW5.dwg	Loaded
EM105_A-SW1.dwg	Loaded
BTA_SPK_00B.dwg	Loaded
BTA_SPK_00.dwg	Loaded
BTA - LVL 0B- FS SLEEVES.dwg	Loaded
BTA - LVL 00- FS SLEEVES.dwg	Loaded
B-E102-2-SW7.dwg	Loaded
B-E101-2-SW7.dwg	Loaded
B-E100-3_SW3.dwg	Loaded
B-E100-3_SW1.dwg	Loaded
B-E100-3_Plan.dwg	Loaded
B-E100-2 - 2.dwg	Loaded
B-E100-2 - 1.dwg	Loaded
B-E100-1_Ref.dwg	Loaded
B-E10B-2_SW8.dwg	Loaded
B-E10B-2_SW7.dwg	Loaded
B-E10B-2_SW5.dwg	Loaded
B-E10B-1_SW4.dwg	Loaded
B-E10B-1_SW3.dwg	Loaded
B-E10B-1_SW2.dwg	Loaded
B-E10B-1_SW1.dwg	Loaded
B-E10B-1_Plan.dwg	Loaded
180301 MIS Bed Tower Sleeves.dwg	Loaded
4242 - Lithko - Duke SW1.dwg	Loaded
113_Level-0B_Exterior wall penetrations.dwg	Loaded
113_Level-0B_Exterior wall penetrations-elev.dwg	Loaded
113_Level-00_Exterior wall penetrations.dwg	Loaded

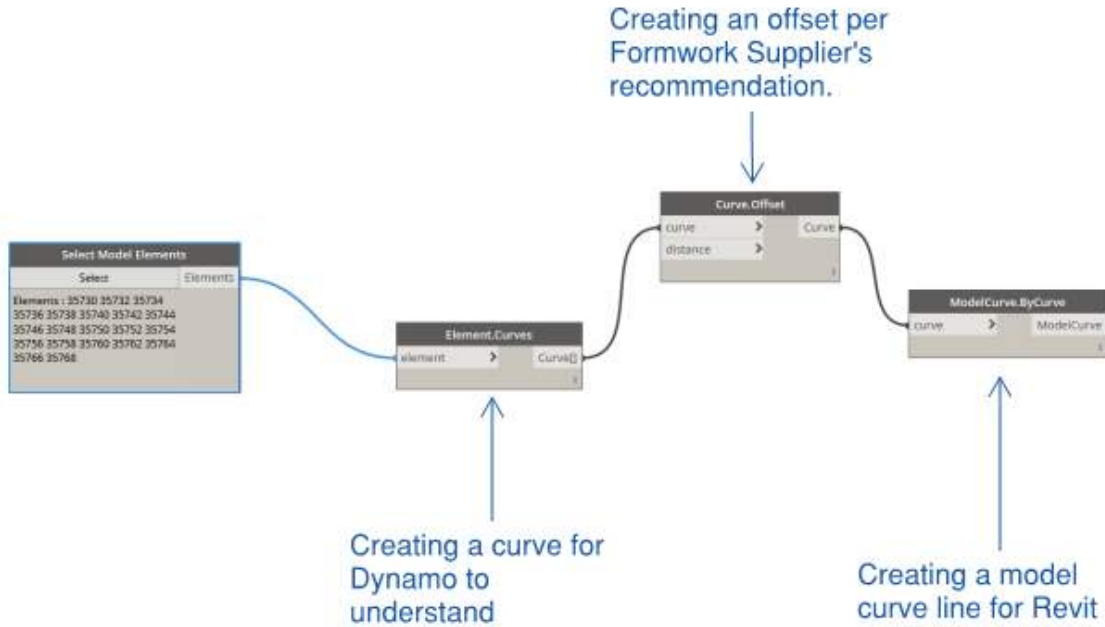View of linked 2D CAD files within the tower elevation views.

AutoCAD
Used to clean up subcontractor provided 2D CAD (DWG) files to allow for use in linking into Revit model
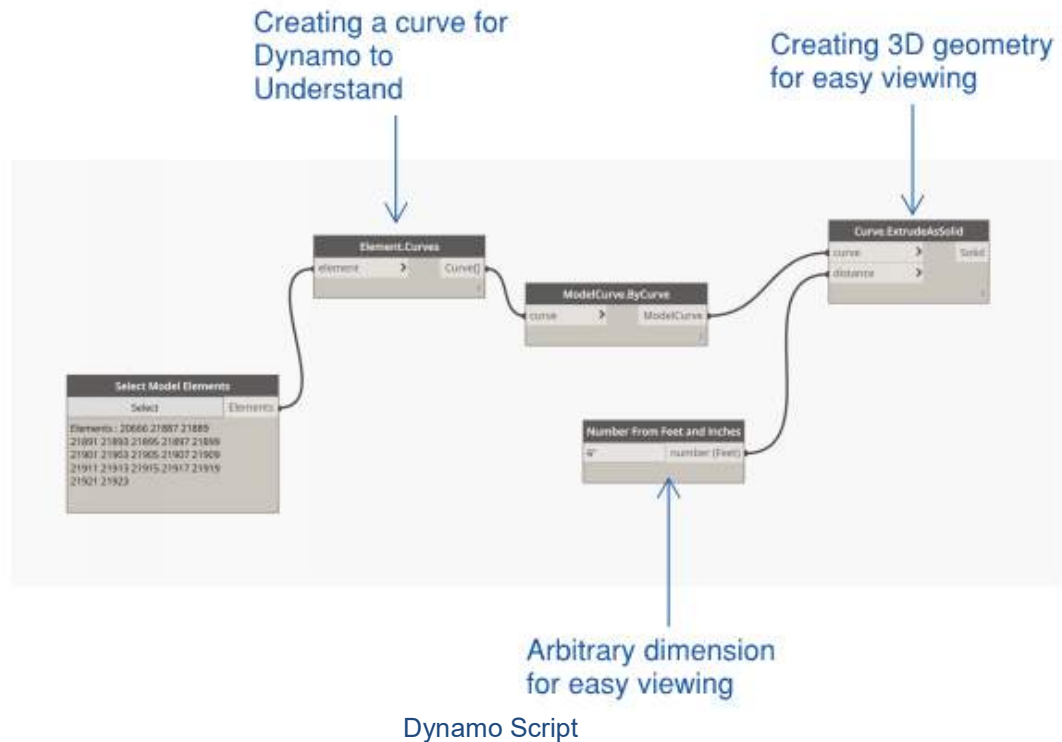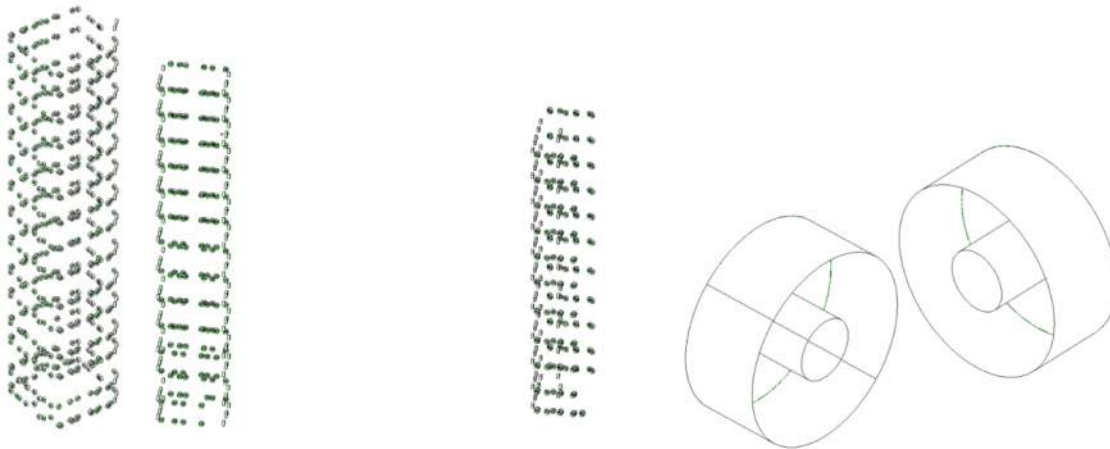
Dynamo
The concrete subcontractor shop drawings that were linked into the Revit Elevations contained critical "no-fly" zones around formwork anchor points where no penetrations or embeds were allowed. It was critical to incorporate this into the overall coordination model and in order to make this process easier and allow for the ability to utilize the clash detection process within Navisworks, Dynamo was used to convert 2D line work into 3D geometry that could then be linked into the overall coordination model.

Step 1 - Converting DWG lines to Revit lines

Creating an offset per
Formwork Supplier's
recommendation.

Curve.Offset
curve → Curve
distance →

Select Model Elements
Select | Elements
Elements : 35730 35732 35734
35736 35738 35740 35742 35744
35746 35748 35750 35752 35754
35756 35758 35760 35762 35764
35766 35768

Element.Curves
element → Curve[]

ModelCurve.ByCurve
curve → ModelCurve

Creating a curve for
Dynamo to
understand

Creating a model
curve line for Revit

Step 2 - Creating an extrusion for 3d viewing in Navisworks

Creating a curve for
Dynamo to
Understand

Creating 3D geometry
for easy viewing

Element.Curves
element → Curve[]

ModelCurve.ByCurve
curve → ModelCurve

Curve.ExtrudeAsSolid
curve → Solid
distance →

Select Model Elements
Select | Elements
Elements : 20886 21887 21889
21891 21893 21895 21897 21899
21901 21903 21905 21907 21909
21911 21913 21915 21917 21919
21921 21923

Number From Feet and Inches
6" | number (Feet)

Arbitrary dimension
for easy viewing

Dynamo Script

Dynamo Objects created from script and used in coordination.

Navisworks & BIM 360 Glue

BIM360 Glue was used to host all models used in coordination. By utilizing the merged models feature of Glue, all parties involved in the coordination process we able to use their own individual versions of Navisworks to open up the Federated model at any time to see the most current models and effectively coordinate on a daily basis. Skanska utilized Navisworks 2018 to utilize the new Section cut feature which allows a better graphic interface when viewing models in section. In addition Navisworks versions 2016 through 2018 are forward and backward compatible making it easier for all parties involved to use the version best suited for their company and workflows.

Navisworks 2018 Section Cut option

Federated model hosted and setup on 360Glue for Field QC use
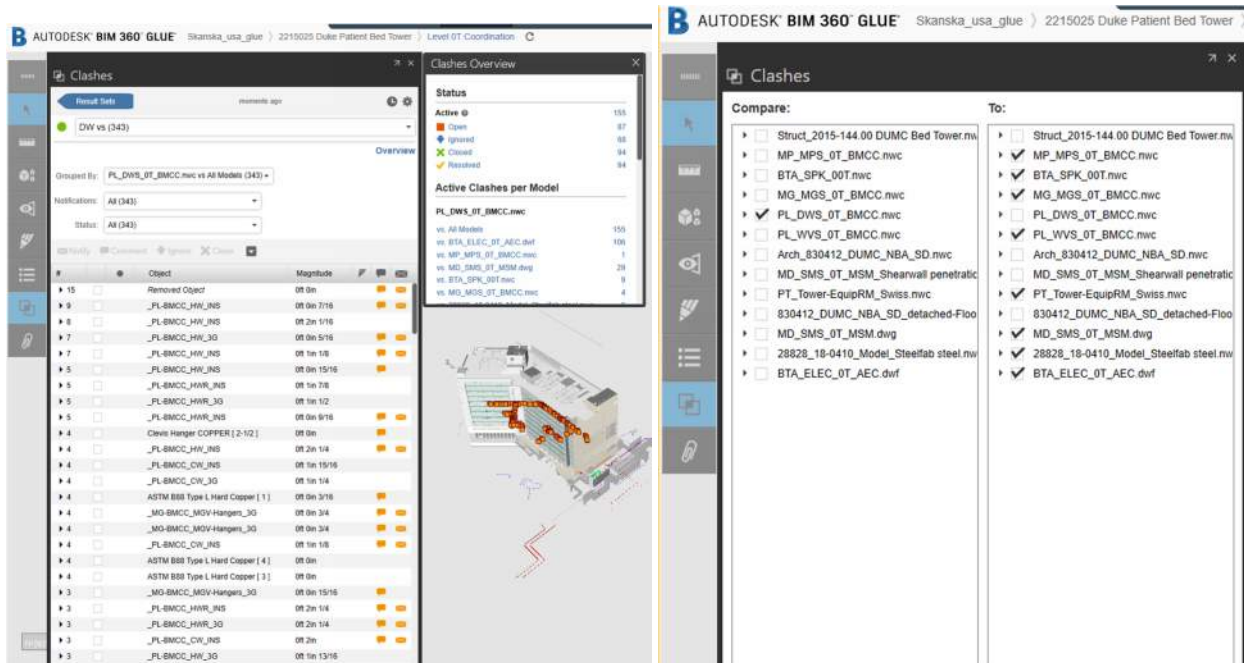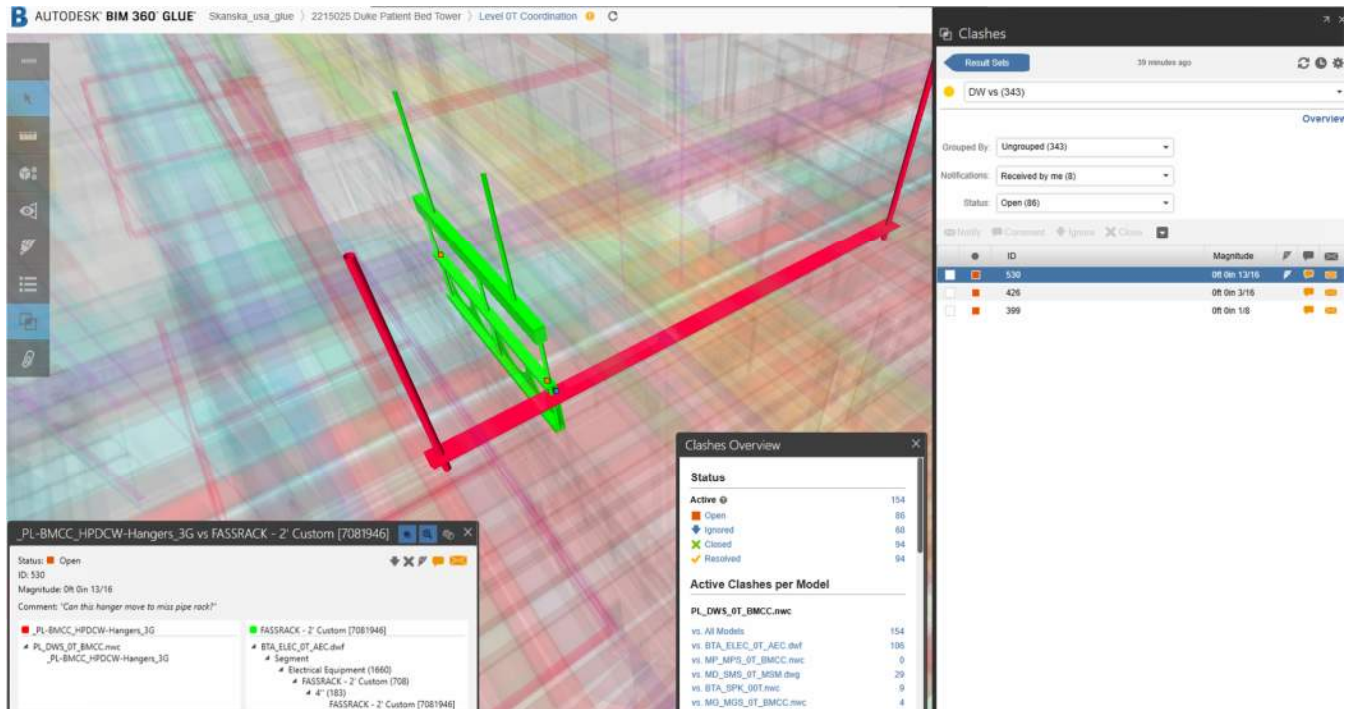
Shared Views for Field use on Tablet
As the wall elevation coordination was completed, the shared views feature of Navisworks was used to create Quality Control views for use by Skanska and subcontractor Superintendents in the field to confirm all openings and embeds as the formwork was erected and prior to pouring concrete.

View of BIM 360 Shared Views in Navisworks that can be accessed through BIM 360 Glue Table app

New Glue

The 360 Glue desktop /web interface has recently been updated and now offers more opportunity to use Glue to find and manage clashes in lieu of Navisworks. This process makes communicating and solving clashes even easier as stakeholders just need a browser to utilize.

Views of New BIM 360 Glue Interface

Tools Used in Reality Capture Process

Drones and Laser Scanner

Drone

Mini Drone

- Designed for both indoor and outdoor applications that require scanning up to 70 meters and with accuracy of +/- 1mm
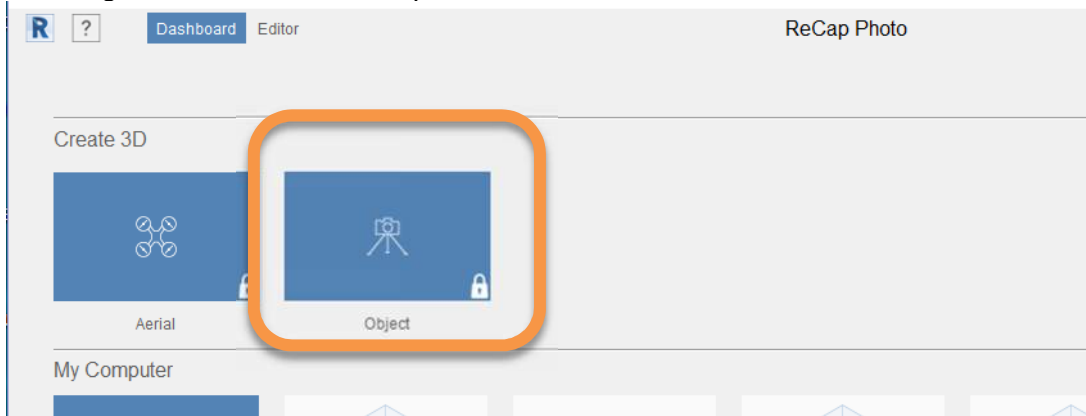
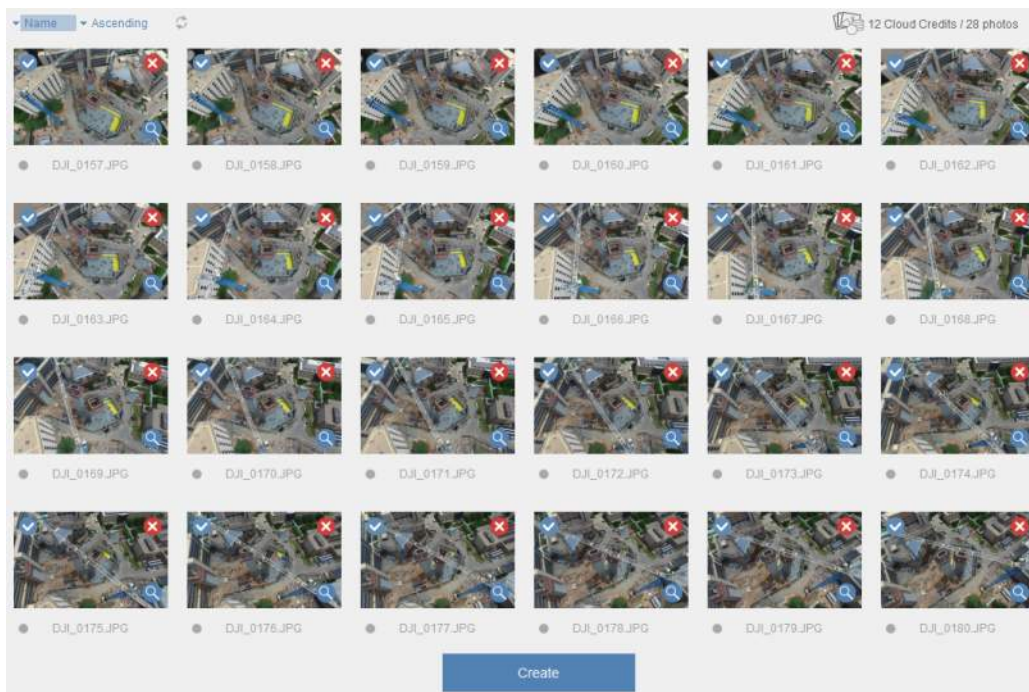Laser Scanner – Faro S70 ($40,000 total cost)

Recap Pro

Used to import and stitch all scans from the laser scanner. Also used to stitch the drone photogrammetry generated point cloud into the laser scan point cloud for comparison. This combined scan was then appended into Navisworks for ease of comparison between both point cloud types.

Recap Photo

The Photos generated from the drone flight were uploaded through Recap Photo to be able to get a point cloud. Processing usually takes several hours and when completed notification is received to login and download all requested data.
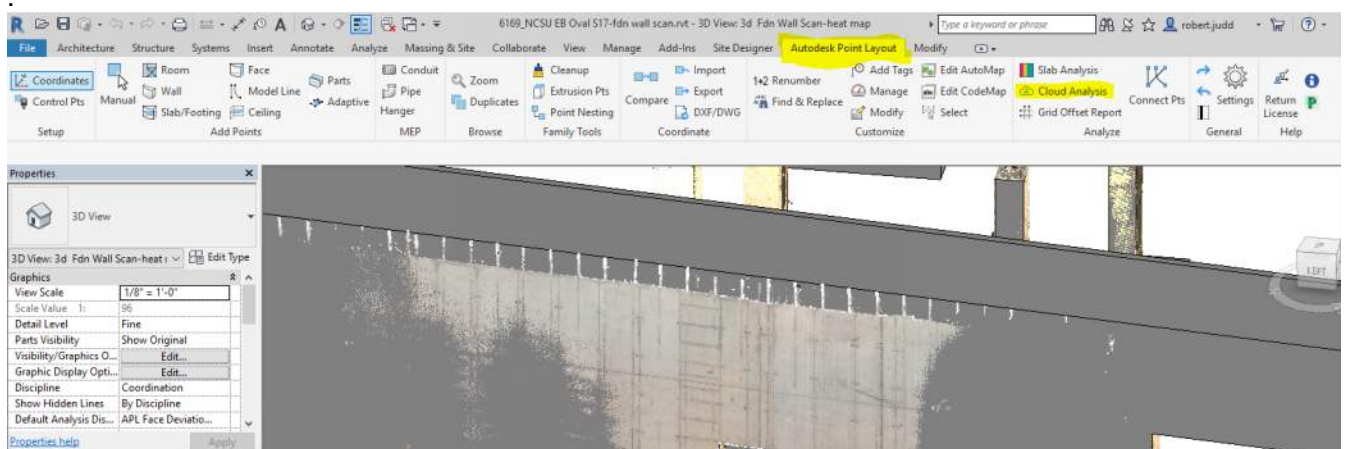

Open ReCap Photo and select Create 3D / Object

Select images taken from Drone and upload and hit Create button

Point Layout

Although not originally intended to be used as a quality control measure, as part of utilizing the laser scanner and subsequent analysis in both Navisworks and Revit, we discovered the power of Autodesk Point Layout which is a plug-in for both programs. Although designed for creating points files for use in field surveying equipment such as the Trimble Total Station, Point Layout has a Analyze Tab that allows the user (after aligning a scan to best fit the model) to easily perform a Cloud analysis or deviation analysis of walls or floors to see a color coded "heat map" that indicates the plus or minus delta from the model face selected. As part of our QC analysis, this feature was utilized to understand where walls deviated from plumbness, allowing the project team time to understand any potential issues and remediation. The process requires aligning or "best fitting" the cloud to the model and then from the Point Layout Tab, select Cloud Analysis and when prompted select the surface of the object to be analyzed.   Revit will then automatically create a color coded heat map of deviation along with an accompanying legend

.

View of Point Layout Plug-in in Revit

Drone Process

Steps to using Drone

1. To commercially operate, must have FAA license for UAS (Unmanned Aircraft System).

2. Obtain approval from any governing authority prior to any flight operations.

3. Use a web based platform (skyward.io or similar) to plan and document flight including confirmation of any FFA height restrictions.

4. On flight day, plan on having a second person to act as a visual line of sight spotter to assist with observing the drone flight while operator focuses on flying drone..

5. Images and video is typically stored on a SD card which can be used to transfer data to the desired processing platform, (Web, Recap Photo, etc)