

Auto Generating and Optimizing Modular Air Duct Layouts in Revit

BES502811

Daniel Kaye
Design Technologist | EvolveLAB

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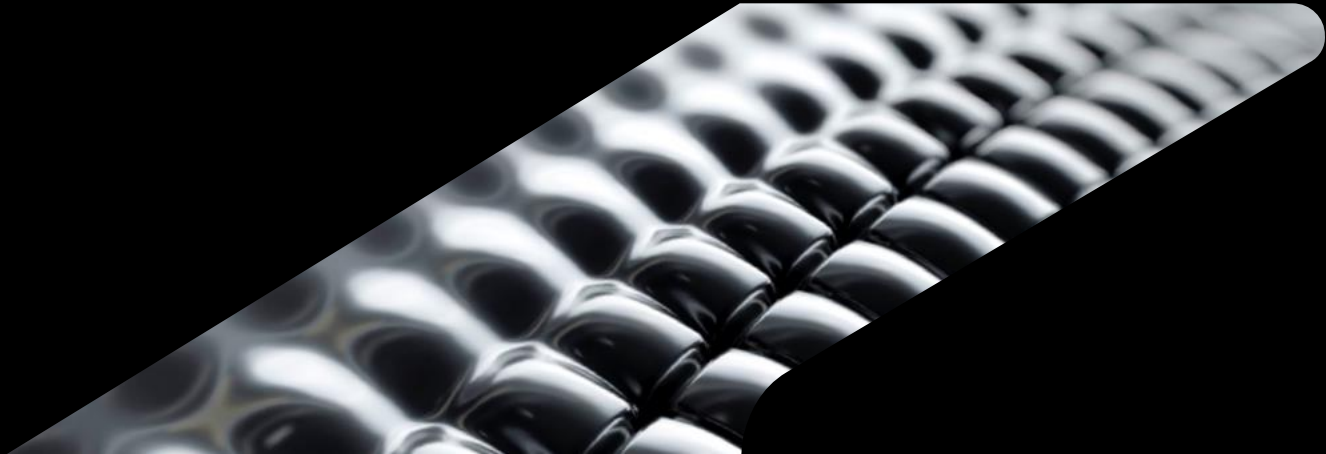
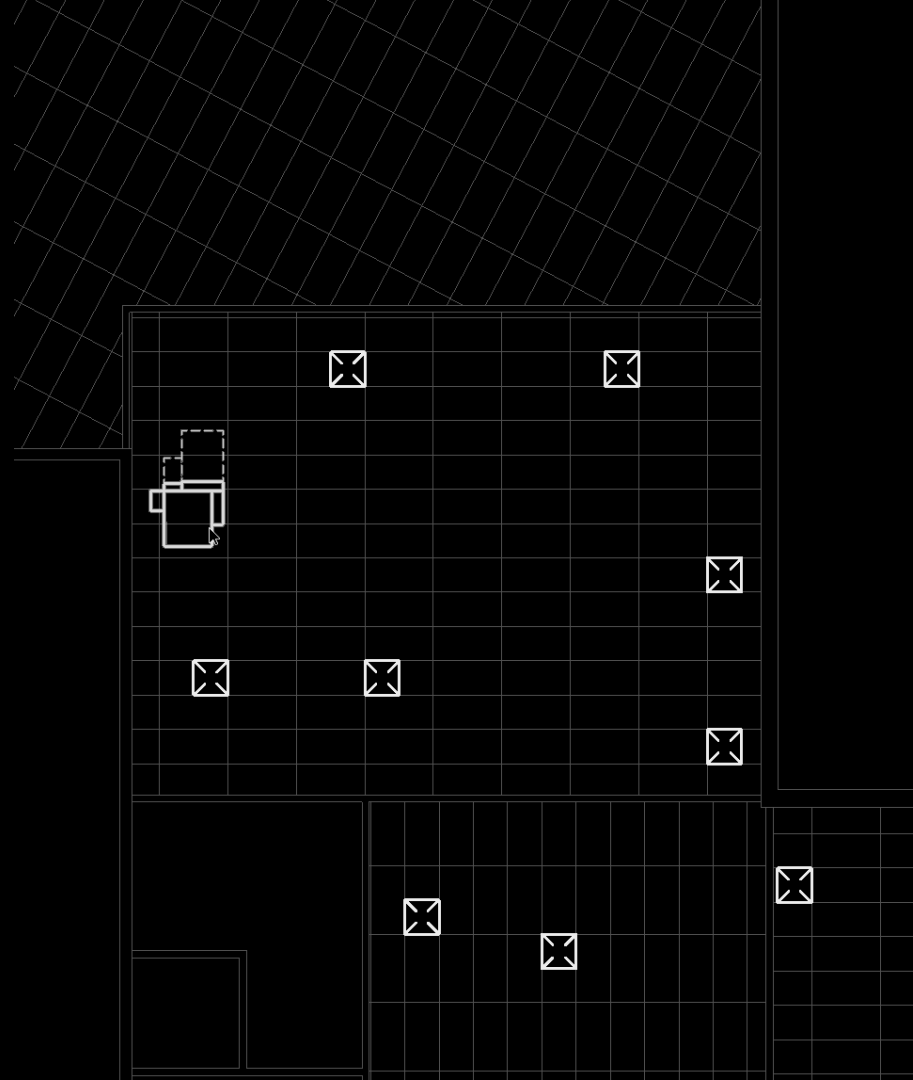
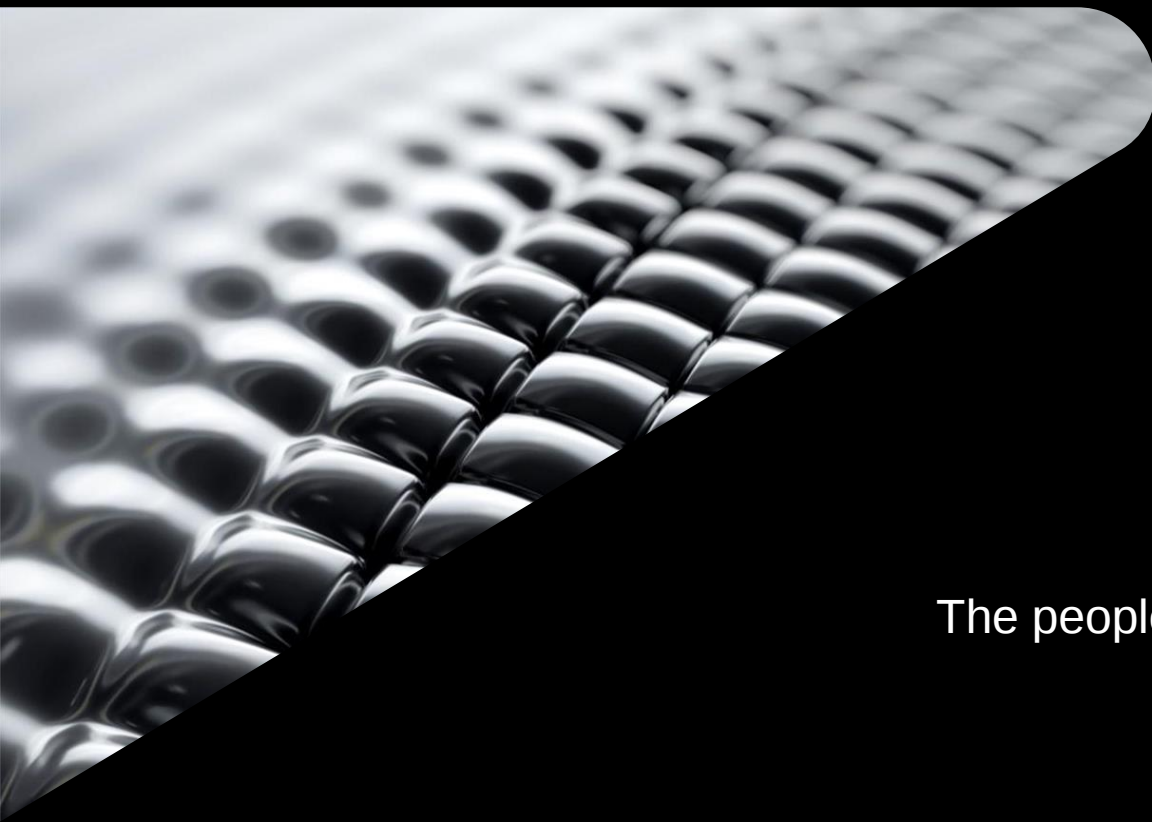


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2. The Problem
3. The Solution
4. Simulated Annealing
5. User Adoption
6. Beyond Ducts





1 - The Team

The people and companies behind the tool

Daniel Kaye

Design Technologist | EvolveLAB

- Syracuse University (NY)
 - 5-Year B. Arch
 - Minor in Computer Science
- Licensed architect (CO) turned software developer
 - 7 years as an architect & BIM Manager
 - 2+ years as an (official) software developer
- Interest in Computational Design and Geometric Algorithms
- Enjoys rock climbing and playing music
- EvolveLAB Director of Memes



Ben Guler

Partner + CTO | EvolveLAB

- 15+ Years experience in AEC Project and BIM Management Roles
- Experience with (and will happily nerd out over) almost every AEC technology out there (BIM, Dynamo, C# and Python, you name it he'll know it)
- Education
 - University of Illinois Chicago - BA Science of Architecture
 - Triton College, IL - Architecture and Fine Arts
- Enjoys hiking with his wife & daughters





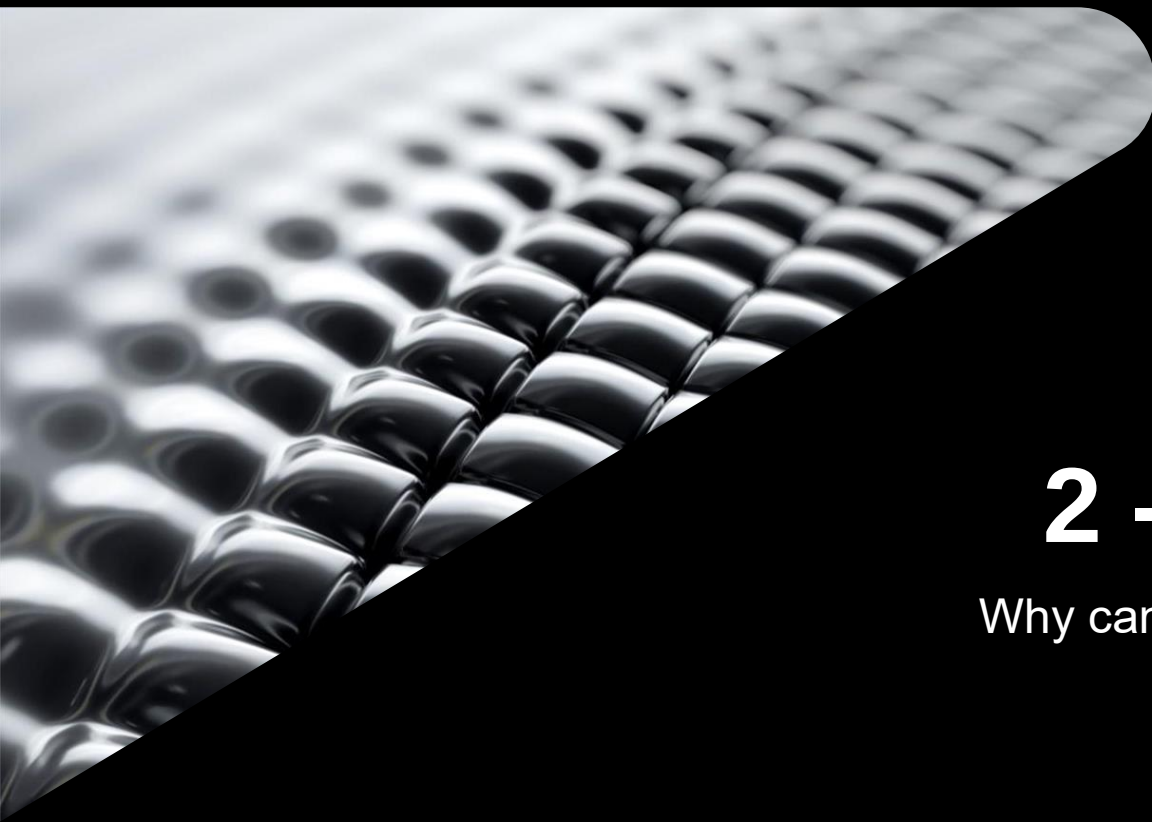
"Helping Architects, Engineers, and Construction Professionals Implement Design Technology"



"We provide a wide array of building system design engineering services across a variety of building types"



- Adam Roth | BIM/VDC Director, Associate
- Dustin Schafer | CTO
- Nick Boyts | Senior BIM/VDC Application Specialist
- VJ Qureshi | Director of Software Development
(not pictured)



2 - The Problem

Why can't the contractor just work it out?

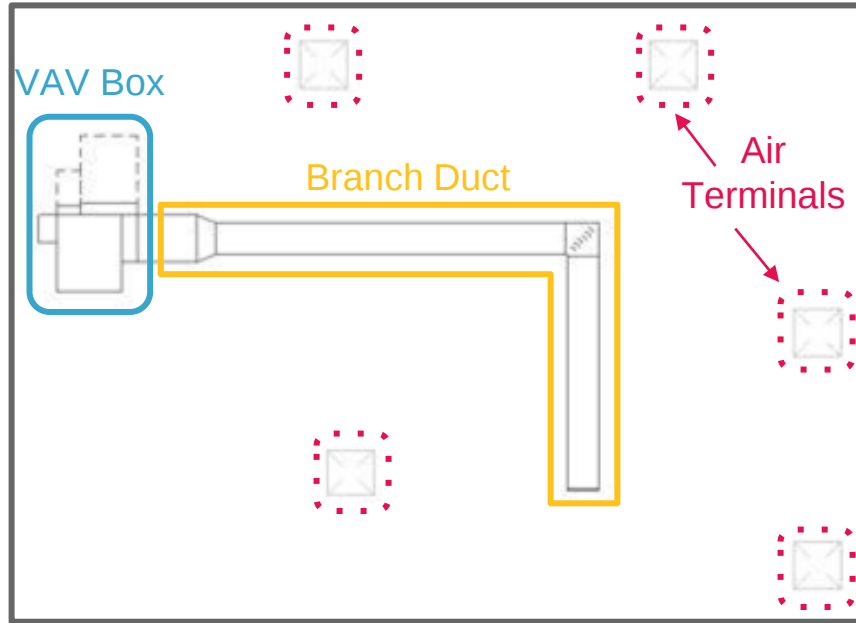


Modularized Ducts

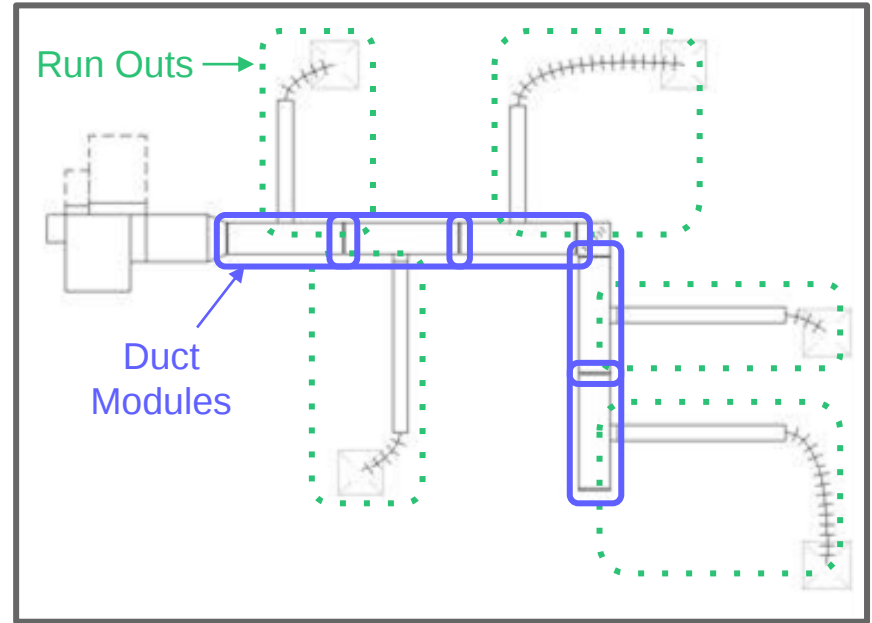
A kit-of-parts for mechanical systems

- *DfMA for MEP with Generative Design and BIM Automation*
 - Autodesk University white paper by Adam Roth and Sean Turner
 - Partnered with US Engineering Innovations
- How can we intuitively design with this system inside of Revit?

Connecting VAV Boxes to Air Terminals



input

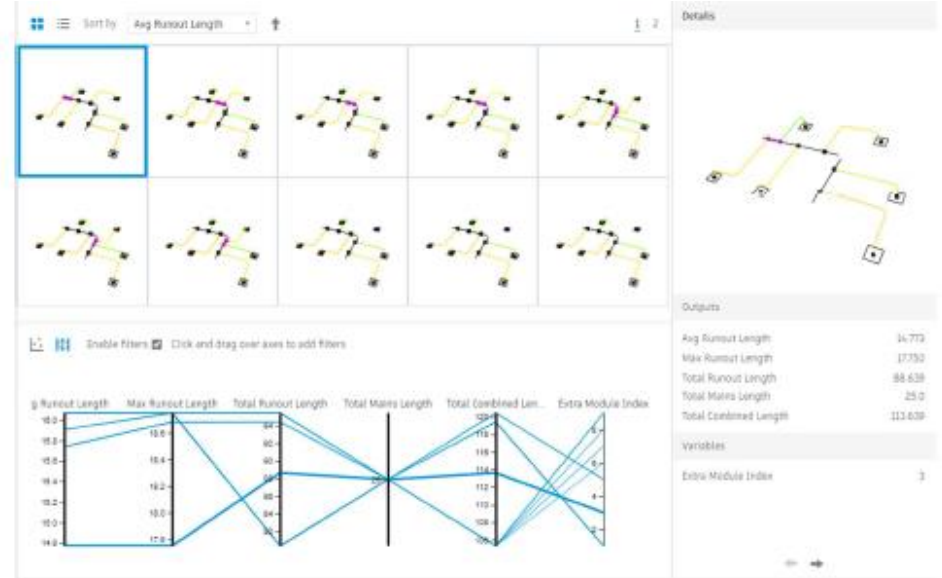


goal

Prototyping with Dynamo & Revit GD

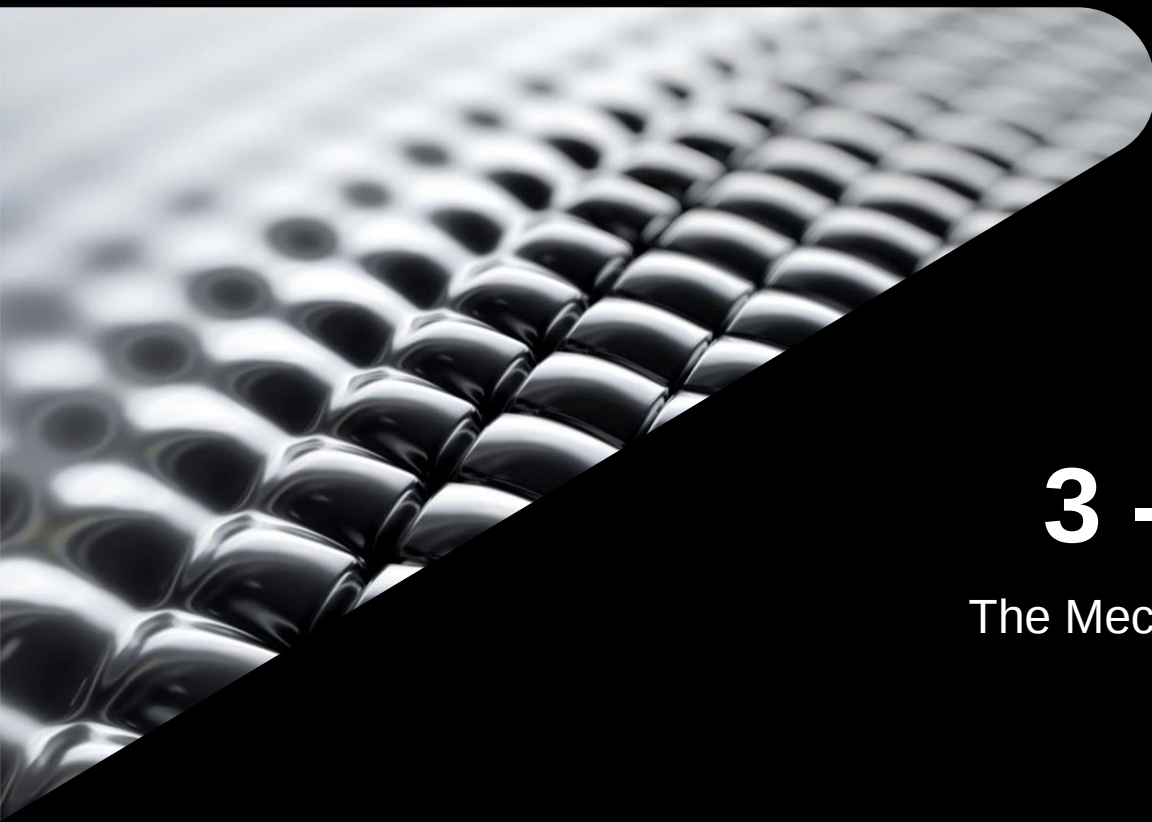
Building on a strong foundation

- Build parts in Revit
- Proof of concept with Dynamo
- Optimization with Revit Generative Design
- Ideal for Power Users



2 - The Problem Recap

- Modular Duct System
- Prototyped with Dynamo and Revit GD
- Connect VAV to Air Terminals
- User Adoption

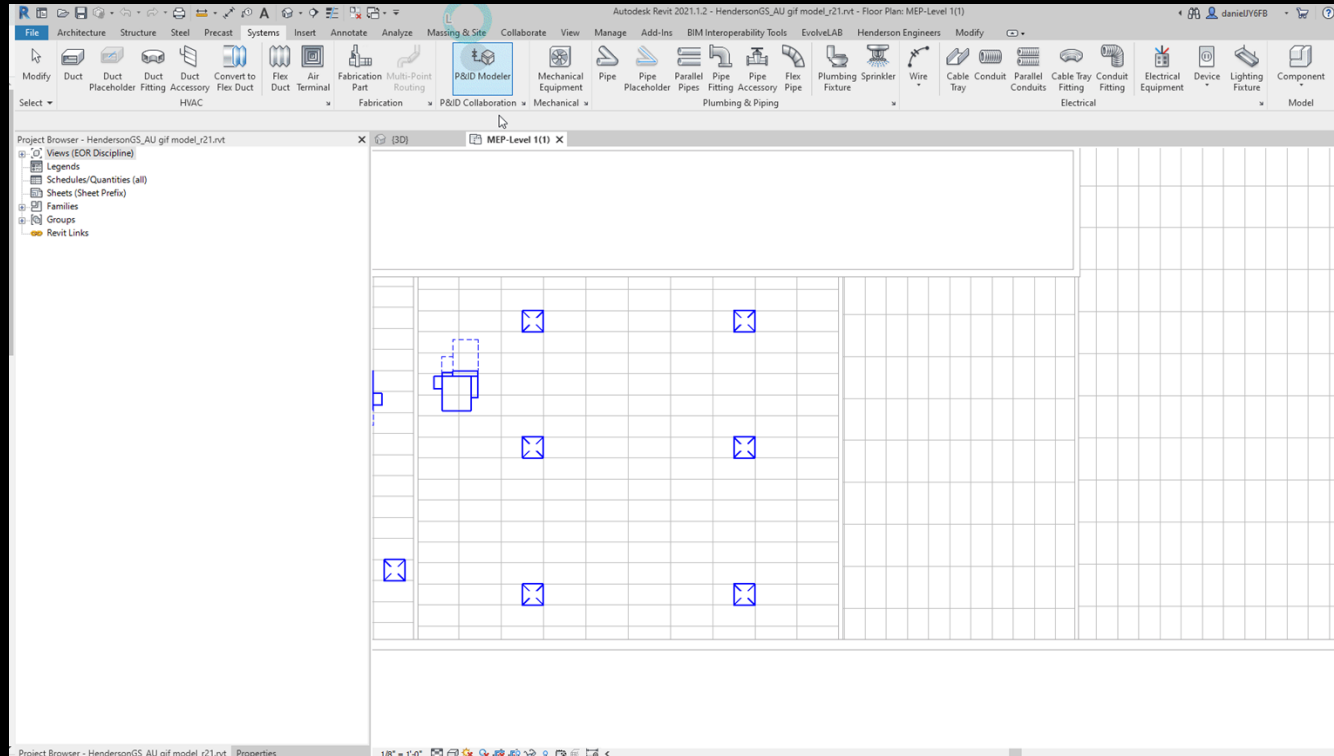


3 - The Solution

The Mechanical Run-Out Duct Generator

The Modular Duct Generator App

A Revit Add-In that generates optimized modular duct runs



The Modular Duct Generator App 101

A simple 'how to' for using your custom mechanical generative design application.

1. Select VAV Box & Options
2. Draw Main Branch Duct
3. Generate Solutions
4. Examine Solutions
5. Bake to Revit
6. Auto-Gen Branch Duct

The Modular Duct Generator App

A simple 'how to'

1. Select VAV Box & Options

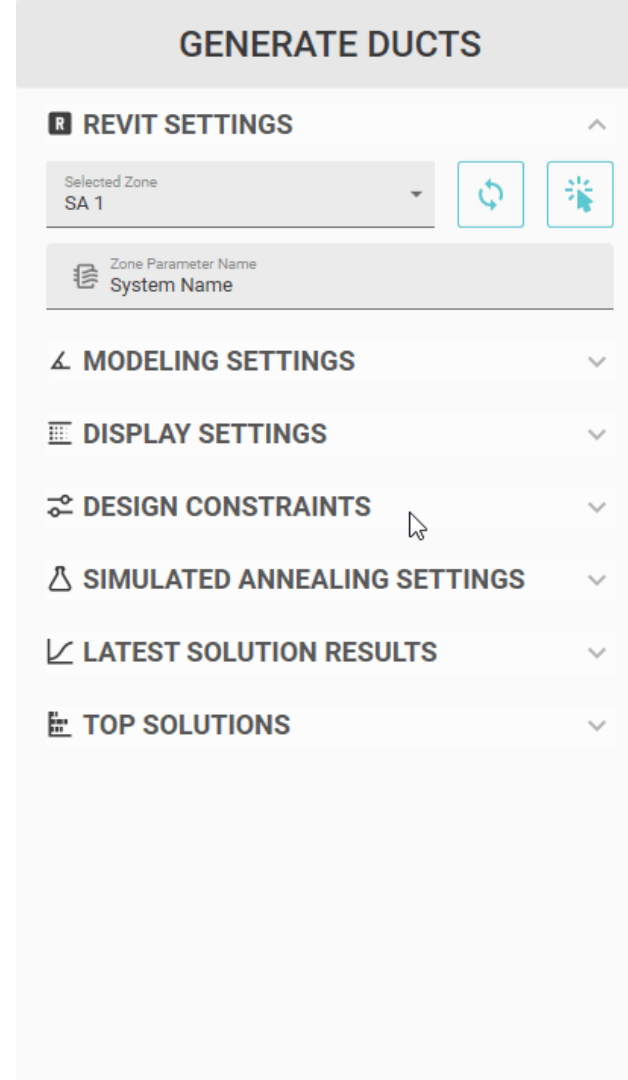
2. Draw Main Branch Duct

3. Generate Solutions

4. Examine Solutions

5. Bake to Revit

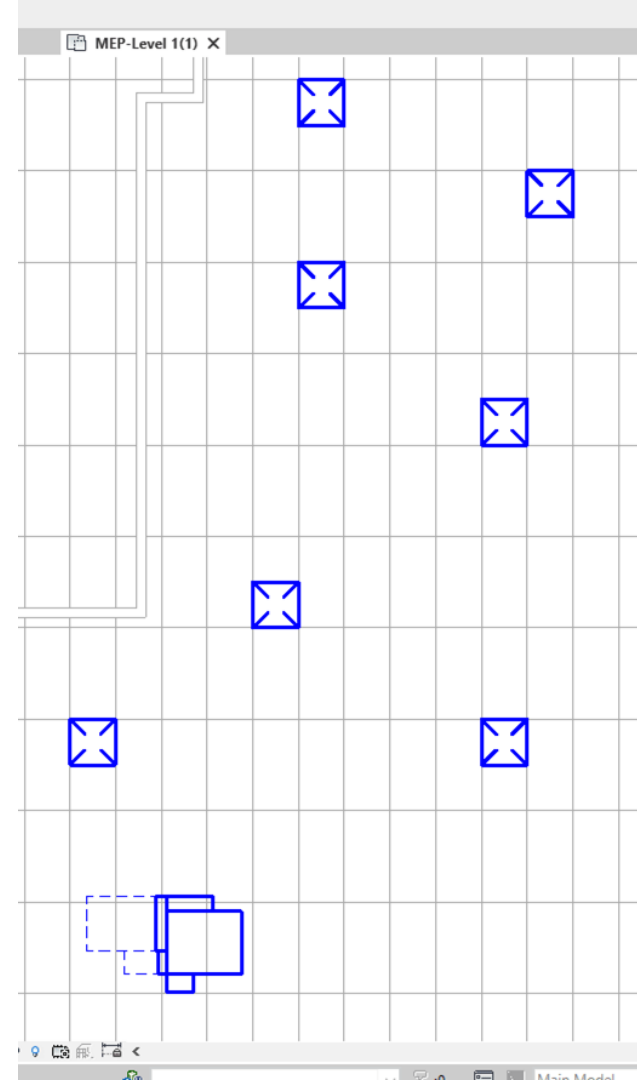
6. Auto-Gen Branch Duct



The Modular Duct Generator App

A simple 'how to'

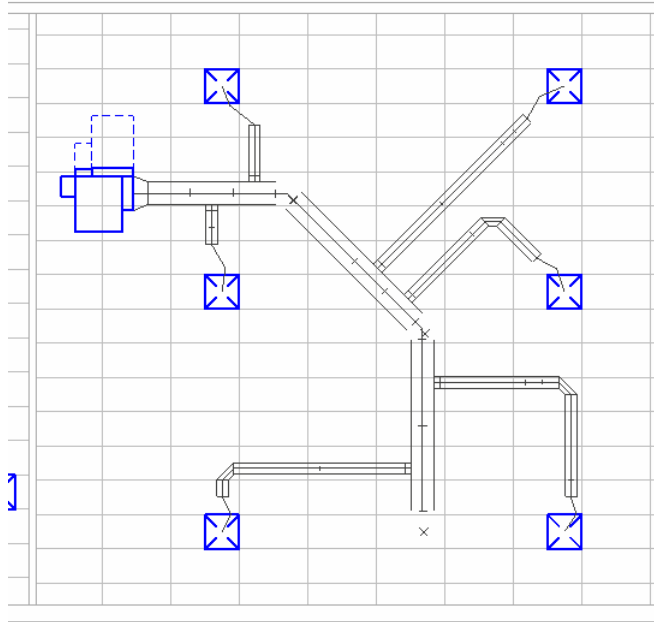
1. Select VAV Box & Options
- 2. Draw Main Branch Duct**
3. Generate Solutions
4. Examine Solutions
5. Bake to Revit
6. Auto-Gen Branch Duct



The Modular Duct Generator App

A simple 'how to'

1. Select VAV Box & Options
2. Draw Main Branch Duct
- 3. Generate Solutions**
4. Examine Solutions
5. Bake to Revit
6. Auto-Gen Branch Duct



Henderson Engineers v0.0.6.3

DESIGN CONSTRAINTS

SIMULATED ANNEALING SETTINGS

Simulated Annealing Level
Low

SA Start Temperature
100

SA End Temperature
1

SA Cooling Rate
0.1

Max Frames
100

LATEST SOLUTION RESULTS

Initial Score 324.424777960769	Final Score 503.424777960769
Number of Solutions Tried 1	Number of Times Improved 3
Sum Run Out Duct Length 61.1415926535898	Intersections Detected 1
Number of 5' Modules 1	Number of 2.5' Modules 9

TOP SOLUTIONS

● Run Out Lengths ● Module Count ● Intersections ● Disconnected AT

Design 240	52.9	1	0
Design 340	59.94	1	0
Design 261	61.14	1	0

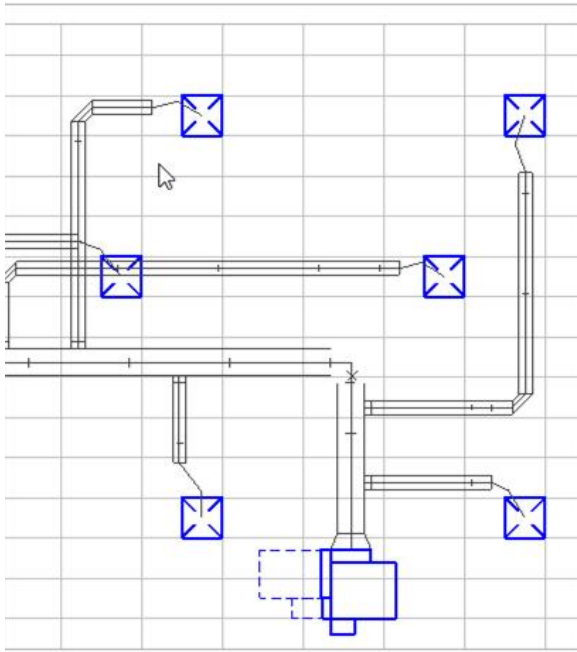
Draw Regen X

Auto-Gen Path BETA Bake to Revit ✓

The Modular Duct Generator App

A simple 'how to'

1. Select VAV Box & Options
2. Draw Main Branch Duct
3. Generate Solutions
4. Examine Solutions
 - a. Adjust Settings, Regenerate
5. Bake to Revit
6. Auto-Gen Branch Duct



Henderson Engineers v0.0.6.3

Medium

SA Start Temperature
1000

SA End Temperature
1

SA Cooling Rate
0.003

Max Frames
3000

LATEST SOLUTION RESULTS

Initial Score 339.566370614359	Final Score 389.566370614359
Number of Solutions Tried 2300	Number of Times Improved 23
Sum Run Out Duct Length 78.1887902047864	Intersections Detected 1
Number of 5' Modules 5	Number of 2.5' Modules 4

TOP SOLUTIONS

● Run Out Lengths ● Module Count ● Intersections
● Disconnected AT

Design 181	91.28	9	
Design 182	92.28	9	
Design 168	58.19	11	
Design 189	89.28	10	
Design 268	78.19	9	1

0 200

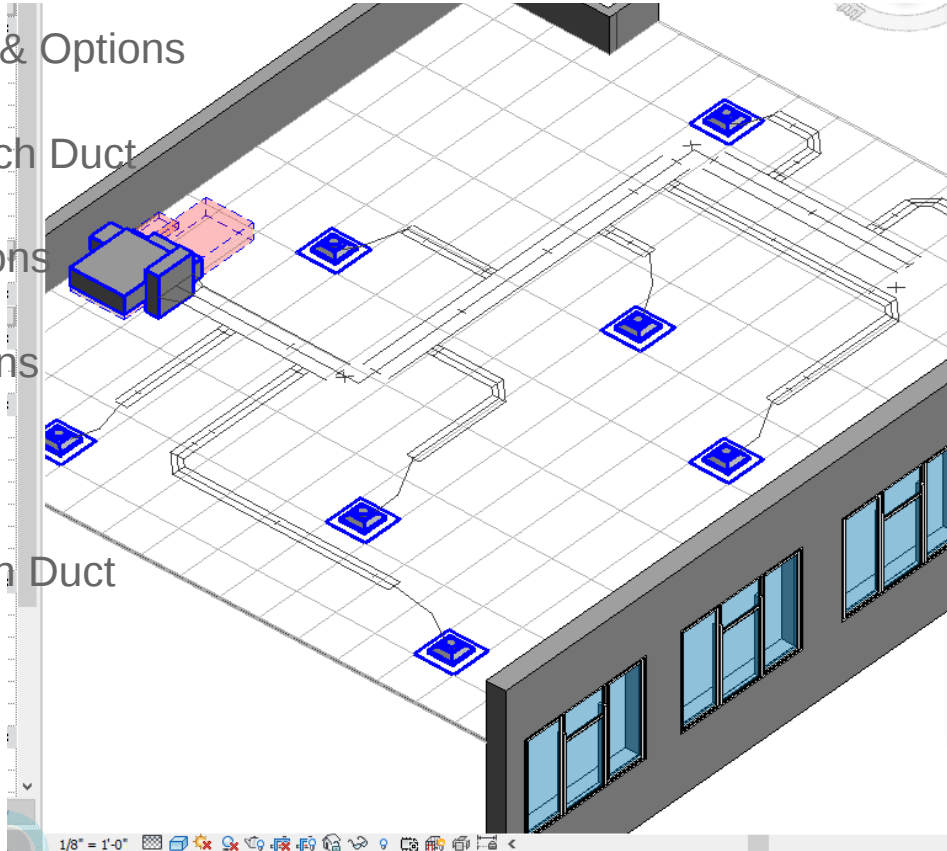
Draw Regen X

Auto-Gen Path BETA Bake to Revit ✓

The Modular Duct Generator App

A simple 'how to'

1. Select VAV Box & Options
2. Draw Main Branch Duct
3. Generate Solutions
4. Examine Solutions
- 5. Bake to Revit**
6. Auto-Gen Branch Duct



Henderson Engineers v0.0.6.3

DESIGN CONSTRAINTS

SIMULATED ANNEALING SETTINGS

Simulated Annealing Level
High

SA Start Temperature
10000

SA End Temperature
1

SA Cooling Rate
0.001

Max Frames
10000

LATEST SOLUTION RESULTS

Initial Score 339.566370614359	Final Score 326.707963267949
Number of Solutions Tried 9206	Number of Times Improved 12
Sum Run Out Duct Length 72.235987755983	Intersections Detected 0
Number of 5' Modules 4	Number of 2.5' Modules 6

TOP SOLUTIONS

● Run Out Lengths ● Module Count ● Intersections
● Disconnected AT

Design 147	67.24	8	
Design 148	68.24	8	
Design 163	63.24	10	
Design 172	72.24	10	

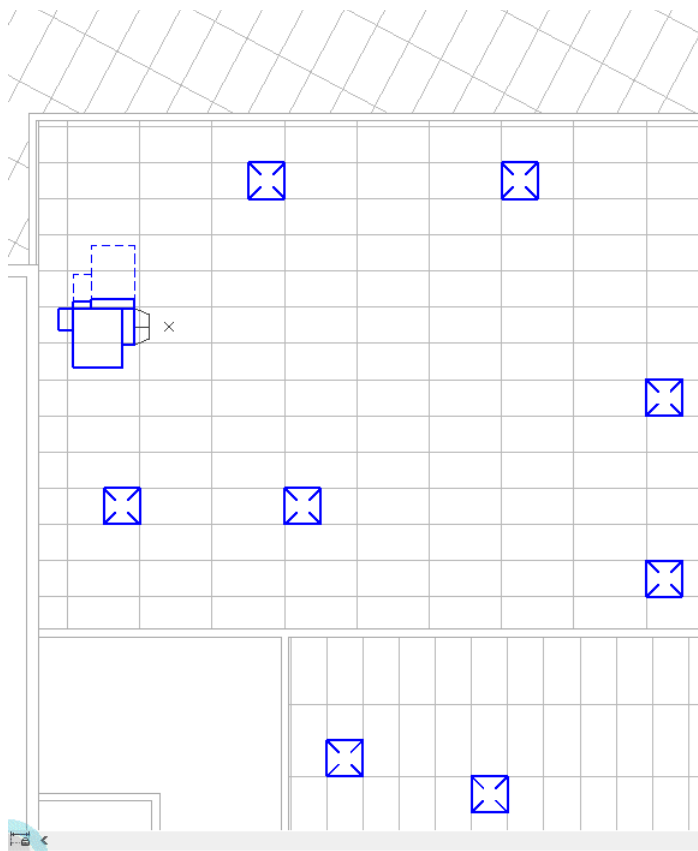
Draw Regen X

Auto-Gen Path BETA Bake to Revit

The Modular Duct Generator App

A simple 'how to'

1. Select VAV Box & Options
2. Draw Main Branch Duct
3. Generate Solutions
4. Examine Solutions
5. Bake to Revit
6. Auto-Gen Branch Duct



Henderson Engineers v0.0.6.3

DESIGN CONSTRAINTS

SIMULATED ANNEALING SETTINGS

Simulated Annealing Level: Custom

SA Start Temperature: 5000

SA End Temperature: 1

SA Cooling Rate: 0.002

Max Frames: 10000

LATEST SOLUTION RESULTS

Initial Score: 1200	Final Score: 1200
Number of Solutions Tried: 4255	Number of Times Improved: 0
Sum Run Out Duct Length: 0	Intersections Detected: 0
Number of 5' Modules: 0	Number of 2.5' Modules: 0

TOP SOLUTIONS

Run Out Lengths (blue circle), Module Count (red circle), Intersections (yellow circle), Disconnected AT (grey circle)

Design 600

6

0 500 1000

Draw Regen X Trash

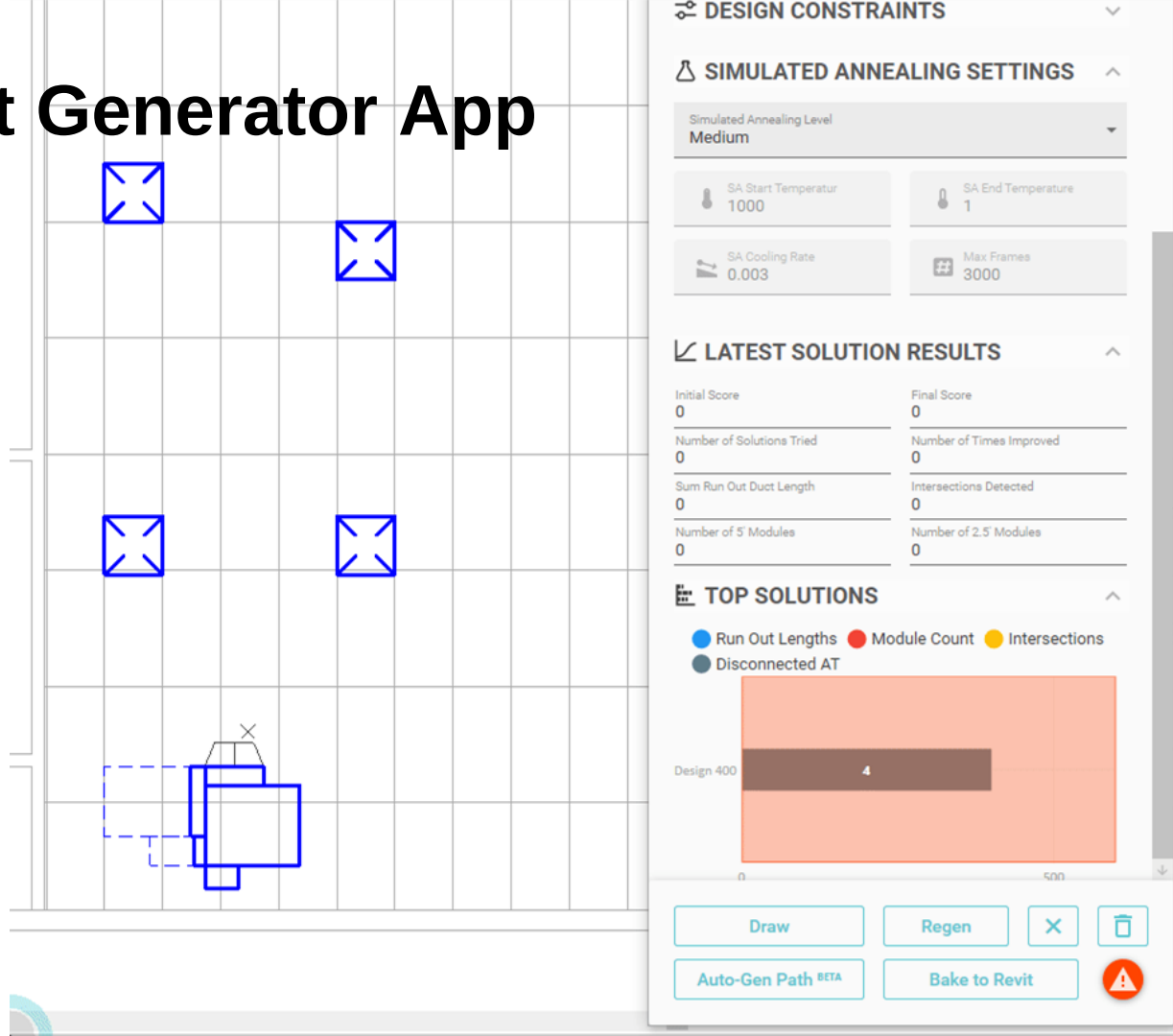
Auto-Gen Path BETA Bake to Revit Warning

The Modular Duct Generator App

A simple 'how to'

1. Select VAV Box & Options
2. Draw Main Branch Duct
3. Generate Solutions
4. Examine Solutions
5. Bake to Revit
6. Auto-Gen Branch Duct

a. Fails

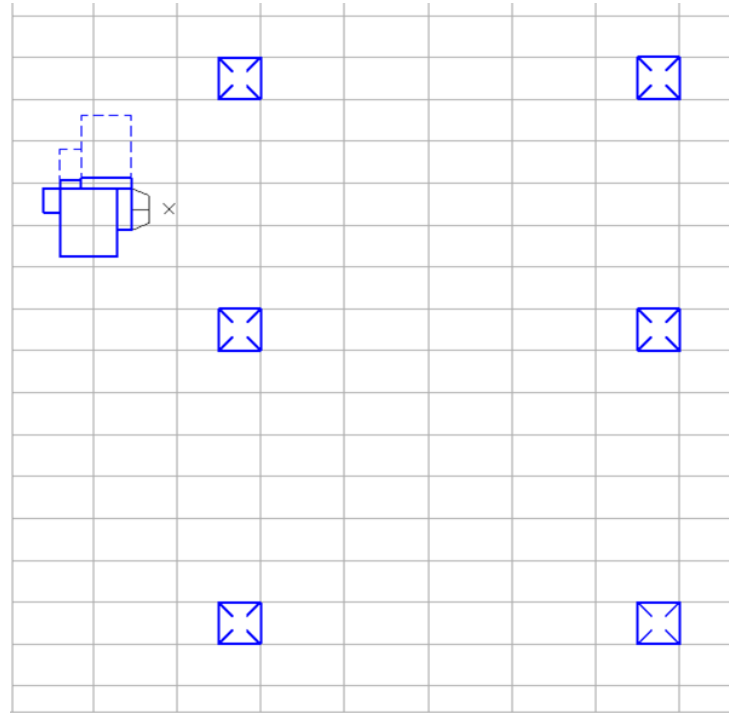


The Modular Duct Generator App

A simple 'how to'

1. Select VAV Box & Options
2. Draw Main Branch Duct
3. Generate Solutions
4. Examine Solutions
5. Bake to Revit
6. Auto-Gen Branch Duct

a. Fails



Henderson Engineers v0.0.6.3

DESIGN CONSTRAINTS

SIMULATED ANNEALING SETTINGS

Simulated Annealing Level: Custom

SA Start Temperature: 5000

SA End Temperature: 1

SA Cooling Rate: 0.002

Max Frames: 10000

LATEST SOLUTION RESULTS

Initial Score: 1200	Final Score: 1200
Number of Solutions Tried: 4255	Number of Times Improved: 0
Sum Run Out Duct Length: 0	Intersections Detected: 0
Number of 5' Modules: 0	Number of 2.5' Modules: 0

TOP SOLUTIONS

Run Out Lengths (blue dot), Module Count (red dot), Intersections (yellow dot), Disconnected AT (grey dot)

Design 600: 6

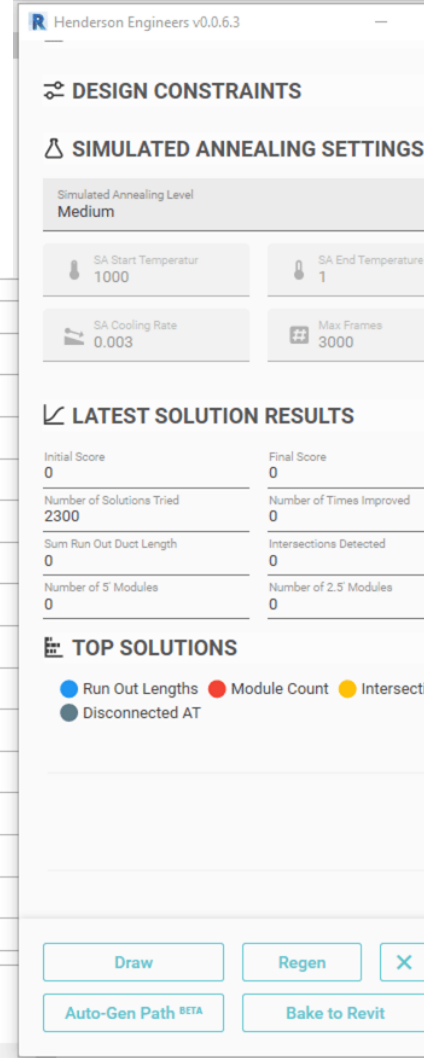
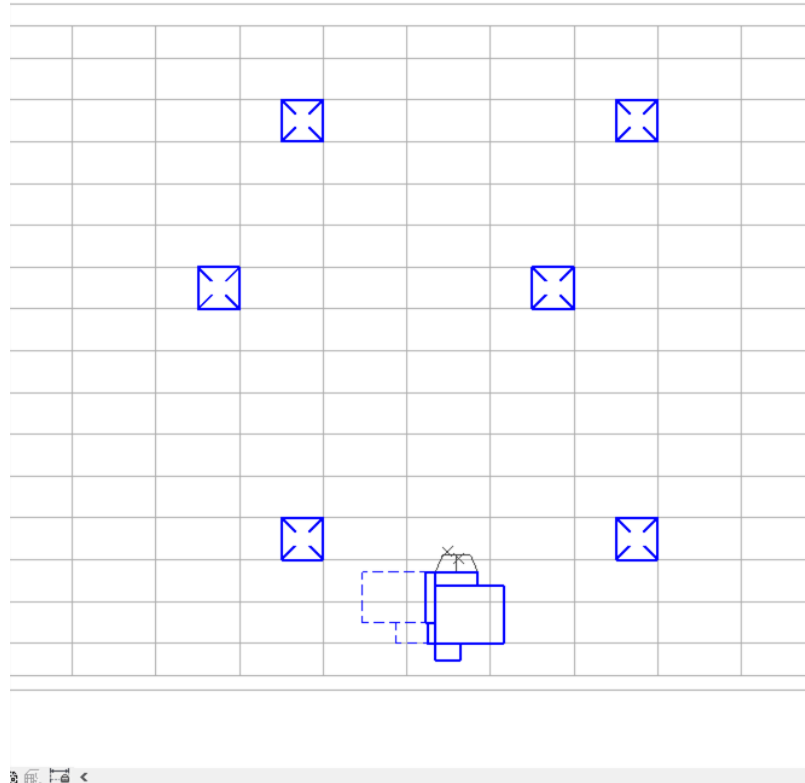
Buttons: Draw, Regen, X, Trash, Auto-Gen Path BETA, Bake to Revit, Warning

The Modular Duct Generator App

A simple 'how to'

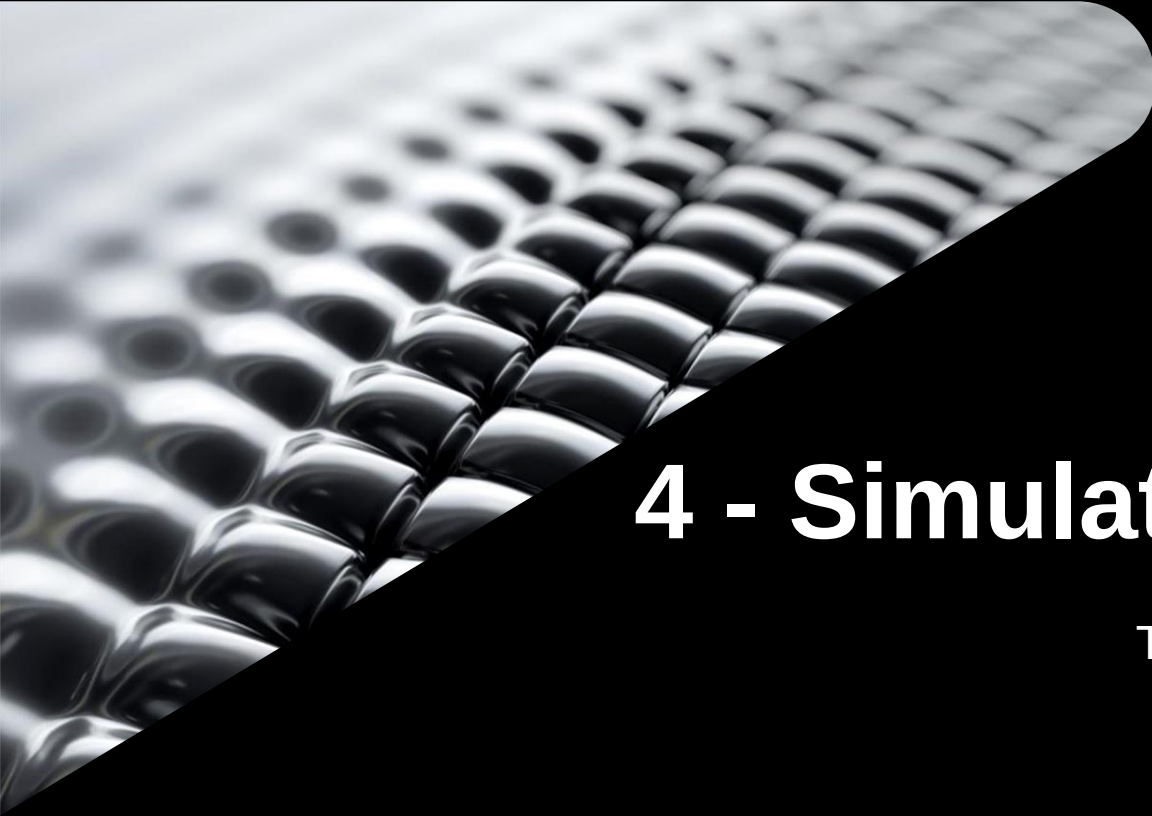
1. Select VAV Box & Options
2. Draw Main Branch Duct
3. Generate Solutions
4. Examine Solutions
5. Bake to Revit
6. Auto-Gen Branch Duct

a. Fails



3 - The Solution Recap

- Select VAV Box & Options
- Draw Main Branch Duct
- Generate Solutions
- Examine Solutions
- Bake to Revit
- Auto-Gen Branch Ducts



4 - Simulated Annealing

The brains behind the ~~brain~~ BIM

Generative Design

“the” industry buzzword?

What is generative design?

“If it can be done without a designer, it will be.”

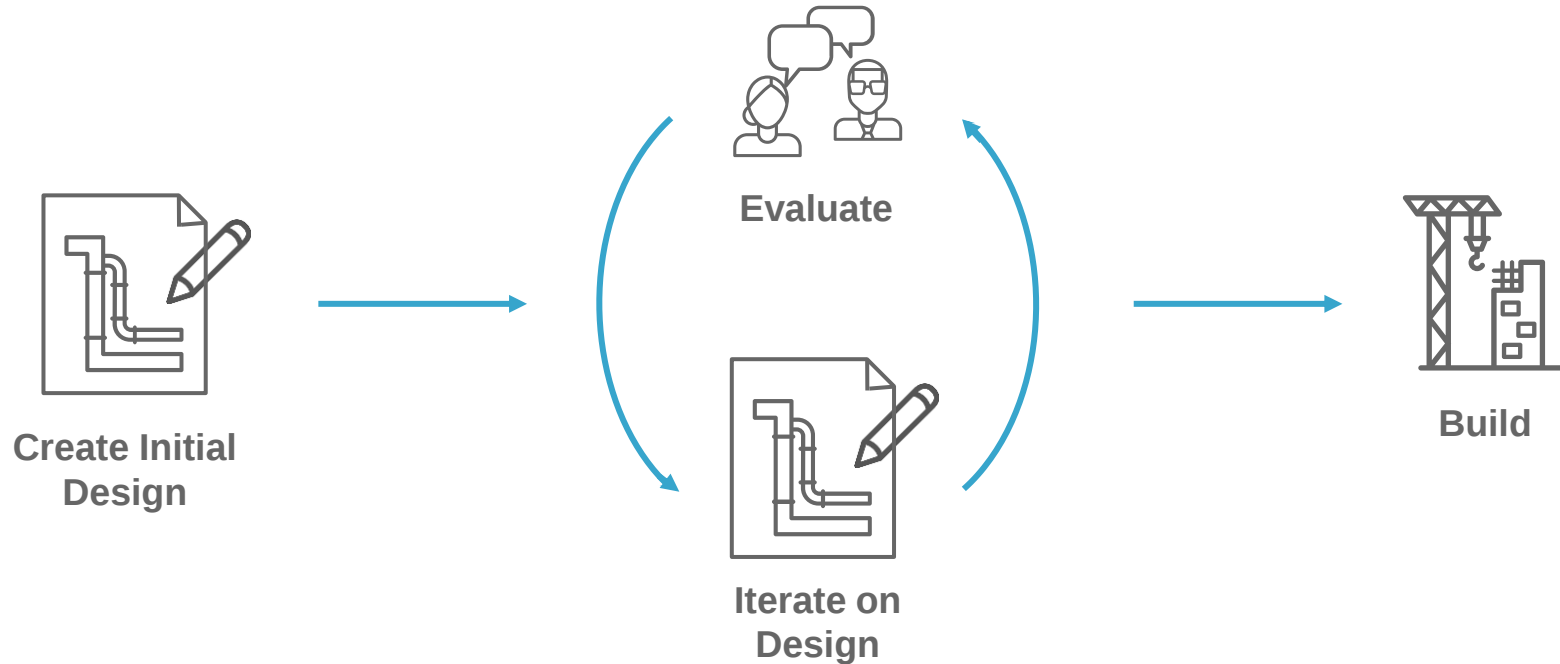
“Quickly generate high-performing design alternatives—many that you’d never think of on your own—from a single idea. With generative design, there is no single solution; instead, there are multiple great solutions. You choose the design that best fits your needs.” -Autodesk

“An iterative process from a computer’s point of view.”

“Generative design is a design exploration process. Designers or engineers input design goals into the generative design software, along with parameters such as performance or spatial requirements, materials, manufacturing methods, and cost constraints. The software explores all the possible permutations of a solution, quickly generating design alternatives. It tests and learns from each iteration what works and what doesn’t.” -Autodesk

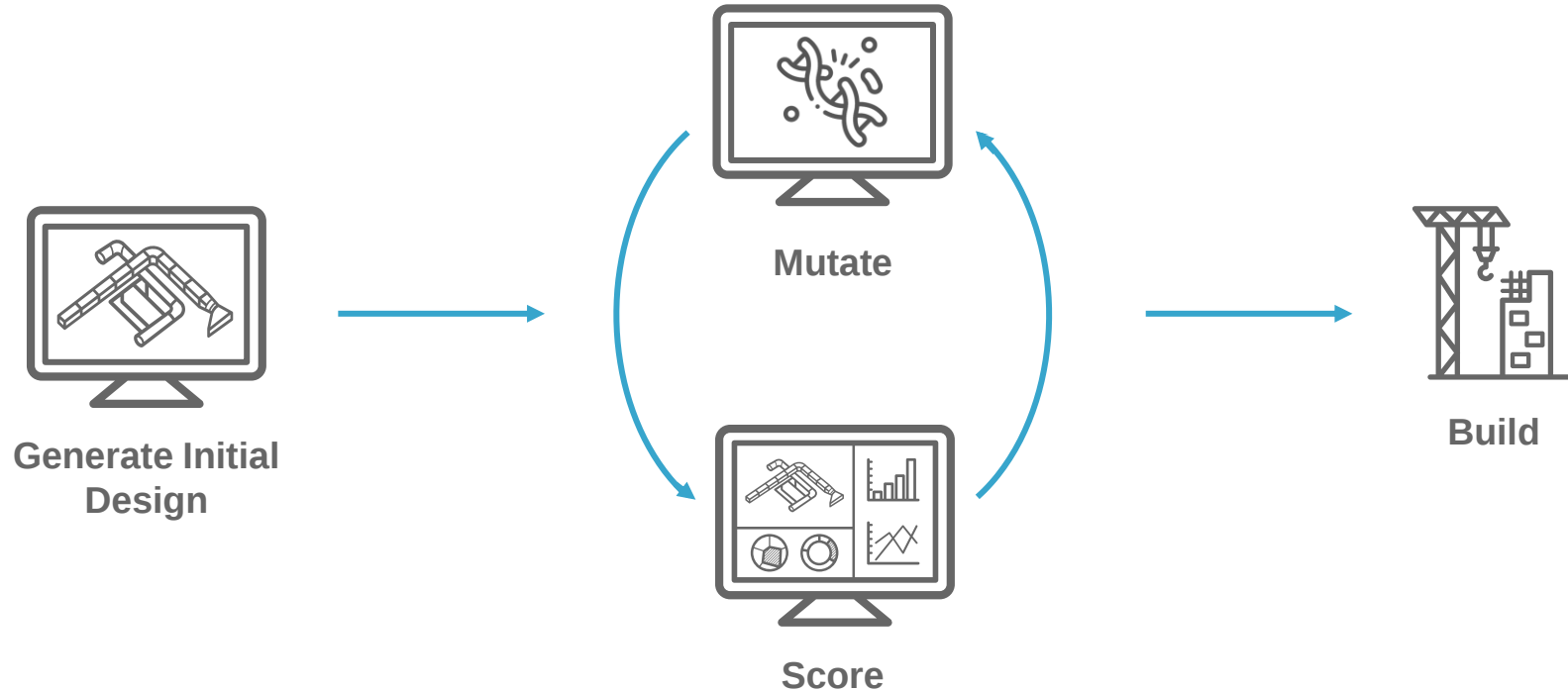
The Generative Design Process

The 'Manual' way



The Generative Design Process

The 'Computational Design' way



The Traveling Salesperson Problem

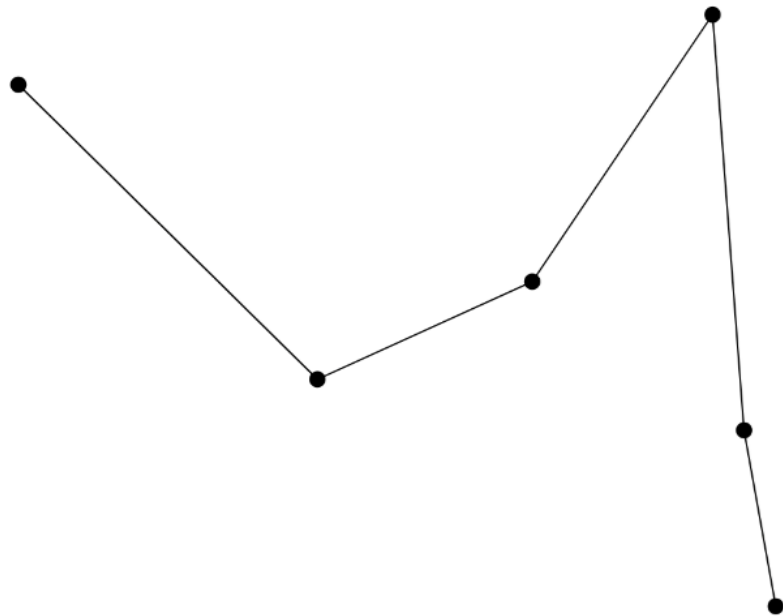
A yet unsolved problem



Traveling Salesperson

A yet unsolved problem

- 6 cities
- 720 Possibilities (6!)



Shortest Distance: 965.44 (46% eff.)
Improvements / Attempts: 4 / 720(100% com.)

Total Possibilities (6 Cities = 6!): 720
Algorithm: Lexicographic Order

Random

Lexicographic Order

Genetic Solver

GS Crossover

Simulated Annealing

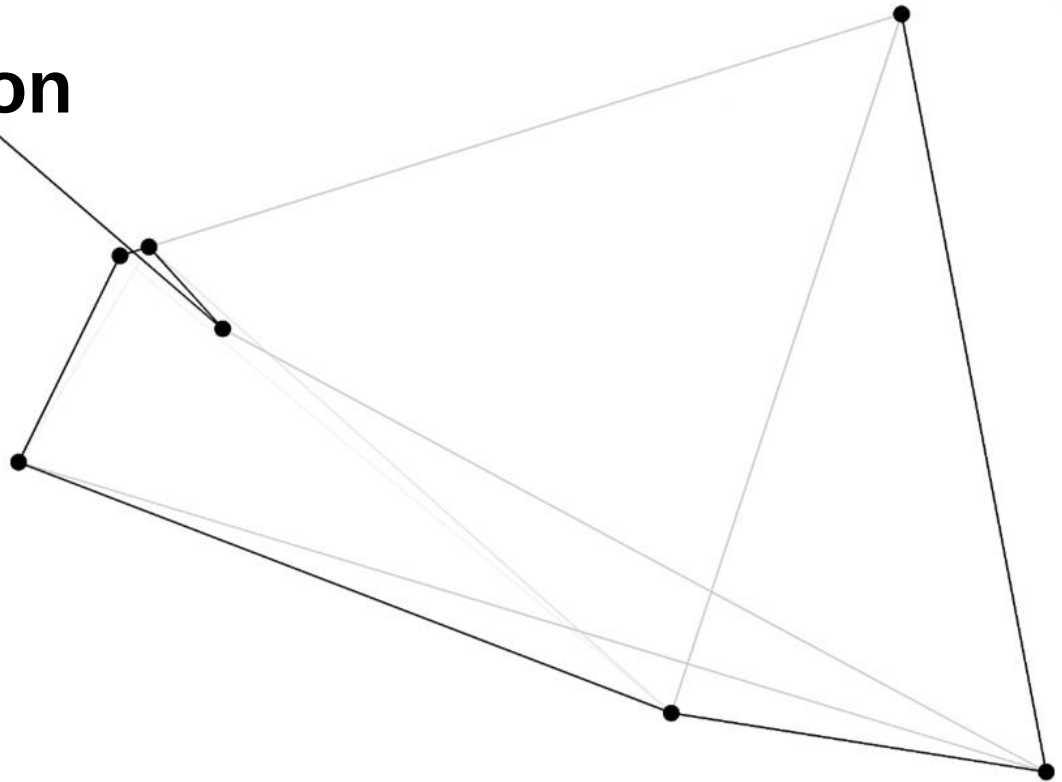


Number of Cities: 6

Traveling Salesperson

A yet unsolved problem

- 6 cities
 - 720 Possibilities (6!)
- 8 cities
 - 40,320 Possibilities (8!)



Shortest Distance: 1593.47 (57% eff.)

Improvements / Attempts: 6 / 178(0.44% com.)

Total Possibilities (8 Cities = 8!): 40320

Algorithm: Lexicographic Order

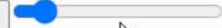
Random

Lexicographic Order

Genetic Solver

GS Crossover

Simulated Annealing



Number of Cities: 8

Traveling Salesperson

A yet unsolved problem

- 6 cities

- 720 Possibilities (6!)

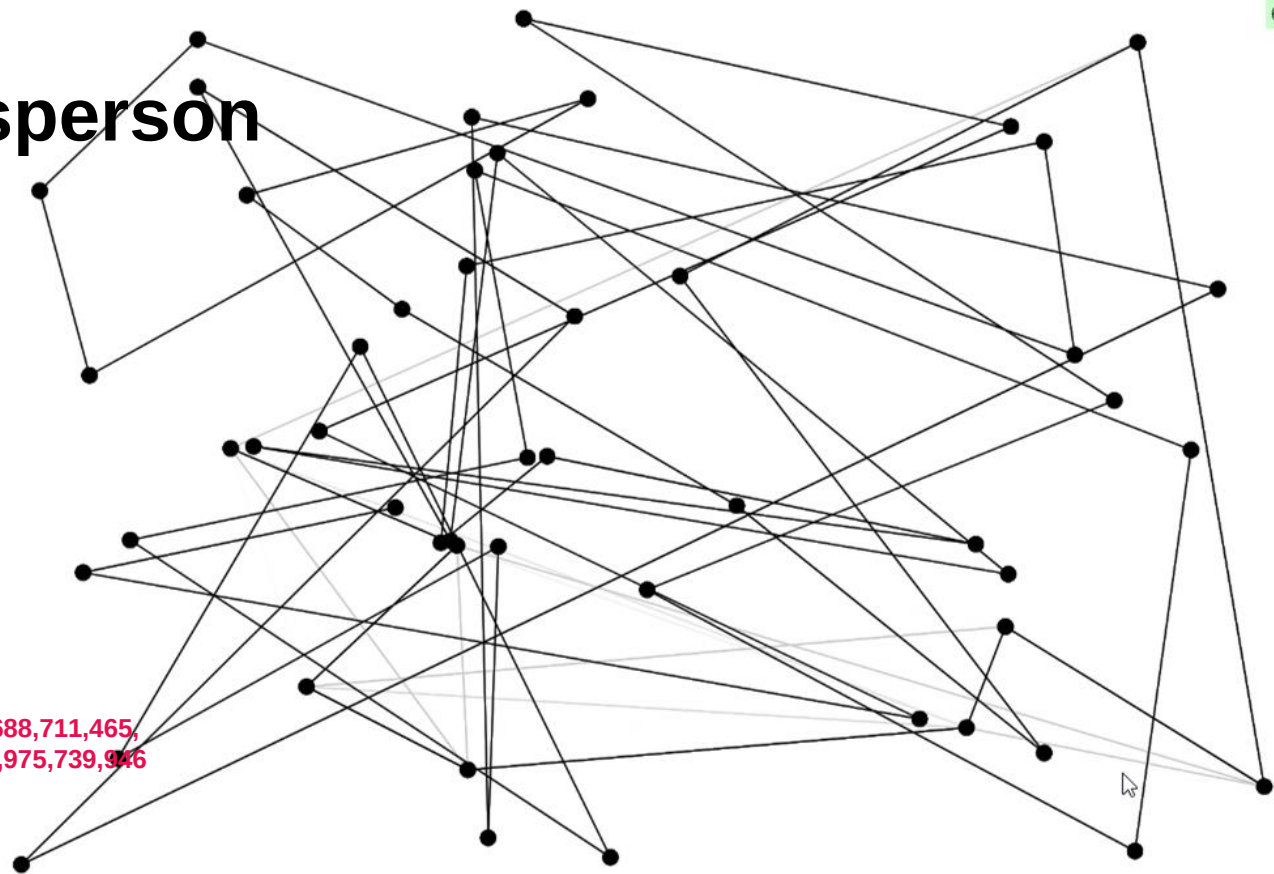
- 8 cities

- 40,320 Possibilities (8!)

- **50 cities** 16,055,627,510,117,791,688,711,465,
754,571,818,807,680,369,975,739,946
years (?)

- 30.4 Vigintillion
Possibilities

- 34,000,000,000,000,000,
000,000,000,000,000,000,
000,000,000,000,000,000,
000,000,000,000



Shortest Distance: 14992.32 (86% eff.)				Total Possibilities (50 Cities = 50!): 3.0414093201713376e+64	
Improvements / Attempts: 16 / 2162(NaN% com.)				Algorithm: Lexicographic Order	
Random	Lexicographic Order	Genetic Solver	GS Crossover	Simulated Annealing	

Number of Cities: 50

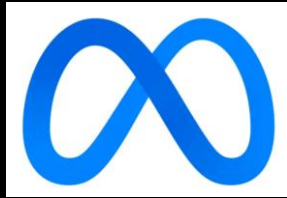
Metaheuristics

‘Meta’ - ‘Heuristics’

‘Meta’ - ‘Heuristics’

“Examples that employ heuristics include using trial and error, a rule of thumb or an educated guess.” -Wikipedia

‘Meta’ - ‘Heuristics’



Meta Platforms, Inc., formerly named Facebook, Inc., is an American multinational technology conglomerate based in Menlo Park, California. The company owns Facebook, Instagram, and WhatsApp, among other products and services.

‘Meta’ - ‘Heuristics’

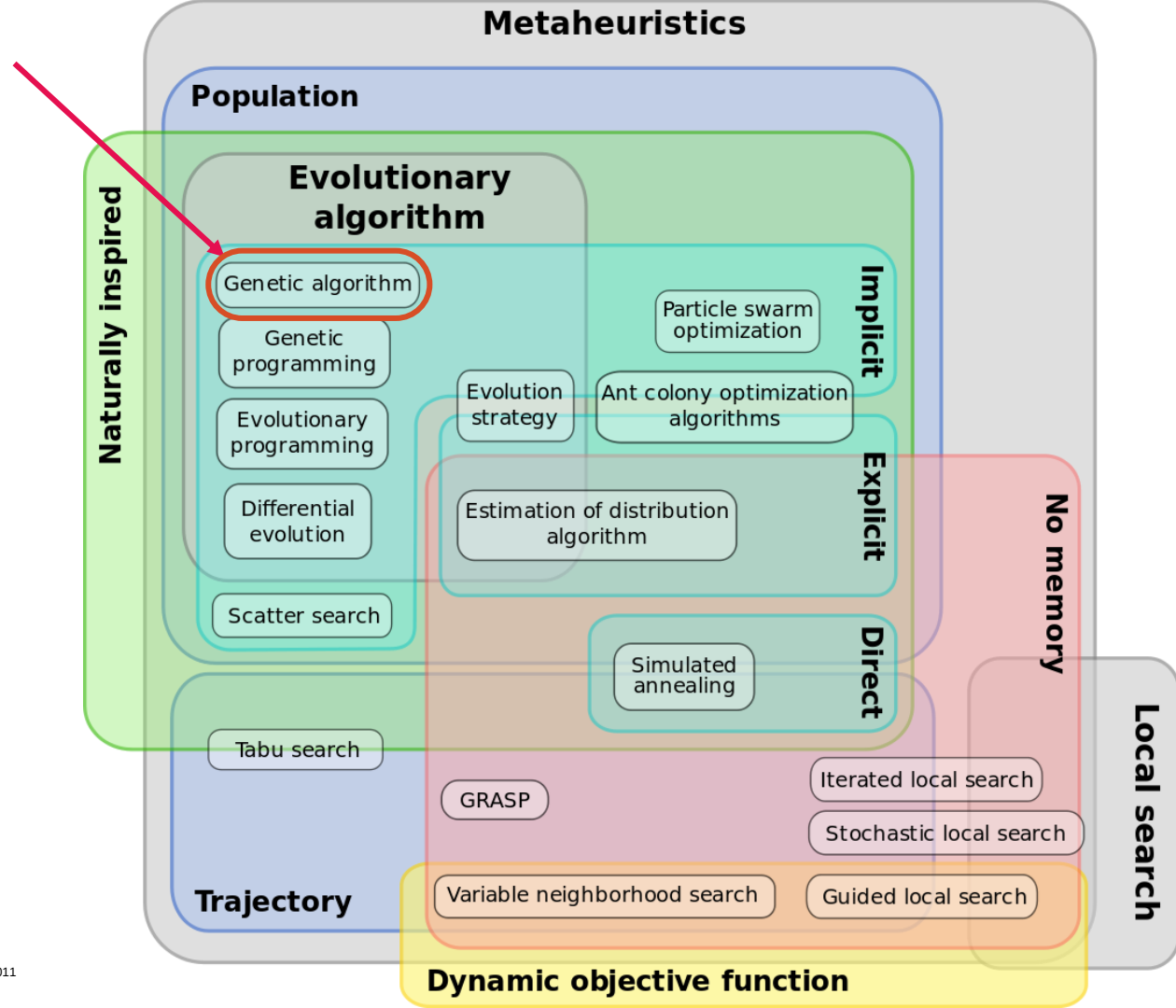
*“...seeing the thing from a higher perspective
instead of from within the thing.”*

- Urban Dictionary

Metaheuristic Algorithms

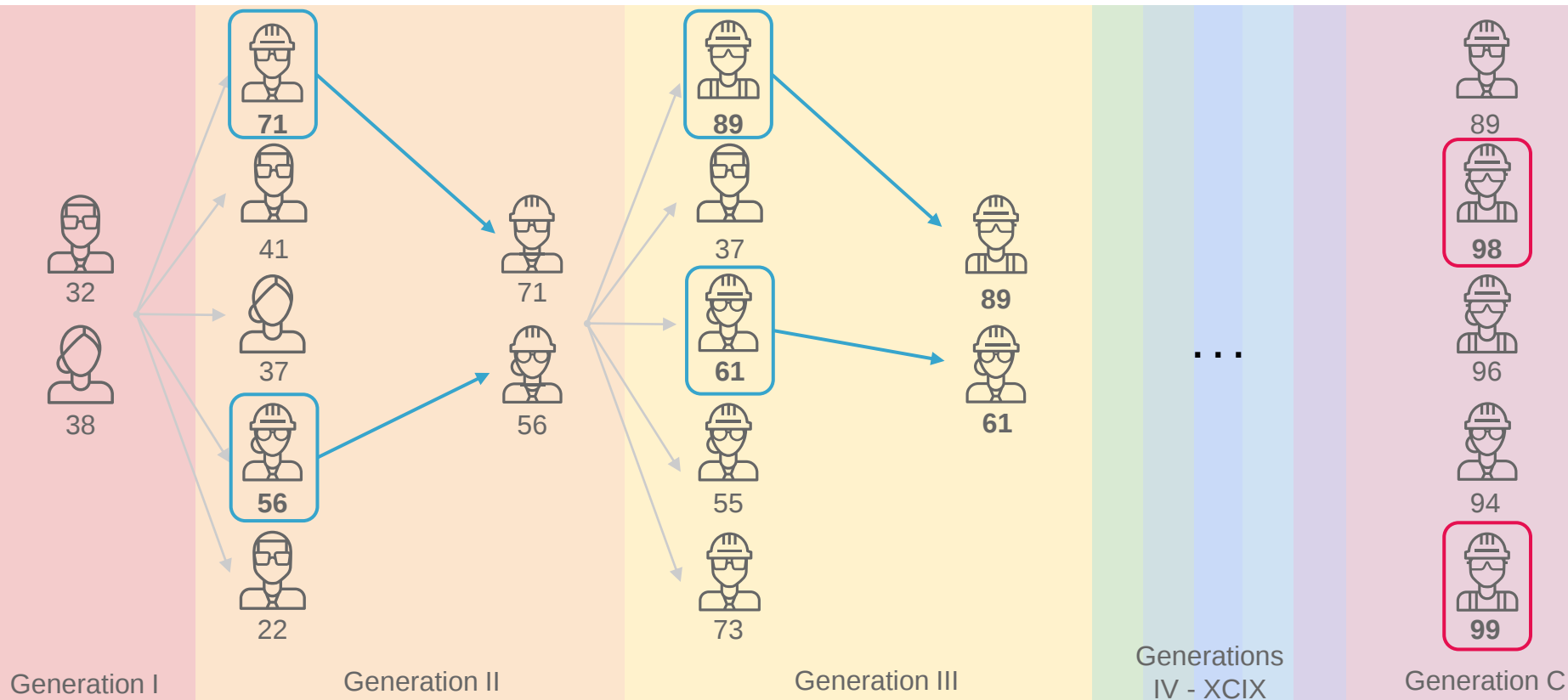
A computer's best guess

- Autodesk Revit GD uses a 'Genetic Algorithm'
- Specifically, I believe, the NSGA-II algorithm (Non-dominated sorting genetic algorithm II)



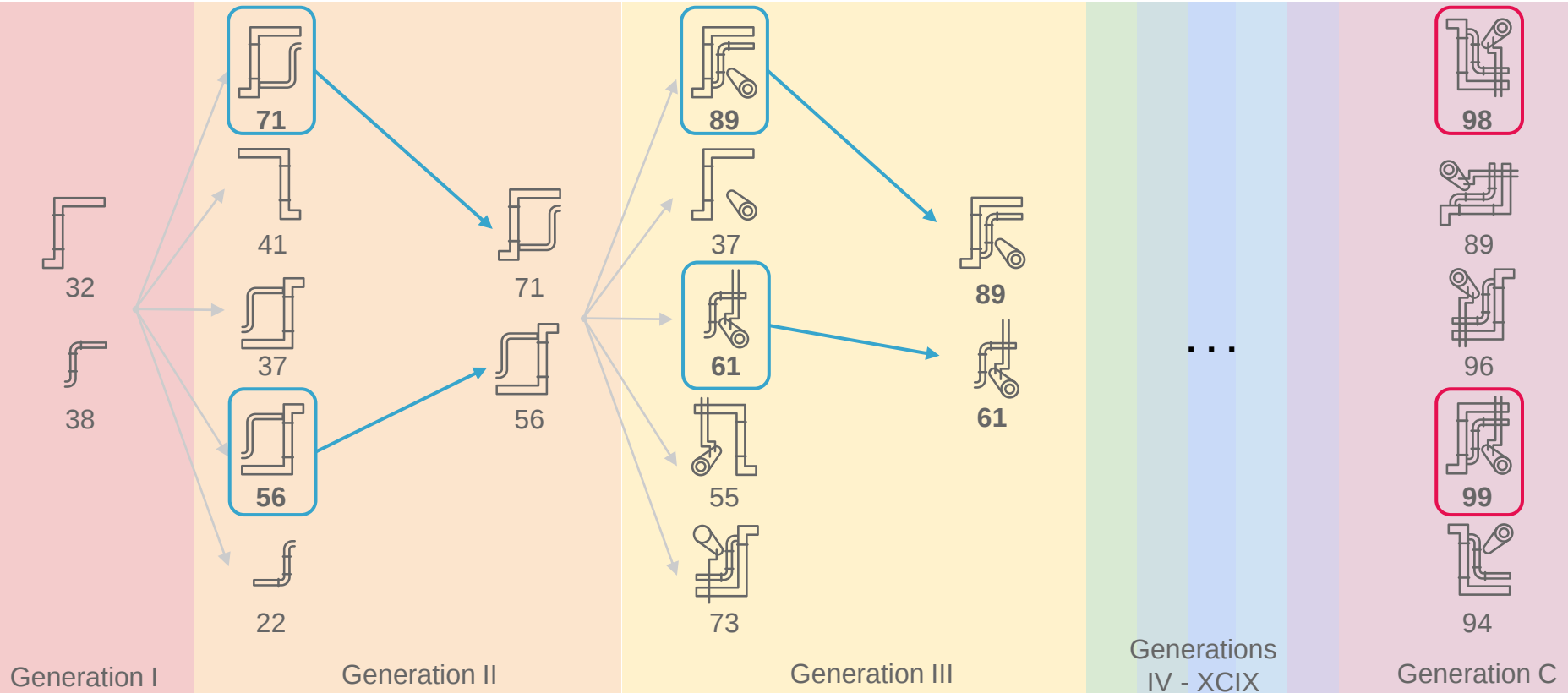
Genetic Algorithm

It made us, so that's something right?



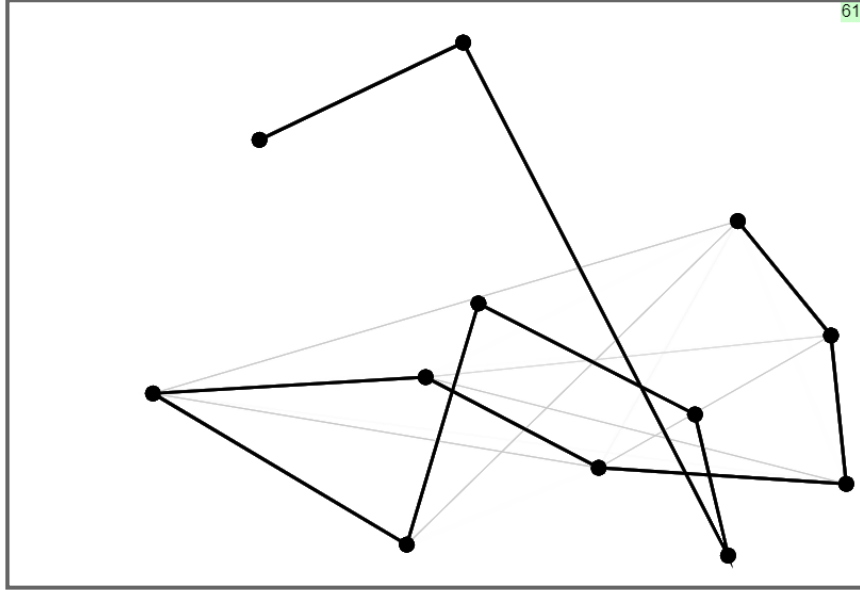
Genetic Algorithm

It made us, so that's something right?

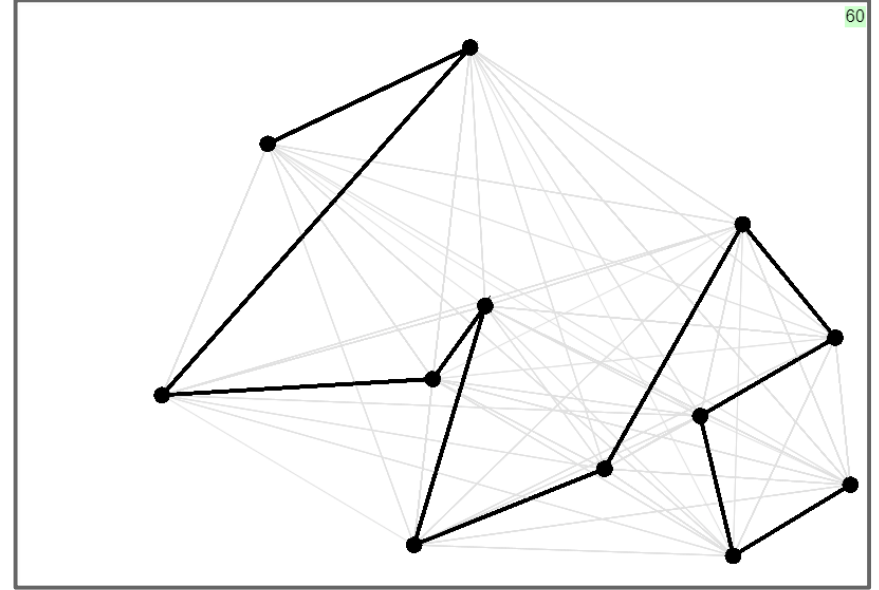


Genetic Algorithm applied to TSP

Traveling Salesperson Problem revisited



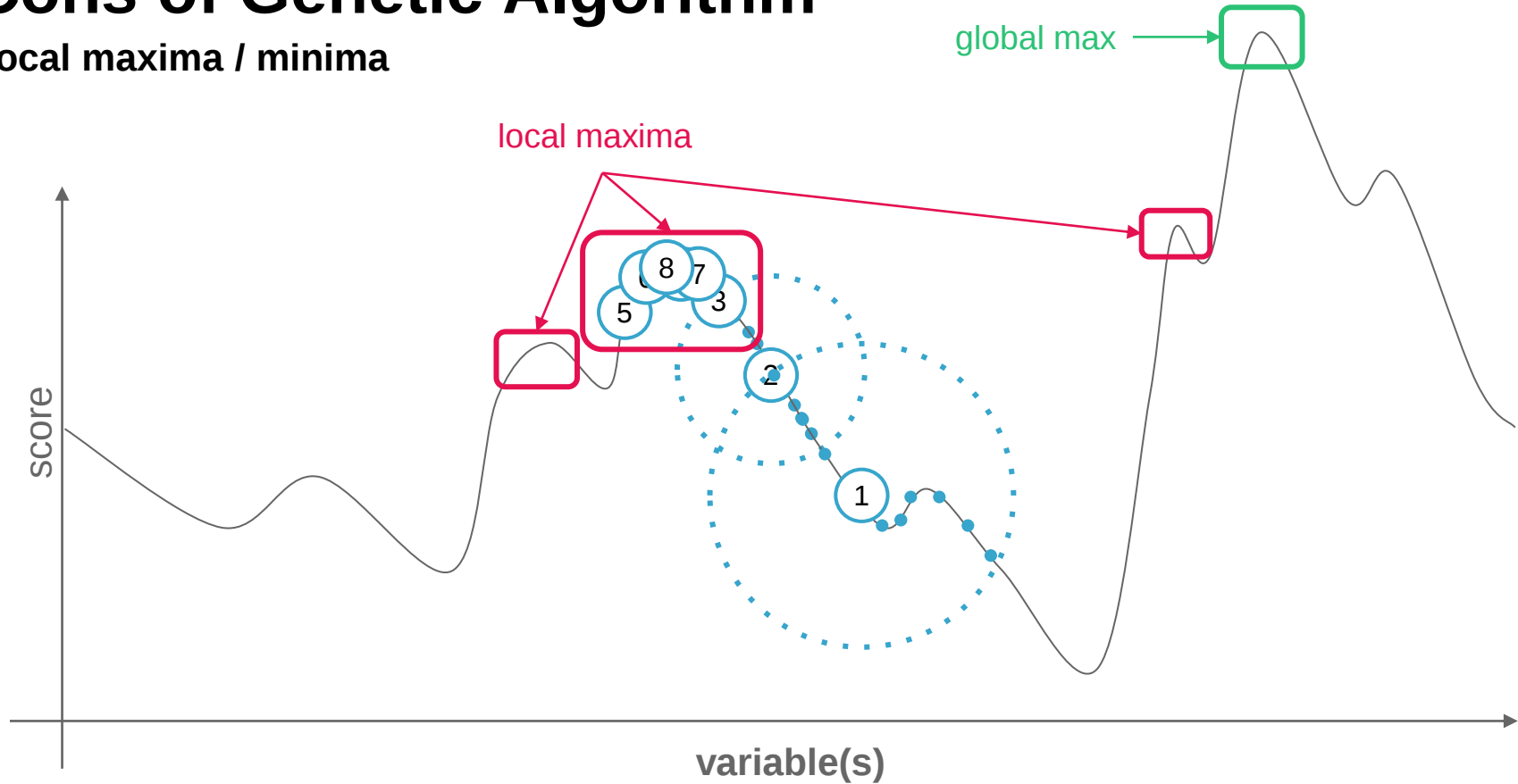
Lexicographic Ordering
(try every single possibility in order)



Genetic Algorithm
(with crossover)

Cons of Genetic Algorithm

Local maxima / minima

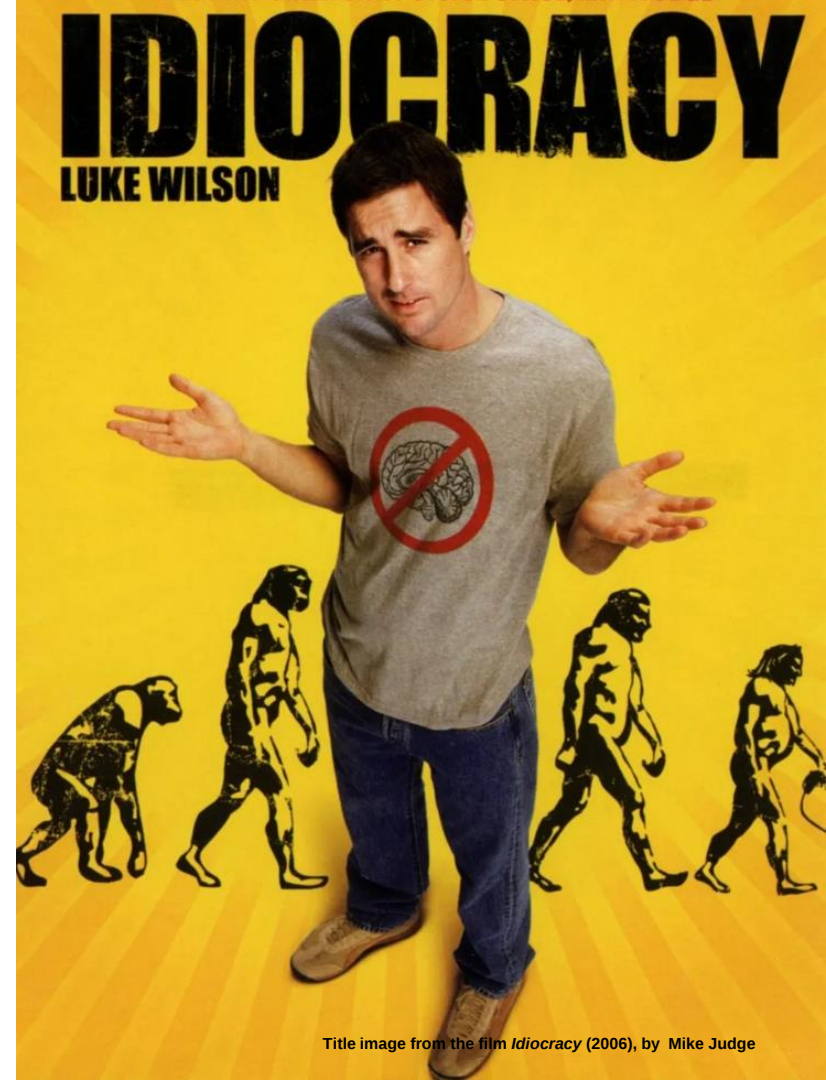


Cons of Genetic Algorithms

Idiocracy effect possible



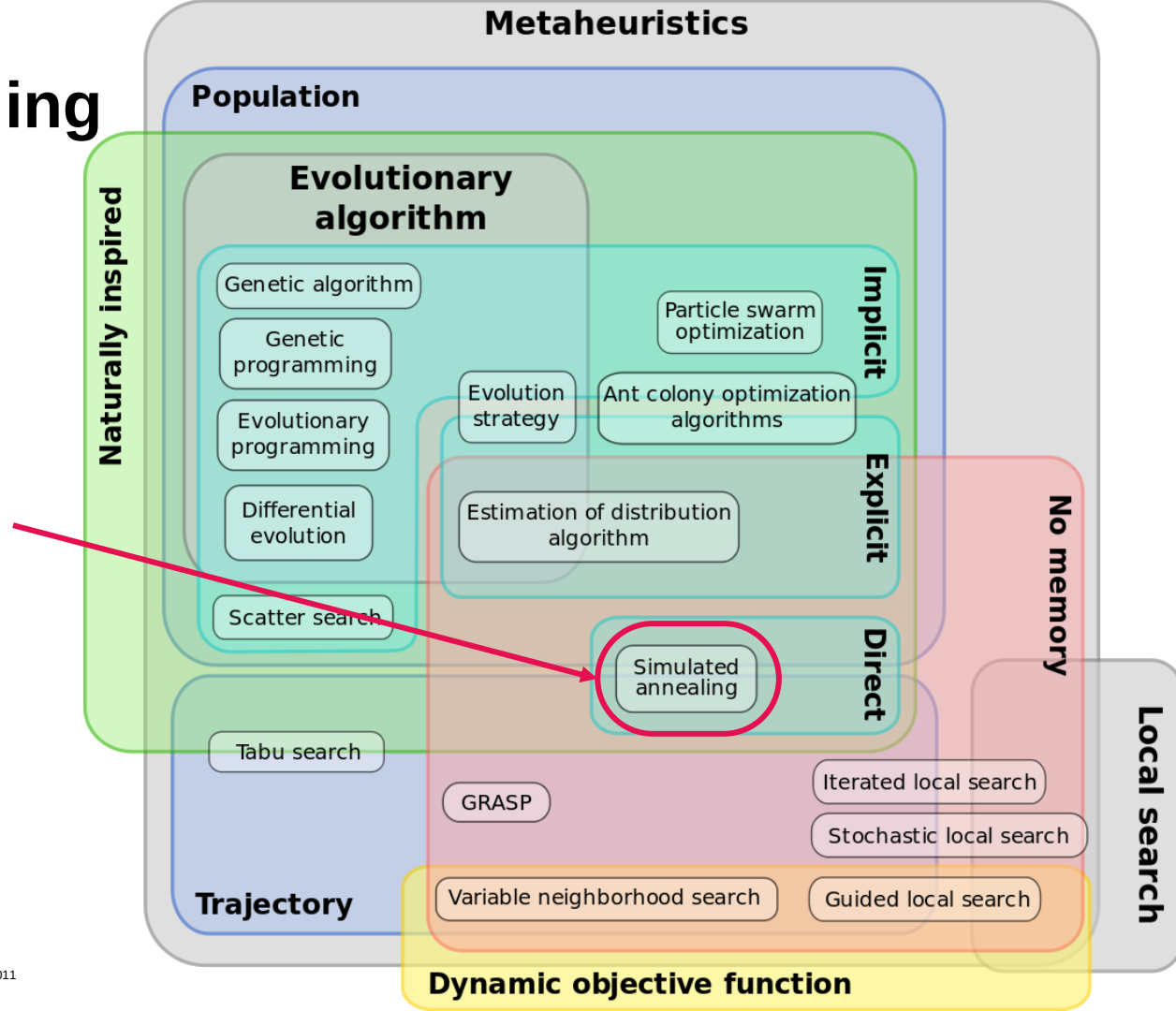
Image created from screenshots of the film *Idiocracy* (2006), by Mike Judge



Title image from the film *Idiocracy* (2006), by Mike Judge

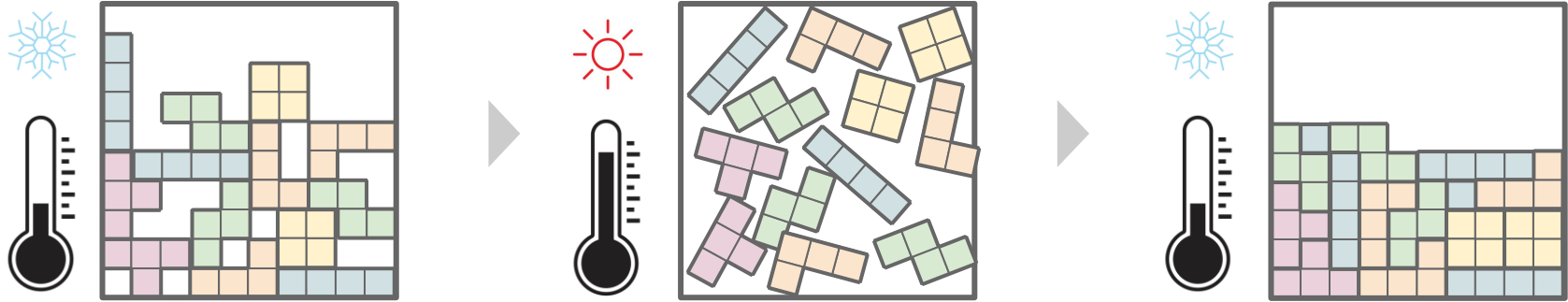
Simulated Annealing

- Inspired by process of annealing metal
- Avoids local minima/maxima better
- Very customizable



Annealing Diagram

Strengthen a metal by quickly heating and then slowly cooling



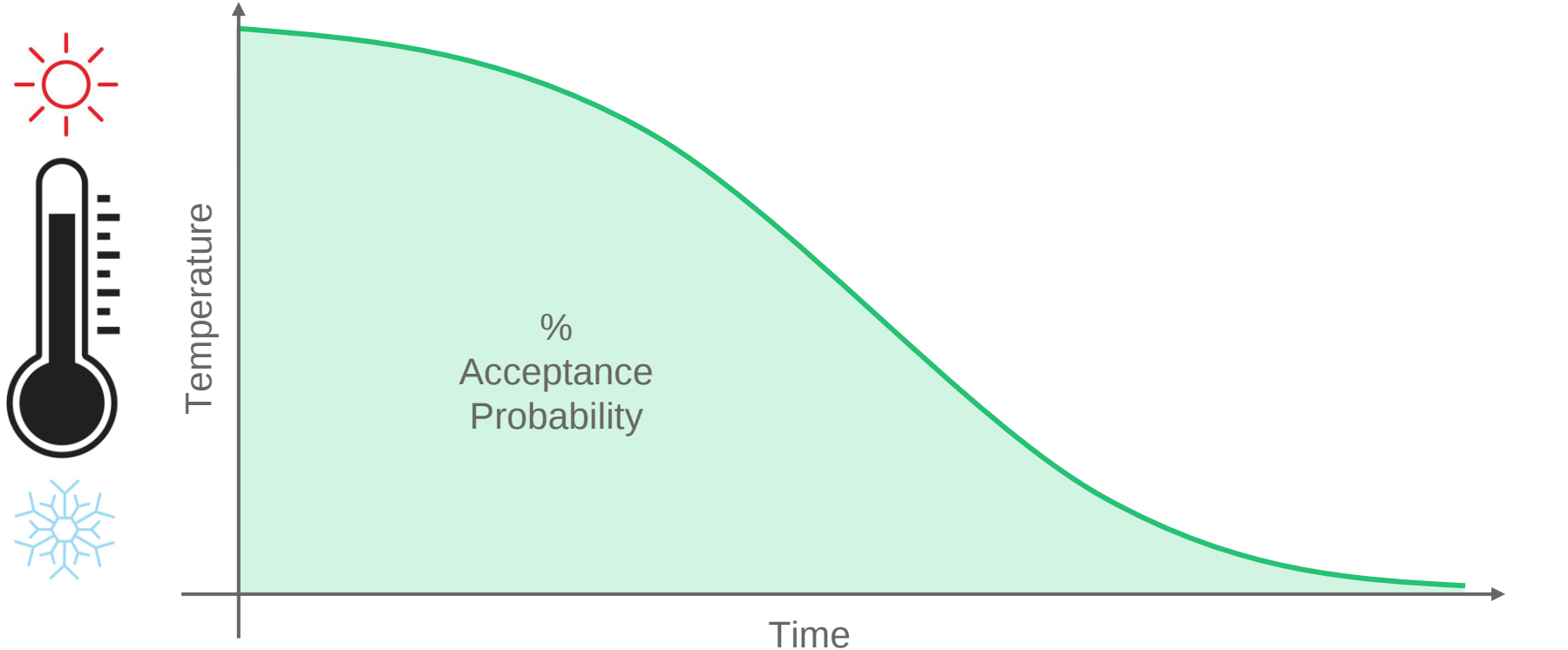
Take a metal at room
temperature

Quickly apply heat

Slowly cool

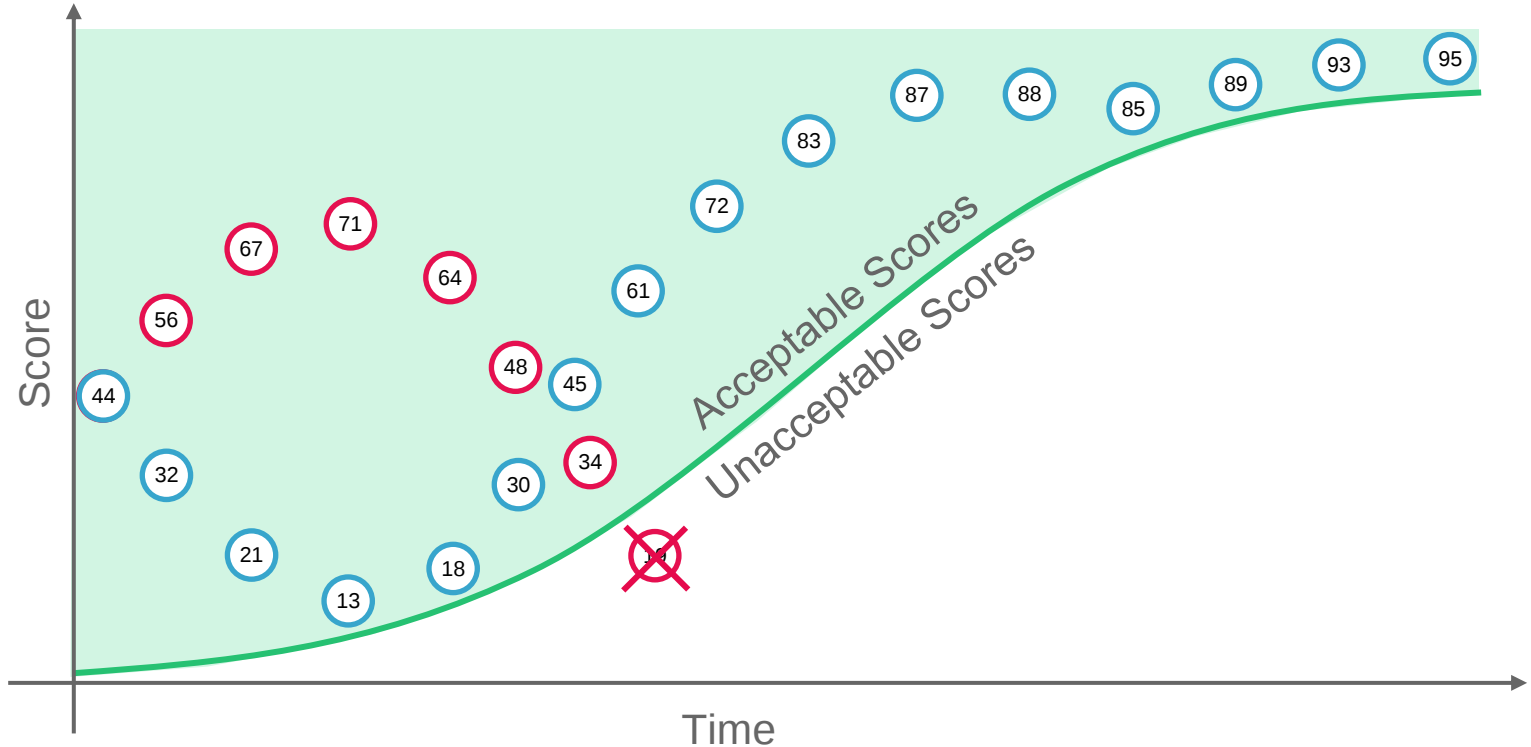
Simulated Annealing Diagram

A 'cool' way to find a solution



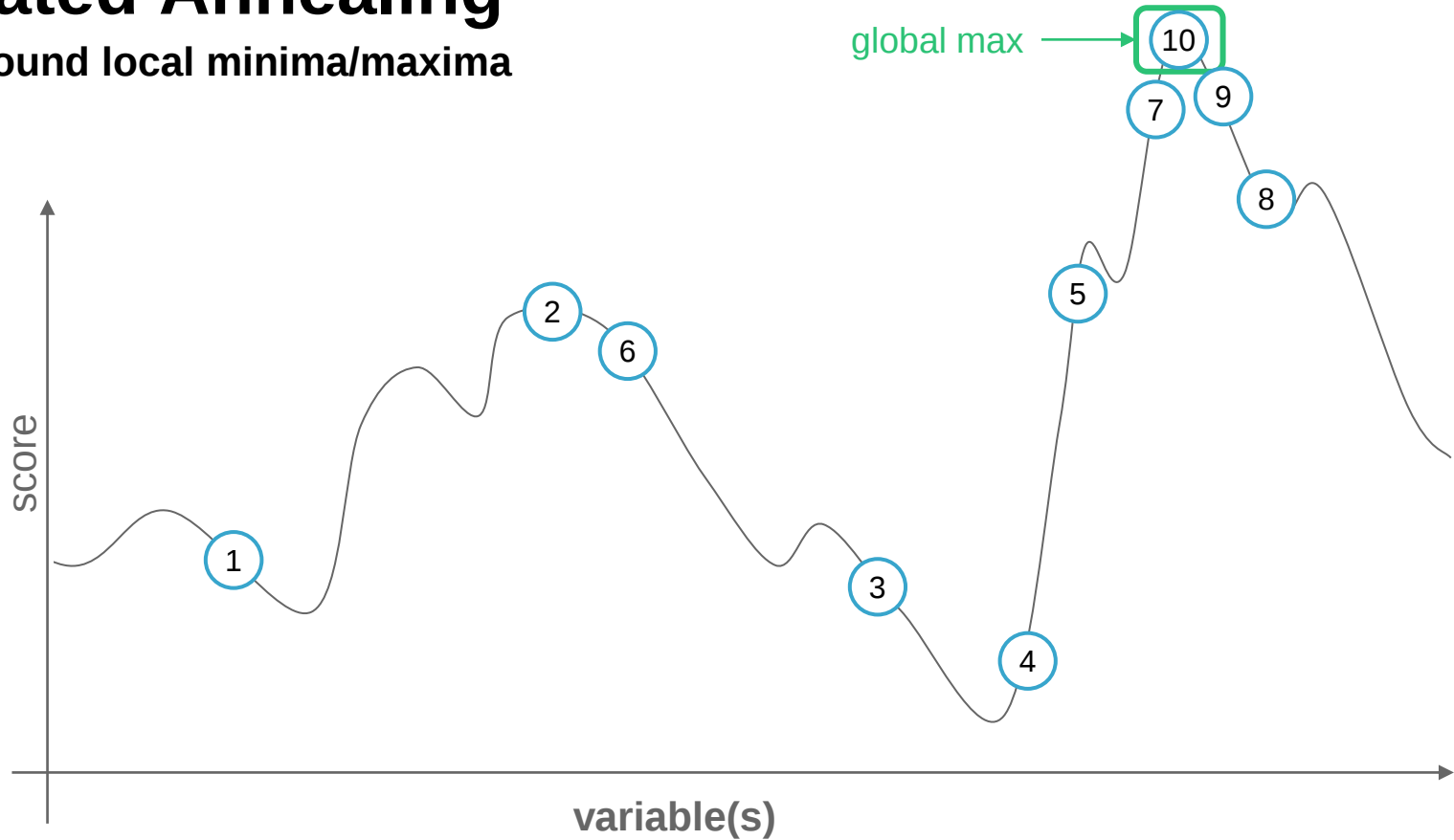
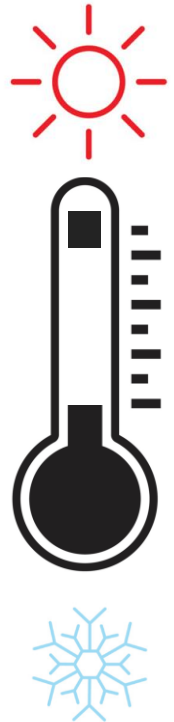
Simulated Annealing Diagram

A 'cool' way to find a solution



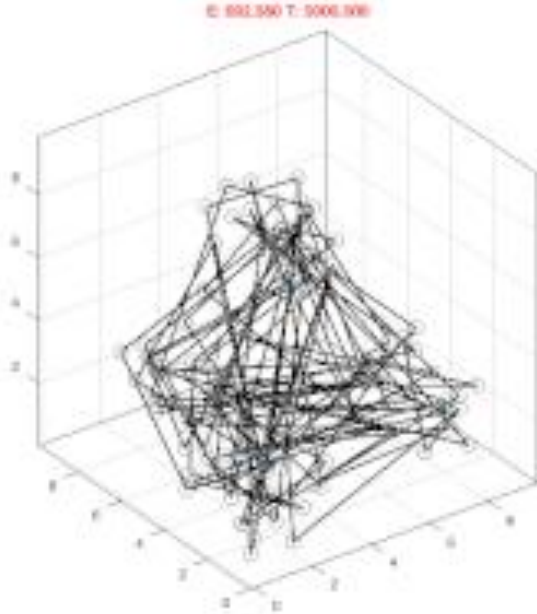
Simulated Annealing

Getting around local minima/maxima



More Simulated Annealing animations

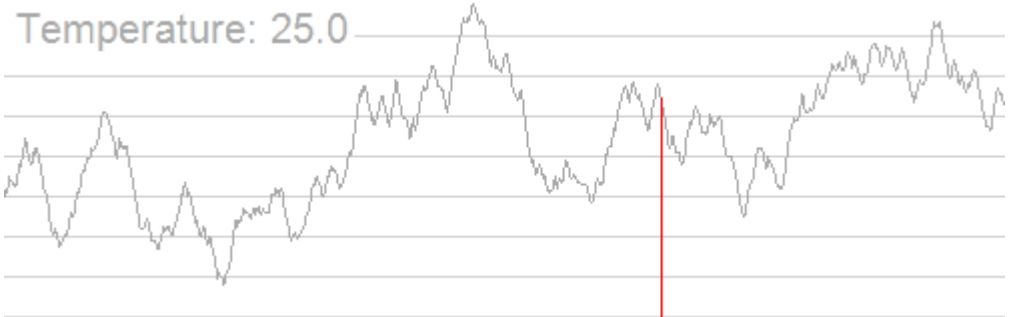
Traveling Salesperson Problem in 3D, Hill Climbing Problem



- Left: Traveling Salesperson Problem in 3D with 120 Cities

- E = Solution Efficiency(?), T = Temperature

- Below: Hill Climbing Problem being solved using Simulated Annealing

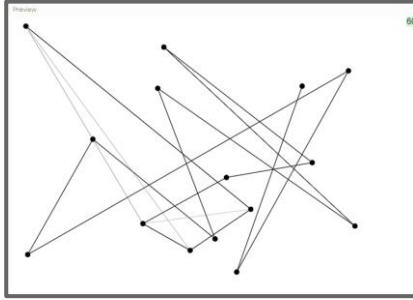


"Travelling_salesman_problem_solved_with_simulated_annealing.gif" by Geodac, licensed in the public domain (no copyright)
https://commons.wikimedia.org/wiki/File:Travelling_salesman_problem_solved_with_simulated_annealing.gif

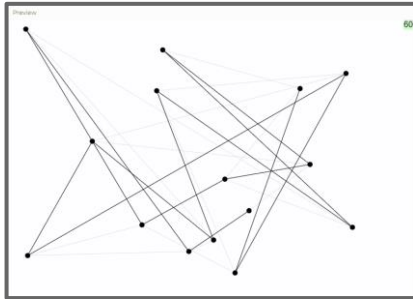
"Hill_Climbing_with_Simulated_Annealing.gif" by Kingpin13, licensed in the public domain (no copyright)
https://commons.wikimedia.org/wiki/File:Hill_Climbing_with_Simulated_Annealing.gif

Simulated Annealing applied to TSP

Traveling Salesperson Problem reprise

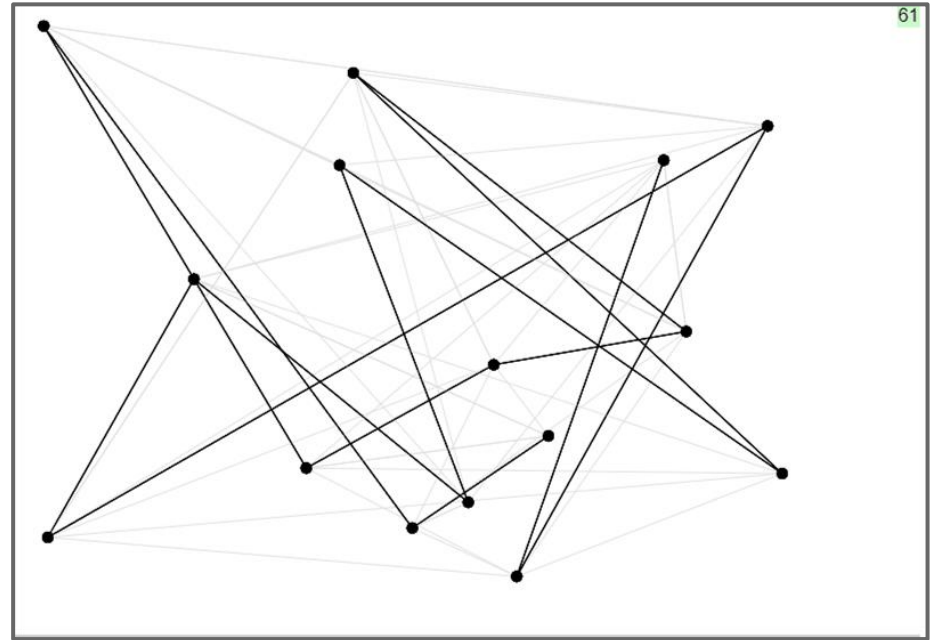


Lexicographic Ordering
(try every single possibility in order)



Genetic Algorithm
(with crossover)

Simulated Annealing



Simulated Annealing for Duct Layouts

Simulated Annealing
Settings

Simulated Annealing
Results

SIMULATED ANNEALING SETTINGS

Simulated Annealing Level
Medium

SA Start Temperature
1000

SA End Temperature
1

SA Cooling Rate
0.003

Max Frames
3000

LATEST SOLUTION RESULTS

Initial Score 299.424777960769	Final Score 1637.56637061436
Number of Solutions Tried 2308	Number of Times Improved 146
Sum Run Out Duct Length 77.1607392677004	Intersections Detected 4
Number of 5' Modules 4	Number of 2.5' Modules 2

TOP SOLUTIONS

● Run Out Lengths ● Module Count ● Intersections
● Disconnected AT

Draw

Regen

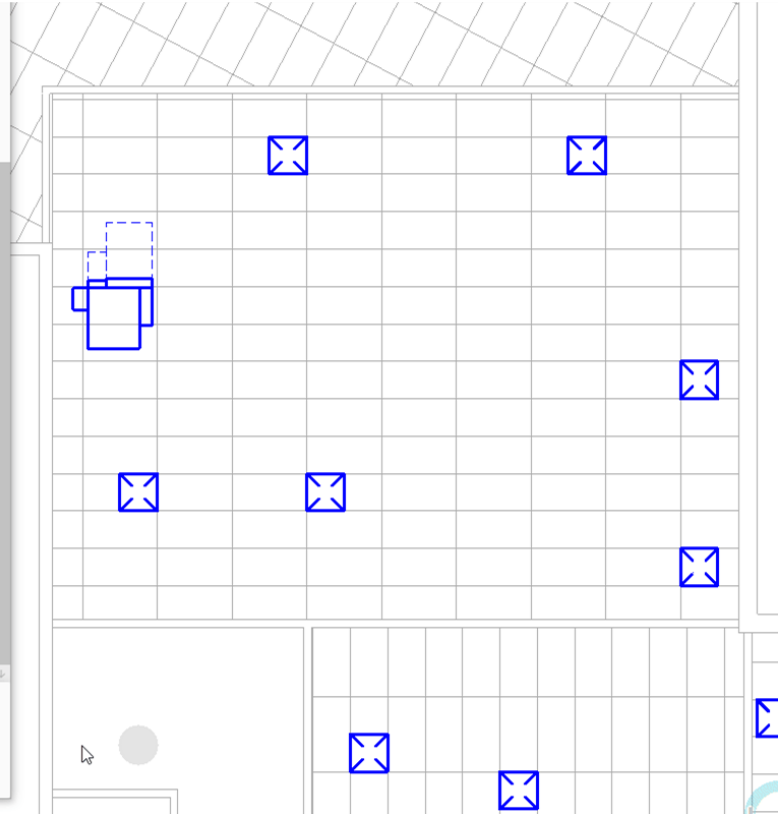
×

🗑️

Auto-Gen Path BETA

Bake to Revit

✓



4 - Simulated Annealing Recap

- Generative Design
- Traveling Salesperson Problem
- Metaheuristics
 - Genetic Algorithm
 - Local Minima and Maxima
 - Simulated Annealing



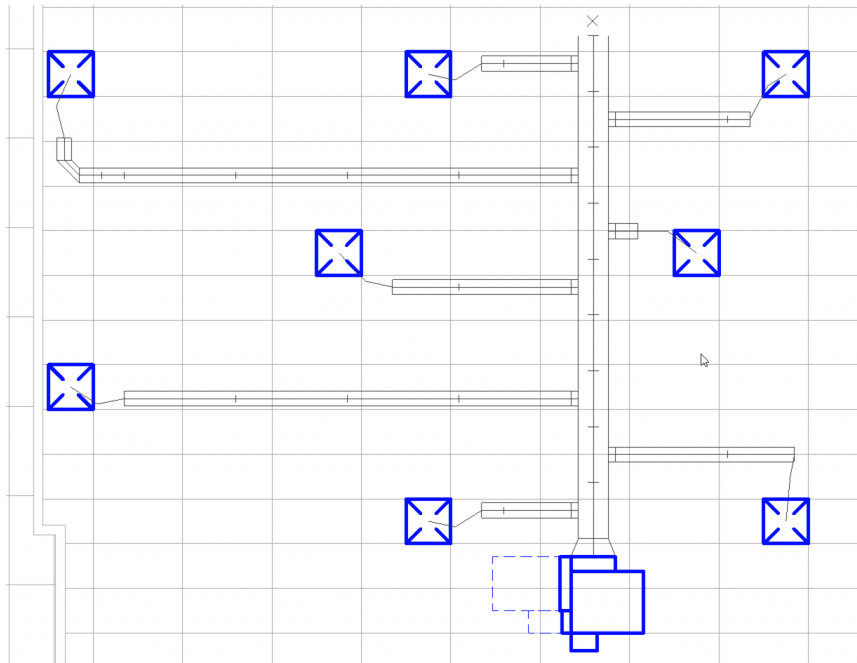
5 - User Adoption

Without adoption, your tool is just expensive marketing material

Integrated within Revit

Minimize Learning New Behaviors

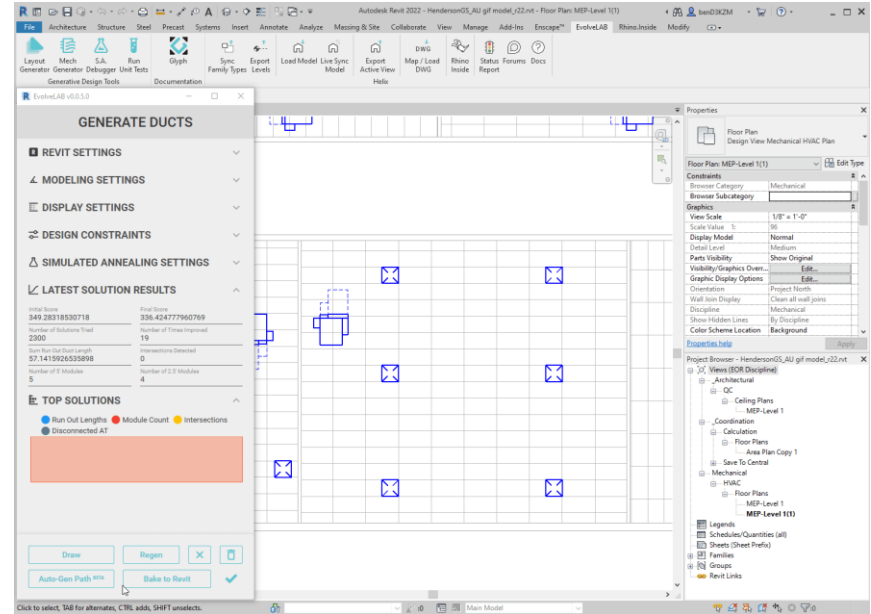
- Build it **directly** within the Revit canvas
- Use already learned **behaviors** in Revit
 - Use Revit's **navigation** controls
 - Use the same **shortcuts**
 - Use the same **click** release order
- Uses native Revit **elements**
- Support **co-authoring**



App Architecture Tradeoffs

Supporting Co-Authoring

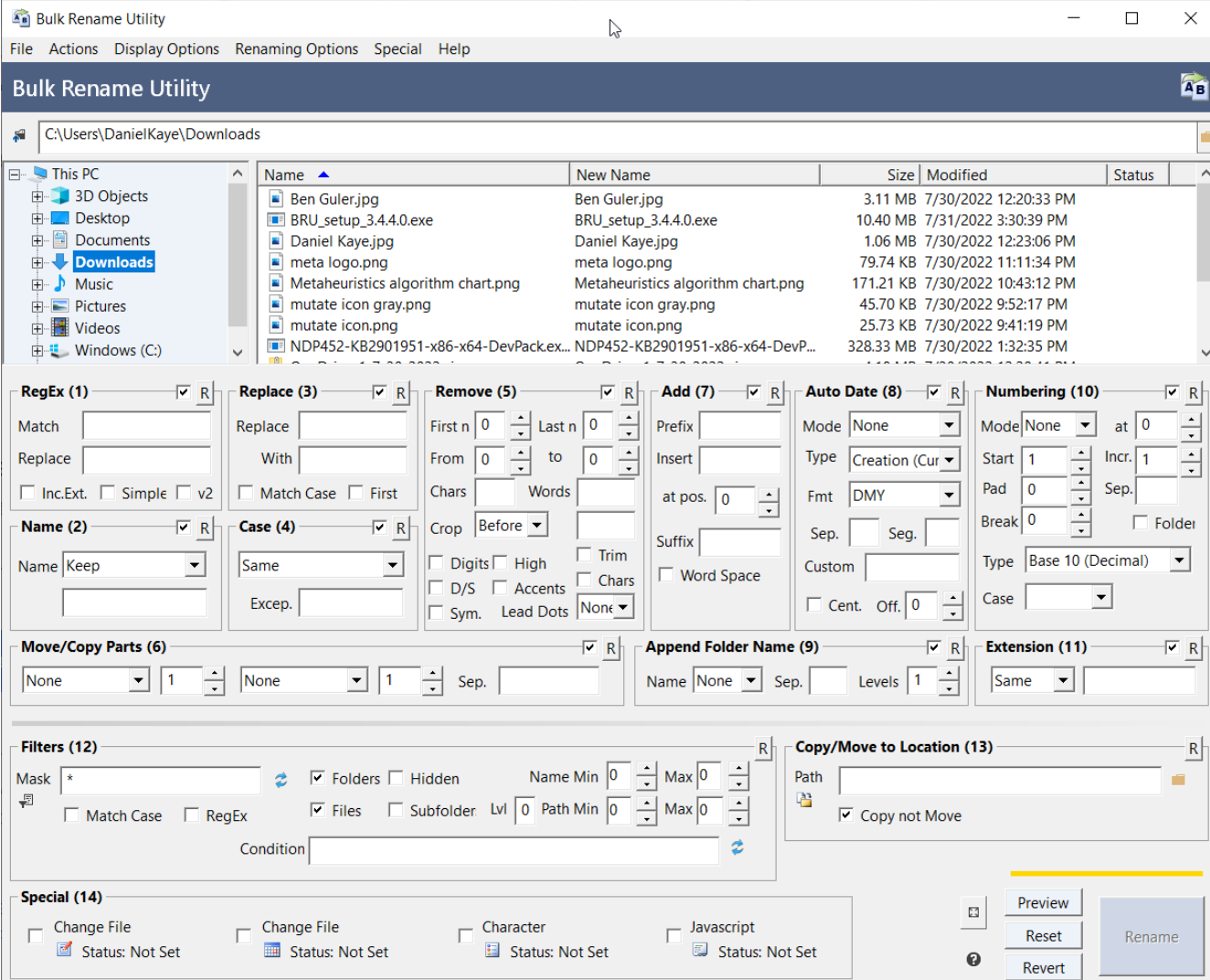
- **Interactivity over Speed**
 - Never Feel like it's frozen
 - Partial success is ok
- **Speed over Accuracy**
 - Choice in metaheuristic solver
 - Quick solutions with decent results
 - Inaccuracy gap filled by designer
- **Simplicity over Customizability**
 - Not many options exposed: settings are externally saved and loaded
 - Make it as simple and quick as drawing a wall
 - Minimize number of clicks
- **Specific over General**
 - Modular problem solving
 - Specific problem to solve, not solving all



Henderson Engineers & EvolveLAB Partnership on Modular Duct Generator Tool

UI Design

- Not like this



UI Design

- Vertical Design
- Input At Top
 - VAV Box Selection
- Adjustments & Settings in the Middle
 - Simple Sliders (Design Constraints)
- Simple Design Options Graph
 - Bar Chart for Design Option
- Action Buttons at Bottom
 - Regen Solution
 - Draw Button / Auto-Gen

GENERATE DUCTS

REVIT SETTINGS

Selected Zone
SA 9

Zone Parameter Name
System Name

MODELING SETTINGS

DISPLAY SETTINGS

DESIGN CONSTRAINTS

MINIMIZE LENGTH

Less ImportantMore Important

MINIMIZE MODULES

Less ImportantMore Important

SIMULATED ANNEALING SETTINGS

LATEST SOLUTION RESULTS

TOP SOLUTIONS

Run Out LengthsModule CountIntersections
Disconnected AT

Design 114	54.09	6	
Design 116	56.14	6	
Design 117	57.19	6	
Design 121	61.09	6	
Design 129	69.19	6	

Draw

Regen

×

🗑️

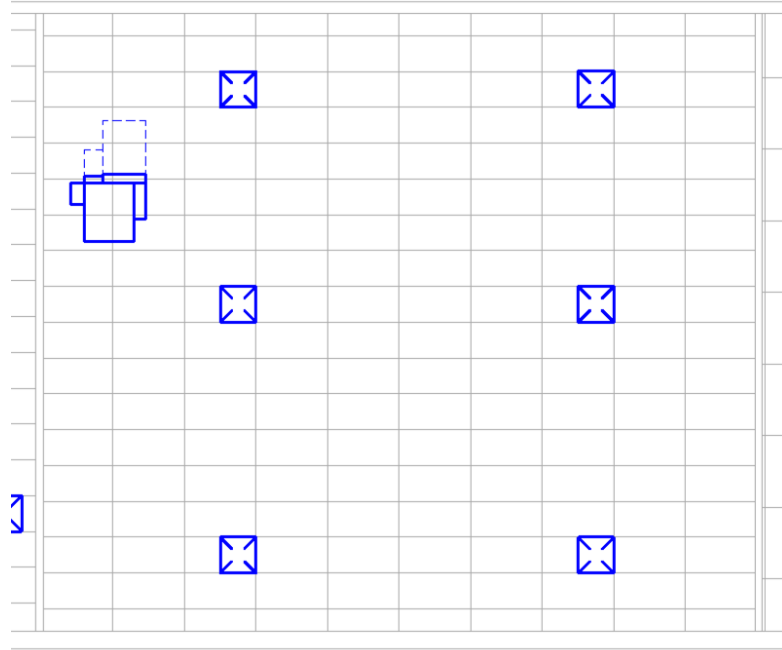
Auto-Gen Path BETA

Bake to Revit

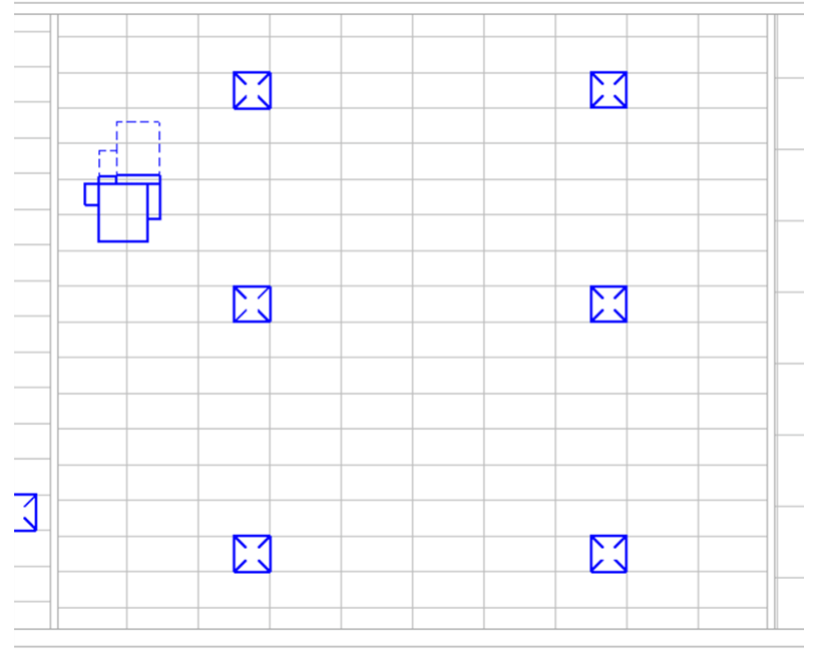
✓

UX Design

Visualize feedback with lightweight geometry



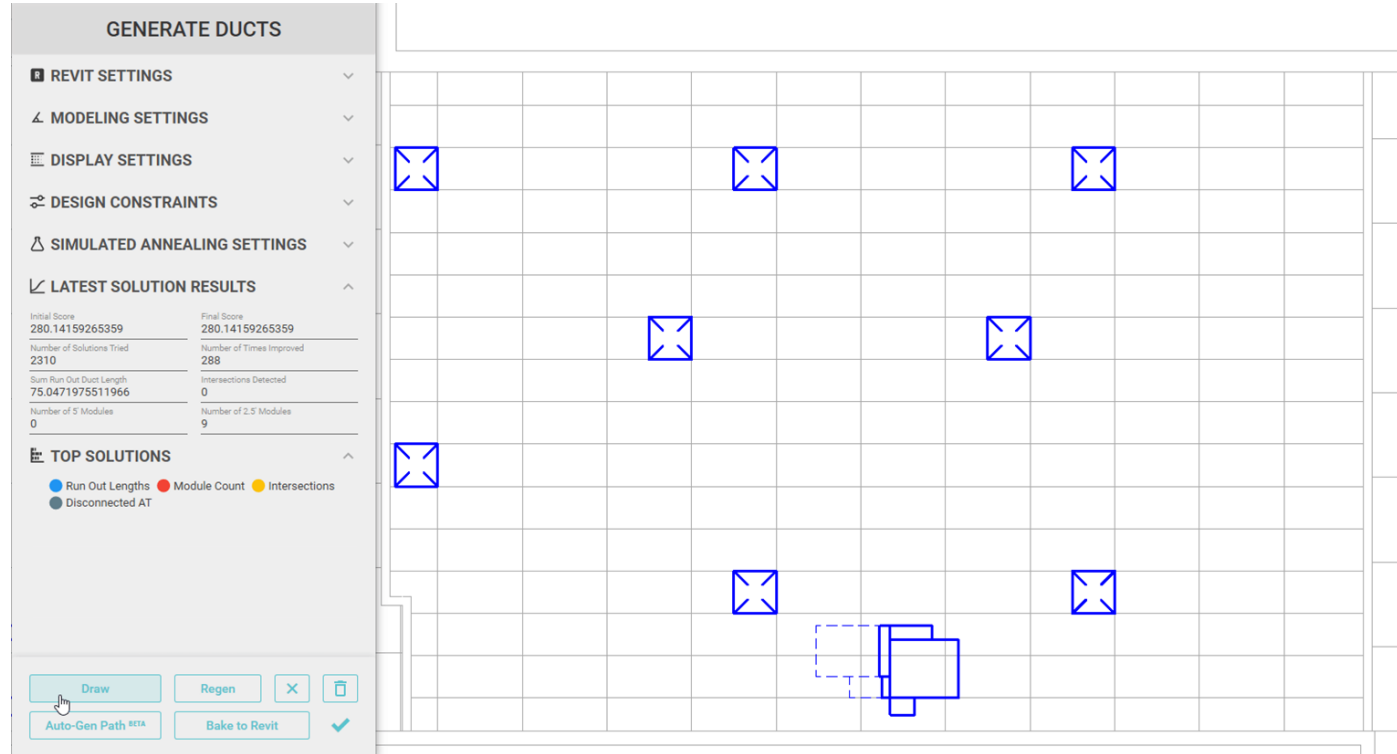
Ortho Mode: **On**



Ortho Mode: **Off**

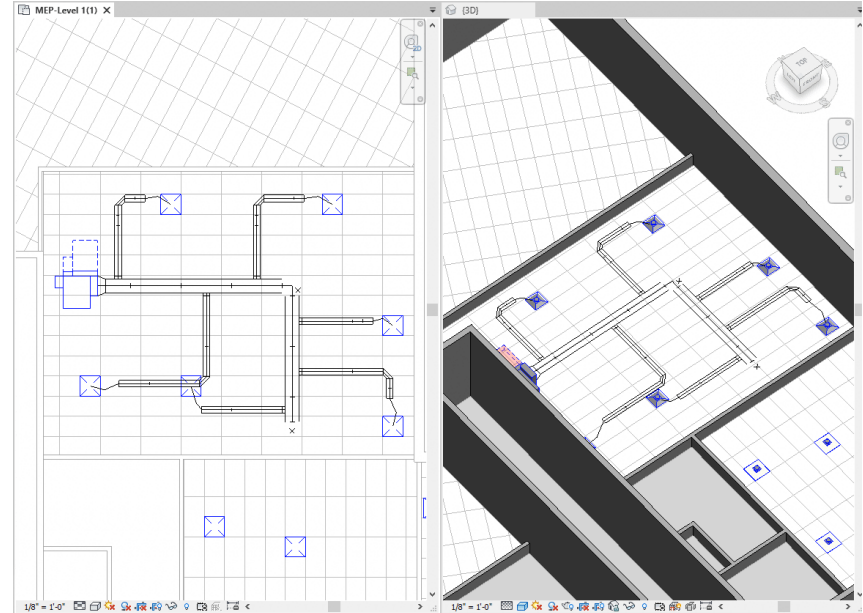
UX Design

Visualize what the algorithm is thinking, the “work-in-progress” solution



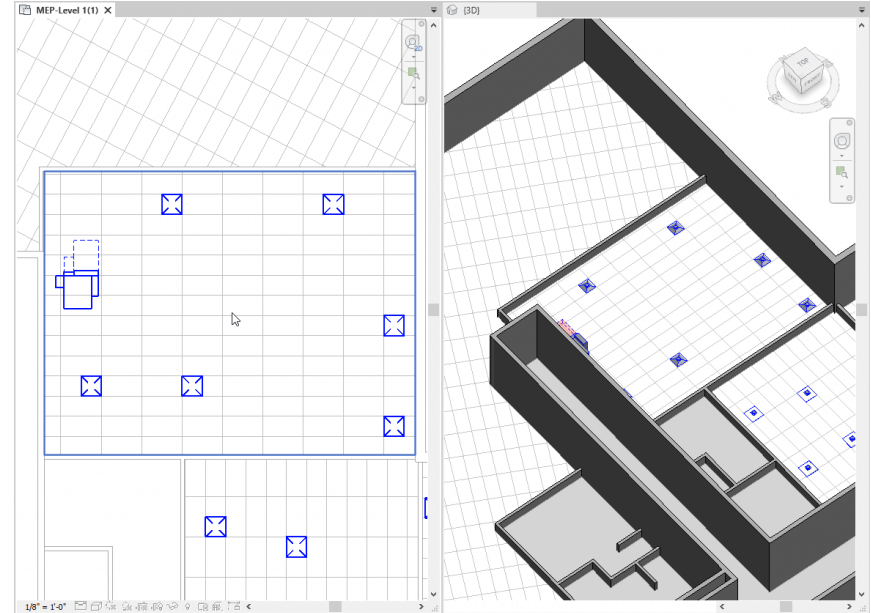
Workable Output

- Generate native Revit elements
 - Ducts & Connector
 - All connected as a system
- Can generate partial success
 - Don't have to get the solution 100% correct 100% of the time
 - Manual way is always available for fallback
 - Partial success still reduces modeling efforts
- Post App Modifications
 - Allows user to make further adjustments



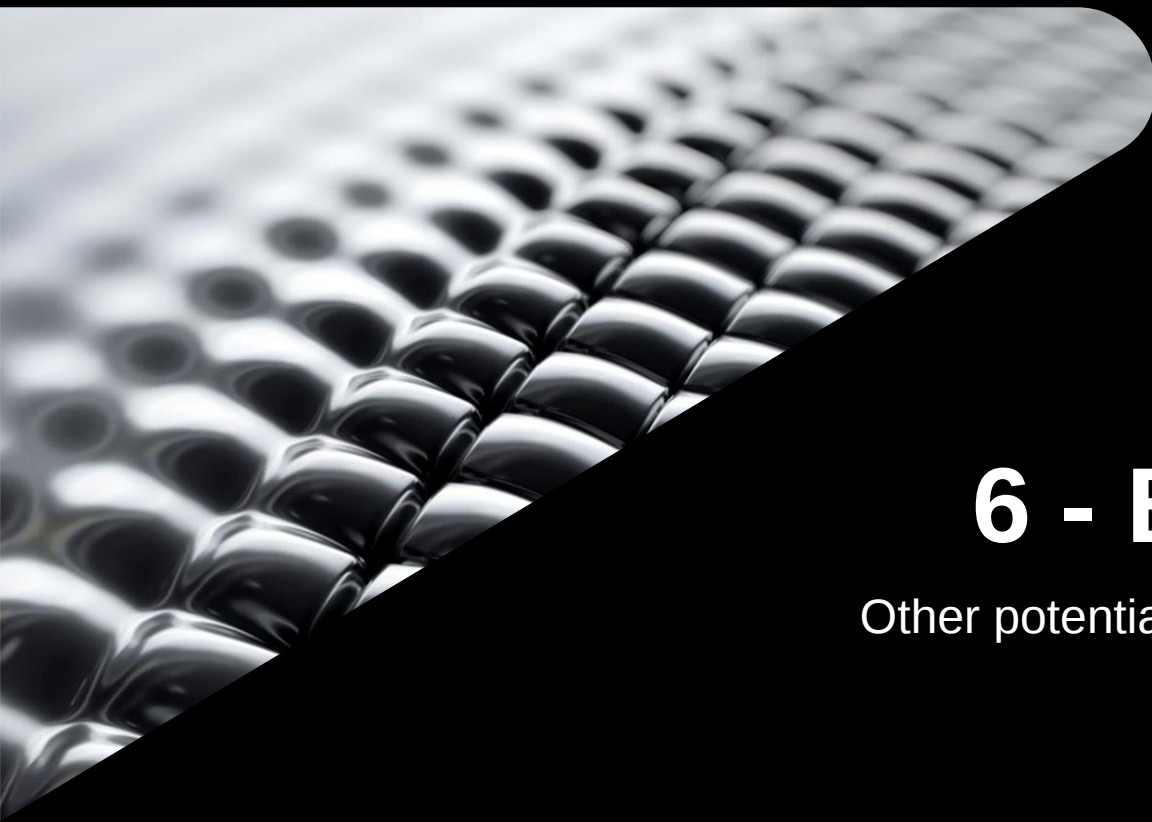
Make It Fun

- Rewarding by completing the task faster
- It's *fun* working with interactive graphics
- Feels Good to generate all that Revit content



5 - User Adoption Recap

- Integrated Within Revit
- App Architecture Tradeoffs
- UI/UX Design
- Workable Output
- Make It Fun



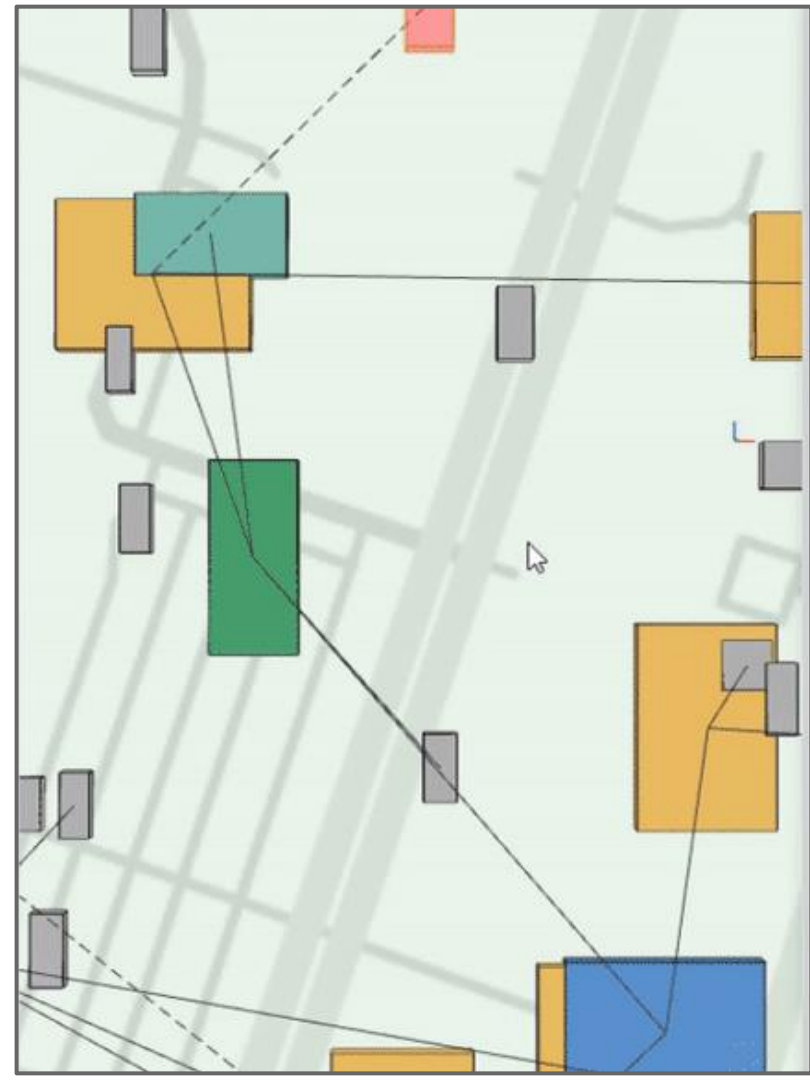
6 - Beyond Ducts

Other potential applications for this technology

Schematic Plan Generation

Using physics to create designs

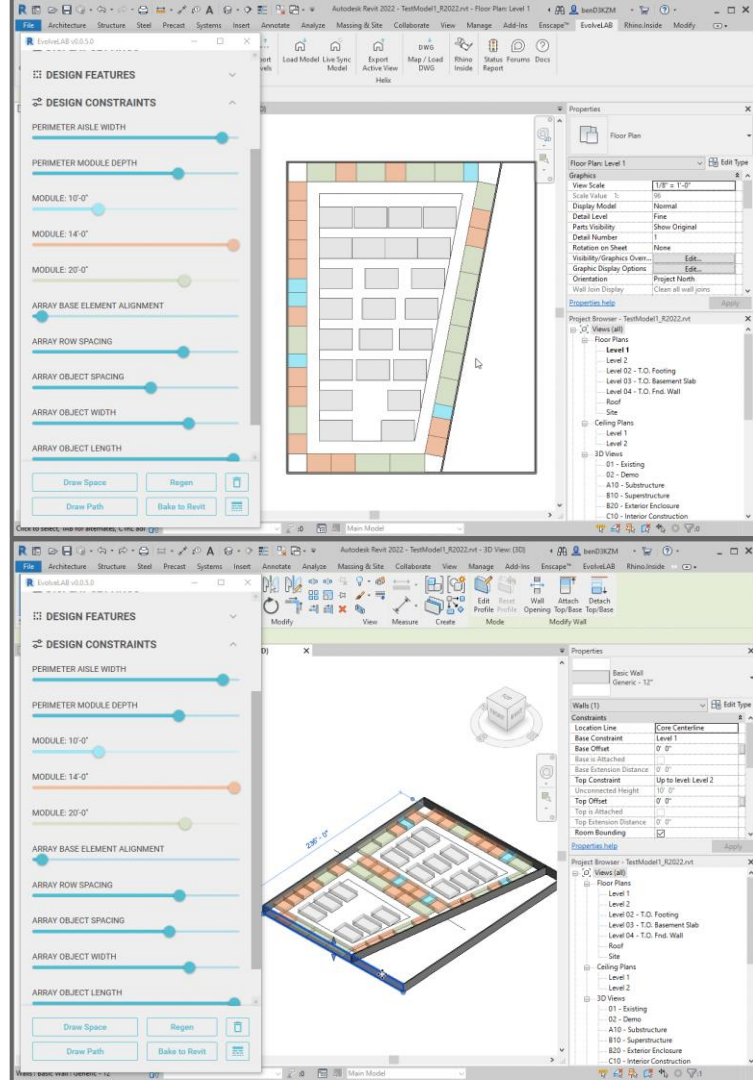
- Project for large architectural client
- Create interactive and scored floor plans
- Uses a physics-based metaheuristic generative design algorithm
- Employs similar co-authoring techniques, but on a very different platform
 - Exports to Revit
- Multi-objective optimization
 - 30+ different constraint sliders



Morphis

A space layout and array tool gone wild

- Responsive and snappy
- Completely inside Revit
- Lays out perimeter spaces and central arrays
- GD Optimize Engine
- Bakes into native Revit geometry



Endless Possibilities

What else can you do with this technology?

- Expand on Mechanical Duct Generator
 - Air Terminal Layouts
 - Branch Duct Paths
 - VAV Box Locations
 - Zoning Efficiency
- Electrical
 - Lighting layouts
- Fire Protection
 - Sprinkler Plans
 - Gravity-drained Pipe Layouts
- Plumbing
 - Fixture arrangements
 - Pipe Routing
- Architectural
 - Schematic plan layouts
 - BOMA rental unit optimization
 - Stadium, auditorium, and conference hall seating and booth layouts
 - Facade design and optimization
 - Curtain wall layouts
- Construction
 - Panel board placement optimization
 - Modular wall panel segmentations

Presentation Recap

[What] did we learn?

- The Problem - Generating Modular Ducts
- The Solution – Modular Duct Generator
- Simulated Annealing - Metaheuristic Algorithm
- User Adoption - UI/UX Design and human-computer interaction
- Beyond Ducts - Endless Possibilities

Questions?



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