Auto Generating and Optimizing Modular Air Duct Layouts in Revit

BES502811

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Table of Contents

1. The Team
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
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The Modular Duct Generator App

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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
   a. Adjust Settings, Regenerate
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
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   a. Fails
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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 brawn of 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

Create Initial Design → Evaluate → Iterate on Design → Build
The Generative Design Process

The ‘Computational Design’ way

- Generate Initial Design
- Score
- Mutate
- Build
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
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

Number of Cities: 8
Traveling Salesperson
A yet unsolved problem

- 6 cities
  - 720 Possibilities (6!)

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

- 50 cities
  - 30.4 Vigintillion Possibilities
    - 16,055,627,510,117,791,688,711,465,754,571,818,807,680,369,975,739,956 years (?)
Metaheuristics
‘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?

Generation I

32
38
22

Generation II

41
37
56

Generation III

71
37
56
71
73
55
89
61

Generations IV - XCIX

...
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

- Global max
- Local maxima

Score vs. variable(s)
Cons of Genetic Algorithms

Idiocracy effect possible
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

Score vs. Time Diagram
Acceptable Scores
Unacceptable Scores

Scores: 56, 67, 71, 64, 61, 48, 45, 34, 30, 18, 13, 21, 32, 44, 61, 87, 88, 85, 89, 93, 95
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
  - $E = \text{Solution Efficiency(?)}, T = \text{Temperature}$

- 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
4 - Simulated Annealing Recap

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