

FORMLABS WHITE PAPER:

3D Printing Architectural Models: A Guide to Modeling Strategy and Software Workflow

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Model by T.Y. Lin International

Abstract

3D printing presents tremendous benefits to the conventional architectural workflow. It is possible to print complex designs without the need for skilled manual fabricators, and rapidly iterate on these designs with relative ease. Stereolithography (SLA) 3D printing offers incredibly high surface quality and fine detail, which makes it very suitable for architectural applications. This white paper covers modeling strategies and software workflows that allow architects and designers to easily integrate 3D printing into their existing design methodology, pulling best practices from Formlabs' internal testing and from architecture firms successfully using the Form 2 to produce models.

WHAT YOU WILL LEARN:

Strategies for designing 3D printed architectural models

Tips for improving the pre-print software workflow

- BIM (Revit, ArchiCAD)
- Surface modeling (Rhino, SketchUp)

Effective post-processing techniques

- Bonding
- Finishing

Introduction

The 3D printing market today offers accessible options both in price and scale. While professional-level technology has previously been cost-prohibitive, desktop stereolithography 3D printers allow architects, designers, and modelmakers to affordably produce high-quality parts in-house. For most models, the cost per part is under \$10.

3D printing opens up possibilities to produce complex designs with less labor and fewer materials, but a successful transition from a CAD model to a printable file relies on a baseline understanding of design for 3D printing. This white paper will help you parse through how regular modelmaking constraints relate to preparing a file for 3D printing, and how to approach and make smart modeling decisions, from choosing scale to designing for assembly to post-processing.

In order to integrate these strategies into existing workflows, the white paper covers how to tactically approach modeling strategies through the lens of the three most common software ecosystems:

BIM (Revit and ArchiCAD)

Rhino 3D

SketchUp



SLA 3D printing makes it possible to include fine detail on even the smallest models. This example of a small-scale urban model is at 1/32" = 1' scale and printed entirely on a Form 2 3D printer. This design's numerous small parts and details would take significantly longer to be cut and assembled by hand.

Model by LaneyLA Inc.



This auditorium section was 3D printed as one single piece on a Form 2 with Black Resin.

Model by DLR Group.



Model by Laney LA Inc.

Note: Remember, you are still working at 1:1 scale—some quick conversions will be required to achieve the correct dimensions at the print scale.

Modeling Strategy

Architectural models are conventionally assembled with a variety of materials and components. 3D printers help fuse these components into as few individual parts as possible, but some assembly is still required for two reasons:

- 1. The constraints of the build volume:** printers with large build volumes are either cost-prohibitive or compromise on surface quality. The Form 2's build volume is $5.7 \times 5.7 \times 6.9$ in ($145 \times 145 \times 175$ mm).
- 2. The need to show interior detail or materiality:** certain models require components that come apart to reveal more information about the design.

DESIGNING FOR ASSEMBLY

All 3D models require some preparation before they can be sent to the 3D printer. In the case of architectural models for the Form 2, this often involves splitting the model into smaller parts to accommodate the size of the Form 2 build envelope. Parts can then be easily joined together through chemical adhesion or mechanical assembly; the high accuracy of the prints ensures that the parts join together seamlessly.

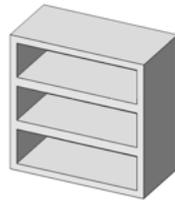
When choosing dimensions for splitting parts, the final orientation of the model should be taken into account. Most architectural prints need to be oriented at a 45 degree angle due to the floor slabs, which are considered to be large horizontal overhangs. Breaking the model down into long and thin parts helps maximize the diagonal length of the build volume while simultaneously achieving an ideal orientation.

Strategy Overview

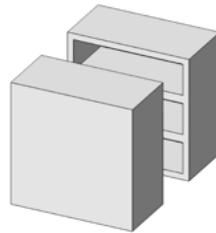
There are several strategies for 3D printing models for assembly. Your strategy will depend on what you hope to represent with the design, and the scale and geometry of the model. Consider these parameters:

- Need to show interior vs. exterior detail
- Ease of split (you'll want to split it along the least complex part of the model)
- Need to show a certain part of the program: unit typology, structure, floor layout

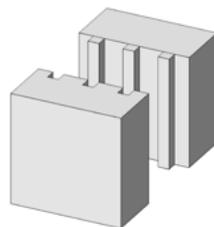
Split by Seam



Section Model

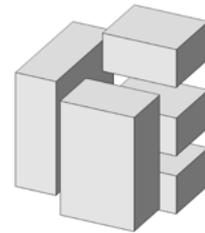


Straight Cut

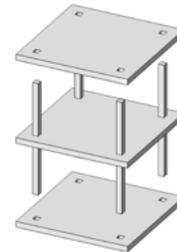


Aligners

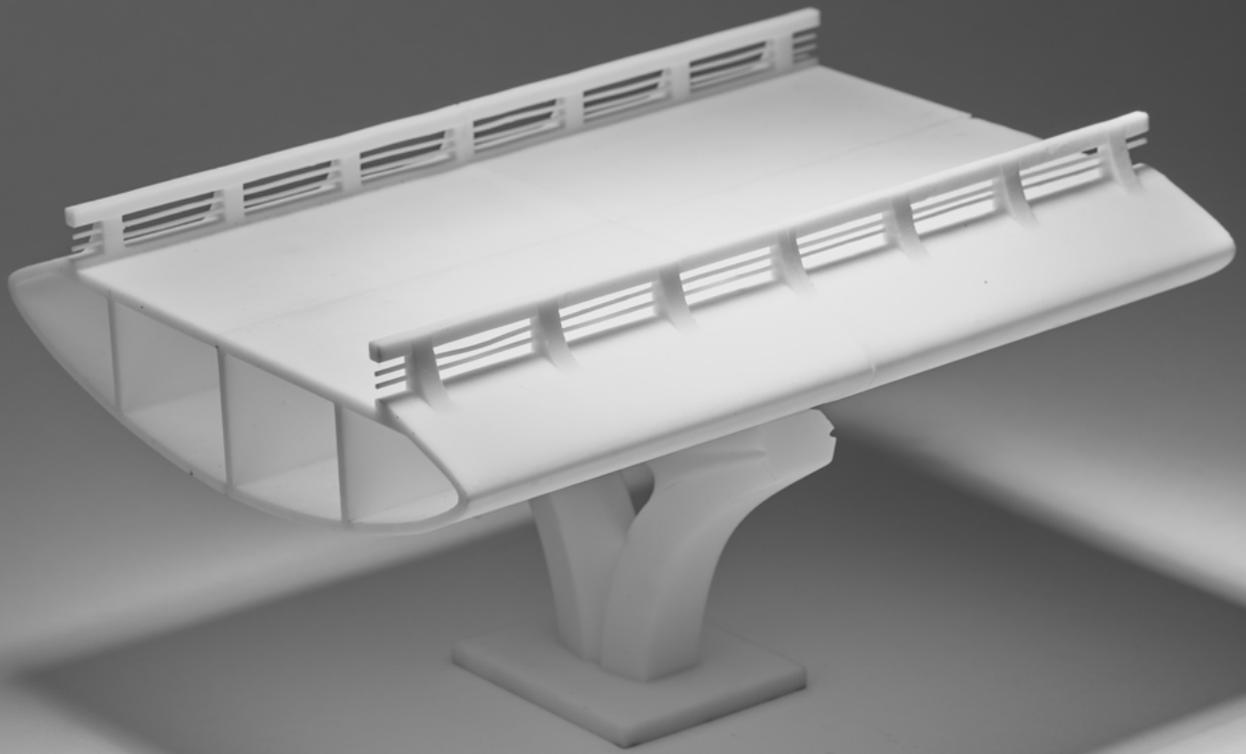
Split by Component



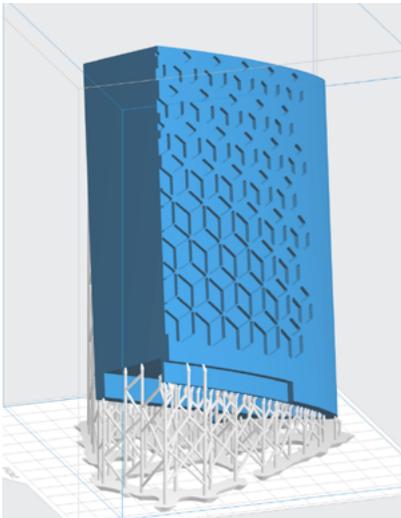
Split by Program



Split by Structure



Model by T.Y. Lin International



Try to print all components in a similar orientation, so that the layer lines and consequent dimensional inaccuracies follow the same pattern.

Split by Seam

STRAIGHT CUT

The simplest method for splitting a model is with a straight cut. It is an easy command to perform in most CAD packages. A model of a bridge is split into four parts along its length using straight cuts, one section of which is shown above. Each support underneath is inserted into a mating hole that does not require adhesive. Regardless of which method you choose, if you have a large number of parts (more than 10) it's helpful to add a unique identifier to each part to help you solve the puzzle during assembly.

Pros:

- Least CAD intensive
- More forgiving for prints that warp or have a higher degree of dimensional variation

Cons:

- Assembly requires manually aligning each part and clamping in place until the adhesive fully bonds them

USING ALIGNERS: JOINERY METHODS



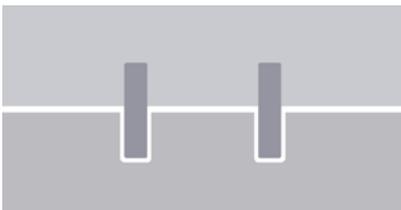
Printed bump and groove



Lip or recessed area



Recess with glue



Hole and slot with metal pins

ALIGNERS

Another approach is to add features to your design that will allow the prints to align themselves. When adding aligners, try to split the model in an area that has the least complex geometry. Use the CAD tool of your preference to split your model and add basic aligners like slots, pins, grooves, recesses, and lips or more complex aligners like dovetails and cuts that follow existing creases in the model. Additionally, it is important to design in a tolerance of ~ 0.25 mm between mating parts, in order to prevent extra sanding in the post-print stage.

Pros:

- Easy alignment
- Easy to assemble (mating parts help to create more surface area for adhesion)
- High accuracy SLA allows for snug fits with high tolerance, and can be used without glue

Cons:

- Parts that are not dimensionally accurate will not fit well together. Tall, thin prints are often less dimensionally accurate.

SECTION MODEL

Splitting a model with a seam has the added benefit of showing a section model for designs with compelling interior details. The model can initially be presented as a whole to the client, and then disassembled to reveal interior detail when desired. These examples by LaneyLA show how the same model conveys different types of information based on the open and closed configurations.

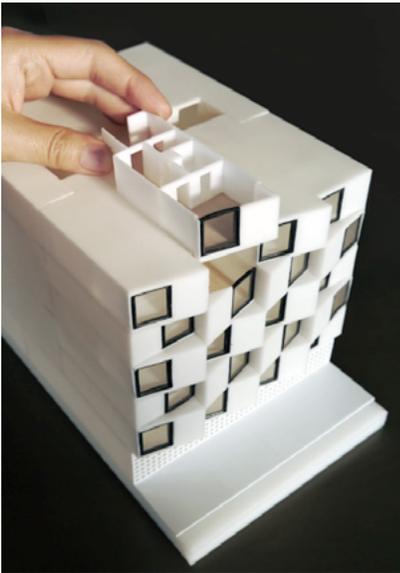


This model from LaneyLA was printed on a Form 2 with White Resin.

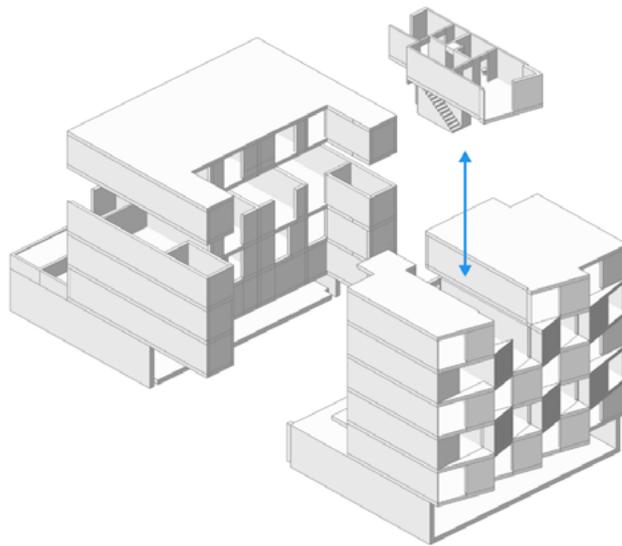
Split by Component

SPLIT BY PROGRAM

By breaking a building down by program, you can present a building as a kit of parts, providing a clear understanding of all the design components without plan and section drawings. You can either print each floor slab separately and then assemble with mating features, or simply print one component of the entire building separate from the rest. A good example is this model from Stanley Saitowitz | Natoma Architects Inc. (SSNAI), who used the Form 2 to create a model of an apartment complex.



Model by Stanley Saitowitz | Natoma Architects Inc.



Since each housing unit followed the same design, it made sense to simply print one removable unit that would allow the client to understand the generic unit typology.

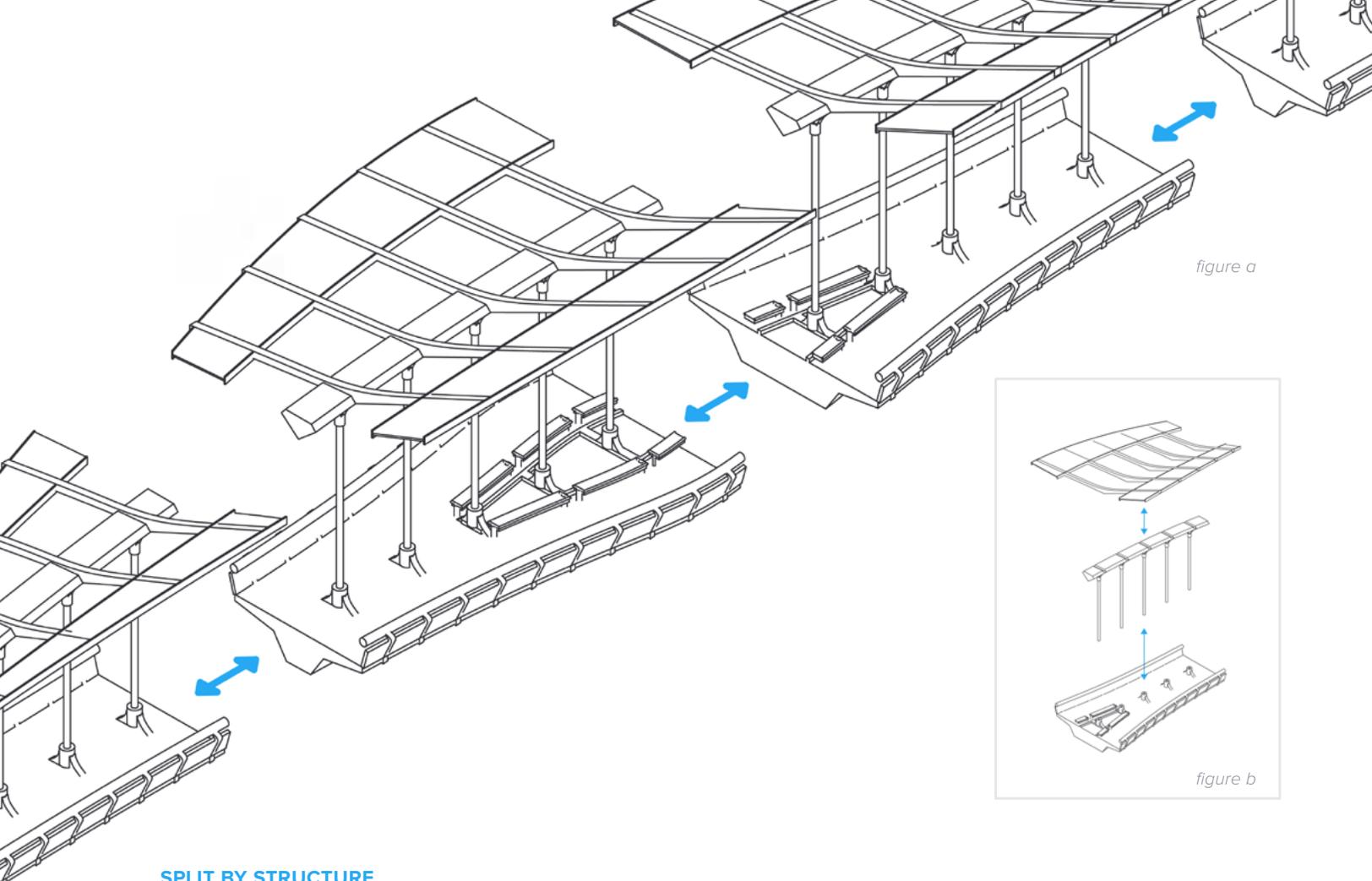


figure a

figure b

SPLIT BY STRUCTURE

Some models lend themselves to being split up by their structural components, rather than printing as a single block or splitting along a seam. This technique usually works for models that aren't characterized by rectilinear forms, such as regular building envelopes, but are instead complex structures, such as detailed components of a building, bridges, pavilions, or airports.

First, break down these models into components that lend themselves to 3D printing with minimal supports. This saves time on post-processing (support removal for delicate models can be tedious) and also saves material cost and print time.

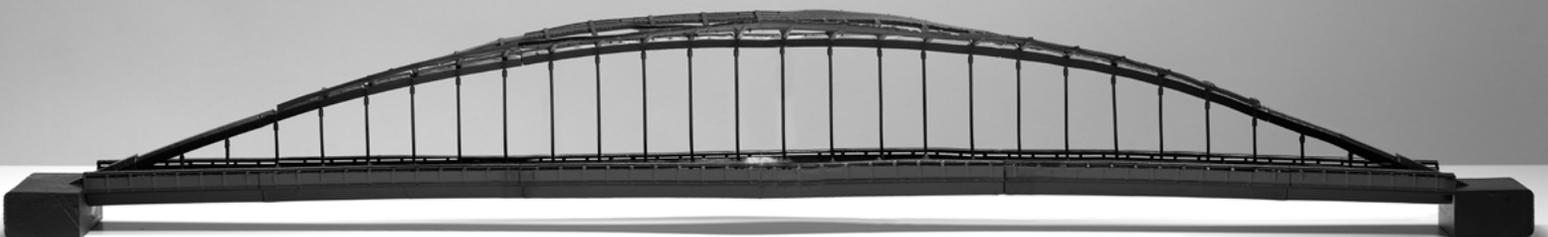
This example of a bridge demonstrates multiple splitting techniques. First, the model is split into multiple parts (*figure a*). Although these fit on

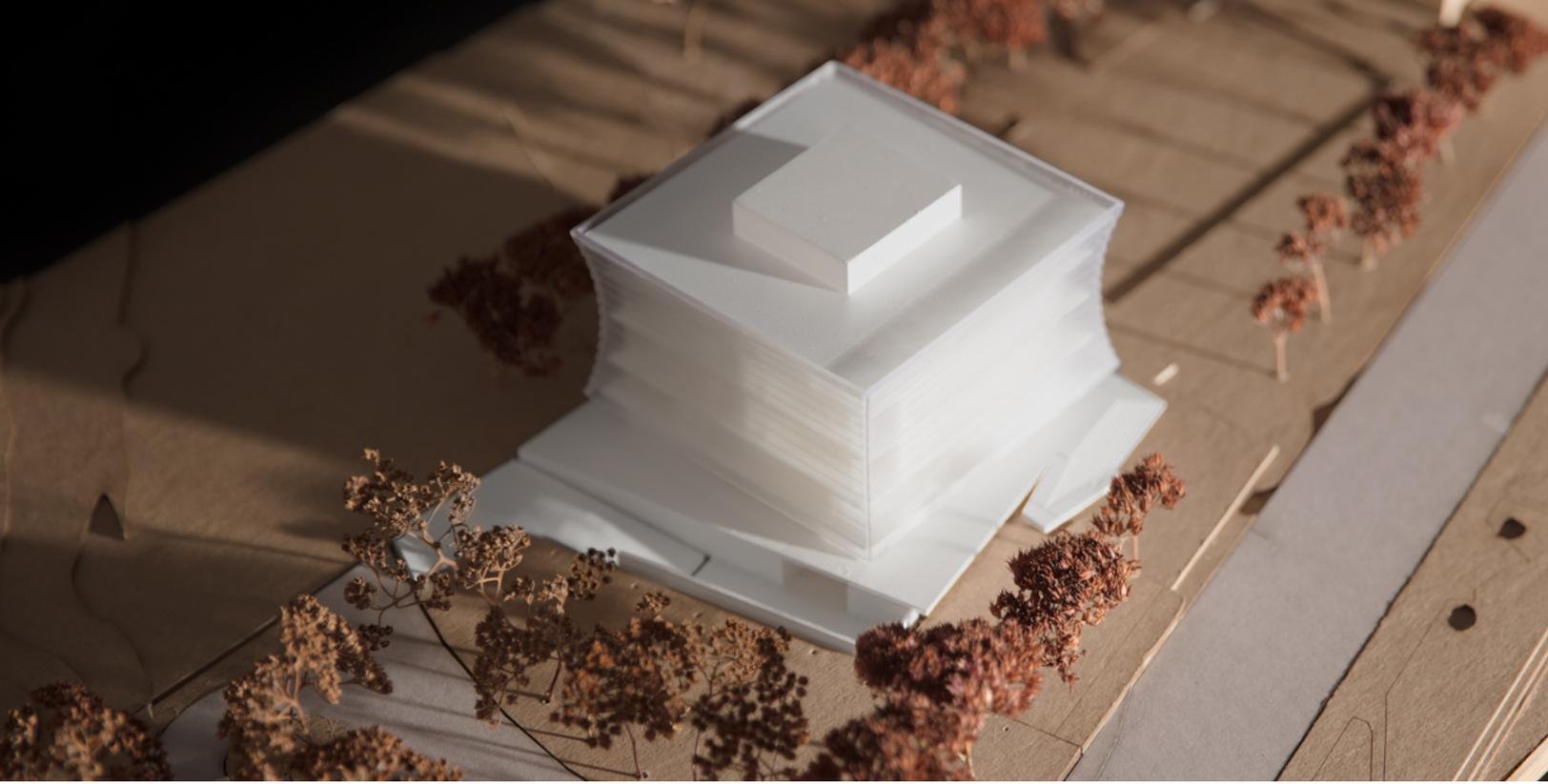
the Form 2's build platform, they require tedious support removal around the more delicate areas such as cables and railings.

To solve for this, each part is broken down into three sub-components: the base plate and railings, vertical tensile cables, and the solar wings on the top (*figure b*). These can be printed with significantly fewer supports, allowing for easier finishing.

Upon finishing, the components simply need to be assembled with the help of mating features that were included in the design step. Smaller parts are also easier to pack into a single build platform, with the entire bridge being printed in five prints of roughly 100 mL each.

Model by T.Y. Lin Architects

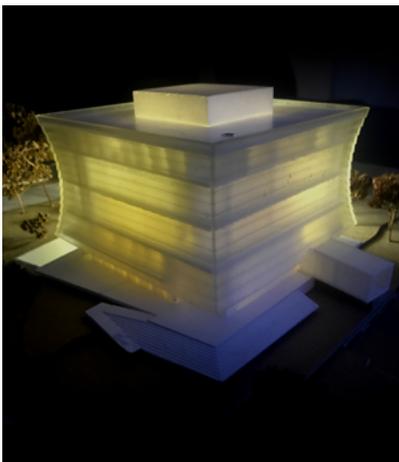




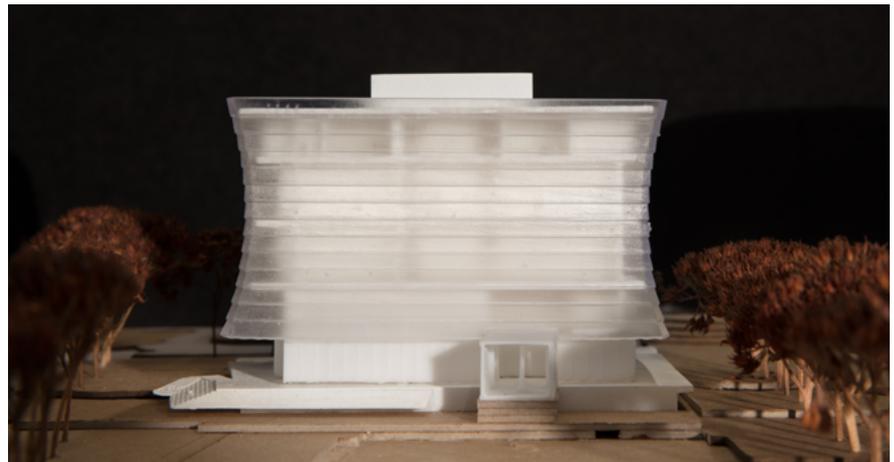
*This site model was created with laser-cut chipboard. The primary building was 3D printed with both Clear and White resins. **Model by Schwarz Silver Architects***

Materials

Materials play an important role in conveying the underlying concept of a design. It isn't always imperative to simulate the exact color and texture of a material, but it can help to distinguish between different materials. Splitting a model by its components makes it possible to display materiality, as parts can be printed in separate materials, or individually painted with different colors.



The clear facade is illuminated from within, simulating the visual conditions of this site at night.



Formlabs matte Black, White, and Grey resins have a smooth, opaque surface finish straight out of the printer, and provide a great neutral palette for architectural models. Grey Resin and White Resin are also easy to finish and prime with just a few coats of paint, which is further discussed in the finishing section of this white paper.

Formlabs Clear Resin is great for printing elements that simulate translucent materials. If the model requires more transparency, it is possible to simply dip the printed part into Clear Resin and allow it to dry uniformly, as outlined in [this article about creating transparent parts with clear resin](#). It is also possible to spray the model with any clear coat sprays to increase surface transparency and glossiness.

3D PRINTING ALONGSIDE TRADITIONAL MATERIALS



*This model uses the Form 2 to print extremely fine details, such as the cornice, clock, and railings. **Model by Myles Burke Architectural Models Inc.***

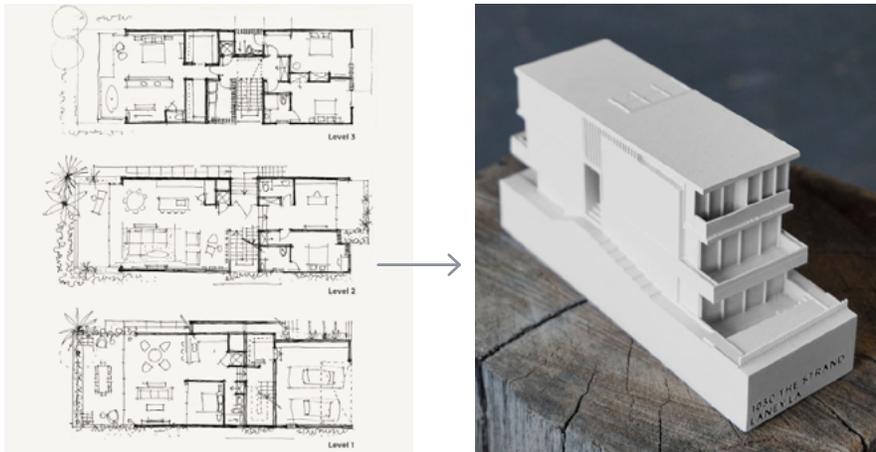
Instead of 3D printing an entire building, it is sometimes better to 3D print only the complex components. Complex facades, trussing, and cornice details are great candidates for SLA 3D printing. Flat walls, floor slabs, and topography can be laser cut or even made by hand.



This complex facade is parametrically designed based on a sun path analysis, and would be incredibly difficult to fabricate by any other means at such a scale.

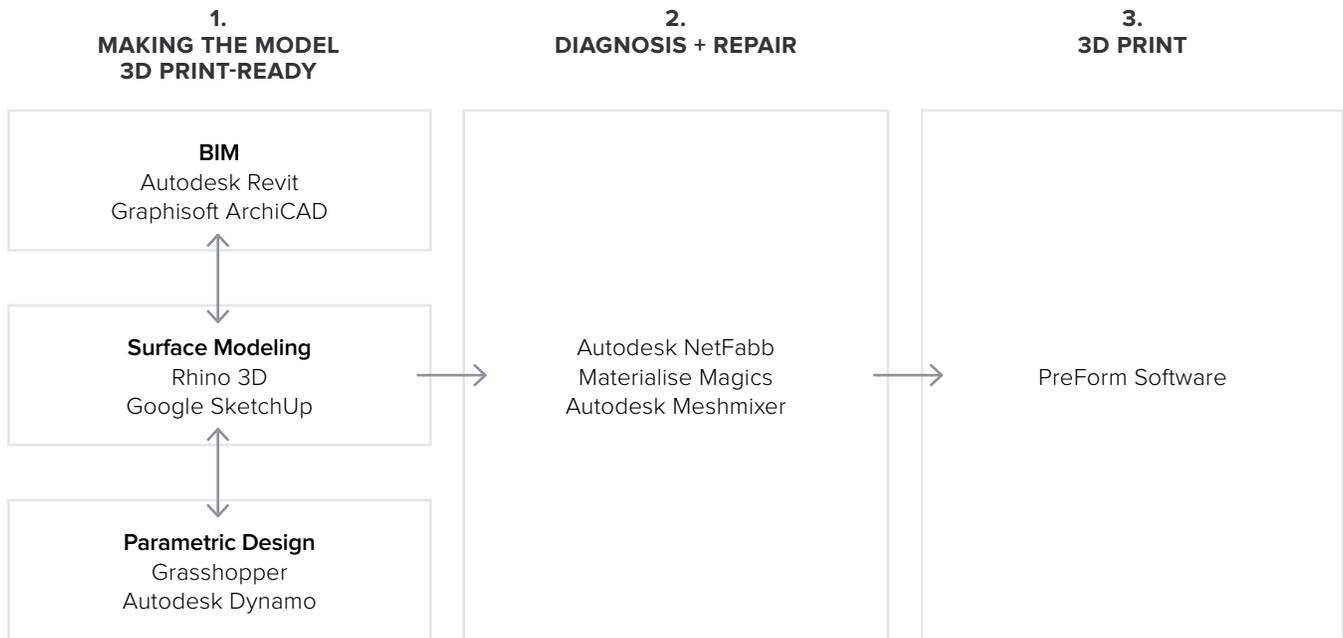
Software Workflow

A good print relies on a well designed 3D model. This section will go over best practices and workflows for modeling for printability in some of the most common CAD environments: Revit, SketchUp, and Rhino.



CAD software is usually the biggest bottleneck in getting from a drawing to a printable 3D model.

Common Workflows



BIM Workflow

Revit → Rhino/SketchUp → Model Diagnosis → PreForm

Though BIM (Building Information Modeling) software is popular amongst architecture firms, it doesn't always lend itself to directly 3D printable models. These are some high-level steps that can be taken to produce a 3D printable model from these softwares. This workflow applies broadly to Autodesk Revit or Graphisoft ArchiCAD software, both of which are parametric BIM modelers.

PREPARE THE FILE

STEP 1: Create a separate standalone file.

STEP 2: Manage components: remove ductwork, double glazed windows, HVAC units, and interior details that won't be visible in the model.

STEP 3: Select all components that need to be thickened (e.g., doors, windows, walls, slabs). The parametric nature of the model makes it possible to simultaneously thicken the dimensions of multiple objects.

EXPORT THE FILE

Select the scale at which you want to export the file. Choose export settings based on the needs of your model:

EXPORT AS STL

Exporting the file as a mesh will make it very difficult to manipulate, so this is only advisable if you are not looking to edit any geometry after this stage. You can then take it to your mesh repair software of choice, and also split the mesh along basic cartesian planes.

EXPORT AS 3D DWG

Exporting as surfaces will allow you to easily manipulate and edit the geometry in Rhino or SketchUp. This step is encouraged for those who are looking to split the model by program or component, or split along a seam that isn't along a regular cartesian plane. You can then export as an STL file from Rhino or from SketchUp using a [plugin](#).

EXPORTING WITH ARCHICAD

Convert geometry to Morphs and 'check the solidity' before exporting the model as an STL. If printing in parts, use the Split tool to slice the model for multiple print beds, if required. This mostly produces printable files, but a quick pit stop at a mesh repair/analysis software never hurts.

STL REVIT EXPORTER

Using this method automatically removes finer details, such as door handles and railings. It isn't foolproof, though, and still often requires some post-processing in other CAD environments before sending to print.

Surface Modeling Workflow

[AutoCAD](#) → [Rhino/SketchUp](#) → [Model Diagnosis](#) → [PreForm](#)

This workflow is often an easier approach, starting from 2D drawings solely with the intention to 3D print.

PREPARE THE FILE

STEP 1: Hide irrelevant layers.

STEP 2: Identify and remove unnecessary elements such as small furniture, trees, etc.

EXPORT THE FILE

STEP 1: Export simplified drawing to Rhino as DWG.

STEP 2: Import to Rhino.

STEP 3: Scale down (it helps to create a small box with the dimensions of the build volume for reference).

STEP 4: Begin extruding and trimming until you have the external shell.

STEP 5: Export as an STL.

STEP 6: Analyze/repair mesh.

STEP 7: Import into PreForm.

Note: If the model will be printed in multiple parts, split it before exporting as an STL.

THICKENING WITH RHINO

Instead of parametrically controlling the thicknesses of components directly in a BIM file, it is also possible to use the BoxEdit component in Rhino.

This allows you to simultaneously scale a series of items relative to their centroids. BoxEdit is ideal for models that need to be scaled parallel to the three cartesian axes. Non-uniform scaling is a little trickier.

For non-rectilinear geometries, we suggest converting the part into a mesh, and then using the [Weaverbird thicken command](#), which simply offsets any irregular mesh geometry outwards by a given distance. Alternatively, it is possible to 'explode' complex parts into surfaces and then offset them, as opposed to importing volumes from Revit.

SELECTING SMALL GEOMETRIES WITH RHINO

Another valuable Rhino feature is the SelSmall command, which allows you to select all items in the workspace that are smaller than a user-defined bounding box. You can then select these objects and use BoxEdit to individually scale them, or simply delete them. This is useful when you are dealing with a file that doesn't have a well organized layer system.

SOLID/BOOLEAN UNION GEOMETRY

Although performing a Boolean Union on all geometries is ideal, it is often possible to get away with simple overlapping geometries. PreForm will interpret these as one closed geometry in most cases, but be sure to verify printability using the slicer tool on the right-hand side in PreForm.

Note: PreForm is Formlabs' free software that prepares your 3D model for printing on the Form 2. Once a part is set up, you can save it as a FORM file for future use in PreForm.

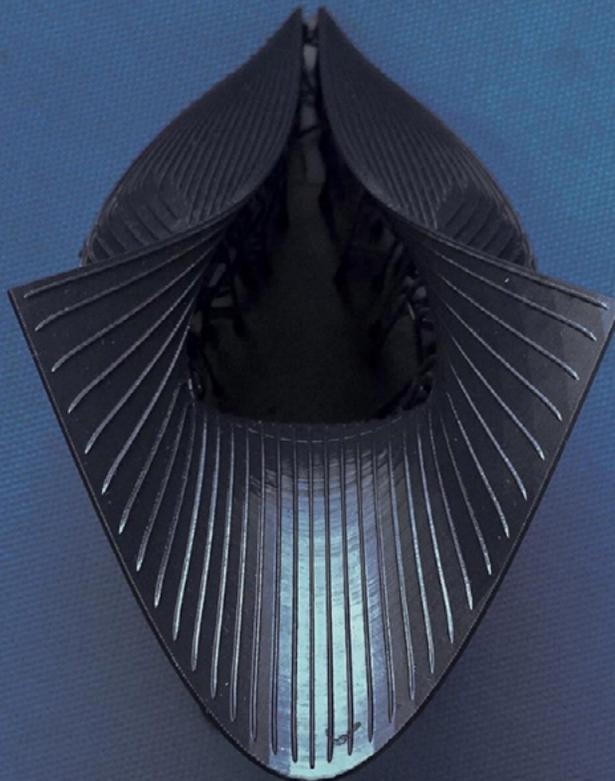
[Download PreForm for free to try it for yourself.](#)

COMPUTATIONAL WORKFLOW

Although this is a less common workflow, computational design is slowly making its way into conventional architectural workflows. Software like Grasshopper and Dynamo are used to create parametrically generated geometries that are often so complex that they can only be fabricated via 3D printing.

Since the geometries are already easy to manipulate, it's usually best to create a separate component that allows easy control over the basic dimensions of all thin features. It is then a simple matter of trial and error; running the exported geometries through a printability test (PreForm, MeshMixer) and changing the dimensions until you arrive at a printable file.

A computationally generated structure printed on a Form 1+ at the [ZHA code workshop](#).



Model Diagnosis

All of the workflows outlined below share a potential ‘model diagnosis’ step. This is an optional (but often necessary) step that ensures that the model is fully printable. Free programs such as Autodesk’s MeshMixer and Netfabb are tools that allow you to repair, thicken, hollow-out, and split 3D print files.

MESH REPAIR

Formlabs’ PreForm software has built-in mesh repair that is powered by Netfabb, so it is only necessary to use NetFabb and MeshMixer for non-standard repairs, or to preview pain points in the print. Materialise Magics is a great proprietary tool that goes over the entire pre-print workflow for a wide range of printer types. The mesh repair part of the software is the most relevant to the Form 2 print workflow, and can save a decent amount of preparation time. Netfabb has a nice built-in model slicer that allows you to efficiently split and repair large files along any of the cartesian planes.

SPLITTING MODELS

It is also possible to split the model in NetFabb, which splits and fixes the split parts into printable volumes. In Rhino, you would need to cap the open volumes. Be sure to leave a tolerance of ~0.25 mm between adjacent parts, this will allow for frictionless insertion.

Read more about tolerances in our [engineering fit white paper](#).

PREFORM SLICER

Architectural models are highly detailed and it is often difficult to isolate every single print issue. A combination of the practices outlined above and mesh repair software usually takes care of almost all issues, but it is always prudent to use the PreForm slicer tool to confirm that there are no thin unsupported areas and closed volumes (such as rooms with no doors, elevator cores, and parking spaces).

“Buildings and architecture designs are not meant to be 3D printed, they are meant to be constructed. This creates challenges of scale and complex geometry. By combining the powerful mesh repair tools of Netfabb and the precision of the Form 2, you can prototype and visualize designs faster and with more detail, winning you more business and accelerating your project’s design validation process.”

Matt Lemay

Enterprise Solutions Lead, Autodesk Customer Success

Post-Processing

Bonding

The modeling strategy section of this white paper covers some ways to split and align parts together, but an adhesive is always required for a sturdy connection. Architectural parts are bonded in two primary ways:

CYANOACRYLATE

Cyanoacrylate (CA or Super Glue) creates a quick, reasonably strong bond making ideal for small- and medium-sized parts. CA does not bond well to dirty surfaces, so be sure to clean the part thoroughly before applying it to a model's surface.

RESIN

For small prints you can use liquid resin as a bonding agent. Pour a small amount of resin into a tray from the bottle or cartridge, use a dropper or syringe to pick it up, and place it onto the surface of the part to bond. Join the parts and wipe off any excess resin that might spill out around the edges. To solidify the resin and bond the parts, use a 5 mw laser light pen with 405 nm wavelength and direct it to the bonding area around the parts.

This method creates a chemical bond, just as if the part was printed on your SLA 3D printer, but is only applicable to small bonding surfaces, as the low power light pen cannot penetrate the model deep enough to create a strong bond.

FINISHING

Parts printed on the Form 2, especially in matte Standard Resins, have a smooth surface finish right out of the printer. However, visible areas with support marks almost always require sanding. Additionally, it is possible to prime and paint the parts to any desired color.

SANDING

Sanding will help you remove support marks and any remaining inaccuracies from your model. Start with carefully dry sanding the part's surface using ~150 grit sandpaper to remove large support marks and level the edges where parts meet. Once the part's surface is even, wet sand it with ~320 grit sandpaper to remove all remaining layer lines. Move the sandpaper in a random motion to avoid creating a grain.

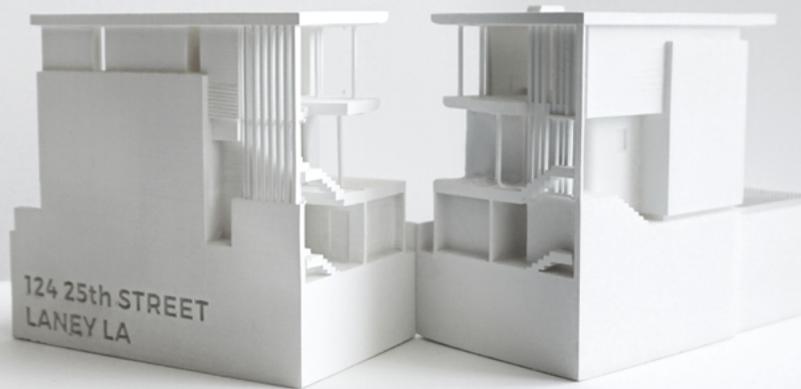
In most cases, these two steps will create a smooth enough finish, but you might continue increasing the sandpaper grit count by a factor of ~2 and wet sand the entire part until the surface reaches the desired smoothness. Once you're finished sanding your model, rinse the model in soapy water to remove any dust or debris and dry it thoroughly before moving onto the last step.

Architectural models are very detailed, and it can be rather difficult to access certain areas with only sandpaper. An assortment of nail files can help get to the more troublesome areas of the model.

PRIMING & PAINTING

Priming is required prior to painting parts to ensure paint adheres well to the surface. Priming can also make it easier to spot areas that need more finishing. A quick primer spray over a model makes support marks very bright, so you can instantly identify spots that require additional sanding.

Generic plastic primer in matte grey shows details exceptionally well. Apply it to the surface in several thin coats for the best results. Continue sanding on critical areas, apply a light coat of primer again, and repeat this process until the full part has an even surface. Most spray paints work best in warm, slightly humid, and not-windy conditions, but always check the specific paint can or technical documentation for the manufacturer's recommendations.



Model by Laney L.A. Inc.

"Models are becoming increasingly rare in a field where photorealistic renderings and VR technology are advancing, but physical models allow architects to test spatial qualities in ways that digital models cannot. If we were not using the 3D printer, we would feel compelled to spend more time visualizing the design through renderings and drawings. The ability to have a physical model of a complicated design straight from the 3D model in CAD gives us multiple impactful images in less time."

Paul Choi
LaneyLA Inc.