BES500053

DfMA for MEP with Generative Design and BIM Automation

Adam Roth
Henderson Engineers

Sean Turner
Henderson Engineers

Learning Objectives

- Identify applications of different levels of DfMA approaches.
- Apply DfMA concepts to generative design and BIM automation for building systems.
- Validate the design optimization.
- Create a quality review process integrated into the design process.

Description

DfMA doesn't have to be an exclusive club of certain project types. We will walk through the story of identifying levels of DfMA, working with a large contractor to develop design modules, then on through design, fabrication, and installation. Building on the concepts of modular construction, DfMA is the next evolution for an automated AEC industry. This class will make the concept more accessible to different project types. The BIM process and VDC process need to fit with the design process. The final output also needs to meet hard coded engineering standards. Systems design and sequencing challenges were overcome with modularization and automation. We'll show you how!

Speaker(s)

Adam Roth
BIM/VDC Director | https://www.linkedin.com/in/adam-roth-72047a33/

Sean Turner, PE
Innovation Director | https://www.linkedin.com/in/seanmturner/

Introduction

We're going to discuss a couple of different topics in silos, and then show how they all come together in the end. First, we're going to cover DfMA from an engineering standpoint, and then finish it off with generative design and BIM. These are not new concepts but we feel that they are underutilized in the building systems design area of the AEC industry.

Identify applications of different levels of DfMA approaches

One important concept is the way we talk about DfMA in the AEC industry. We often see DfMA used interchangeably with terms like modular construction, pre-fabrication, and off-site construction. Really, that's not the best representation of DfMA. A better statement is that DfMA produces components in support of these construction principles in an effort to make them more effective.

Why scale matters

Another important concept is scale. Take these two Yodas for instance. The one on the left has a module scale (size of the Lego brick) that is really close to the overall scale of that Yoda figurine. The one on the right has a module scale that's quite a bit smaller in relation to the overall scale of the model and you're able to see more detail.

Image Credit: http://www.brickfinder.net/wp-content/uploads/2020/03/the-mandalorian-the-child-75317-05.jpg

Image Credit: https://mymodernmet.com/wp/wp-content/uploads/2020/09/baby-yoda-lego-set-3.jpg

Engineering design principles follow similarly; as the scale of the module gets smaller in relation to the building, you can get more definition with your designs. Modular construction also follows similar principles. Modules can be assembled into buildings and, as engineers, we can design our systems around those modules.

Combination of DfM (creation of component) + DfA (use of component)

A majority of conversations related to modular construction are about the scale of the module and the scale of the assembly. Whether you're choosing volumetric modules like really large shipping containers that they snap together, or multifamily housing headwall assemblies used in patient care rooms, or even just single modular components, all of those conversations that inform the design are focused on assembly. Those conversations are about designing for assembly (DfA). The sweet spot is when you can design a module that is not only easy to assemble but also cheaper to manufacture.


Image Credit: Karmod


Image Credit: Amico

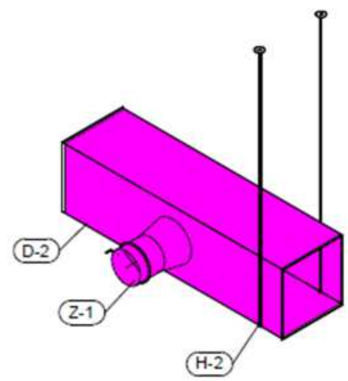


Image Credit: US Engineering Innovations

If we have a duct module with several intricate parts on the ends that made it really easy to assemble, it would make it extremely hard and expensive to manufacture. The point of DfMA is consider both the manufacturing and assembly.

Image Credit: US Engineering Innovations

Image Credit: US Engineering Innovations

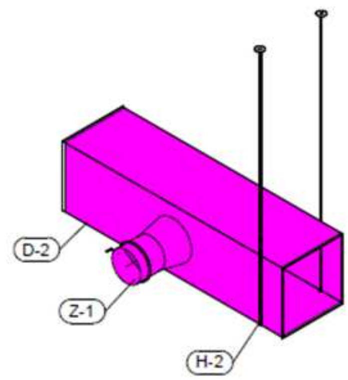


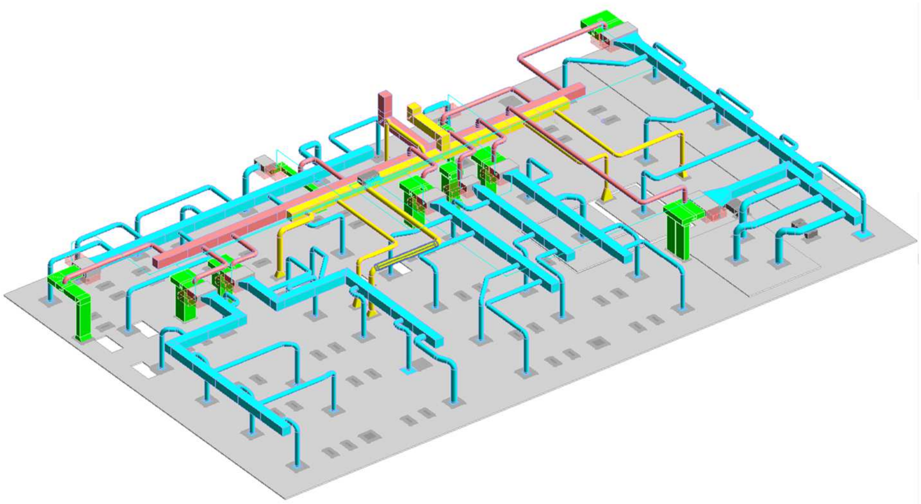
Image Credit: US Engineering Innovations

We took a module that was built for assembly and worked with [US Engineering Innovations]() to refine what it looked like so that it was easier and faster to produce, but still easy to assemble and install in the field. That's DfMA – the process of designing for manufacturing, as well as the assembly process.

What do the following images have in common? You'll see a retail store, a patient room, and an arena.

Their common thread is HVAC systems that contain low-volume ductwork where you could use a repeatable module as an installation and it can be an air conveying method. Our approach was to use a repeatable component that's easy to manufacturer and that you could build up into a HVAC system for retail, something that serves a patient room, or something that serves a project as large as an arena.

A specific example of this was a recent project opportunity we had on a wellness clinic.

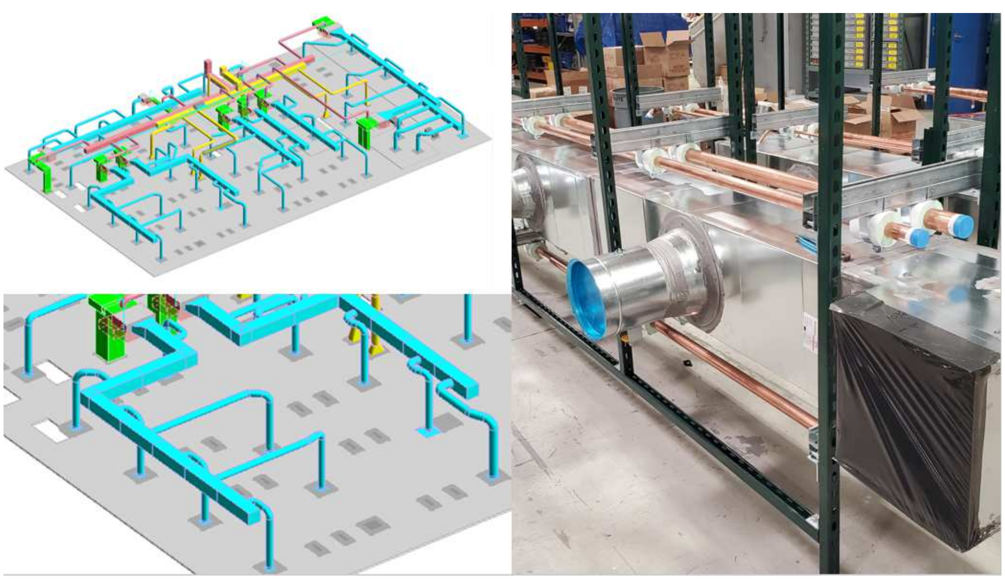


The project goals were to modularize as much of the design as possible in order to shorten the construction schedule and create design solutions for different configurations that use the same components.

The client was already investigating using modular components for assemblies for the walls, lighting, and power.

They hadn't looked at the HVAC system yet, so we were able to identify this as an opportunity to apply DfMA – and we just so happen to have a duct module we'd developed with US Engineering.

The first step was to change our engineering mindset to orient around using the ductwork modules in our design.



We had to rethink not only ductwork routing but also our unit sizing and even our zoning. We ended up using the duct module for the main trunks of the air side system, reducing the number of unique components. The round duct run outs going to air terminals were all standardized to be the same size as well.

Another advantage of taking this approach was that we could standardize most of the unit sizes. This allowed us to go from having five or six different engineered units to two.

An important aspect of this concept is that design does not exclude the option of the traditional stick-build approach. This mean that a contractor could take this exact set of construction documents and they could build it using the traditional methods *or* using the modular approach.

Applying DfMA concepts

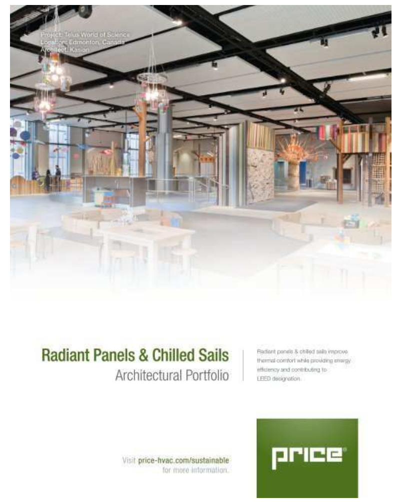
The basis of automation is standardization. By standardizing around a component, we are able to unlock more efficiencies and opportunities with BIM automation and generative design. It's important to understand the parts/pieces that are actually installed in the field and how they impact the layout.

How do we apply those DfMA concepts to generative design? First let’s consider standard design. Standard design is an iterative process to identify options using set project constraints. This process is basically the same for anything you design. If you were designing a dog bed, you would still go through an iterative process to identify options around project constraints.

Generative design adds a computer in that process to rapidly identify all those options using set project constraints. So, it doesn't identify all the options available. Instead it starts with given project constraints and outputs all the possible combinations within that framework. This allows the designer to explore those options faster than if you had done all the iterations by hand.

Generative design = Computational design + Optimization

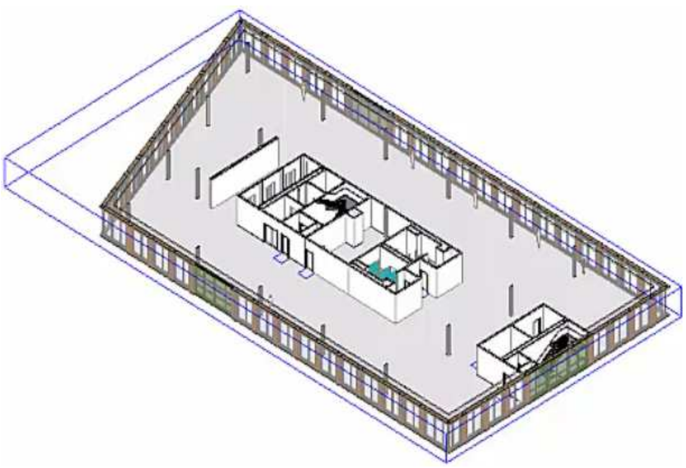
Computational design and optimization are both distinctly separate things, and you have to have both for generative design. Computational design, most commonly Dynamo, is also referred to as BIM automation.



Generative design success story

Here's an example of generative design in MEP without using DfMA. This involves optimization and computational design part. This seven-story building is a unique layout. The interior space design was also unique. It was open to structure and the architect wanted to use Price chilled sails as a ceiling plane/object. With the system type already selected, our goal was to maximize the load for the cooling offset. A secondary goal was to minimize the open space in the layout so aesthetically it looked as close to a ceiling as possible. The layout also had to fit into structural bays because the "ceiling" was to be recessed up in the bay.

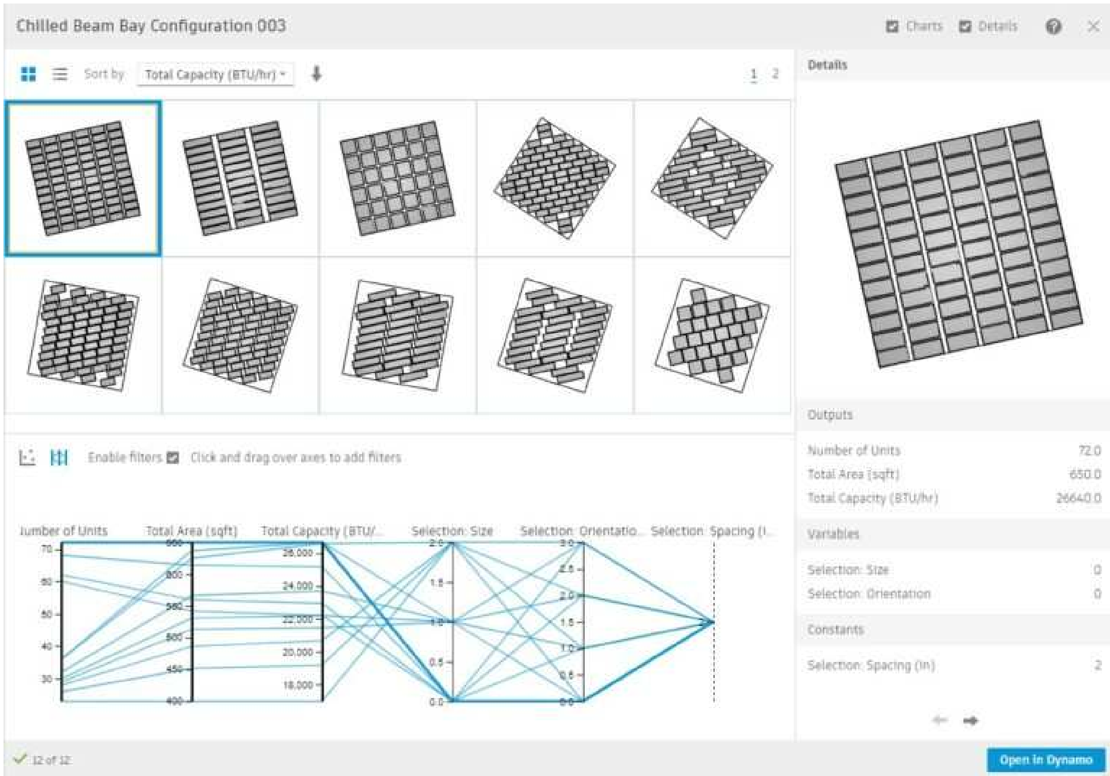
In addition to that list, we of course had to consider cost. The key there is to do so without doing full cost estimation.



We also wanted to provide different options for aesthetics, because we knew that it was going to be a higher end space. We wanted to present options, instead of just asking the team over and over as a guess and check scenario.

At Henderson we do all building systems design in house, so we wanted to be able to coordinate our layout quickly with other disciplines, to make sure that the design wouldn’t conflict with other systems.

We had three different sizes of units (2'x4', 4'x4', and 2'x8') to consider. The cost cooling offset power consumption was not a linear equation across all three options; a 2'x8' was not just simply 2'x4' doubled. There was also a maintenance clearance and installation clearance considerations.



We targeted [Autodesk Generative Design](https://www.autodesk.com/) to iterate through each size of the panel on an array and then rotated that array on 1° increments all the way up to 45°. With a wide variety of options, we could sort by coverage area, cooling offset, and price.

Generative design allows you to pull elements from the Revit model using that as a foundation for computational design and optimization. Using these calculations, generative design can produce multiple design options, select one from a sort list, and populate those back in Revit.

In this example, we had square bays and non-square bays. Optimizing fitting a rectangle into a square bay is not that hard. However, whenever you apply that across all the other unique shape spaces and sizes of units, that's where it became difficult. This is an example of sorting and selecting the final option, based on load which is what the primary goal from the architect was.

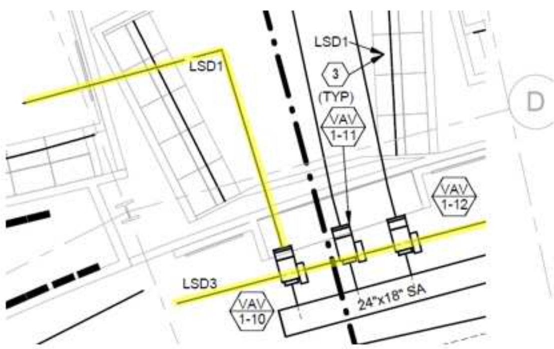
In the end, we were able to round trip the selection back into Revit with real mechanical systems. We placed them into design options for layout in the architect's model before we committed to them.

Including DfMA

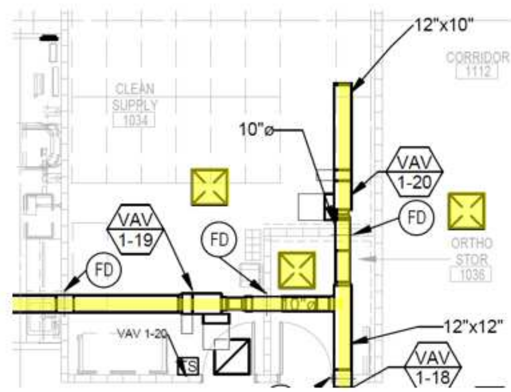
Now that we've shown generative design in the MEP world, we're going to apply DfMA (our duct module) to generative design.

This is how our design progresses naturally. Below you can see the difference between the main duct runs laid out in Design Development (DD) and 50% Construction Documents (CD). Notice that the equipment, terminals, and the duct all change between different milestones. We intentionally design this way to be as flexible as possible for as long as possible. That way, it's not always a last minute rush and allows for easier adjustment if/when things change.

Design Development



50% Construction Documents



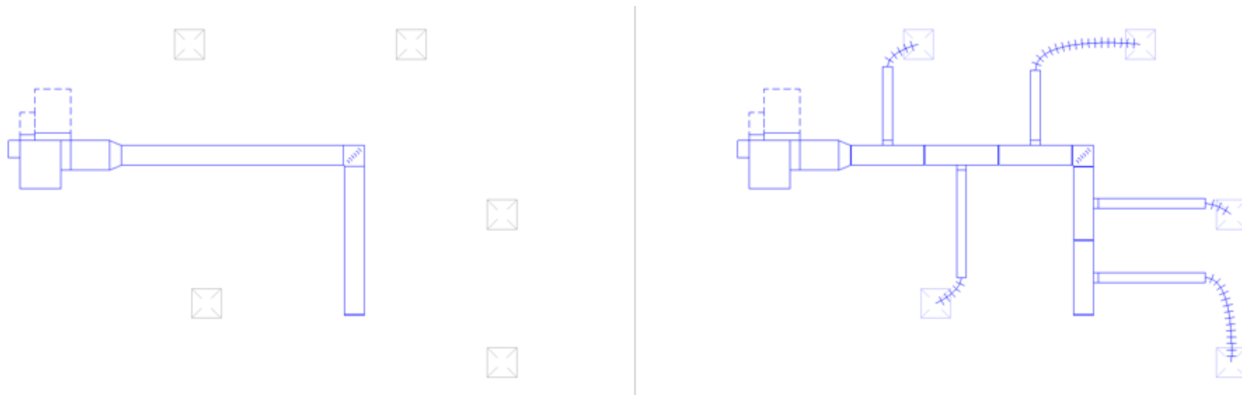
There's an innate emotional element to design. You have an emotional investment in the time and energy you spent putting that design together. If something changes, it can feel as if it's a personal attack on your design when really they just needed to add another wall.

We wanted to take that emotional component out of the design and be able to redesign accurately and very quickly, while still maintaining our design workflow.

This is where we tried generative design and failed because we were looking at the wrong problem or the wrong tool. We tried to automate this entire milestone deliverable. We tried to optimize terminal, duct main, and unit placement. All of those components have an interaction with each other and the math became simply too complicated.

Our design steps change based on the design phase. What we were really looking for was an easy button to go from milestone to milestone, so we could still be as flexible as possible for as long as possible. However, there simply is no easy button for 100% CD layout.

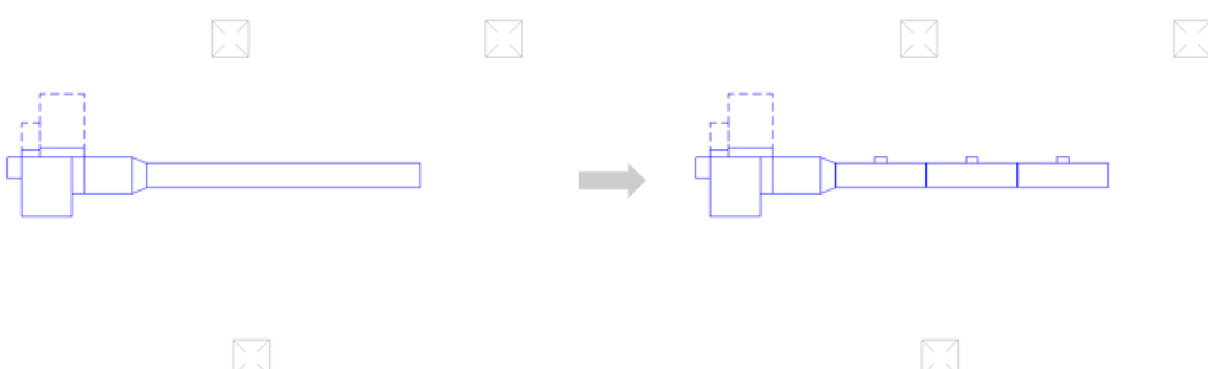
Generative design is best used for a single design step to be able to automate that layout and optimize the calculation. We backed up a bit and looked at our design process and we decided to focus on moving from 50% CDs to 100% CDs. You can see the see the difference in the layouts here.



Our backup plan was straight up BIM automation since we really don't need computational design and optimization to say "this is the nearest point on the main where this terminal can connect to." We wrote BIM automation through dynamo to make those connections. So what that left was with is a problem statement, and that we could automate. Problem statements are very important.

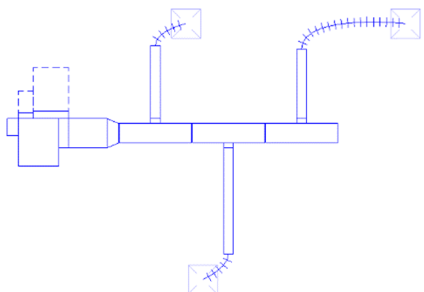
The problem statement here is “place the duct module on the main line of the identified duct and connect in the terminal into that module.” The duct was replaced as the components were placed because the module was actually a ducting fitting that was 5’ wide.

Here's an easy example that.



The easy part here is that our duct happened to be 15 feet long our duct modules were 5’. Since we have three modules and three terminals, the math is easy.

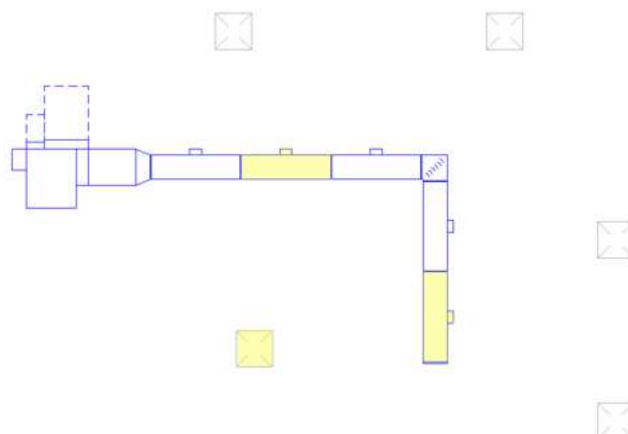
The important part here is that you don't have to create a module and work with contractors to create new things, you just simply have to understand what the components are you're applying in the field. If your components are 10' long, design in 10' increments. Traditionally, we would simply just lay out mains in the general length and location.



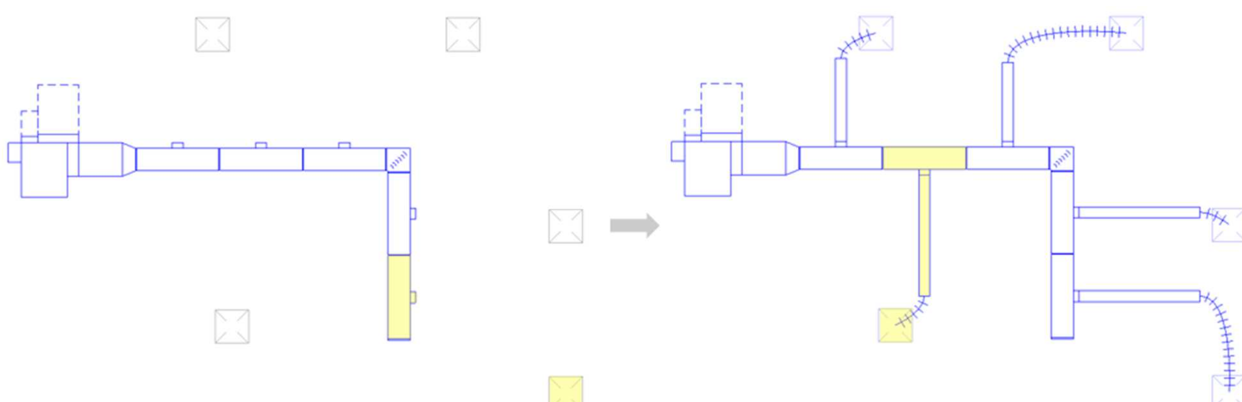
In this scenario, we have three modules and three terminals. We are able to automate connecting those together.

That layout becomes more difficult whenever you go around a corner. You wouldn't think this is that hard, but from a programming standpoint, it becomes increasingly complex.

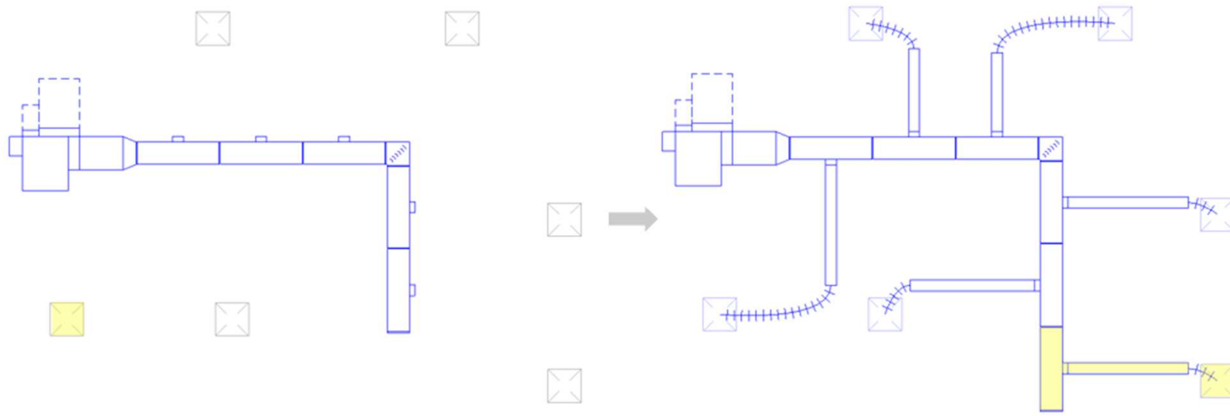
We replaced our mains with our modules just like we've done before. However, the math isn't so simple because the terminal on the lower left is equidistant between the two highlighted modules. It's a tie for which one to connect to via automation.



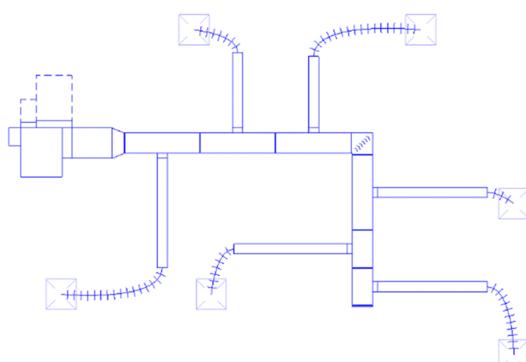
However, whenever you look at it in context of the entire design from a human eye, you're able to see that this module is most logically connected to this last terminal on the right. Therefore, the lower left terminal connects most logically to the center, upper module. That's where the human decisions come in. It's not always easy math.



Where it becomes hard is whenever you actually have more terminals than you have modules. In this scenario, we added another terminal because of design requirements and we only had so much room to run our main line of our ductwork. The simple solution there is you just add another module. But since we live in the real world we found that our modules were still too big. We needed smaller pieces!



Instead of a 5' design, we also created a 2.5' design in conjunction with US Engineering. This allows us to make more granular changes and fit into the smaller spaces than we would be with just a 5’ module.



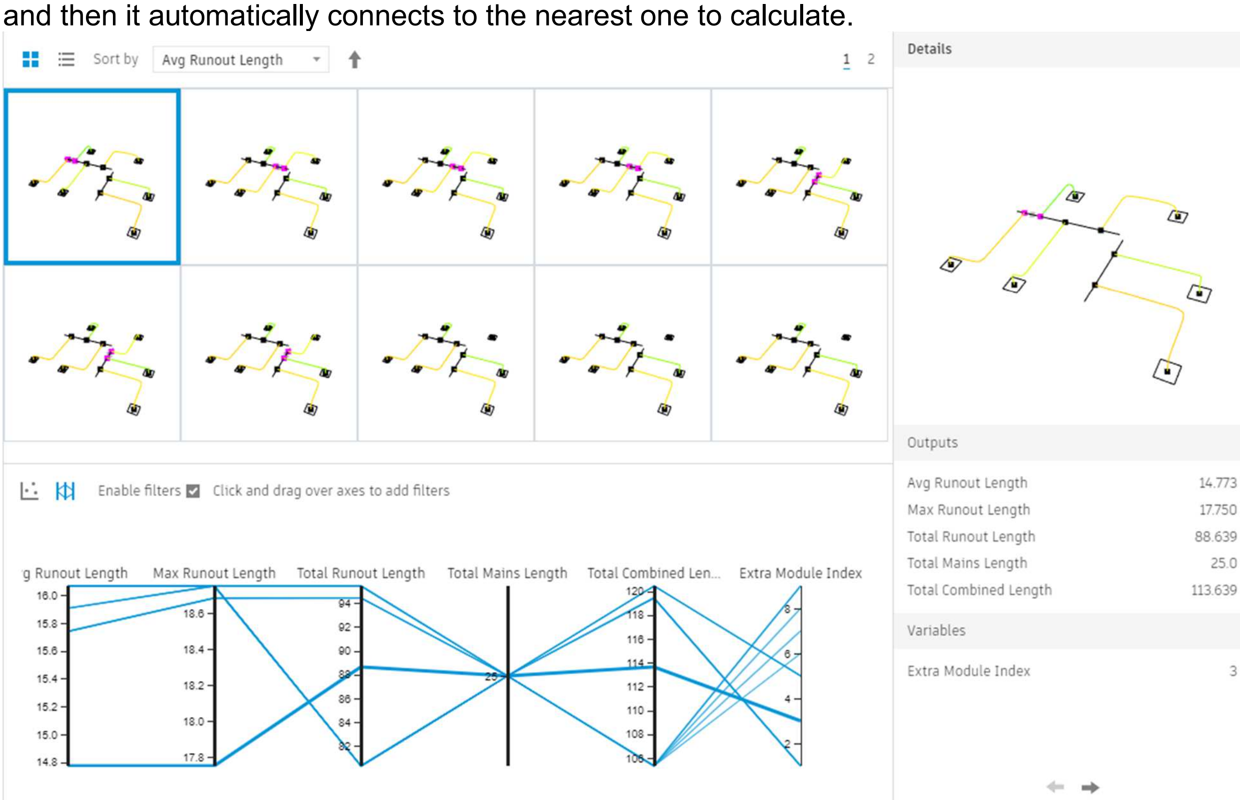
We lay out ducts based on the location, size of our terminal, and airflow. This is normal standard practice for engineering. What's not normal is going back and modifying the duct to be optimized for assembly and manufacturing.

With a little bit of effort, we can set our designs up for success. We used BIM automation to replace the last 5' module with two 2.5' modules. We split out the connection into a final step as well, so they are scripts that run back to back to back. Instead of making them one giant script, we allowed humans to be involved in the process and make decisions. They can visually see how many terminals and modules they have to make educated decisions instead of having the machine do it for them.

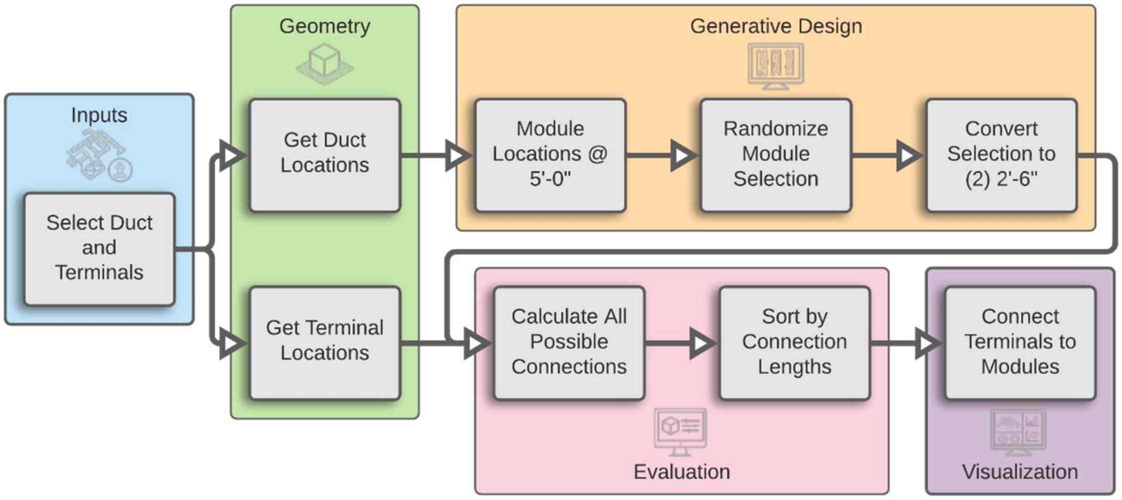
Back to our layout that we previously had. Instead of just replacing the last 5' module with two 2.5', it becomes an issue of which is the best module to replace. What happens if I replace the first module and align with two 2.5' instead of the last module?

The last module was our target because, simply because we had already connected all the other modules – that's where the emotional part of the design comes in. If I have already done all this work, then I'm not going to go back and redesign it because I may think I have a better answer. Our problem statement becomes "iterate replacing each module with smaller modules and optimize the duct length." Optimizing the entire duct length is what we're after. That overall includes the mains and the run outs added together.

For this we would use generative design, because we have a computational design problem and an optimization problem. We have our mains/terminals placed and there's the magenta designation there that is the two 2.5' modules. You can see that moving throughout the design and then it automatically connects to the nearest one to calculate.



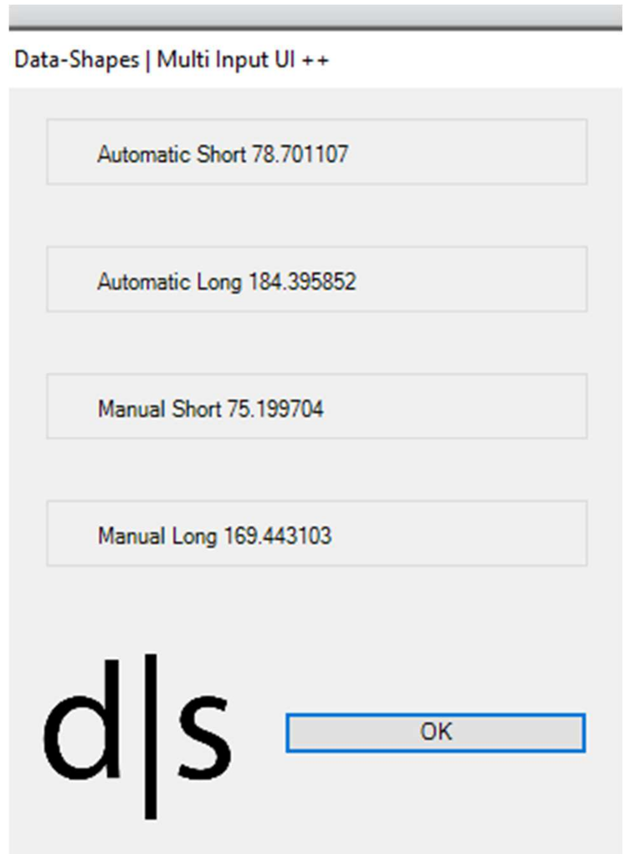
Below is the rough outline of the generative design process that includes getting objects, which is the inputs and geometry, and feeding them through the generative design algorithm and evaluation stages, finally presenting them through the generative design interface for design visualization and analysis. This is the process that we use to develop our code.



Sorting by overall duct length, we can iterate through a couple of the options and decide which one was our best of total combined length. Some are very close and that is where the engineering judgement comes in. This helped us decide that the first module in that line was the best one that would give us the optimized length.

It's actually really hard to round trip that decision back into Revit so we ended up just getting it back to the BIM automation instead of relying on generative design to try to connect all those systems. Revit systems can be very finicky to reconnect all those connectors. We ended up using generative design to find the solution and then relied on the human to actually implement that design, giving them complete control over the design process.

Validate the design optimization



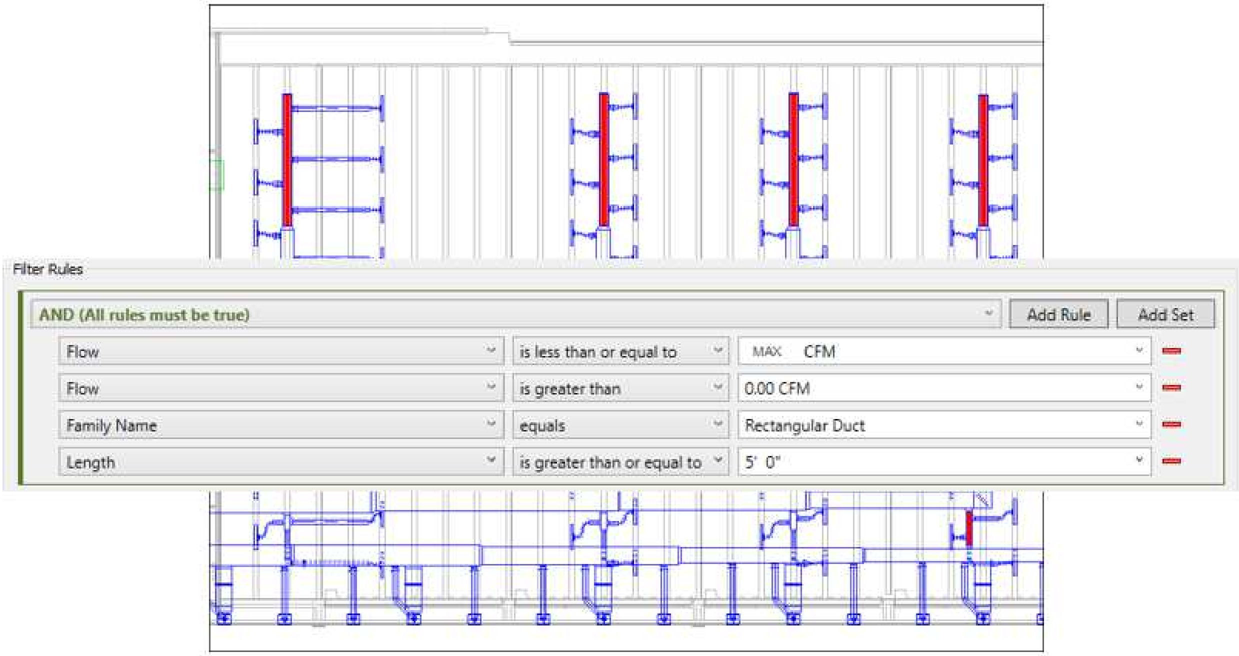
Next up is to validate that optimization. Engineers are inherently skeptical people, especially with automation and math.

We ended up creating more automation to prove our existing automation. We developed a "beat the machine" script so that designers can see the totals from the optimization from generative design and a redo of the layout if they have a better idea.

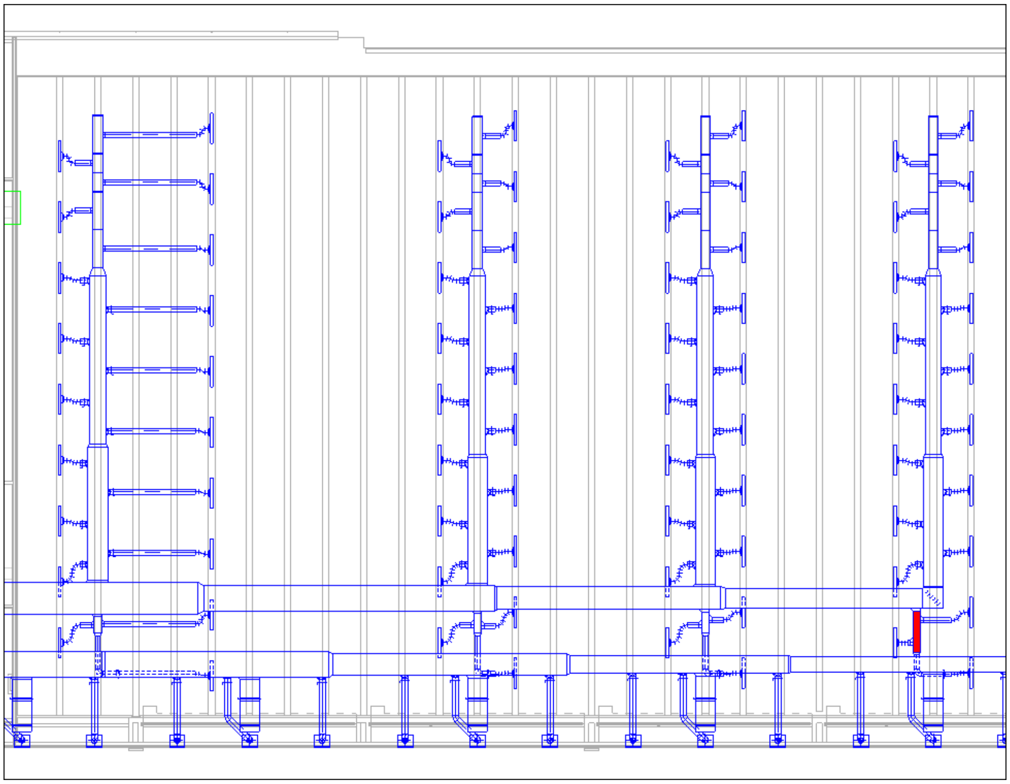
What that allows us to do is to challenge the assumptions that we have whenever we created this process to begin with. This process was created relying on the assumption that all the duct is the same size. It is all running on an X/Y grid and there is no connections made in the Z axis. If you had a 45° angle and were able to cut out two modules, reduce the overall length, and then 45° back, then generative design is not going to give you that answer. Once you validate that design optimization for that design step, we also want to evaluate the overall design in context. We automated QA/QC scripts as well.

Create a quality review process integrated into the design process

There are a couple of methods here. Views and schedules, which are out of the box and then we also automated exports for quality review.



This is simply a view in Revit with the duct layout and a filter for that design view to highlight ducts. The target was anything longer than our 5' module. This isolated that duct and turned it red so that was a graphical indication to the designer that they needed to replace that ductwork with modules.



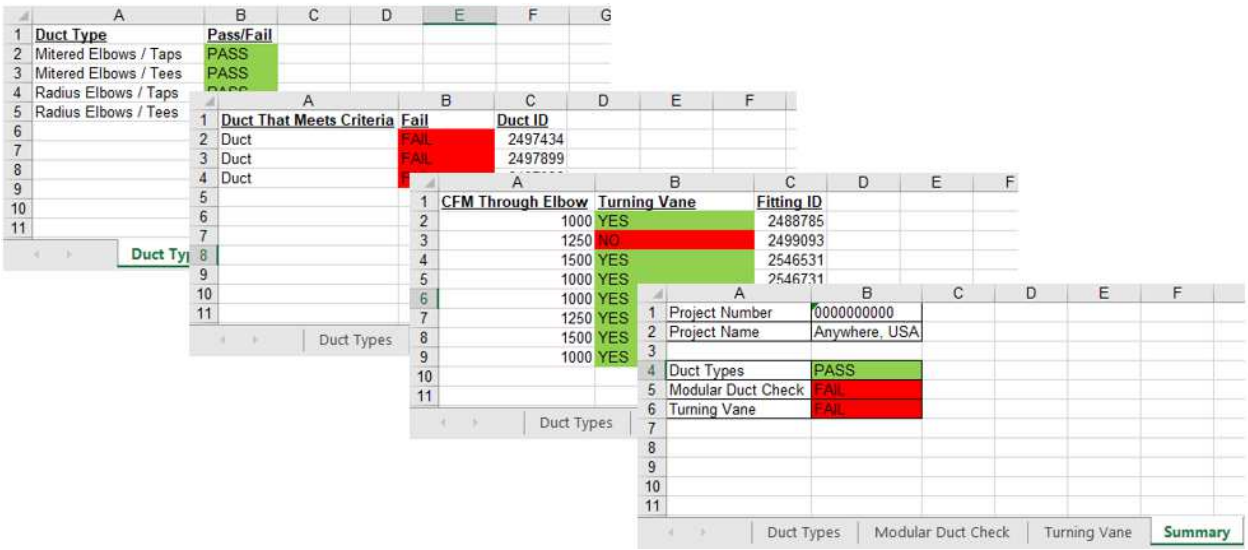
Above you can see in the lower right hand corner there's still one duct that's remaining red. That's a good example of a situation where a duct module may not have been best for that. Maybe for that area it's best to do stick built instead of prefab. This allows you to have a conversation with a reviewer or senior engineer and explain why you think that the module wouldn't be the best fit.

Another out-of-the-box component is a schedule. We are able to isolate our low volume ductwork for a specific flow/size over that 5' length and simply divide by five. That allowed us to provide an opportunity cost and be able to say you would be able to replace this with four modules instead of stick building this duct that's 20 feet.

<Duct Schedule>

A	B	C	D	E
Family and Type	Flow	Size	Length	Number of Modules
Rectangular Duct: 233113-Mitered Elbows / Taps	1790 CFM	36"x24"	28' - 8 7/8"	6
Rectangular Duct: 233113-Mitered Elbows / Taps	1000 CFM	18"x12"	20' - 8 1/16"	4
Rectangular Duct: 233113-Mitered Elbows / Taps	1000 CFM	18"x12"	20' - 9 19/32"	4
Rectangular Duct: 233113-Mitered Elbows / Taps	1000 CFM	18"x12"	20' - 9 19/32"	4
Rectangular Duct: 233113-Mitered Elbows / Taps	1000 CFM	18"x12"	20' - 6 19/32"	4
Rectangular Duct: 233113-Mitered Elbows / Taps	600 CFM	12"x10"	5' - 5 15/32"	1
Rectangular Duct: 233113-Mitered Elbows / Taps	2000 CFM	20"x14"	29' - 4 15/16"	6
Rectangular Duct: 233113-Mitered Elbows / Taps	1790 CFM	28"x24"	28' - 7 7/8"	6
Rectangular Duct: 233113-Mitered Elbows / Taps	2000 CFM	20"x14"	30' - 4 21/32"	6
Rectangular Duct: 233113-Mitered Elbows / Taps	1350 CFM	30"x10"	7' - 10 9/16"	2
Rectangular Duct: 233113-Mitered Elbows / Taps	1350 CFM	30"x10"	8' - 2 9/16"	2
Rectangular Duct: 233113-Mitered Elbows / Taps	1350 CFM	30"x10"	8' - 4 9/16"	2
Rectangular Duct: 233113-Mitered Elbows / Taps	1350 CFM	30"x10"	8' - 6 9/16"	2
Rectangular Duct: 233113-Mitered Elbows / Taps: 13				49

We took it a step further than that, though. We then created a process to integrate into our QA/QC workflow. That allowed us to automate to Excel. First, we check that our duct types are set to our standards. Then, we move on to checking to see if there's any ductwork that meets the criteria that we showed in the filters before. If there is, then it simply says that it failed and gives a duct element ID to quickly locate that item.



There are also other checks that we perform in our QC process. This example was that we have a certain level of CFM through an elbow that should have turning vanes but does not so that fails as well. We then give a summary sheet that we would print out and hand in for QC. This aids in a thorough checking of our design, even though we automated a good portion of it.