Back to Reality: From Scan to Model to VR

Paul F Aubin

Paul F. Aubin Consulting Services, Inc.

https://paulaubin.com/

Speaker:

Paul F. Aubin is best known as the author of many books and video training courses for Revit and other Autodesk tools. He has over 30 years of experience in the Architectural industry and has worn many hats in that period, from designer, to CAD Manager, technologist, and trainer. He continues many of these in his current role as an independent Architectural consultant based in Chicago. Paul is the founder of ChiNamo; the Chicago Dynamo Community and a member of the Volterra-Detroit Foundation board of directors. He lives in Chicago with his wife and their three children currently attend universities around the country.

Learn more about Paul's Revit, Dynamo and Autodesk ReCap online training courses at: https://linkedin-learning.pxf.io/XEA0a

Description:

Perched atop the majestic hilltops in Tuscany, Volterra is an ancient Italian city, continuously inhabited for 3 millennia. This session explores the use of lidar and photogrammetry to capture and compile point clouds, mesh models, Revit models and virtual reality experiences documenting the city's priceless treasures. Participants in International Reality Capture Workshops, held annually in Volterra, gain unique access to equipment, expertise and timeless architectural and archaeological treasures. The team consists of professionals from around the globe and local practitioners living and working in and around Volterra. This session will take you on a tour of Volterra and the data captured there (over 3 terabytes!) We'll explore the point clouds, the tools we used to process them, Building Information Models created from the data, and finally some video and virtual reality experiences of the results. This session will show you a small cross-section of this exciting and ongoing work!

Learning Objectives:

- Learn about the tools: laser scanners, UAV (drones), cameras, etc.
- Explore use cases: including historic preservation, archaeological study, AEC, public outreach, reconstruction after tragedy, etc.
- Discuss the best ways to use point clouds in modeling tools like Revit.
- Experience the reality captures first-hand in desktop tools, online tools and virtual reality headsets.

Introduction

Most architectural projects begin with some sort of existing conditions. Even in projects with all new construction, the land or the site that project sits on is “existing.” So, having some efficient and accurate way to capture existing conditions is a common requirement. The simplest way to capture existing conditions is to use a tape measure and a pad of paper. While certainly effective, it is not always quick, convenient, or completely accurate. Modern reality capture tools like laser scanners (or LIDAR) and drone, as well as terrestrial based photogrammetry offer an alternative.

Volterra

This session will share examples from recent participation in the [International Reality Capture Workshop](#) hosted by the Volterra-Detroit Foundation. This workshop is conducted annually onsite in Volterra Italy. During its two-week duration participants get to use laser scanners, drones, and reality capture software first-hand and learn about the procedures and the advantages and disadvantages of various techniques. This all takes place amid the majestic Tuscan countryside and within the ancient walls of Volterra and its surroundings (see Figure 1).

Figure 1 – Volterra, Italy

Volterra has been continuously inhabited for over three millennia. The city boasts archeological treasures from the Etruscans, the Romans, and mediaeval times. Each of these time periods is layered upon one another blending artifacts from multiple time periods into one unique whole. Nowhere is this more evident than in the Porta all'Arco – the Etruscan Arch (see Figure 2).

Figure 2 – Porta all'Arco, an ancient Etruscan arch with the medieval city wall subsuming it

This is one of only two arches in all of Italy from Etruscan times that remains intact. The large porous stones of the original arch remain, as do the sculpted heads in the keystone and spring line of the arch. Surrounding this, we can see smaller stonework built right up to and around the arch and fully incorporating it into the medieval defensive wall. To further emphasis the layering of time periods and history, there is a private patio at the top of the wall above the arch. Someone's house overlooks this ancient artifact! Examples like this can be seen throughout the city.

Volterra also boasts a large Roman theater that was only unearthed in the middle of the last century (see Figure 3).

Figure 3 – Teatro Romano

Restaurants and shops frequently have remains of Roman and Etruscan ruins in their lower levels. You can see stones and capitals reused throughout town. For example, some of the column capitals recycled from the Teatro Romano can be seen on the entrance to Volterra's cathedral (see Figure 4). It is truly an amazing place.

Figure 4 – Recycled column capitals from the Roman theater grace the entrance to the cathedral

While Volterra is for me the ideal place to have gained first-hand experience with reality capture, you do not need to have access to ancient ruins or fly halfway around the World to get started. All you need is a subject to capture and the tools to do it!

Reality Capture Technologies

There are many devices available for reality capture. In very simple terms, reality capture equipment falls into two big buckets: laser-based (LIDAR) and photo-based (photogrammetry). Let's start with a couple quick Google searches for definitions:

LIDAR: *a detection system that works on the principle of radar but uses light from a laser.*

https://en.wikipedia.org/wiki/Lidar

Lidar (also called LIDAR, LiDAR, and LADAR) is a surveying method that measures distance to a target by illuminating the target with pulsed laser light and measuring the reflected pulses with a sensor. Differences in laser return times and/or wavelengths can then be used to make digital 3-D representations of the target.

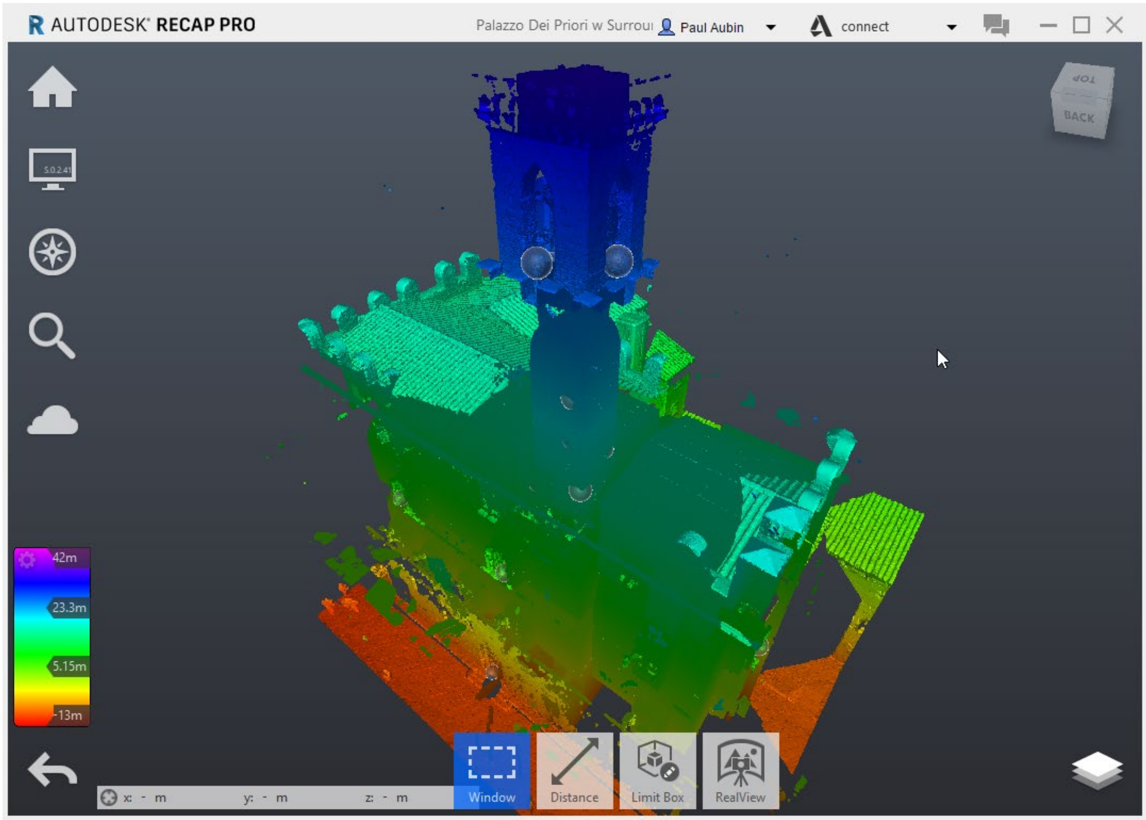


Figure 5 – Laser Scans loaded into Autodesk ReCap

Photogrammetry : the use of photography in surveying and mapping to measure distances between objects.
https://en.wikipedia.org/wiki/Photogrammetry
Photogrammetry is the science of making measurements from photographs, especially for recovering the exact position s of surface points.

Figure 6 – Photogrammetry relies on multiple images from varying vantage points

Naturally there are some distinct differences in the two technologies; LIDAR uses bounced laser light to take measurements. Photogrammetry interprets features visible in several overlapping photographs to construct a 3D form. But there are some similarities as well. Both are "line of sight" technologies. This means that if a feature is obscured from view of the laser (in LIDAR) or the camera (in Photogrammetry) no data will be recorded and the item or feature in question will be omitted or poorly represented. In both cases, the best solution to this issue is to take several vantage points (with plenty of overlap) for the best results. However, this means that post-processing will be required to "stich" the various viewpoints together and interpret the results. Often the result of this process is a file called a "Point Cloud." A Point Cloud is quite literally a "cloud of points." Each point in the cloud will have a collection of data: its location (X, Y and Z), its color, its normal direction, etc. Point clouds can then be imported into most design software like Revit and AutoCAD to use as an underlay of existing conditions. Point clouds give us a highly accurate representation of existing conditions directly in design software.

Focus of the Volterra Workshop

For the reality capture workshop in Volterra, we had access to Faro scanners (330x and 350x), Leica scanners (BLK and RTC) and we also had a Matterport scanner on one of the trips. Matterport uses "structured light" instead of a laser to capture 3D distances. This is coupled with a cloud-based service that registers, hosts and processes the scan data. We have had access to other devices as well. One year we had a Pegasus Backpack scanner that you wear on your back and walk around with it as it scans. We've used various spherical cameras and even had ground penetrating radar one year. We also did some aerial drone photogrammetry, but given the tight regulations in Italy, particularly regarding non-Italian pilots, we were restricted to non-urban areas for our flights, or we had to hire native pilots for flights in the city. We also did ground-based photogrammetry (of smaller objects) using everyday DSLR and cell phone cameras. No regulations here, so everyone could participate.

Once we captured the data, we used mostly the Autodesk suite of tools for post-processing. This includes ReCap Pro for importing, registering and indexing scan data to create point clouds. ReCap Photo (previously ReMake) was used for performing photogrammetry and creating and editing mesh models and we used Revit for creating building information models from the resultant point clouds and mesh models. Several other tools were used as required (like Register 260 and Cyclone), but these three were the primary tools.

Photogrammetry

If you are anxious to get started with reality capture, you might be unsure how to begin. Furthermore, if you are like me and do not work for a big firm with the resources to purchase and maintain high-end reality capture equipment like the laser scanners noted above, then just how can you get some first-hand experience? (Well, one way is to consider joining us on a future Reality Capture Workshop…) But if you don't anticipate being able to attend a workshop, then look no further than the device in your pocket. That's right you can use nearly any modern smart phone to capture photos suitable for photogrammetry and use them for viewing results both traditionally and in VR applications. (Naturally if you have a higher end camera, you can use that instead).

The first thing you'll need to do is take some photos. It is best to start with an object. Perhaps a sculpture or some other reasonably sized stationary object. You will need at least 25 photos, but you can do considerably more. You want your photos to overlap one another (see Figure 6 above and Figure 7 below).

Figure 7 – Planning your shots

So, try to capture about 50% of the same content in each photo as you had in the previous one. If you are doing a sculpture, this means slowly walking around the piece and taking photos at regular intervals as you go. You will also want to capture from at least 3 or 4 different heights as well. So maybe about a dozen photos around the object and then go around again shooting at a lower or higher height. You will want there to be overlap both as you go around and vertically.

If you can move all the way around the object, you will get the best results. Also, be mindful of lighting, focus, glare and camera movements. There are plenty of other things to consider. I found a good article here that you can review for some tips:

https://www.tested.com/art/makers/460142-art-photogrammetry-how-take-your-photos/

But just Google photogrammetry tips and you are likely to find plenty of good resources. One last tip. Make sure that your subject fills at least 80% of the frame. You also want some stationary information in the background. This will help in registration, but not too much! If you can't avoid getting too much background, you can open the photos in a photo editing program and crop them. But hopefully, you can avoid this step by carefully composing your shots. Once you have the photos, you need to process them.

We used ReCap Photo for this. (There are other alternative products. Just Google photogrammetry software).

ReCap Photo is a separate application that is included with a ReCap Pro subscription. When you do a photogrammetry project, ReCap Photo will process your photos and create a 3D model. If you start in ReCap Pro, it will prompt you to launch ReCap Photo. Next you will be prompted to select your photos, and that's it. Your photos will be uploaded to the Autodesk cloud servers and will analyze the features shown in each photograph and then look for features that are shown in more than one photo. Once it identifies that these features are the same, it can use the vantage points in the different photos to calculate distances and create a 3D mesh (see Figure 8).

Figure 8 – Mesh created in ReCap Photo

Once your mesh is complete, you will be emailed and can download it to your local machine. It is advised to open it in ReCap Photo first and see how it turned out. There will usually be some weird artifacts that require cleanup. ReCap Photo has a basic suite of mesh editing tools. You can adjust the orientation and coordinates, change the units, correct defects like filling holes or smoothing rough areas. You can slice the model, delete unwanted portions and decimate the mesh.

Your mesh will be made up of thousands of small triangular surfaces. This is sometimes very dense with many small triangles. One of the last steps that you will perform in ReCap Photo is exporting the model to a format supported by whatever software you intend to use next in the process. If you find that the mesh is too dense (too many triangles), you can "decimate" it. This will reprocess the mesh to use fewer vertex points and triangles. But this necessarily will result in some details being smoothed or lost entirely, depending on how much decimation you employ. If you are familiar with saving an image file to a JPG with high levels of compression, then this is like the 3D version of that. I try not to decimate if possible. But it all depends on what I plan to do with the model.

One very simple and satisfying thing you can do is to 3D print it! In this case, export the model to STL or OBJ format and either print it on your own 3D printer if you have one, or upload the file to a service like Shapeways or iMaterialise (see Figure 9). This takes your reality capture full circle; (and that is after all, the point of this session).

Figure 9 – 3D printed models from photogrammetry meshes

Using Mesh Models in Design Software

Another place to use these models is of course in our design software. ReCap Photo exports to OBJ, FBX, STL, PLY and PTS. If your software of choice supports one of those, you can export and then open it directly. In the case of Revit, none of those formats are supported. So, you will have to export from ReCap Photo and then convert the file before loading into Revit. I usually export to OBJ or FBX, open and process in 3ds max, and then export that out to DXF or DWG for importation into Revit. I have a detailed explanation of that workflow below. If you have one of the Autodesk collections, you most likely have 3ds max, so this workflow should be achievable. However, you can also use any other 3D capable software that you have that supports the formats to which ReCap Photo exports. If you are anxious to see the procedure, you can skip below now, otherwise, I will talk a little about laser scanning and point clouds first.

Laser Scanning

As noted above, laser scanners capture data by firing a laser in all directions from the spinning scanner head and recording the distances as those points return to the scanner (see Figure 10). Generally, the resultant file generated from the scanner is a point cloud. Some scanners and technologies return a mesh model as well, but typically we get a point cloud. Most design applications in the Autodesk collections (like AutoCAD, Revit, InfraWorks, Navisworks, etc) include support for point clouds. These are linked into the current project and can be reloaded if the point cloud changes externally.

Figure 10 – Faro scanner capturing a point cloud

Capturing Scans —Preplanning

The first step is capturing the data. Keep in mind that like photogrammetry, laser scanners rely on "line of sight." This means that if a feature in your scene is not in a direct line of sight to the scanner, it will be obscured from view and not captured. When you open a scan file, you can see these "shadowed" areas as voids that will contain no points or data. This means that unless the space you are capturing is completely smooth and featureless, to do a full capture of the space you will need to take more than one scan (see Figure 11).

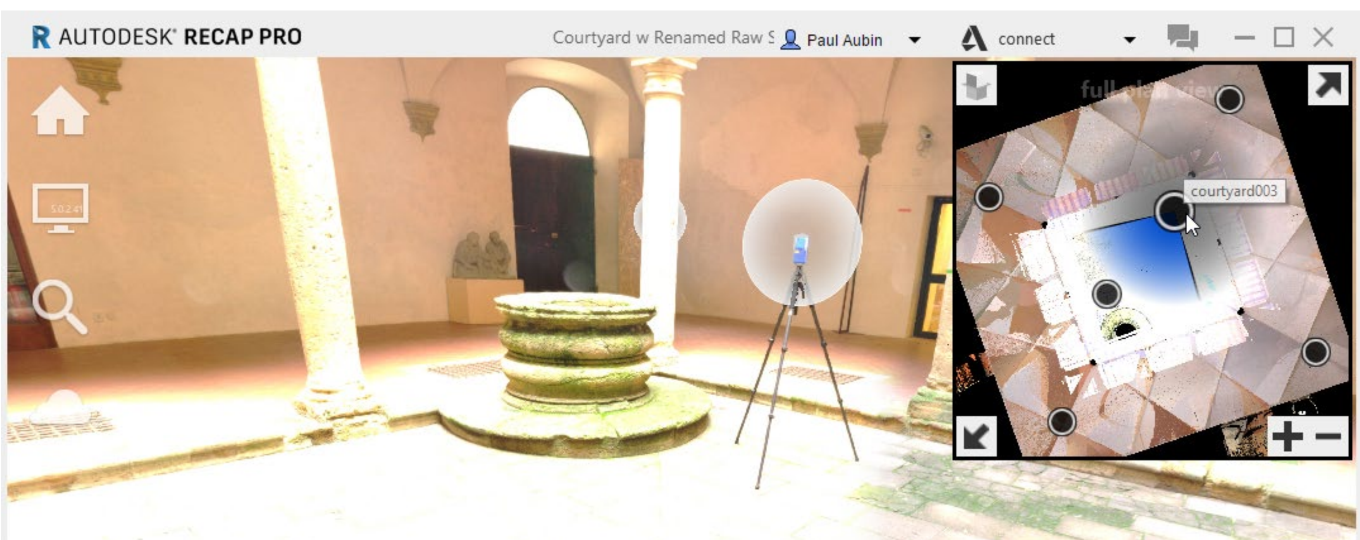


Figure 11 – Plan to have several scans in each space

The exact quantity will vary with the complexity of the space, but it is not uncommon for there to be dozens or even hundreds of scans required to fully capture a complex space. Keep the "line of sight" notion in mind as you decide where to put the scanner. If you can't see a feature that you wish to capture from the vantage point where you are standing, then your scanner can't see it either! Often it can be a good practice to walk the space before you begin and sketch out a plan of attack (see Figure 12).

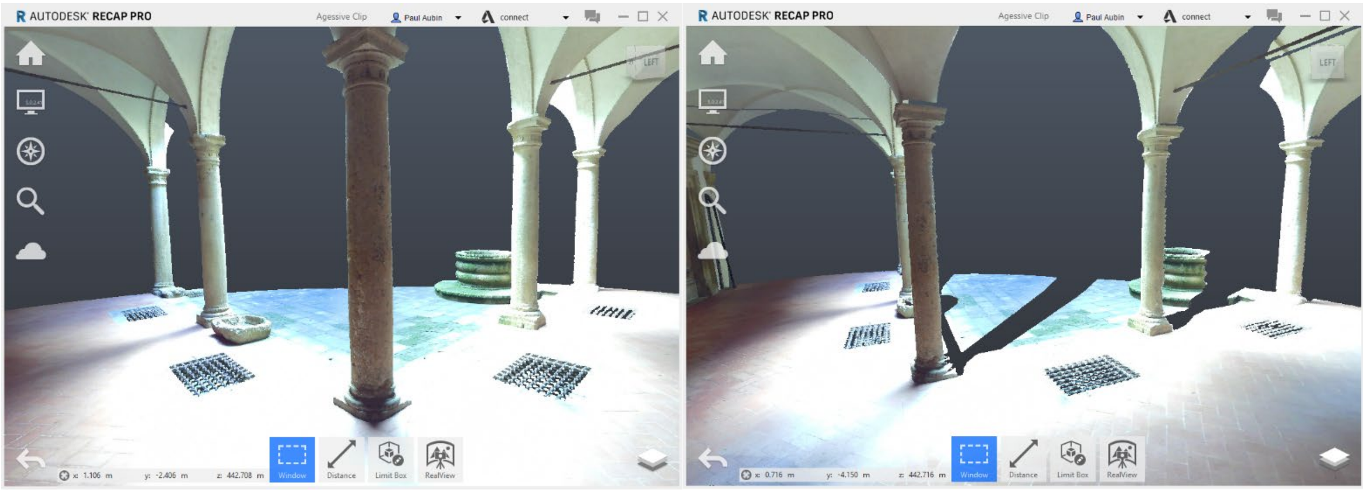


Figure 12 – The line of sight on the left does not "see" behind the columns as seen on the right

Another consideration in this preliminary planning is how the scans will register. When you drag a folder full of raw scans into ReCap Pro, they will import in order of how you add them. So, if you simply drop an entire folder (which is the typical approach), they will import in the order in which they were created. Knowing this, you can plan not only where you place the scanner in the space to achieve the best coverage and overlap, but also plan the order in which you take the scans to simplify the importing process later. It does not take much to add this extra bit of planning to your workflow, but it can prove quite valuable overall.

Capturing Scans —Scanner Settings

The next factor for consideration in scanning is configuring the settings of the scanner. Naturally, this will vary with specific hardware you have available to you, but there will be similarities regardless of the machine used. Primary factors include: distance to the object (from the scanner), resolution and quality[1].

Distance: This is the physical distance from the scanner to the item being measured. The distance will vary for each point being measured.

Resolution: This is a measure of the density of the grid of points delivered by the scanner and is expressed as a ratio such as 1/1, 1/5 or 1/16[2]. Choosing a denser resolution increases the time it takes to perform the scan, while decreasing the density reduces the amount of time it takes. Denser resolutions produce more points per area and therefore generally produce higher quality results. But this comes at the cost of more time.

I found a nice resource that explains resolution here:
http://www.laserscanning-europe.com/en/news/correct-resolution-laser-scanning

Quality: Think of quality as a redundancy setting of sorts. With a 1x quality, the scanner sends one beam to each point on the grid. A 4x quality measures those same points 4 times and returns an average of the measurements. Presumably the more measurements you make of each point, the better that average

---

[1] The names of these settings/factors might vary from device to device.

[2] Since resolution is related to distance, most scanner manufacturers specify resolution values at a fixed distance such as 10 meters.

distance will be. However, as you might expect you pay a cost in increased time with each increase of the quality setting.

Color or Black and White: Most scanners not only capture points, but they also take photog raphs around the scanner in all directions. Software like ReCap can use the photos to help in visualization and navigation of the scan data. Color photos give the nicer result but take more time to capture. So, in some cases you can choose Black and White photos to speed up scans without sacrificing the other settings like quality and resolution.

The following table compares the various settings and their effects on the time to scan. Thank you to David Drefts of Cintoo for this table.

Black and White scan s in minutes

Quality \Resolution	1\1	1\2	1\4	1\5	1\8	1\10	1\16
1x	15.33	4.50	2.00				
2x	29.66	8.15	2.66	2.15	1.50		
3x	58.15	15.33	4.50	3.33	2.00	1.50	1.25
4x	115.00	29.66	8.15	5.50	2.66	2.15	1.50
6x		118.00	29.66	19.33	8.15	5.50	2.66
8x			118.00		29.66	19.25	8.15
Points per scan (in millions)	699.10	174.80	43.70	28.00	10.90	7.00	2.70
Point spacing mm \10m	1.53	3.07	6.14	7.67	12.27	15.34	25.54

Color scans in minutes

Quality\Resolution	1\1	1\2	1\4	1\5	1\8	1\10	1\16
1x	18.50	7.66	5.00				
2x	32.66	11.25	6.00	5.25	4.50		
3x	61.00	18.50	7.66	6.50	5.00	4.66	4.30
4x	118.00	32.66	11.25	8.66	6.00	5.25	4.50
6x		118.00	32.66	22.50	11.25	8.66	6.00
8x			118.00		32.66	22.50	11.25
Points per scan (in millions)	699.10	174.80	43.70	28.00	10.90	7.00	2.70
Point spacing mm\10m	1.53	3.07	6.14	7.67	12.27	15.34	25.54

For most of the scans that we performed in Volterra, we used a resolution of either 1/5 or 1/8 with a 4x quality. Most were captured in color. We did do some black and white ones and certainly adjusted the other settings when called for. Speed also varies considerably with the scanner hardware itself. In 2016, the year of our first workshop, our average scan time with the settings noted here was between 6 and 8 minutes. Last year, with the newer RTC scanner, we were able to scan at similar quality in about 2 ½ minutes!

Capturing Scans —Managing the Environment

The next consideration is how congested the space is. You want to try to minimize the number of extraneous items in the scene as possible. This includes any moveable objects that can be easily moved, people, cars, other scanners and of course you and your scanning team (notice that another scanner appears in Figure 11 above for example). It is easy to inadvertently end up in the scan. So typically, you want to try to scope out a place to hide while the scan is capturing. Pedestrians and cars are tougher to avoid.

The Leica RTC has a feature that can detect and remove moving elements during the scan! If not using a scanner with this feature, you can use various tools in the software to clean the scans up later.

Capturing Scans —Other Considerations

There are several other items to consider. Let me cover just a few more that you are likely to run into. When you set up the scanner and choose your settings, you will be able to name the scans. Usually you are choosing the prefix for the file name and the scanner will then automatically increment the name numerically in the order in which you capture your scans. I can't tell you how many times we forgot to change this name when moving to a new location and ended up with scans whose names don't match the site. For example, we have scans in the Teatro Romano that are named: "Townhall." And scans in the Baptistry that are named: "Piazza." And my favorite, scans in a few locations that inadvertently ended up with the generic name: "New Project." It turns out it is not that hard to rename them later, but it does create that extra step. Furthermore, once you import the raw scans into ReCap, you will no longer be able to rename them. So, if you do wish to rename them, be sure to do it *before* you load them into ReCap (see Figure 13).

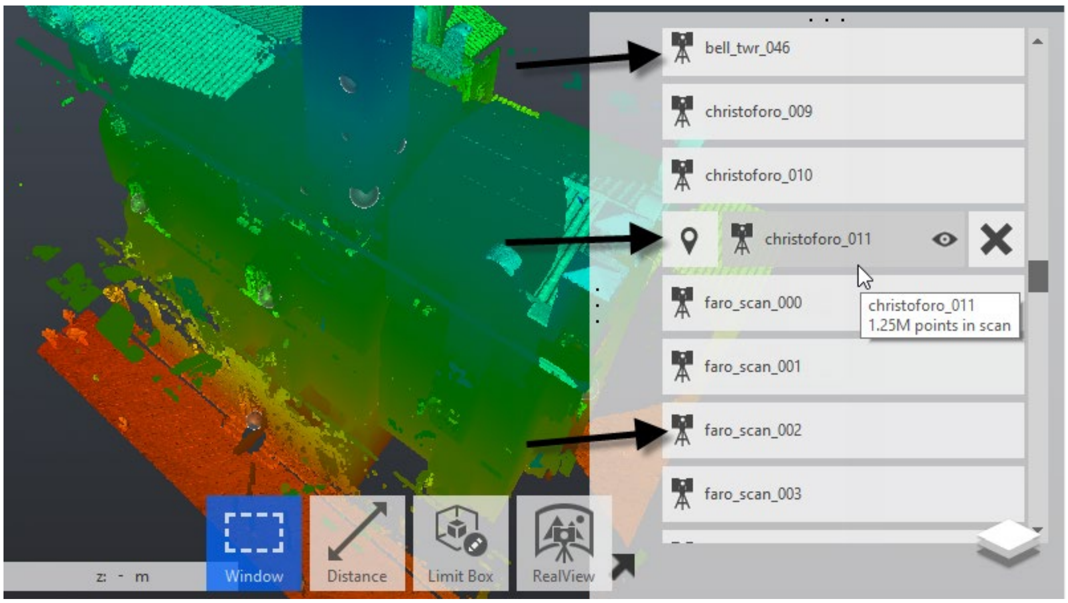


Figure 13 – If you are not careful, several naming conventions can appear in a project

To assist you in registration and to help geo-locate your scans correctly, targets can be used during scanning. Targets are either small checkboard signs or small globes that you can place throughout the space. Registration software like ReCap can recognize these targets easily making it easier to achieve registration in otherwise tricky spaces. If you are scanning a space that has large open spaces and many repetitive features, you might consider targets as it could prove difficult for the software to tell the difference between various parts of the space that look very similar to one another. Another advantage to targets is that they can help with geo-location. Some targets have GPS or other locating features that tie into known GIS coordinate systems. In other cases, if you have known survey control points on your site, you can locate them later in the software to tie your scans to a coordinate system and geo-locate them. We are still working on this aspect with our Volterra datasets.

The final consideration that I want to stress is making sure that you have sufficient overlap in your scans. I mentioned above that it can take several minutes (depending on your settings) to generate each scan. So, if you have dozens of scans to capture, it can be tempting to spread them out a bit thereby doing fewer. The trouble is, that you might find it very difficult to register them later in ReCap Pro. Always think about how the scans will regi ster. Remember that successful registration requires a good degree of overlap between scans. The software must "see" enough common features to be sure that the two scans show the same elements. Related to this, when you transition from room to room, always scan directly in the doorway (see Figure 14).

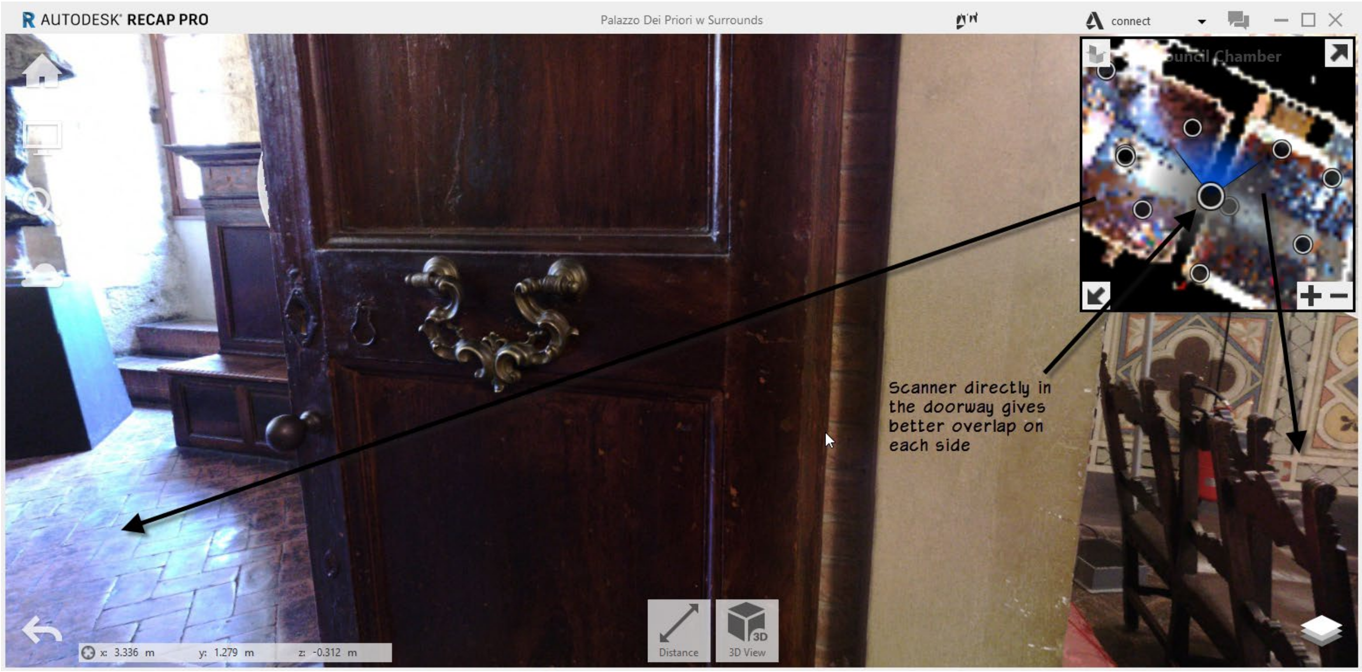


Figure 14 – Place the scanner directly in the doorway for the best overlap

This will make registration MUCH easier. When this is not done, it is sometimes impossible to find enough overlap to get registration between two neighboring rooms (see Figure 15).

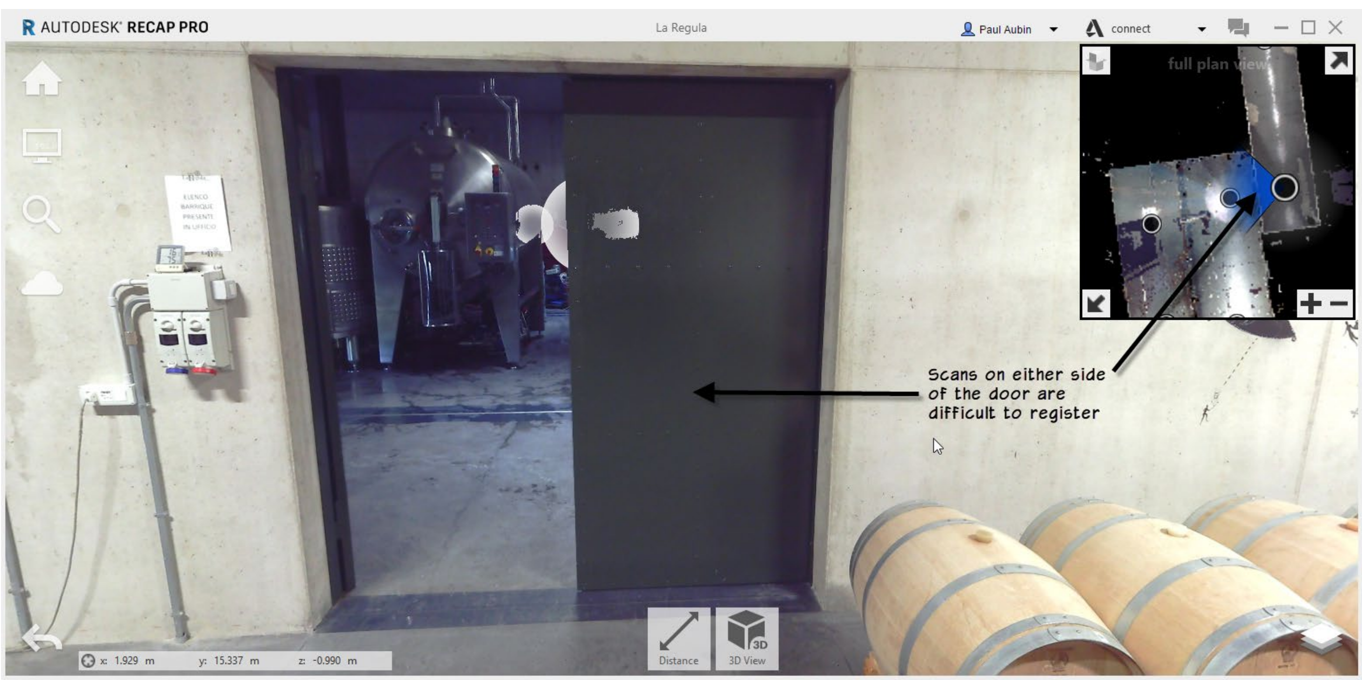


Figure 15 – Nearby the door may seem OK, but is very difficult to register

Modeling

Capturing data is just the beginning. The real question is: what do you plan to do with the captures? Reality capture is not new. You can say that any time we previously went out with a tape measure and a sketchpad we were capturing reality. We were simply using a manual process to do the data capture in those cases. When using the tools, we have discussed here, the capture takes place digitally using modern devices. But what you do with these captures is largely the same as it has always been. Reality capture facilitates many types of projects including: new construction, renovation and remodel, historic preservation, as-builts and simple documentation. Reality capture tools and techniques are used in construction, archaeology, forensics and many other fields. In Volterra, our interests are documentation, historic analysis, facilitation of preservation efforts and of course education. As you might expect, with so many varied goals stemming from the reality capture process, not every project will be concerned with the same things, nor will they approach it the same way. Data captured for a renovation project may not be suitable for the needs of a historic documentation project nor would it necessarily be useful for reconstruction or archaeological analysis and study. Sure, any reality capture will offer some value to all these endeavors, but knowing ahead of time what the goals of your specific project are will influence everything you do from the settings of the device, to the number of captures you take to what you do specifically with the captures and what formats you save them in. Obvious? Perhaps, but when considering the work that we have done so far in Volterra, this issue is poignant. The extended team has had multiple visits now. And over the course of those trips, our goals have evolved. However, the educational aspect of the workshop has remained at the forefront. Therefore, and perhaps somewhat unique to an endeavor like this, showcasing as many of these possible outcomes remains one of the most important goals. That is not to say that we don't plan to use the data for other things. It is just that we tend to allow some flexibility given the goals and interests of workshop participants. There are always common themes. And among them are creating models.

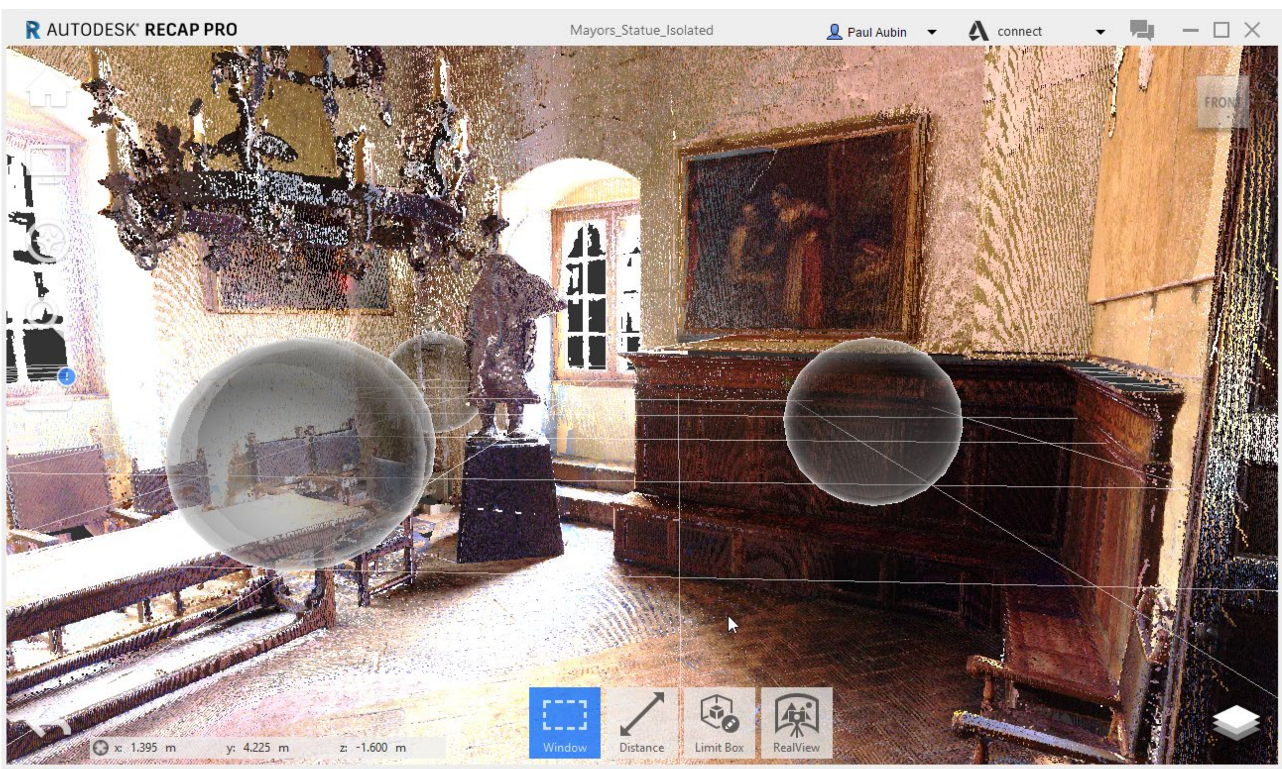


Figure 16 – Point cloud of one of the meeting chambers in the Volterra City Hall

Modeling with Native Geometry

We scanned many sites in and around Volterra. Some of these locations have been brought into Revit for further study and modeling. Modeling existing conditions always presents some challenges. One of the first is deciding if you want or need to create native geometry from the point cloud. In the case of the Volterra dataset, this was one of the goals for certain sites. So, the decision was easy.

There are two basic approaches that I have been taking to achieve this:

- **Linking in the Point Cloud and tracing over it with Revit geometry.**
- **Creating mesh models from the point cloud and using them directly in Revit.**

Figure 17 – Many custom families in the Revit model of the meeting chamber

While creating a Revit model from a point cloud can produce terrific results, in your own work, don't always assume that you *must* create a model from the point cloud. Sometimes you can simply include the point cloud in your documentation views. Especially if much of the area in the point cloud is being demolished. You can simply annotate those portions of the point cloud as being demolished and then turn them off in new construction views. This will save you tremendous time and effort versus modeling the existing conditions. However, when you do need or want to create a native model from the point cloud data in Revit, you will encounter a few challenges. Point cloud support in the project editor is quite good, but unfortunately, you cannot link a point cloud to a family file. Point clouds must be linked. They cannot be inserted. This of course presents certain challenges when modeling family components. I'll address a few of those below. But in this topic, let's keep the discussion to the project environment and system geometry. The key to being successful with using point clouds in Revit is carefully controlling what portion of the point cloud you see. Fortunately, this is easily accomplished with cropped views, sections, detail cuts and visibility graphics. You will typically want to create sections, sometimes very thin, that cut through important areas of the point cloud and reveal insights on how the existing space is constructed. This is invaluable when dealing with spaces that are not easy to get up close to like high vaulted ceilings or complex stairways. But remember what the point cloud is. It is millions of individual points floating at their true coordinates in space. Nowhere is it more obvious that walls and floors are rarely plumb and level and smooth then when trying to trace a point cloud. This means you will have to make decisions about an "appropriate" level of detail and fidelity to which you intend to model the space. For example, if you try to model every deviation in a wall's surface you will find yourself abandoning the native wall tool in favor of in-place massing models that take an enormous amount of time and effort to produce. Unless the work that you are being asked to do requires that level of fidelity to the original, you will almost always want to average over differences in and variations and create a "idealized" representation of the existing space (see Figure 18).

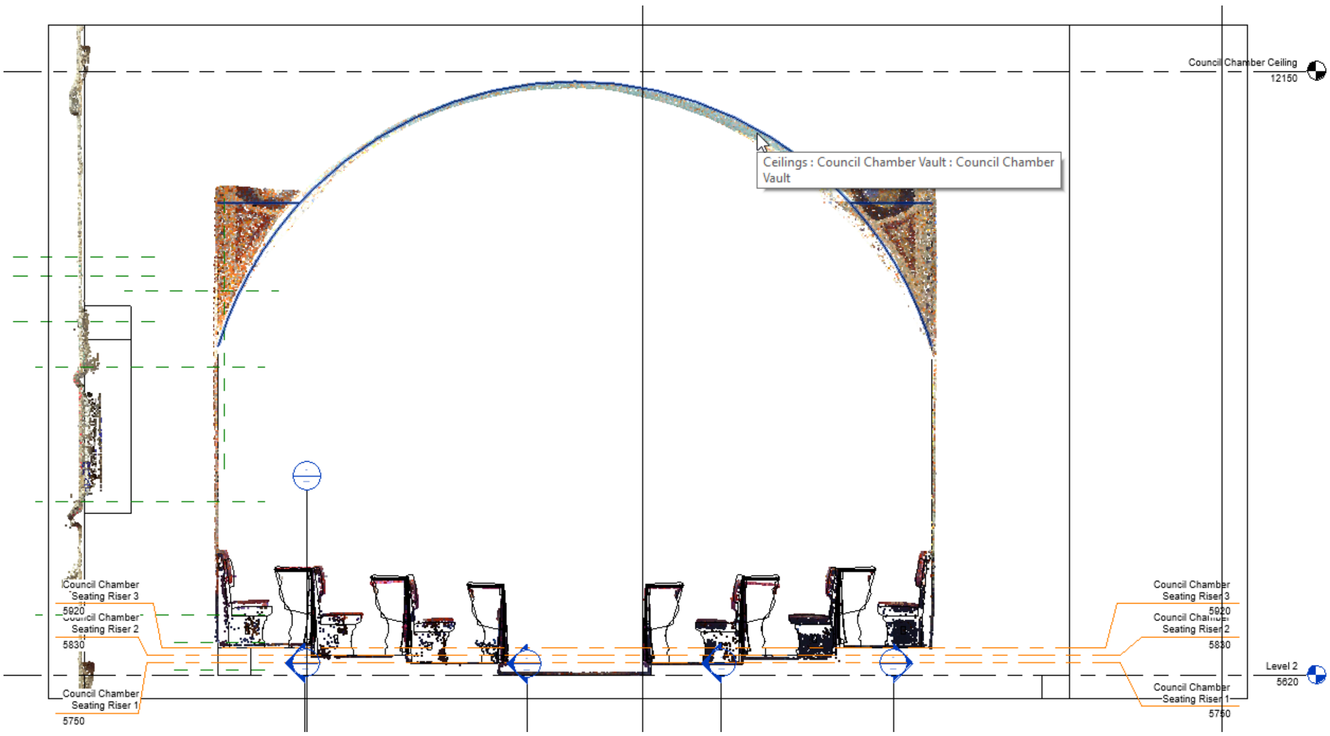


Figure 18 – The point cloud provides guidance for modeling

Usually the variations of the points are within a few millimeters of one another which for all intents and purposes can be thought of as flat, plumb or level depending on the orientation of the surface. So, before you do any work in your modeling software, address these two issues:

- **What *must* be modeled?**
- **What level of fidelity is appropriate for the specific model you are creating?**

Once you have the answers to those two questions, you can build a strategy accordingly. For most of the models we created, we used simple Generic walls for vertical surfaces (Edit Type, Duplicate and change thickness as required), floors, roofs or ceilings for mostly horizontal surfaces and architectural columns or other mass-like forms for pilasters and similar forms. For vaulted ceilings and the like, I usually resorted to in-place ceiling elements. For windows, doors and fixtures, you can usually make something in the family editor that is quite convincing.

Point Clouds in Family Modeling

As noted above, when using a point cloud in Revit, you must link it into a project file. Revit does not support point clouds in the family editor. This is unfortunate since there are many times when it would be useful to be able to do so. To overcome this limitation, I have used three different techniques:

- Option 1 —Link a point cloud into a temporary project, use it to take measurements and build the family separately with the data captured from the measurements.
- Option 2 —Link a point cloud into a temporary project, create an in-place family and then build geometry relative to the point cloud. In-place geometry can then be copied and pasted into a component family while in-place edit mode is active.
- Option 3 —Link a point cloud into a temporary project, take screen captures of various views and then save these as image files to be loaded into the family editor for reference.

Each of these methods can be effective, but they also each have their own challenges as well. I tend to rely on the first method more often. I will often take measurements and then physically print out views of the model with these dimensions to help me model separately in the family editor (see Figure 19). If you prefer not to print, you can place these dimensioned views on a second monitor while you work. I find it helps to have them printed since it minimizes the amount of back and forth between multiple screens and views.

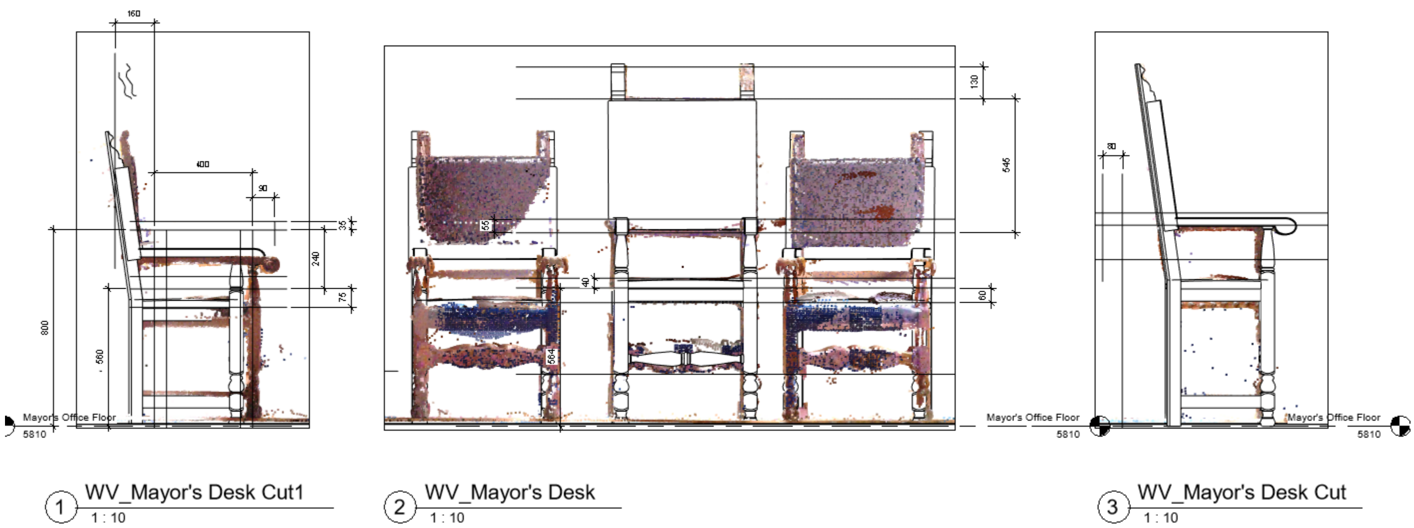


Figure 19 – Add dimensions on working views and use to assist in modeling

The figure shows a flexible family superimposed over the point cloud that was measured and printed out to help build it. These measured views are used in conjunction with photographs of the same items. This method allows for good results. There are places where compromises must be made. Particularly in areas where the point cloud might be missing information or distorted as sometimes happens if the line of sight was compromised during scanning. For example, the chair on the left was at a slight angle to the view. So, some adjustments are made. Furthermore, I decided to make a chair family that could flex to the three or four of the variations needed. This seemed a good way to reuse effort in this case. But naturally it takes some extra effort to make a flexible family versus preforming a simple save as and modeling each unique instance. It is easy to get lost in the details. Your challenge is to know when to put on the brakes!

Chandelier

The chandelier in this model presented a nice modeling challenge. It was complex, had some organic detailing combined with regular geometry and it had to be a light fixture. The resulting family uses simple modeling techniques and relies on nested families to create the complexity. The parent family is a lighting fixture (Category), but if you edit it, you will find that the Light Source option is turned off. If you want a light fixture with several separate lamps, create nested families for the individual lamps instead. Be sure to check the Light Source checkbox in the nested families instead of the parent family. But if you want these nested light fixtures to function as light fixtures in the host project, they *must* also be set to "Shared" families (see the lower-right corner of Figure 20).

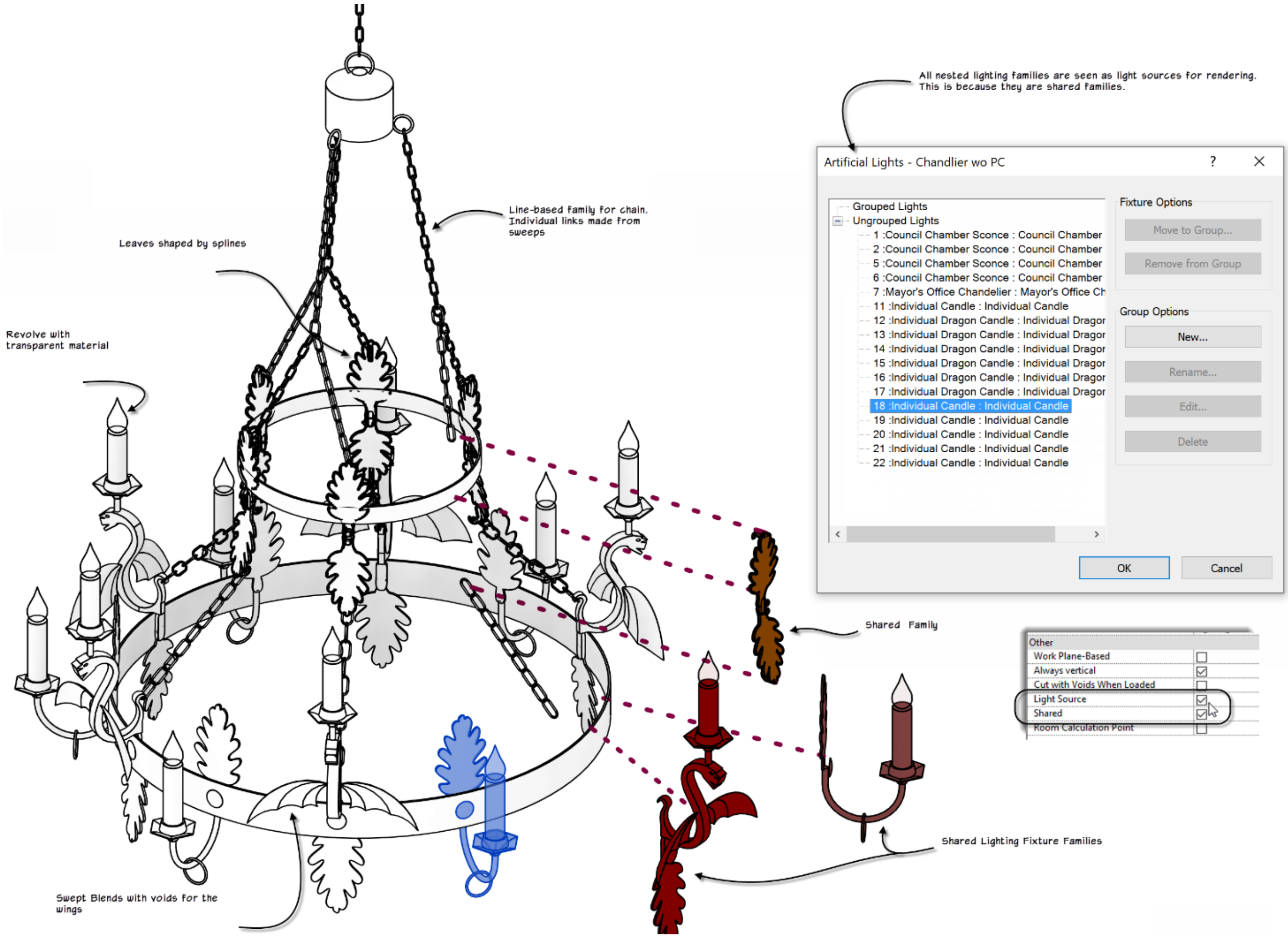


Figure 20 – Chandelier family with its nested components including several nested shared light fixture families

There are a few other points of note in this family. The chains are line-based families with a nested parametric array to repeat the chain links as the family stretches to longer and shorter sizes. To draw them at the proper 3D location and orientation, create work planes with reference planes and/or reference lines. Work planes are important to many of the other details as well: these include the flame-shaped light bulbs (made from a revolve), the dragon wings (made from swept blends and voids), the leaves (made from extrusions using splines for the freeform edges), and finally each layer of the chandelier is built on a reference plane defining the level.

Trajectory segmentation shows up in the nested light fixtures to create the small hexagonal base of the candles. Voids are kept to a minimum but are utilized for the facial features of the dragons and to help sculpt the shape of their wings.

Modeling with Imported Geometry

There are many organic forms in the Volterra dataset. There are plenty of statues and sculptures and there are some flags and other fabric items like tablecloths and draperies. If you want the model to look authentic and realistic, you need an efficient way to deal with such items. For the backs of the chairs and the tablecloths in the council chamber, I relied on sweeps and swept blends whose profiles and paths rely heavily on splines to give them their organic forms. This approach can work well; but can also be quite time consuming.

There are two alternatives:

- **Use the massing environment. (The flags in the meeting space are built this way)**
- **Import mesh geometry directly into the family editor. (The statues in the space are built with technique)**

To comment briefly on the flags, the main feature that is utilized to create their form is the support for lofted forms in the massing family editor. You can select two or more shapes (open or closed) and create a smooth transition between each of them. If you use closed shapes, you get a solid, and open shapes will make a 3D surface. The flags use open spline shapes and make a free-flowing surface.

It is possible to use the massing environment to create nearly any organic 3D form (don't believe me, check out: Renaissance Revit), solid or surface. So, this would certainly be possible for the statues as well. But you will often pay a heavy cost in file size and performance for these forms and not all categories are supported. This is to say nothing of the steep learning curve associated with the mass environment or how radically it deviates from the traditional user interface, and sometimes the time and effort to do it, even if you have the expertise, can be hard to justify.

For these reasons, in the Volterra dataset, I took a different approach for the sculptures. I imported mesh models directly into the family editor! Now, as you may well be aware, there is a common rule of thumb in the family content creation world that says: "**do not use CAD imports**". Well, in this topic, I am going to be **breaking this rule!**

Revit creates solid geometry, and the results from it are often quite nice, but given the simplicity of the solid modeling tools in the traditional family editor, it is often quite challenging to create complex or smooth organic forms. Sometimes CAD is all you have. Or you might have mesh models created in other software; or in the case I am discussing here, you might have point clouds. Such cases are where mesh models provide a viable and compelling alternative.

The approach is a bit convoluted and involves working outside of Revit in 3ds max for some of the steps. However, since it is included with the AEC collection that most firms have, this is not a huge obstacle for many.[3]

---

[3] My good friend Andy Milburn also attended the Reality Capture Workshop in Volterra. It was terrific to have a full two weeks direct access to his keen observation and overall Architectural wisdom and insight. Andy has covered the subject of mesh models on his blog a few times before. His most recent post covers using the same technique I explore here on one of the sites in our Volterra dataset. So if you want to see another example, head over to Andy's blog at: http://grevity.blogspot.com/2018/05/just-so-stories.html. His blog in general is also an excellent resource. And in more recent months, you will see his many posts on Project Notre Dame; a crowd sourced effort which he started to create a BIM of Notre Dame Cathedral after the it caught fire. Over the last several months, Andy and his team (of which I am a small contributor) have been slowly studying, understanding, building and refining a very detailed model of the cathedral from many freely available books, photos and other online resources. As of yet, we have not gotten direct access to the point cloud data that exists of the cathedral, but by cross referencing the many sources we do have, the model has come along quite nicely and is proving to be quite accurate. If you want to learn more or even participate, reach out to Andy from his blog.

Here is the summary of the process:

Get a mesh

The first thing you need is a mesh. You can get these from a variety of sources. For example, this is what you will typically get from ReCap Photo as noted above. I will cover two other possibilities here. The first will be creating a mesh from a point cloud. The second will be using an existing mesh file in another file format.

Make the edges of the Mesh invisible

If you have ever tried importing a mesh into Revit, you were probably less than satisfied with the results. Usually, all the tessellat ion of the mesh will show up in Revit making it graphically unappealing for most drawing types (see the left side of Figure 21).

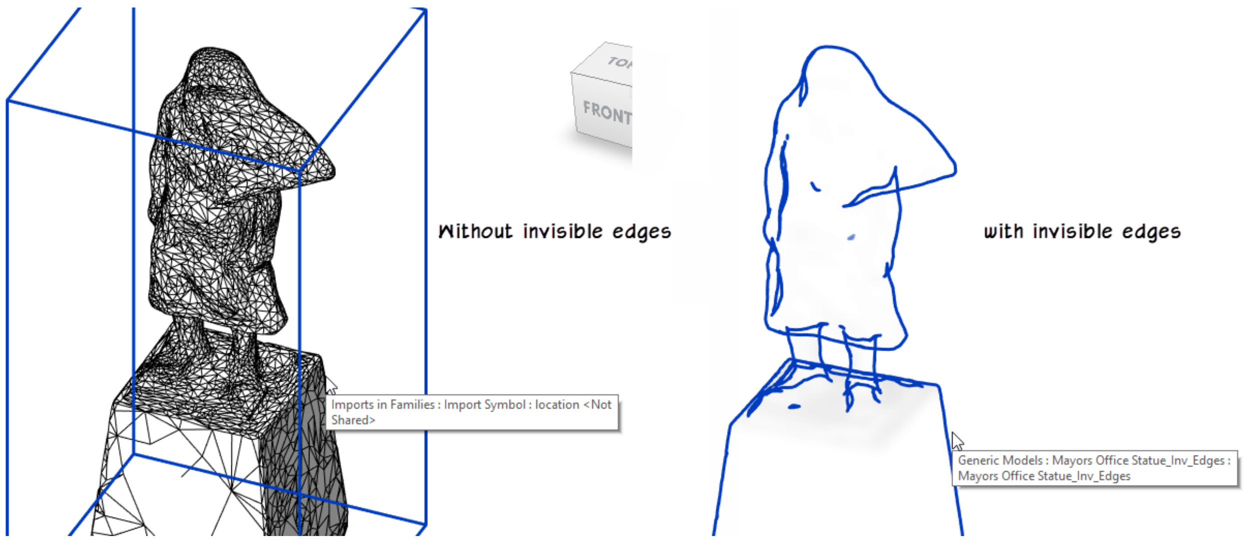


Figure 21 – Mesh models show all their facets when inserted into Revit

The solution to this is to process the mesh in 3ds max first to hide the edges of the mesh. The mesh can be saved with the edges invisible and then brought into Revit yielding much nicer results (see the right side of Figure 21).

Import into Revit

Once you have a processed mesh with invisible edges, import this into a Revit family. Perform a few cleanup steps in Revit and optionally add any view-specific 2D graphics. Save the family and use it in your projects.

Detailed Procedure to Process and Import Models

Let's dig a little deeper into the process. As noted above, you first need a mesh. This can be something you create from a point cloud, create in other 3D modeling software or download from the Internet. Process will vary slightly depending on the mesh model's source. For the statue models in the Volterra dataset, I created them directly from the point cloud using the mesh service from Autodesk that is part of ReCap Pro. If you do not have access to ReCap Pro, similar functions may be available in other point cloud processing software.

ReCap Workflow

I want to quickly create a family from one of the sculptures. The first step is to isolate that portion of the point cloud in ReCap Pro. Use a Limit Box to do this (see Figure 22).

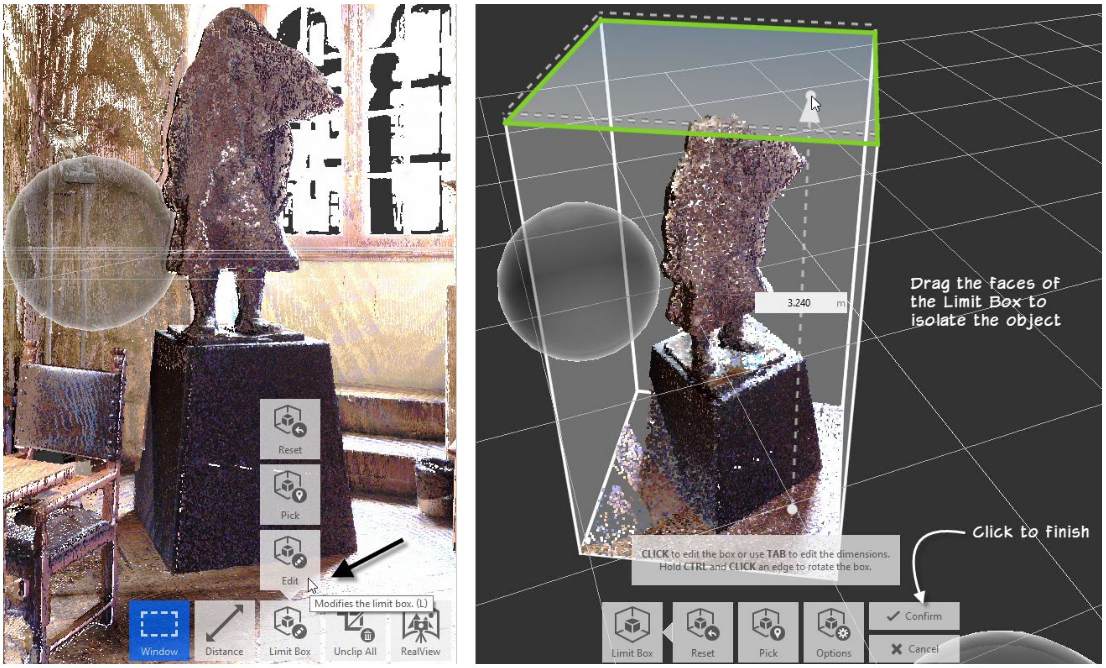


Figure 22 – Isolate the object with a Limit Box

You can optionally isolate collections of points to focus on just the object and remove anything unneeded. This will involve selecting points that you want to isolate and moving them to a named scan region to make them easier to work with. To make the selection easier, you can adjust the point display. In this case the Intensity display mode offers nice contrast. Then use a convenient selection method such as Fence to select unneeded points. You can clip these points to hide them (see Figure 23). Repeat as required to leave just the points you need visible.

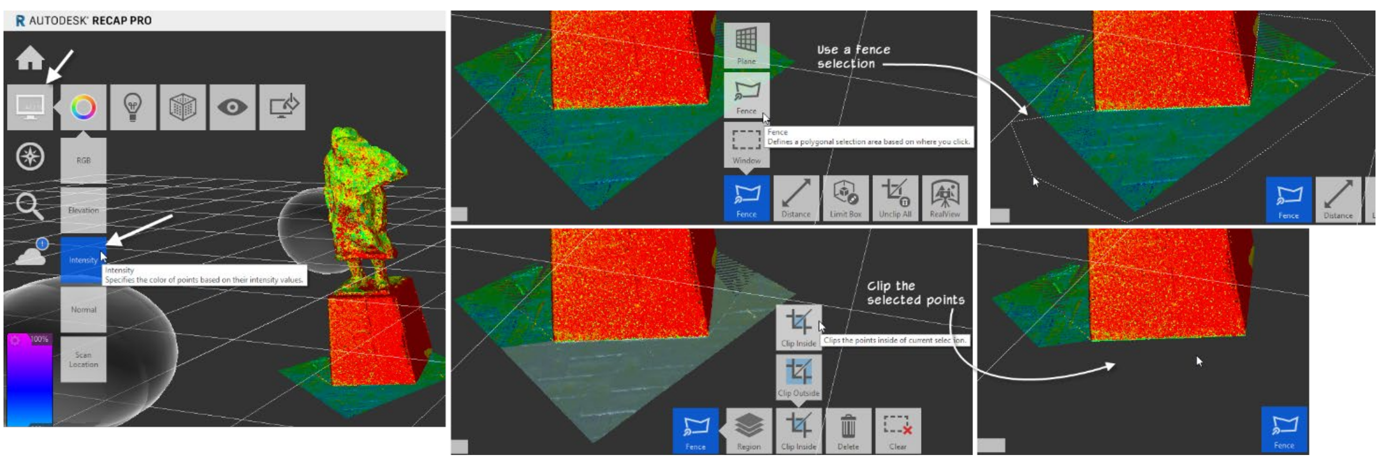


Figure 23 – Use different display modes to assist in selection

There are other handy tools. You can select all the points of the statue and then create a “Scan Region” from them (like a layer). This will make it easier to return to this collection of points later. You can also create a “View State” of the current view. This will allow you to restore the selection and limit box later and zoom right to this portion of the model. None of this is required to create a mesh, but it will prove useful to have these later if you need to repeat any of the steps (see Figure 24).

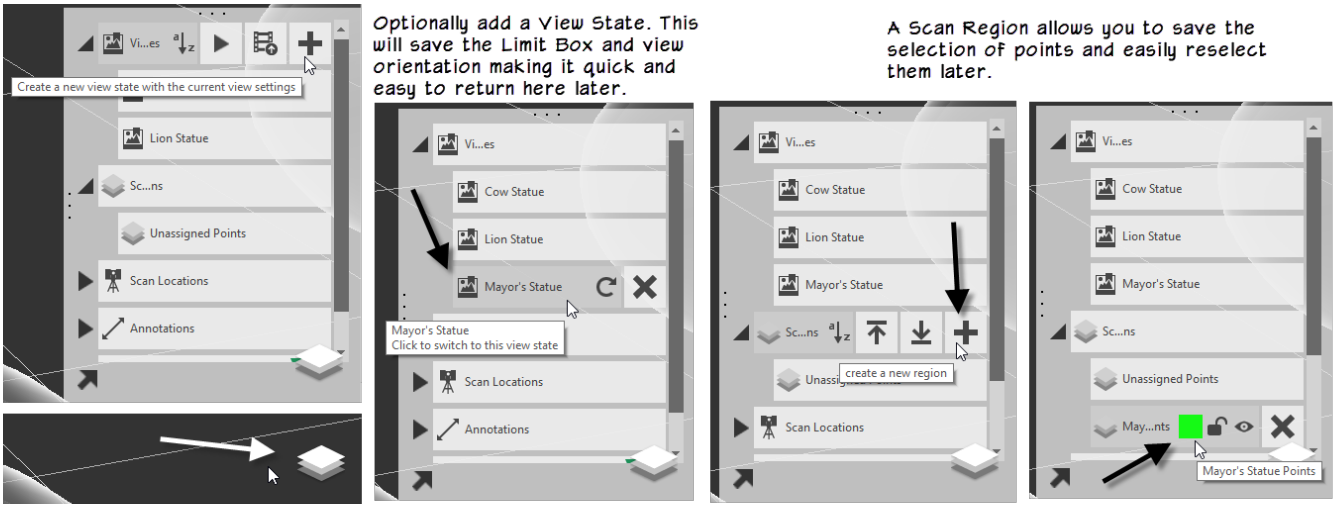


Figure 24 – Save your work with View States and Scan Regions making it easy to return later

With the statue isolated, you are ready to convert it to a mesh. First export the point cloud to a PTS file (see Figure 25). Give your mesh a name and location .

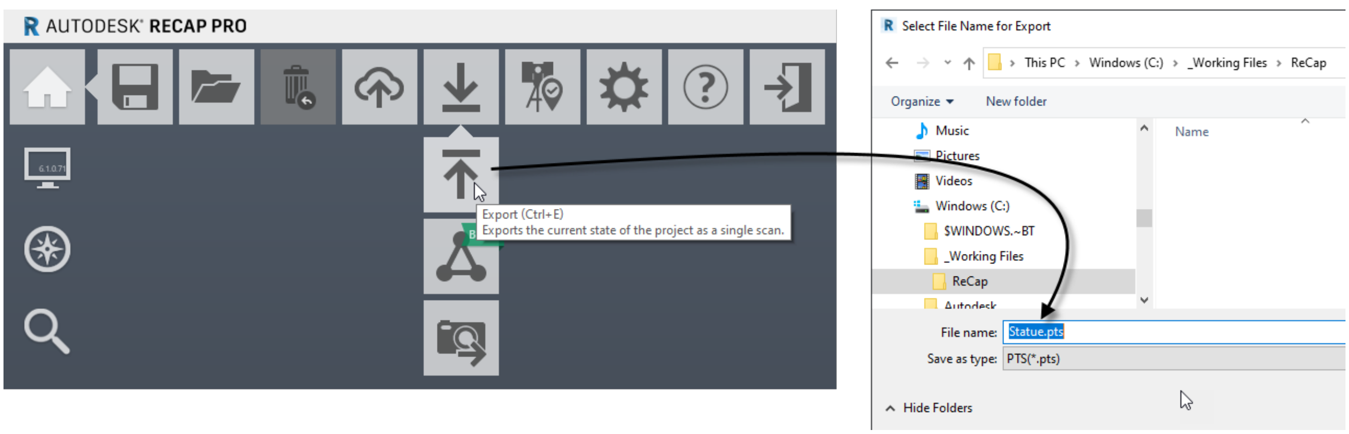


Figure 25 – Export the point cloud as a PTS file

MeshLab

Next you need a piece of software that can turn your point cloud in to a mesh model. There are many programs that can do this. I will discuss [MeshLab] in this example. If you prefer another package (like Cyclone 3DR), you are welcome to use it instead. In order to open the PTS file in MeshLab, rename the file in Windows Explorer changing the PTS extension to ASC. When Windows complains and ask you if you are sure you want to change the file extension, click Yes. (I don't know why this is necessary, but it seems to be). MeshLab is a complex piece of software. So you will have to learn a few things. I am going to summarize the process that I have learned. I found a nice video that goes through the process, the sound quali ty is not that good, but otherwise the information is helpful. You can view it here.

Start on the File menu with the Import Mesh command. When the point cloud comes into MeshLab, you will need to clean it up a bit and then mesh it. MeshLab has dozens of filters. So, you may need to explore a few and find the right combination for your file. In particular, you will want to run some of the filters on the Cleaning and Repairing menu. Look for the one s about **Manifold Edges and Vertices** . But **Duplicate Faces and Vertices** are also good ones to run (see Figure 26).

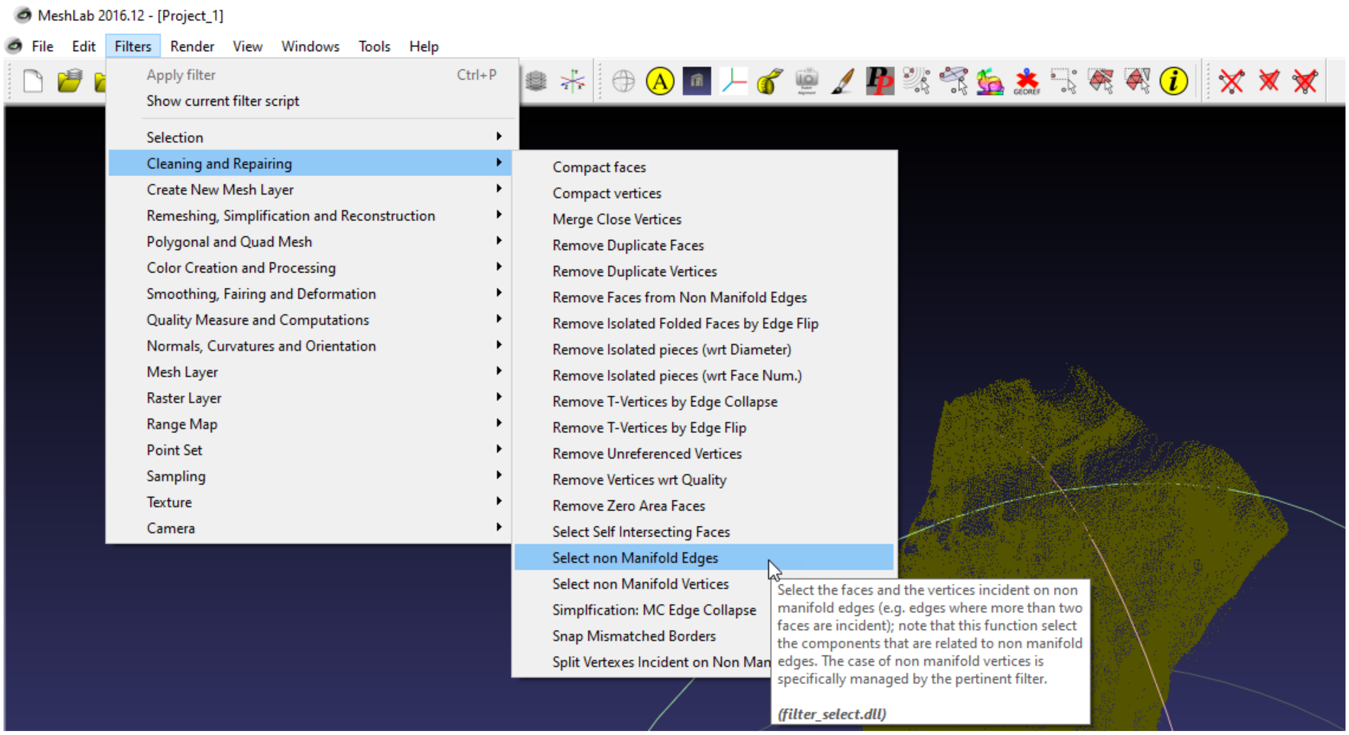


Figure 26 – Run some clean-up filters on your file before meshing

You might also need to run some of the filters on the Normals menu too. A good one to try is **Compute normal for point sets**.

When you are ready to create the mesh, on the Filters>Remeshing, Simplification and Reconstruction menu, choose: **Screened Poisson Surface Reconstruction**. A dialog will appear. There is a small chevron at the bottom. Twirl that open to see more settings. Click the Help button to get descriptions of each setting and when you are ready, click the Apply button to run the filter and create the mesh (see Figure 27).

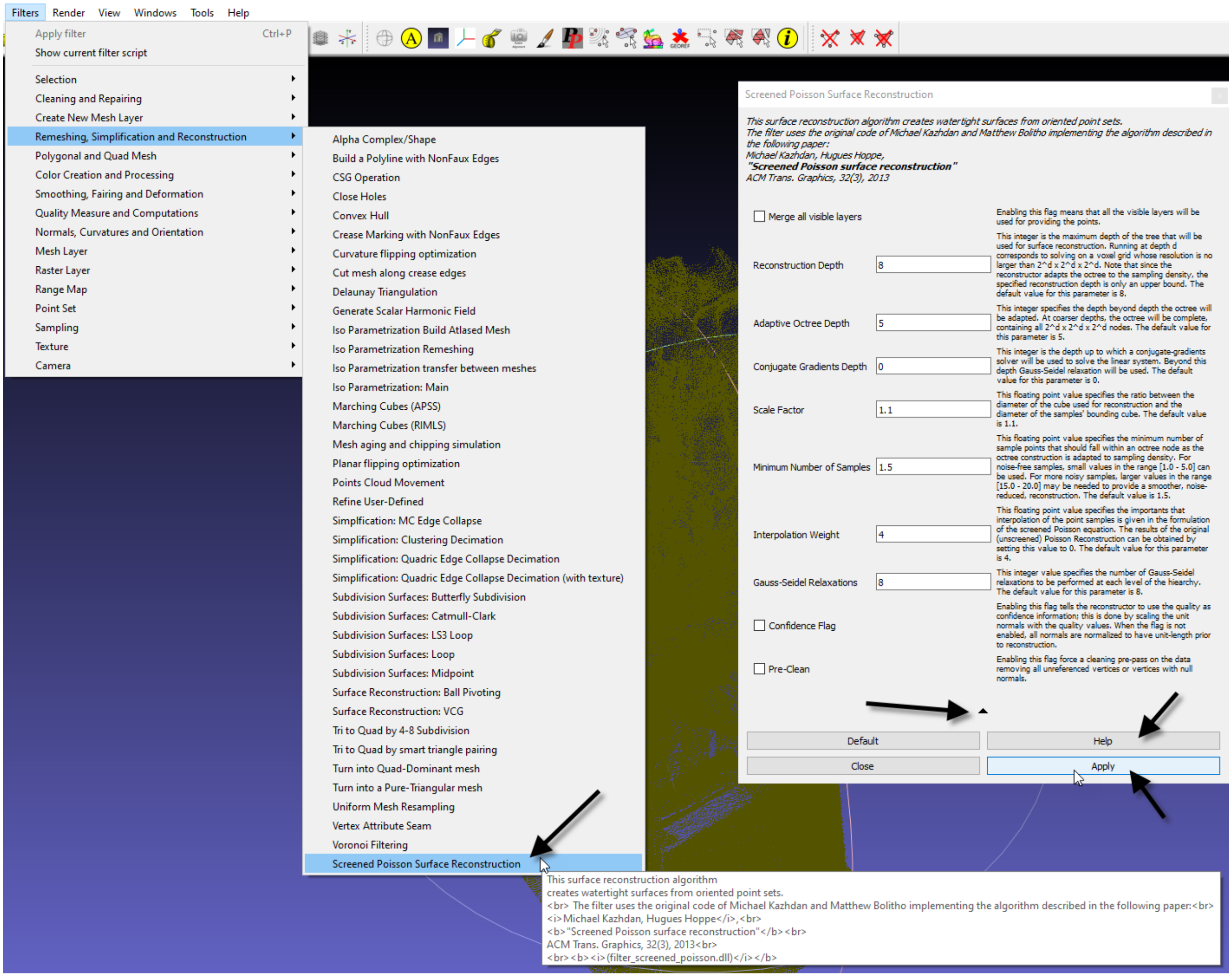


Figure 27 – Create a mesh

If you get an error, return to the cleanup filters and then try again. I ran mine with the default settings, but if you are not satisfied with the results, feel free to adjust. This description barely scratches the surface of what is possible in MeshLab. There are many other tools worthy of exploration. I am more familiar with other meshing tools, so I switched to ReCap Photo to do my final cleanup. But many of the same procedures can be performed directly in MeshLab.

ReCap Photo Workflow

Depending on the results of the previous process, you might have to do some post processing on the mesh. As I noted, this can happen directly in MeshLab or with ReCap Photo. I explored an OBJ model from MeshLab and then opened it in ReCap Photo to do this cleanup. ReCap Photo has tools to clean up the mesh, find issues, decimate, fill holes, etc. (see Figure 28).

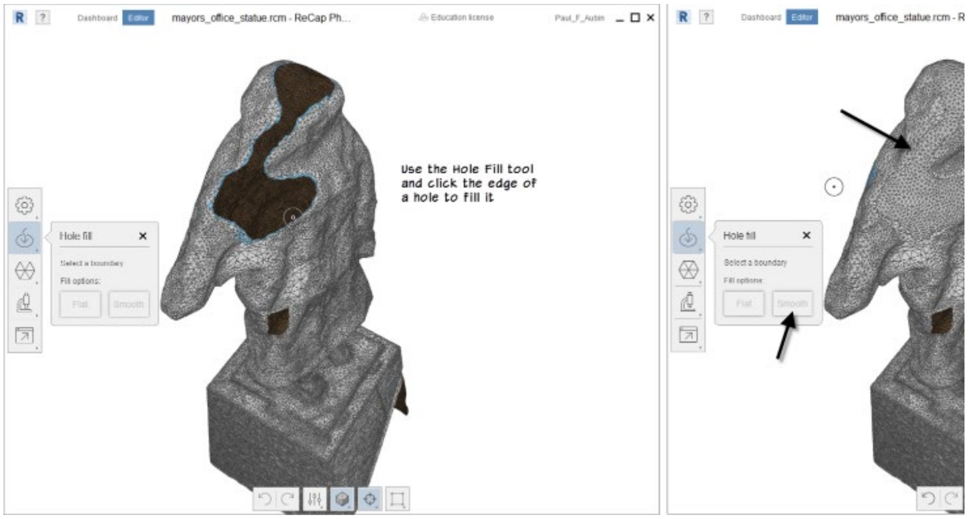


Figure 28 – Fill holes and cleanup the mesh in ReCap Photo

When you are finished with the cleanup, export the model to the format of your choice, such as 3ds Max FBX format or OBJ (see Figure 29).

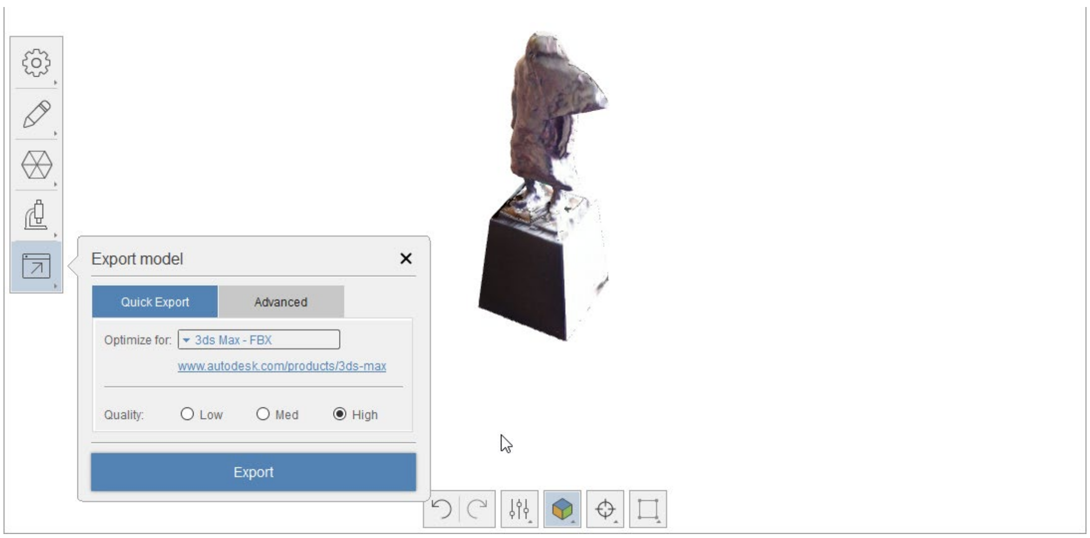


Figure 29 – Export the completed mesh to 3ds Max

3ds Max Workflow

In 3ds Max, load the exported model. You may need to further process the model in 3ds Max. In my experience, the most common things to look for are orientation, scale and number of faces. There may also be some cameras and other items you don't need. Feel free to clean up any of these things (see Figure 30).

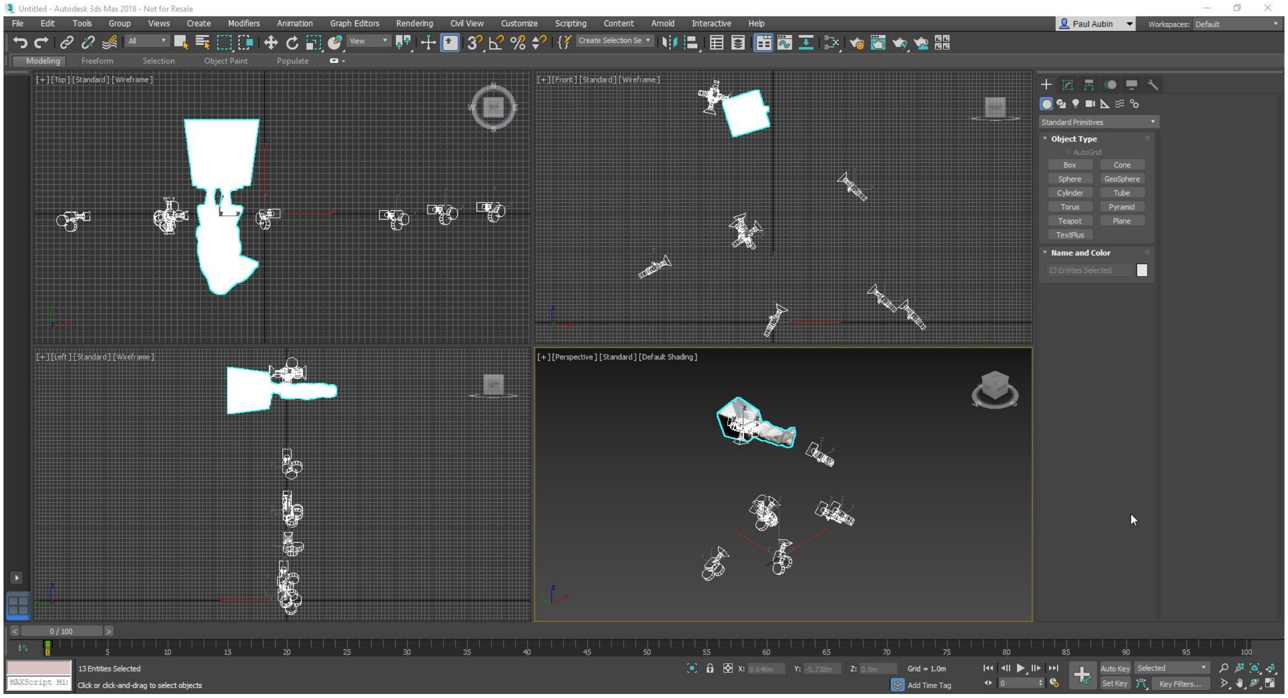


Figure 30 – The Orientation, scale, number of facets and excess cameras may need attention

The most important thing you need to do is hide the facet edges. To do this and to preserve their visibility when importing into Revit, we need to export using the **DXF 2004** format. This format supports up to 32,767 vertices. So, we need to make sure that the total number of vertices is within this limit (see Figure 31).

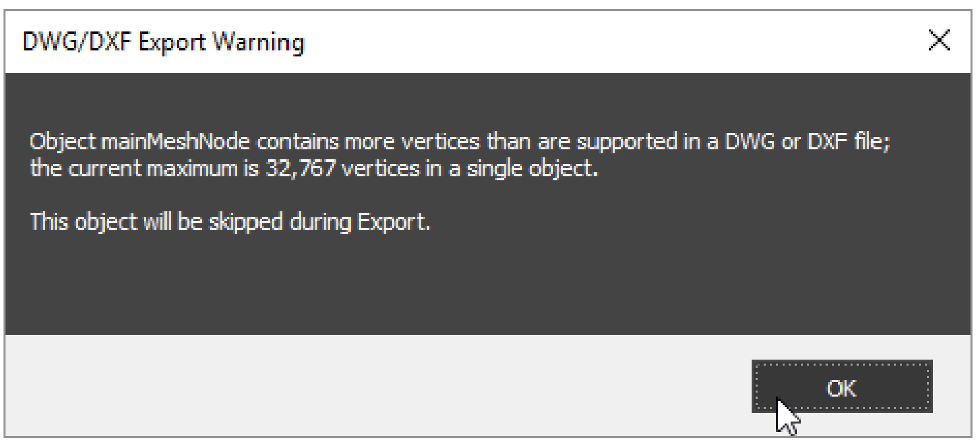


Figure 31 – DXF has a maximum number of vertices allowed on export

To get the number in the allowable range, you can return to ReCap Photo and use the tools to decimate the mesh and then export it to Max again. Or, stay in 3ds Max and use the **ProOptimizer** modifier. This tool will help you quantify the current number of points and faces and allow you to reduce them if there are too many (see Figure 32).

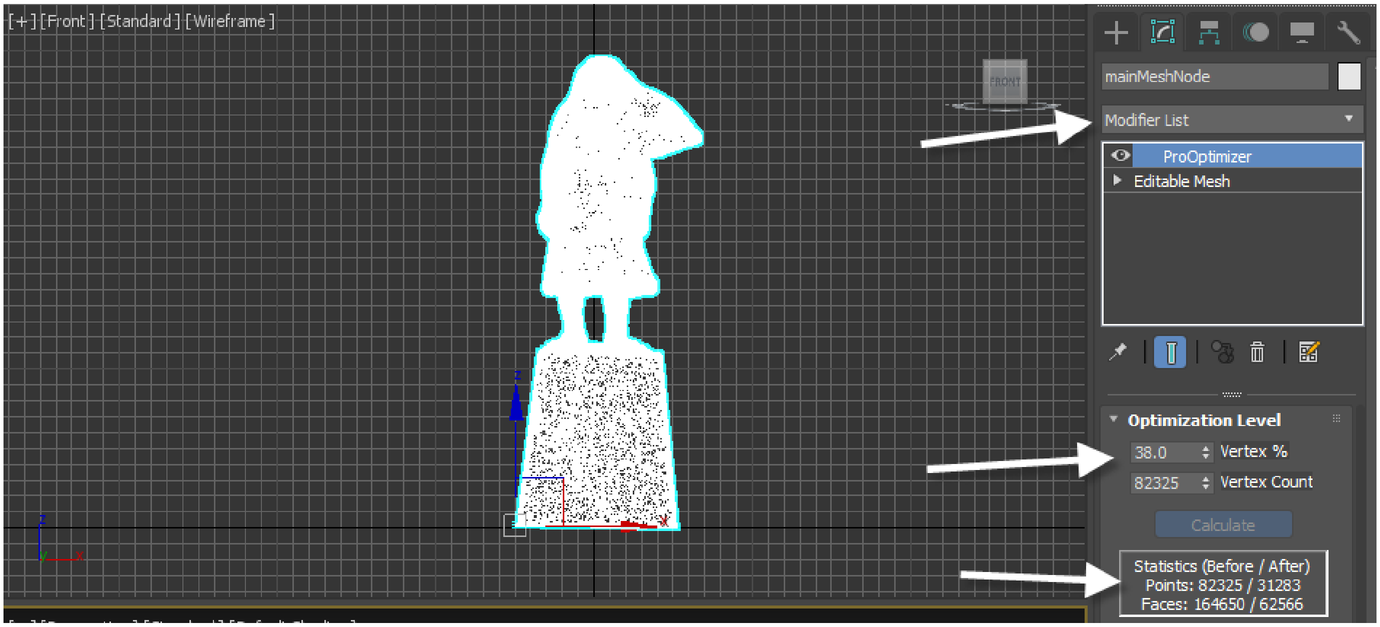


Figure 32 – DXF has a maximum number of vertices allowed on export

One you have the vertices under 32K, collapse the modifier stack to return to an Editable Mesh. Then choose the edge select option. You want to select *most* of the edges. You need to leave at least a few edges visible so that you can still select the object. These can be on the bottom of the statue or some other inconspicuous area (see Figure 33).

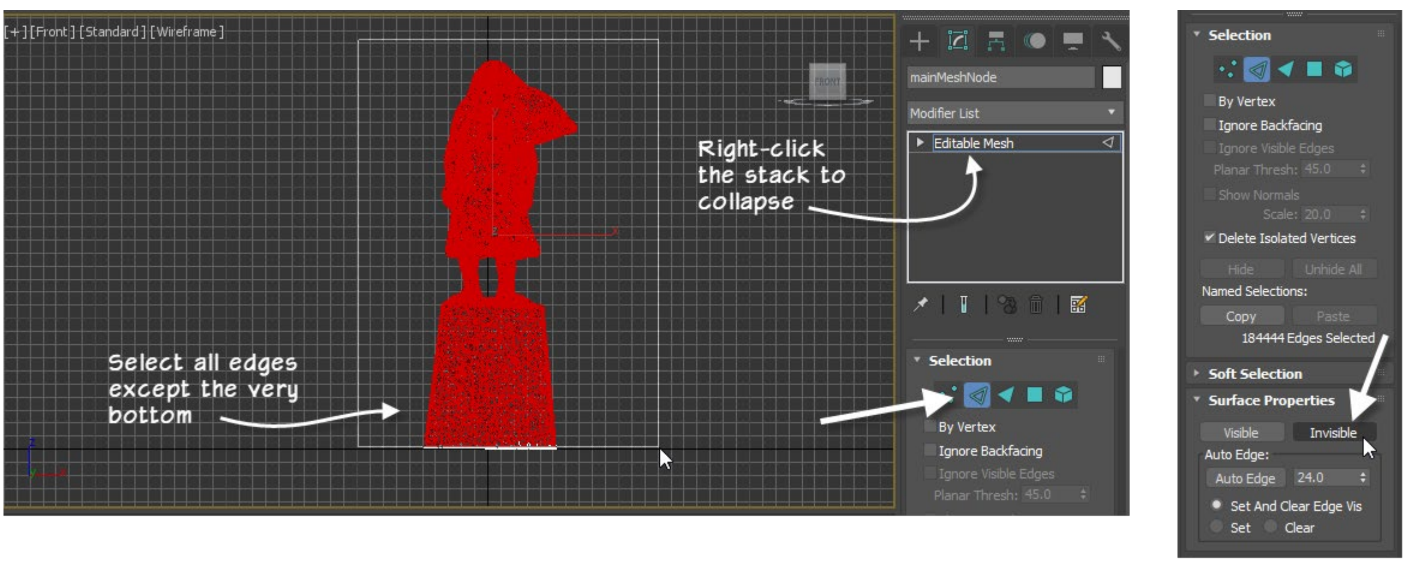


Figure 33 – Collapse the stack and select most of the edges. Make them Invisible

Click the Invisible button to make them invisible.

Alternative with Downloaded Meshes

Another common place to get meshes is from online 3D libraries. These might come in a variety of formats. 3ds Max can read most formats. Shown here is an example with an airplane mesh. In this case, you will be a little more strategic about your edge selection. Remember you need to leave at least some edges visible to allow the mesh to be selected later on. Unlike the statue, with an object like an airplane, there are some obvious edges that would be appropriate to leave visible: items like the windows or other detailing, or maybe the edges of the wings or other features that would benefit from a hard visible edge. Sometimes models have material IDs. This can help in selection of these elements (see Figure 34).

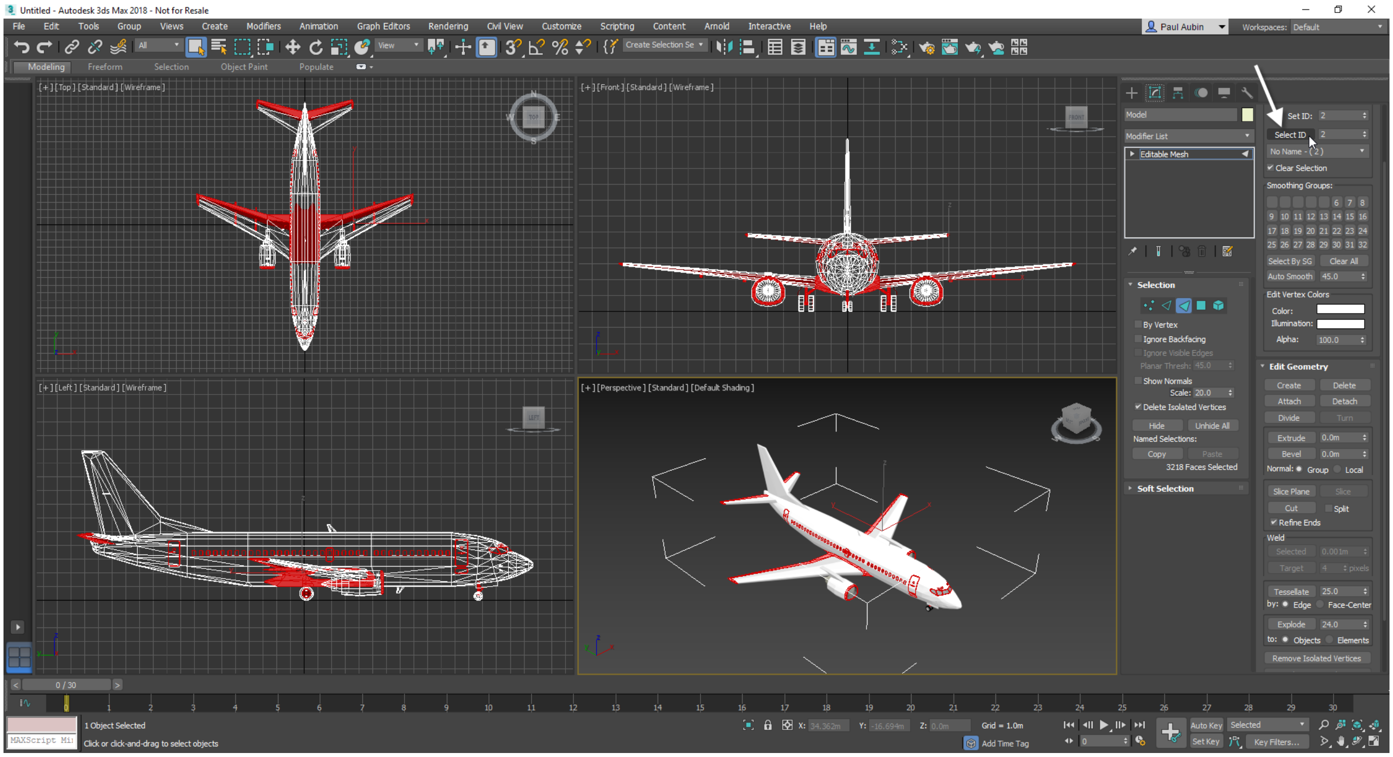


Figure 34 – Use Select ID to select items by material ID

In this case, the material ID 2 grabs all the windows and some detailing on the wings. You can detach these elements to make them into separate objects. This will allow for easier selection and layering (see Figure 35).

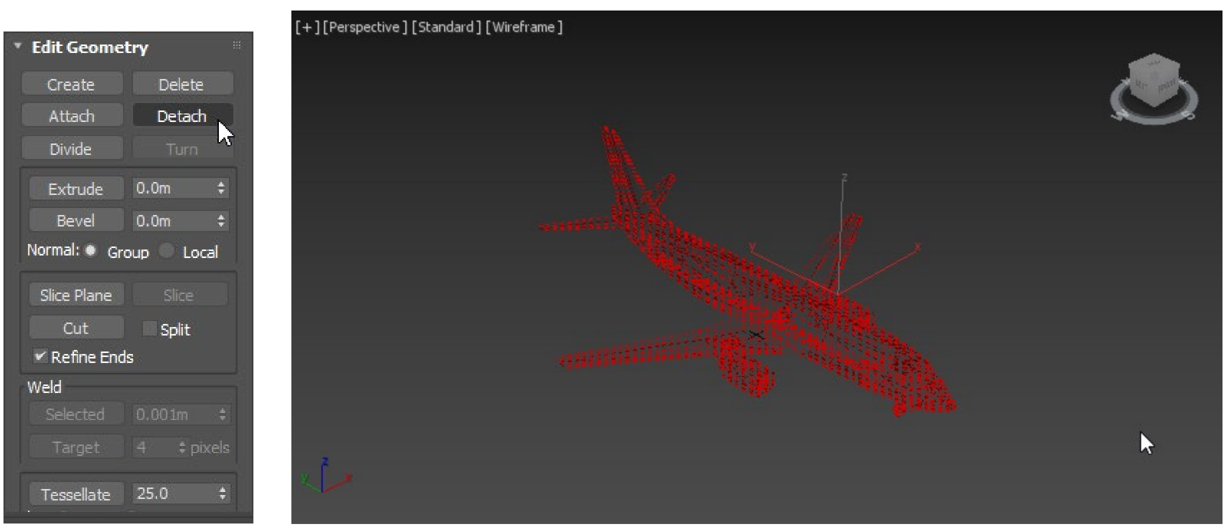


Figure 35 – Detach a selection to create separate elements. Make the fuselage invisible

You can hide the detached items and then easily select the fuselage and other parts that need to be invisible and repeat the process from above. The element will disappear in max when not selected and will appear dashed while selected.

You can open the Layer Explorer on the Tools menu. This will allow you to see the layers in the file (see Figure 36). Right-click each layer and make it By Layer. This will allow us to change color and material once imported into Revit.

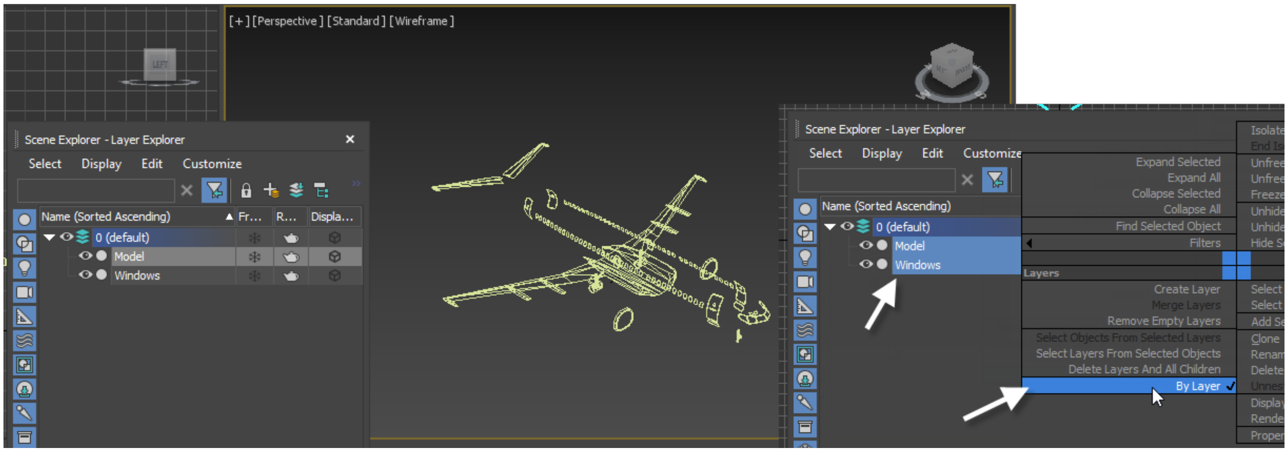


Figure 36 – View the layers after processing the file

From the File menu, choose: **Export > Export** . Choose DXF for Save as Type. Browse to a location and give the file a name. In the dialog that appears, choose: **AutoCAD 2004 DXF** . This is important as this format is required to retain the invisible edges when exporting (see Figure 37).

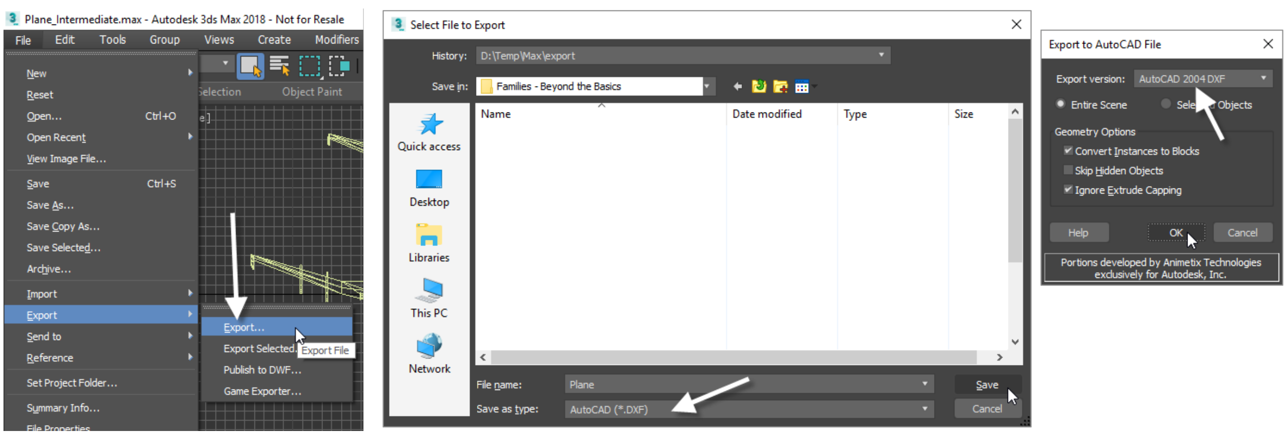


Figure 37 – Export as a DWF 2004

Revit Workflow

We are finally ready to import the file into Revit. In Revit, create a new Family and choose a category and template, then import the CAD file (Figure 38).

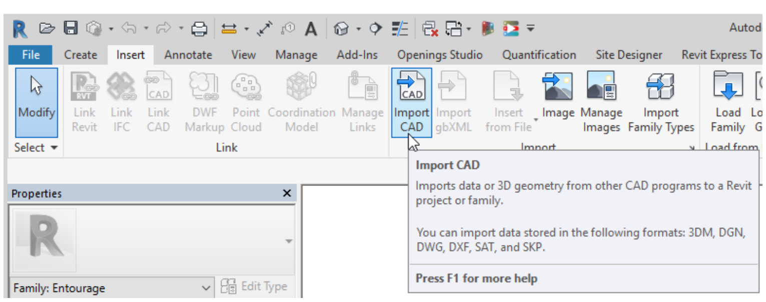


Figure 38 – Import CAD into a new family

You will probably want to disable the "Correct lines that are slightly off axis" checkbox. Choose any other options as required and open the file (see Figure 39).

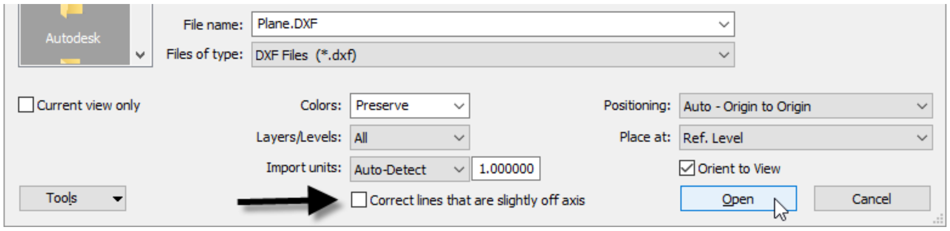


Figure 39 – Configure CAD import options

When the file comes in, all the invisible edges will be preserved making for a very nice result. Any edges you left visible like the windows (in the airplane model) will still show (see Figure 40).

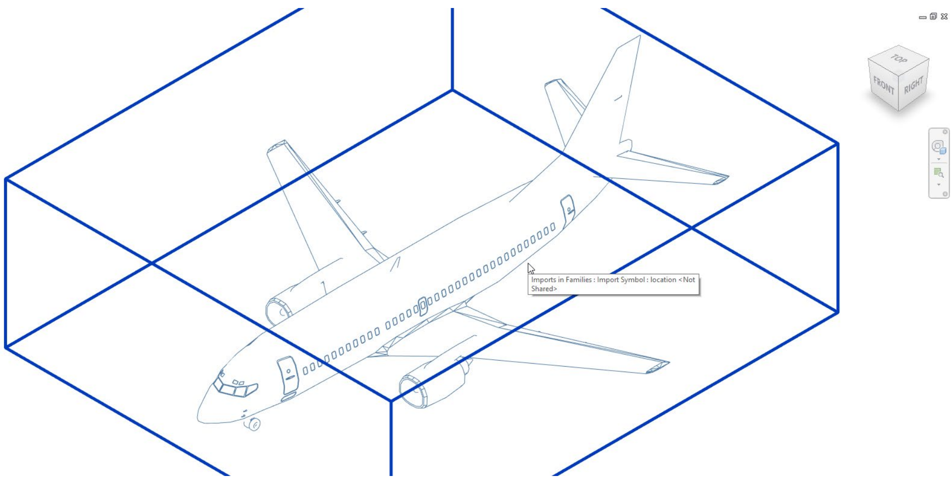


Figure 40 – Invisible edges are preserved

The final step is to adjust color and materials. This is done in the Object Styles dialog. You can remove the material designation and set the color to black. You can also delete any unneeded layers and even rename layer 0 if desired (see Figure 41).

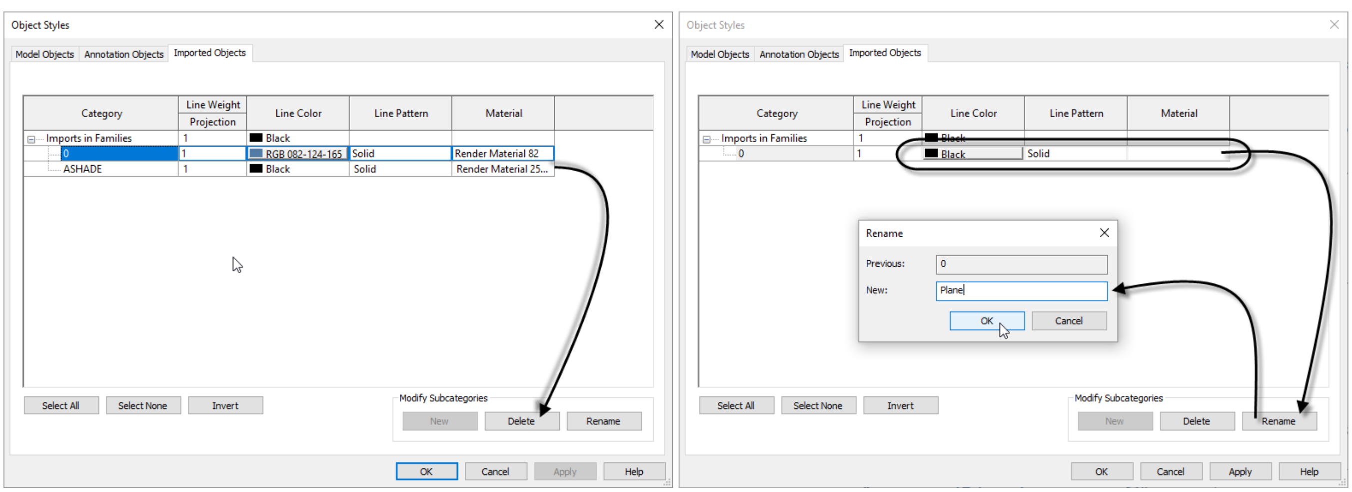


Figure 41 – Adjust colors, materials and layers

If all you need is the 3D, you are done. But optionally, you can import 2D geometry into the elevation and plan views. You can add symbolic geometry, masking and filled regions as required (see Figure 42).

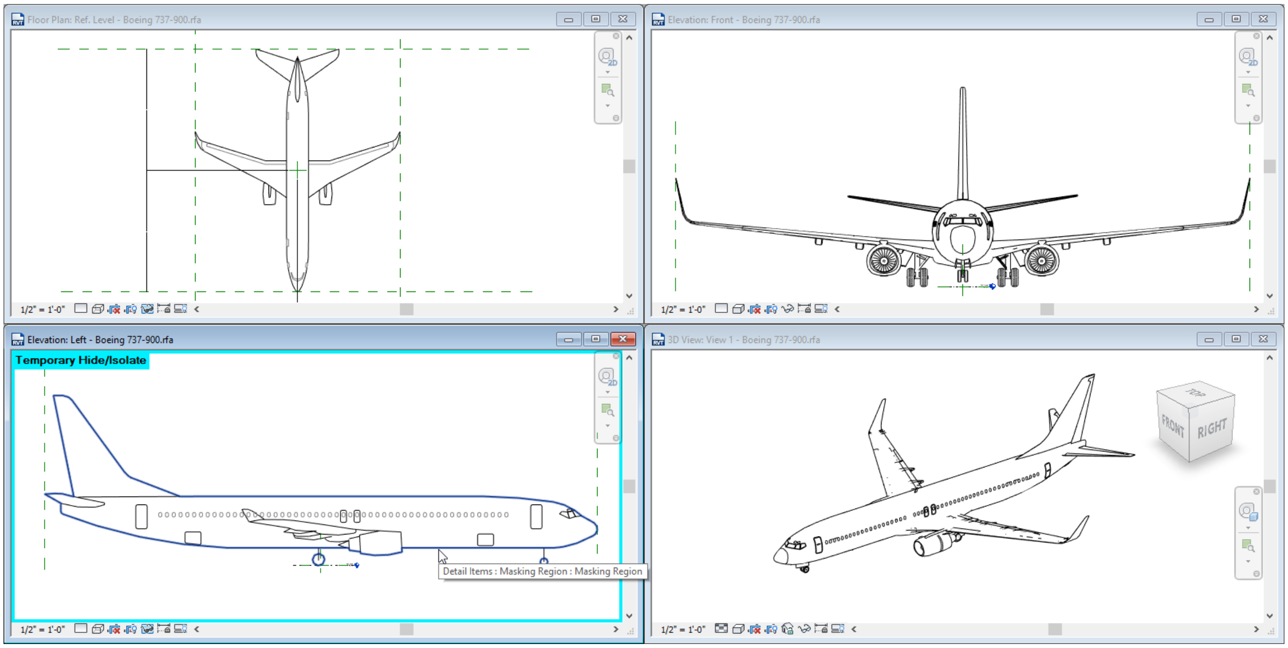


Figure 42 – Optionally add symbolic geometry to the 2D views

The best part of this technique is not only do we get quite satisfactory 3D results without spending hours modeling custom and organic forms, but the files end up quite small! Look at the file size for that airplane! The statue looks pretty good too (see Figure 43).

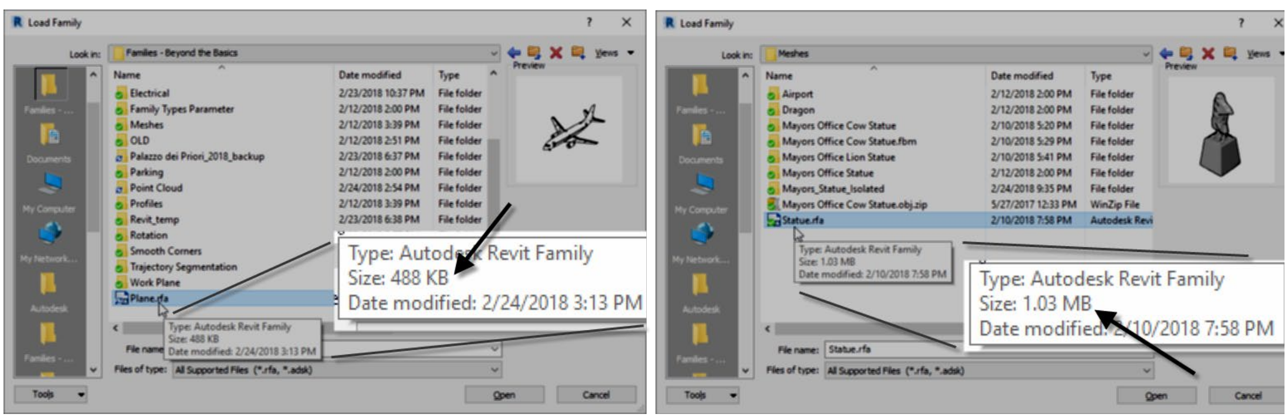


Figure 43 – Mesh imports are quite compact

Naturally, these models are not parametric. You can scale them by editing their type properties, but they will not stretch or have other parametric behaviors. If you need those behaviors, you'll need to consider taking the time and effort to build a native Revit model.

Back to (Virtual) Reality

It's time to take it full circle. One way to do this we have already discussed is to 3D print the models you create from photogrammetry and point clouds. You cannot 3D print directly from a point cloud. You will always need to process it in some way to create a 3D model (surface or solid). Just be sure that the model is

"watertight". This means exactly what it sounds like. If you use mesh models, their surfaces have no thickness, making them difficult or impossible to print. But if the mesh or surface model is fully enclosed (watertight) it should print. Most 3D printing software and services will flag models that have printing problems and some even offer tools to correct the issues.
Virtual Reality (VR) is another option to present the results and it offers an immersive experience not available with other forms of presentation. VR is absolutely exploding right now and there are almost too many tools and services to count. I have used tools by Autodesk, Matterport, Enscape, vCAD and Kubity with the Volterra dataset. I was quite fond of vCAD, but sadly they closed shop and are no longer available. I had found Kubity to be a good replacement candidate, but they recently ended their support of Revit. Now they require the use of their SketchUp conversion plugin to convert Revit models before uploading to their service. I still have some of the models I created on my device and do hope to show them live in the session. The other tools require tethered VR headsets like Oculus Rift and HTC Vive.

Autodesk Panoramic Render

The Autodesk Panoramic Render is the easiest one to discuss because it is already included in Revit and other Autodesk products. Simply perform a cloud render from Revit or other application and then go to your Render Gallery to view it. There you can choose to render the scene again as a panorama. This will be viewable online in a web browser. You can also view it on your mobile device. In which case, if you have a Google Cardboard, you can view it in a more immersive way.
Here are two examples:
http://bit.ly/Priori1 http://bit.ly/Priori2

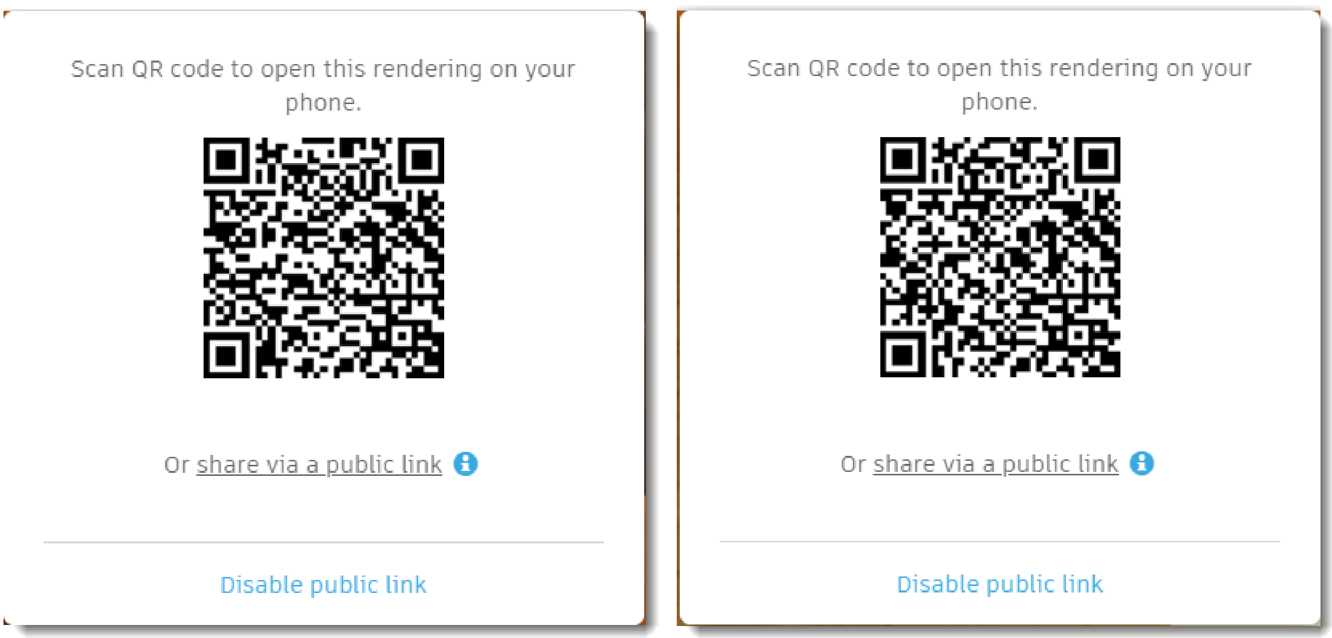


Figure 44 – Share panorama renders from Autodesk cloud render

Cintoo

Cintoo is a web-based platform for hosting and sharing point cloud data. We are using Cintoo quite extensively with our Volterra datasets. Here is what they have to say on their website (www.cintoo.com): Cintoo develops technologies and solutions for managing and leveraging the 3D data coming from Reality Capture devices in the cloud. Cintoo has developed a unique point cloud-to-surface technology that translates data from terrestrial laser scanners into a new generation Reality Data that is versatile,

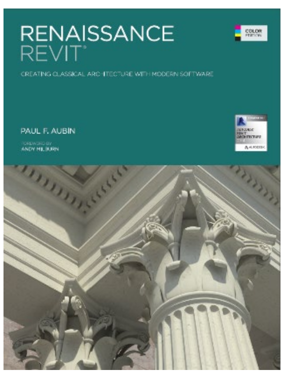
collaborative, distributable, streamable and efficient. This technology is embedded into Cintoo Cloud™, a laser scanning hardware and BIM platform agnostic cloud-based platform.
With Cintoo, your laser scans become BIM-compatible!
It sets a pretty high bar, but they actually meet it! Cintoo makes it easy to upload structured scan data, share it with stakeholders online in a web browser with no plugins necessary. You can even download the original scan data back into authoring programs.
You can download a free 30-day trial from here: https://cintoo.com/trial.html
Cintoo preserves the original structured point cloud data upon upload. But when viewing online, you are seeing a highly optimized mesh generated from the point cloud instead. You can even export this mesh in popular file formats, but in my experience, the downloaded meshes were not ideal. Cintoo also supports VR viewing of projects online. They are streamed to supported devices; currently Oculus Rift and HTC Vive only.

Kubity

I planned to showcase Kubity.com for a live segment in the session. But since the last time I used their service, it seems they have moved to a SketchUp focused workflow. There is more detail on this development here.
I have downloaded and installed their plugin to convert to SketchUp, but I don't use SketchUp in my daily workflow, so this approach is not ideal for me. I do still have some of the previously converted models on my device and hope to show these in the live session.

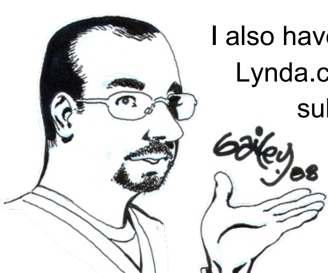
Further Study

You can find more information and tutorials in:

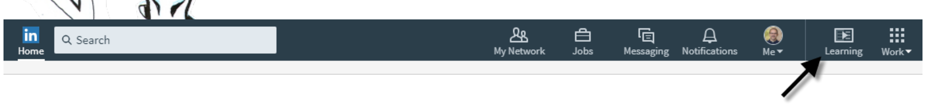


Renaissance Revit: Creating Classical Architecture with Modern Software. This book can be thought of as a "deep dive" into the family editor. It starts with the basics but gets very advanced as well. The entire book is on family creation using classical architectural examples. Both the traditional and massing family editors are covered.

The Aubin Academy Revit Architecture: 2016 and beyond. The book is authored in an earlier release, but most functions are still relevant in current releases.



I also have Revit video training available at LinkedIn Learning.
Lynda.com has recently been rebranded as LinkedIn Learning. If you are a Lynda.com subscriber, you can access all the offerings on that platform as well. If you are Professional member of LinkedIn, you already have access to the entire training library.
If you have any questions about this session or Revit in general, you can use the contact form at https://paulaubin.com/contact/ to send me an email.



Follow me on twitter: @paulfaubin