Hands-on with Project Rediscover: generatively designing Autodesk Toronto's office

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Learning Objectives

- Learn the history of Autodesk's research into Generative Design for AEC
- See how Dynamo and Refinery can be used to implement Generative Design workflows in the AEC space
- Understand the workflow implemented by the Project Rediscover graph
- Implement their own Generative Design workflows based on the principles shown

Description

Project Discover was the original project that launched Autodesk's work around Generative Design for AEC, leading to the creation of Project Refinery, an optimization engine for Dynamo. It involved the generative design of Autodesk's new office in the MaRS district of Toronto, a showcase for using Generative Design for architectural layout. While this project pre-dated the latest Autodesk tools in this space, Autodesk Research embarked on Project Rediscover to go back and retrofit the original approach to work with Dynamo and Refinery. This session takes a close look at the Project Rediscover graph - which is now publicly available for anyone to load inside Dynamo - and how people might use similar techniques to implement their own Generative Design workflows.

Speaker(s)

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Generative Design

Generative design is a framework for combining digital computation and human creativity to achieve results that would not otherwise be possible. It involves the integration of a rule-based geometric system, a series of measurable goals, and a system for automatically generating, evaluating, and evolving a very large number of design options. This approach offers many benefits for designing buildings and cities – including managing complexity, optimizing for specific criteria, incorporating a large amount of input from past projects and current requests, navigating trade-offs based on real data, structuring discussion among stakeholders about design features and project objectives, offering transparency about project assumptions, and offering a “live model” for post-occupancy adaptation. The framework consists of three main components: 1. **generate** a wide design space of possible solutions through a bespoke geometry system; 2. **evaluate** each solution through measurable goals; 3. **evolve** generations of designs through evolutionary computation.

![Diagram of Generative Design Workflow](image)

**Generative Design**

Generative Design is a flexible and scalable framework. It can be applied to a wide range of design problems and scales: from industrial components all the way to buildings and cities.
Autodesk Research into Generative Design

The Bionic Partition | Generative Design for Manufacturing

The Bionic Partition is a next generation airplane component designed for Airbus through the application of generative design. It involved creating a custom algorithm using biological rules and two measurable goals: weight and maximum displacement. The result is a metal 3D printed component that is almost 50% lighter and almost 10% stronger than traditional partitions.
Architecture can often become a more challenging problem than engineering ones. In fact, architecture, unlike engineering projects, involves qualitative aspects of the experience of space that are less tangible and more difficult to measure. In 2017 The Living pushed the boundaries of generative design and applied this framework to architecture for the design of the new Autodesk offices in the MaRS Discovery District in Toronto. The geometric system incorporated several levels of constraints including the size of the space, the number of amenities and meeting rooms and fixed locations for cores and mechanical rooms. The goals combined qualitative aspects of human experience (such as ‘workstyle preferences’ and ‘adjacency preferences’) with quantitative measures (such as ‘daylight’, ‘buzz’ and ‘productivity’). The process allowed the designers to go beyond the one-size-fits-all type of approach to workspace design and offer a space that was diverse and rich in features. Through ongoing monitoring of the space and survey-based data collection, generative design can be used to suggest new design options and the scoring algorithms can be improved.

Design goals: adjacency preferences; workstyle preferences; buzz; productivity; daylight; views to outside.

Geometric system: (0) incorporate constraints; (1) define generative and non-generative zones; (2-3) subdivide space into neighborhoods; (4) generate ‘amenity bars’; (5) generate ‘test fit’; (6) assign teams; (7) evaluate solution.
Van Wijnen is an innovative Dutch development and construction company that seeks to change the way buildings are designed and made. In 2017 they partnered with The Living to apply generative design at the scale of the city. The project involved the design of a geometric model that could meet the local building code constraints (such as number and location of access streets, setbacks, parking rules etc.), and satisfy the developer’s requirements (such as amount of two-story residential units and apartment buildings). Urban design problems generally present many stakeholders, often representing conflicting requirements and interests, thus intensifying the complexity of the design. Generative design is able to aid the management and structuring of such complexity through the definition of the goals. In this case the project involved seven distinct goals, including financial ones (revenue and construction cost), environmental ones (such as solar gain and views), as well as more architectural ones (such as variety).

For urban design problems, the generative design framework can aid the management and structuring of complexity through the definition of goals that can represent the interest of different stakeholders.
Geometric system: (1) create mesh from boundary; (2) generate streets; (3) subdivide into lots; (4) place housing units; (5) place apartment buildings.

Evolutionary process.
Project Rediscover

The original MaRS project was codenamed “Project Discover”, which goes some way to describe the sense of exploration: this was about discovering whether Generative Design could be applied in practice at the Architectural scale.

Given the fact this was research – and that our tools didn’t have the capability to be used directly to solve this kind of problem, at the time – The Living went ahead and used other tools to solve the problem, including a significant amount of their own custom-built code. While this research was clearly very valuable, it was also important for Autodesk customers to be able to get access to examples showing a comparable workflow using Autodesk tools.

Hence Project Rediscover was kicked off, essentially to rebuild the workflow used for the MaRS project within Dynamo and Refinery. There were some functionality gaps that needed filling for this to happen – which led to the creation of the Space Analysis package – but overall we found it was possible to create a graph in Dynamo that worked similarly to the implementation made in Project Discover.

The first version of this graph was released at AU London 2019. At that time it was functional, but we hadn’t yet had the opportunity to fully document what amounted to a highly complex workflow. This class attempts to rectify that situation by examining the logic of the graph, step-by-step, and giving people more context as to what was implemented – and why – which should make it easier to apply similar approaches to other problems.

The Geometry System

The main constraint that defines the geometry system is the outline of the floor area, along with a definition of the window locations. For the purposes of this graph, this information has been hardcoded in a series of points that define a boundary, but it could equally have been implemented by loading this information from Revit or from an external file.
The next step is to define some areas that would be used for the generative design process. In this case we have a rectangular area at the top and an L-shaped area on the left and at the bottom. These are, once again, hardcoded in the graph.

Once we have these “GD regions” defined, we split them with a centerline to define axes for the division into neighborhoods.
All of these items are considered constant for the purposes of the optimization: they don’t change from run to run. There is some potential to cache their results using the Data.Remember node, although the recalculation cost isn’t very high, relative to the analyses performed later in the process.

The next step is to calculate the approximate center points for neighborhoods, specified by parameters along the region spines. This is the first item in the process that will vary based on input parameters (in this case the 8 parameters “nbr1 – spine” to “nbr8 – spine”).

These approximate centers are then moved slightly in a perpendicular direction away from their spine. The amount is controlled once again by input parameters (the 8 parameters “nbr1 – perp spine” to “nbr8 – perp spine”).
At this stage we have no need for the approximate points or the spines, so we'll turn them off.

We're now going to create a simple Voronoi partition of the space based on these neighborhood centers.
This splits the space into the neighborhoods. We can now ignore the centers, so let’s turn these off from here on.

We can clip the Voronoi partition using the boundary geometry to get our neighborhoods.

Next we’re going to divide each neighborhood with a line that’s a fixed distance from one of the edges. The specific edge that’s chosen is controlled by our last set of input parameters (the 8 parameters “nbr1 – am side” to “nbr8 – am side”).
There’s a little more complexity than you might expect in this part of the process, mainly because we want to ignore short edges and make sure the line is placed in the right direction.

At this stage we can place the amenity areas. First we define the boundary curves by offsetting inwards.
These specify the amenity areas.

We then place the entrances to the amenity areas. These are currently specified as always being centrally located on the side of the line used to split the neighborhood.
Next comes the placement of desks in the remaining space. Desks are placed in double rows, with some logic to avoid columns, etc.

We can now remove the lines that split the neighborhoods, to get our final layout.
The Evaluation System

Based on the 24 input parameters – that define 8 neighborhoods in the specified area – the geometry system in our Dynamo graph is able to generate thousands (or perhaps millions) of different layouts for our office, effectively defining the solution space.

The job of the evaluation system – which includes a series of metrics – is to provide a set of scores for each design that can be used to search the space and zero in on “optimal” solutions. With any sufficiently complex system with competing objectives, we’ll inevitably see trade-offs between different metrics. A big part of any generative design system is an environment that allows the designer to explore these trade-offs and identify which solutions are of most interest to them.

There are different search strategies for any complex solution space. Refinery allows us to perform random searches, cross (or Cartesian) product searches – which are comparable with optimeering studies – and a more targeted search using a genetic algorithm: what we refer to as an optimization study.

An important point to consider when defining your evaluation system is that optimization can only be effective if it has some continuity along each of the various metrics. It’s also important to make sure that small changes in input parameters generally result in small changes in the output parameters: otherwise the process is going to struggle.

Much like the original MaRS project, Project Rediscover has 6 different metrics that evaluate each design. Here are the metrics from the original Project Discover paper:
Here's some background information on each of these.

**ADJACENCY PREFERENCE**

*Measurement of travel distance to preferred neighbors and amenities.*

**SCORING EQUATION**

\[
\text{ADJACENCY} = \frac{\sum [\text{Shortest Path Length} \times (1 + \Delta \text{Floors} \times \text{Vertical Multiplier})]}{\text{Number of Shortest Paths}} \times 10.0
\]

**INPUTS**
- Visibility graph (curve-based graph of possible travel)
- Individual neighbor adjacency preferences (JSON-formatted survey data)
- Individual amenity adjacency preferences (JSON-formatted survey data)

**COMPUTATION METHODS**
- Geometric shortest path algorithm (curve-based)
- Horizontal travel distance limit: 1.00 ft
- Vertical travel distance limit: 11.5ft (210 King floor-to-floor height)

**OUTPUTS**
- Individual adjacency scores (from 0 to 10)
- Per floor aggregated adjacency scores (from 0 to 10)
- Global adjacency score (from 0 to 10)

**SCORE RANGE**
- 0.0 SCORE (WORST CASE): All individuals have highest cost travel (max. horiz. and vert. distance)
- 10.0 SCORE (BEST CASE): All individuals have lowest cost travel (adjacent and same floor)

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**WORK STYLE**

*Measurement of suitability of neighborhood to team preferences. Determines how closely team’s preference and weighting of ambient conditions (light and activity) are met by their selected neighborhood.*

**SCORING EQUATION**

\[
\text{WORK STYLE} = \frac{\Delta \text{Pref} \times w_{\text{light}} + \Delta \text{Pref} \times w_{\text{activity}}}{w_{\text{light}} + w_{\text{activity}}} \times 10.0
\]

**INPUTS**
- Team data on preference for ambient conditions (JSON-formatted survey data)
- Daylight data (sampling grid from Daylight metric)
- Activity data (sample points from Low-Visual Distraction metric)

**COMPUTATION METHODS**
- Daylight & activity data aggregated per neighborhood
- Team preferences evaluated against assigned neighborhood values
- Per neighborhood and per floor scoring aggregated from team scoring

**OUTPUTS**
- Per team scoring
- Per neighborhood scoring
- Per floor scoring
- Overall design scoring

**SCORE RANGE**
- 0.0 SCORE (WORST CASE): No teams’ preferences are met
- 10.0 SCORE (BEST CASE): All teams’ preferences are met
INTERCONNECTIVITY

Measurement of active circulation paths. Determined by cross-referencing simulated movement paths with computed traversability data for given space.

SCORING EQUATION

\[
\text{CIRCULATION} = \frac{\sum (\text{Traversed Grid Values})}{\text{Traversed Grid Count} \times \text{Max Value}} \times 10.0
\]

INPUTS

+ Adjacency preference shortest paths (geometry - from adjacency metric)
+ 3D-space model (geometry, including solid obstructions)

COMPUTATION METHODS

+ Generate analysis grid of relative traversability (range of possible moves from given point)
+ Identify and sum values of intersected grid tiles for every shortest path

OUTPUTS

+ Per floor circulation scores (from 0 to 10)
+ Global circulation scoring (from 0 to 10)

SCORE RANGE

+ 0.0 SCORE (WORST CASE): All movement through high congestion areas
+ 10.0 SCORE (BEST CASE): All movement through congestion-free areas

LOW VISUAL DISTRACTION

Measurement of negative visual activity from individual workspaces. Tabulates the number of coworkers visible from a given workstation.

SCORING EQUATION

\[
\text{LOW VISUAL DISTRACTION} = \sum \left(10.0 \times \left(1.0 \times \left(\text{C} \times 1.0\right) + \left(\text{W} \times 0.5\right) - \left(\text{N} \times 0.5\right) - \left(\text{F} \times 0.25\right)\right)\right) / \text{Number of Workstations}
\]

INPUTS

+ 3D Space Model (Geometry, including Obstruction)
+ Workspace positions and orientations

COMPUTATION METHODS

+ Individuals begin with score of 10.0
+ -1.0 Penalty: All visible coworkers in primary peripheral vision (60°)
+ -0.5 Penalty: All visible coworkers in wide peripheral vision zone (100°)
+ Distance modifier: Penalties reduced by 50% for distances > 20 ft

OUTPUTS

+ Individual Desk scoring
+ Teens & Neighborhood scoring
+ Per floor aggregated scoring
+ Overall design scoring

SCORE RANGE

+ 0.0 SCORE (WORST CASE): All workstations high visual distraction
+ 10.0 SCORE (BEST CASE): All workstations no visual distraction
DAYLIGHT

Measurement of daylight levels in workspaces and amenity spaces. Daylight analysis uses industry-validated methods for calculating light levels and utilizes LEED v4 standards for evaluation and scoring.

SCORING EQUATION

\[
\text{DAYLIGHT} = \frac{\text{(% Passing 9am) + (% Passing 3pm)}}{2} \times 10.0
\]

\[
\text{PASSING} = \frac{\text{Floor Area within 300 to 3000 Lux}}{\text{Total Floor Area}}
\]

INPUTS

+ 3D BIM Model (including room definitions and site context)
+ Location Data (Toronto, ON)

COMPUTATION METHODS

+ Method determined by LEED v4 EQc7.1p2 (75% occupied space passing at 9am and 3pm)
+ Evaluated with Revit Daylight Analysis
+ Measured at 30” A/P (typical desk height)

OUTPUTS

+ Analysis grid sample data (1 ft grid)
+ Individual room scoring (% passing)
+ Overall space scoring (% passing)

SCORE RANGE

+ 0.0 SCORE (WORST CASE) - 0% of occupied floor area passing
+ 10.0 SCORE (BEST CASE) - 75% occupied floor area passing

VIEWS TO OUTSIDE

Measurement of exterior views from circulation and workspaces.

SCORING EQUATION

\[
\text{VIEWS TO OUTSIDE} = \sum \left( \frac{\text{Views from Sample Point}}{\text{Number of Sample Points}} \right) \times 10.0
\]

INPUTS

+ 2D Space Model (geometry, including solid obstructions & windows)
+ Workspace locations (geometry, as points)
+ Circulation path (geometry, as curves)

COMPUTATION METHODS

+ Generation of target points (curve subdivision of windows)
+ Generation of circulation sample points (curve subdivision of paths)
+ Sample ray occlusion testing (sample points to target points with solid obstructions)
+ Count number of unobstructed view rays

OUTPUTS

+ Per-floor aggregated views to outside score (from 0 to 10)
+ Global views to outside score (from 0 to 10)

SCORE RANGE

+ 0.0 SCORE (WORST CASE) - No sample points have views to outside
+ 10.0 SCORE (BEST CASE) - Every sample point has views to outside
The goals are named slightly differently in Project Rediscover, but they are essentially equivalent. Let’s take a look at them one-by-one.

**Buzz**

To assess Buzz (or Interconnectivity) – which measures the areas in the office where people are likely to meet casually, as they move from place to place – we test the shortest paths people have from their desks to various landmark points and their local amenities.

Here are the paths without the desks.

These paths can be aggregated to create a congestion map, which effectively tells us where people are likely to bump into one another in the office.
Adjacency

This metric is very simple, once we have the shortest paths within the office defined. This is simply an average of these various distances, which gives us a value we will want to have the optimization engine minimize.

Visual Distraction

For visual distraction we assess the amount of visual distraction people have at their desks. Distractions can come either from people at other desks or parts of the office that have high levels of congestion (see the Buzz metric for this).
Views To Outside

For this metric we need to assess visibility from each desk to the outside world. We do this using the Space Analysis package, which allows us to test visibility within a space.

Here’s the visibility grid that gets created for the design we’ve seen so far. This displays a set of visibility checks between points on the windows and locations in the office. It’s assumed that if a desk can be seen from a window, then someone can see the window from that desk.

Here we can see how this can be visualized for individual desks, with lines showing the closest external viewpoint.
**Workstyle**

This is an interesting metric, in that it's somewhat more fuzzy than the others: it takes employee survey data and assesses how well each neighborhood meets people’s expectations around the lighting and level of distraction. For the sake of this particular graph we’ve used synthetic data (of course).

![Workstyle Diagram]

**Daylight**

In the first version of the graph we “rolled our own” daylighting calculations, estimating them based on raycasting through windows to sun locations at various times of day and year. In this version we’ve swapped out that custom implementation with the Solar Analysis package. This is a wrapper around the former Ecotect engine, which calculates daylight much more efficiently.

![Daylight Diagram]
As reference, here's a graph created by Paolo Serra from Autodesk Consulting that shows the overall layout the first version of Project Rediscover, with some additional “Remember” nodes that would make execution more efficient.
Space Analysis

As an appendix, here are some blog posts that introduce the Space Analysis package and its various capabilities:

February 21, 2019

Interested in space analysis for Dynamo and Refinery?

March 26, 2019

The Space Analysis package for Dynamo and Refinery is now available!

April 12, 2019

Using the Space Analysis package for pathfinding and visibility in Dynamo

April 15, 2019

Dynamo Space Analysis and Revit 2020's Path of Travel

April 17, 2019

Using Refinery to optimise a Dynamo graph using Space Analysis for pathfinding and visibility

June 21, 2019

A nice introduction to DynaMaps and Space Analysis by That BIM Girl

June 25, 2019

Say what? Acoustics in Space Analysis?

August 21, 2019

Using a view cone for targeted visibility in Dynamo with Space Analysis

September 18, 2019

Build your own SoundSystem: Space Analysis now supports multi-source acoustics