TEXAS
The University of Texas at Austin

EDUCATING DESIGNERS FOR GENERATIVE ENGINEERING

LEARNING GOAL 5

Chapter: Generative Design

Learning Objectives: 1) Define generative design; 2) Define a problem within a generative design paradigm; 3) Explore generative design paradigm; 4) Evaluate designs made using generative design; 5) Iterate using generative design

Definition

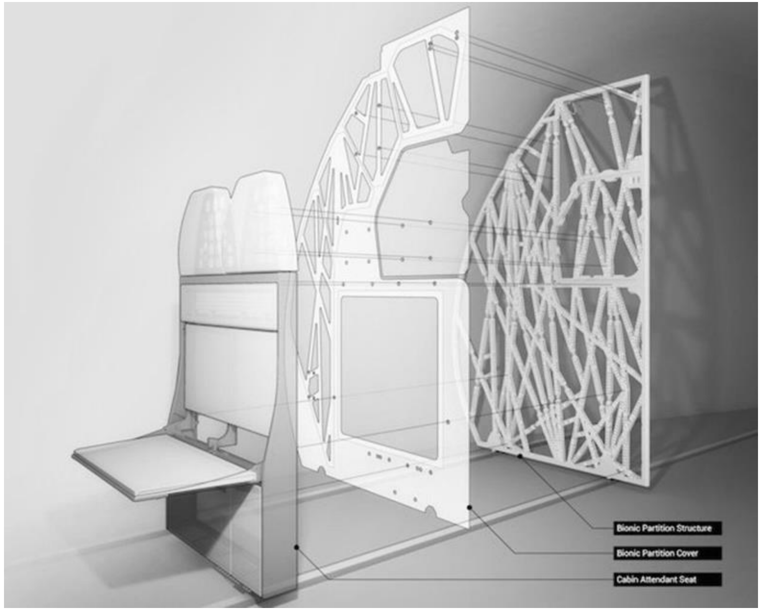
Generative design (GD) is an iterative design process that utilizes explicit programming or implicit learning algorithms to create innovative, efficient, and buildable designs, to meet specific objectives and constraints that are iteratively refined by designers [1-3].

Design variations created by generative design [4]

[1] https://en.wikipedia.org/wiki/Generative_design
[2] Shea et al. (2005). *Automation in Construction.*
[3] Regenwetter et al. (2022). *Journal of Mechanical Design.*
[4] https://www.sw.siemens.com/en-US/technology/generative-design/?sfc=1481

Generative Design in Practice

- GD originated in the 1970s when computers were first used for complex design challenges.
- GD can create novel forms and structures that are not possible with traditional methods.
- It has found applications in various fields, such as aerospace, automotive, and biomedical engineering.
- Example: airplane partitions that are 45% lighter without compromising strength

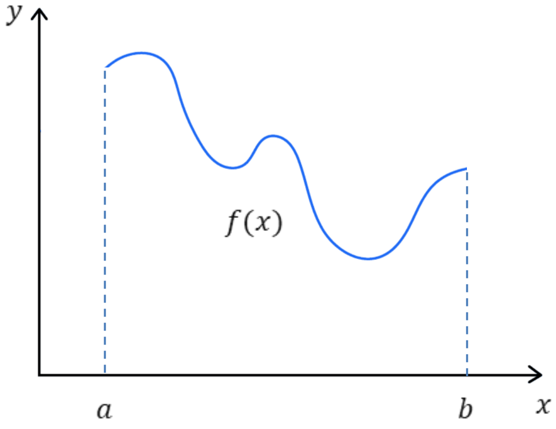


Redesign partitions for Airbus A320 using GD [1]

[1] https://3dprintingindustry.com/news/63046-63046/

Problem Definition

The designer must define the design **objectives** and **constraints**.



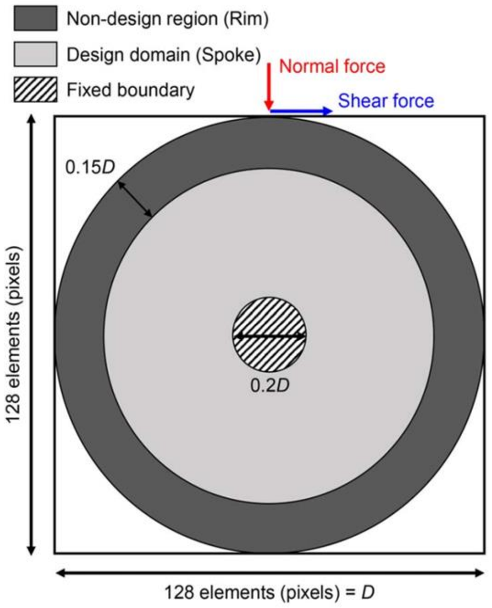
Example 1: objectives as computable expressions

- Objective: maximize $y = f(x)$
- Constraints: $a \leq x \leq b$

I want a futuristic red sedan.

Example 2: Objectives and constraints can also be textual or visual data.

Problem Definition



Example of car wheel design [1]

- The figure sketches the design domain and boundary conditions, which serve as the design **constraints**.

- The design **objective:** maximize the stiffness of the car wheel

[1] Oh, S., Jung, Y., Kim, S., Lee, I., & Kang, N. (2019). *Journal of Mechanical Design*.

Practice Example: Solar Farm Design

Objectives:
Profit: The investors hope to sell the energy produced to cover the cost and eventually make a profit.

Average energy output: The solar farm design needs to generate as much output per solar panel as possible, or the investors may look elsewhere.

Define yearly profit using these known quantities:
- Total yearly energy output (kWh)
- Electricity selling price ($/kWh)
- Number of solar panels
- Yearly cost of solar panels ($/panel)

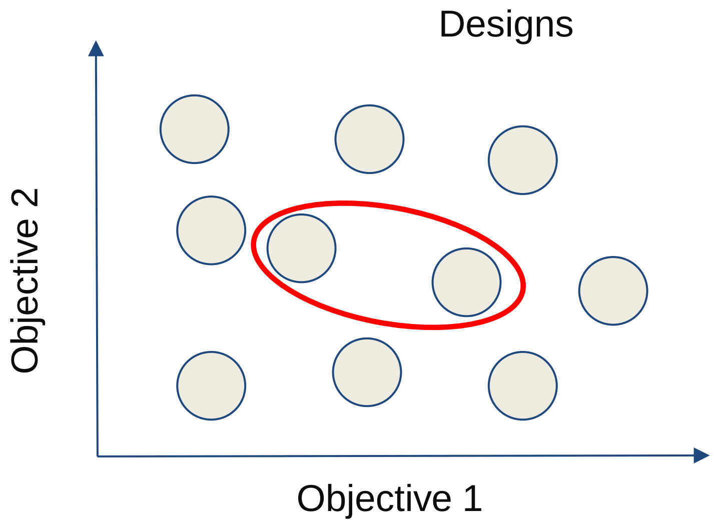
Yearly profit
= yearly revenue - yearly cost

= ?

Exploration

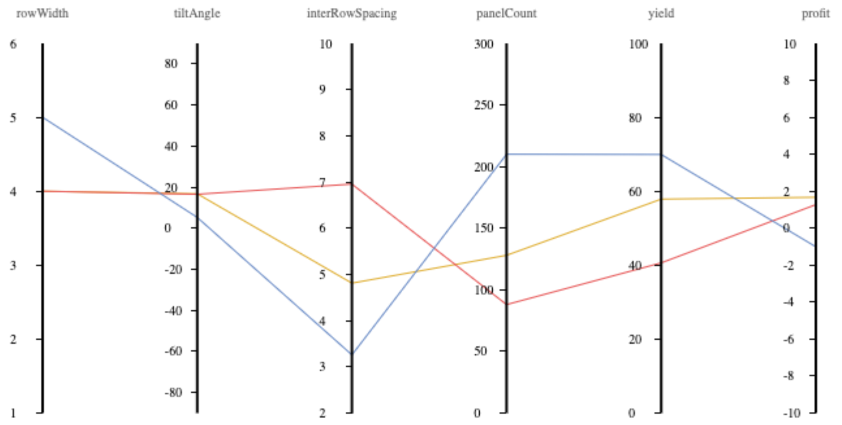
- In GD, you can simply set an objective and enter the search ranges (constraints) for each design variable, and the GD algorithm will generate dozens of designs that meet the requirements.

- It’s good to have more design options to better explore the design space.



Practice Example: Solar Farm Design

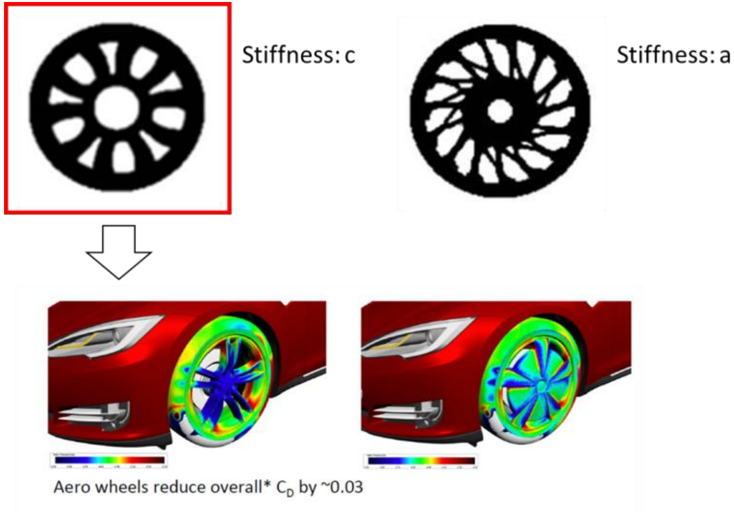
- With GD in Aladdin, you can specify an **objective** and search ranges for each **design variable**. The search ranges are often defined by the **constraints**.
- Generate three different designs for each of the following objectives:
  - Yearly profit
  - Yearly total energy output



Use the figure to compare your generated designs from various dimensions.

Evaluation

- Evaluation in GD is similar to TD, but:
    - there are more designs to evaluate.
    - You can compare preferred designs to better understand the designs.
- Designers might need to make trade-offs among different engineering performance metrics and visual appearances.

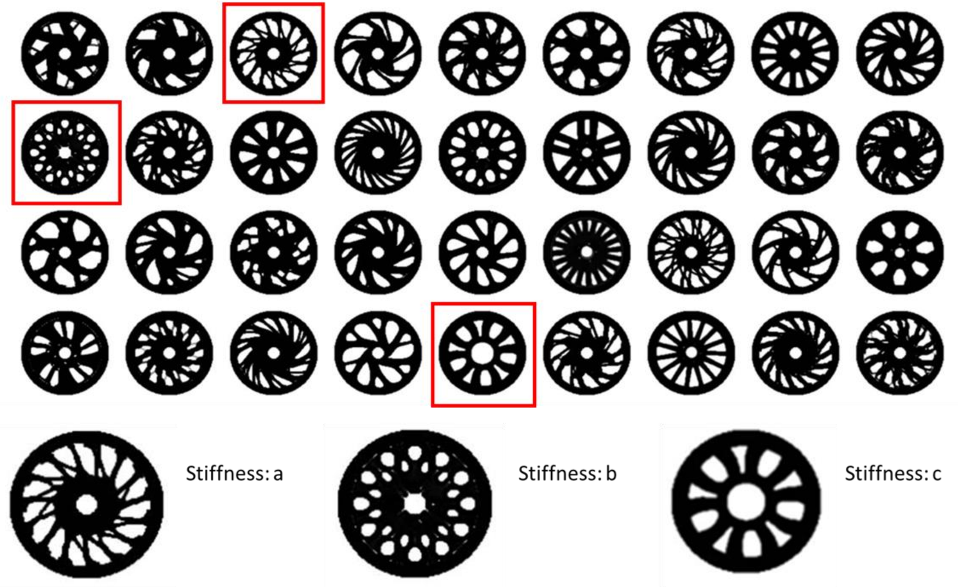


Example of car wheel design [1]

[1] Oh, S., Jung, Y., Kim, S., Lee, I., & Kang, N. (2019). *Journal of Mechanical Design*.

Evaluation

For a car tire, designers could evaluate designs by comparing their aesthetics and mechanical performance (e.g., stiffness).



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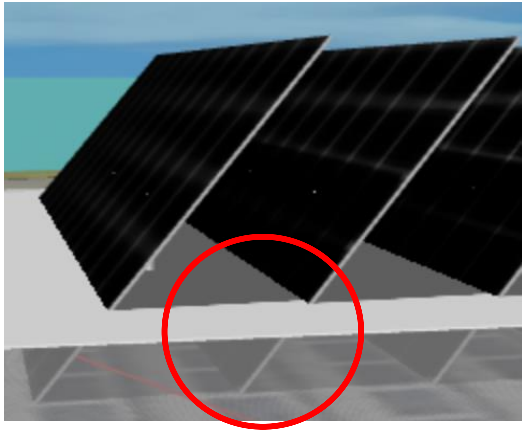
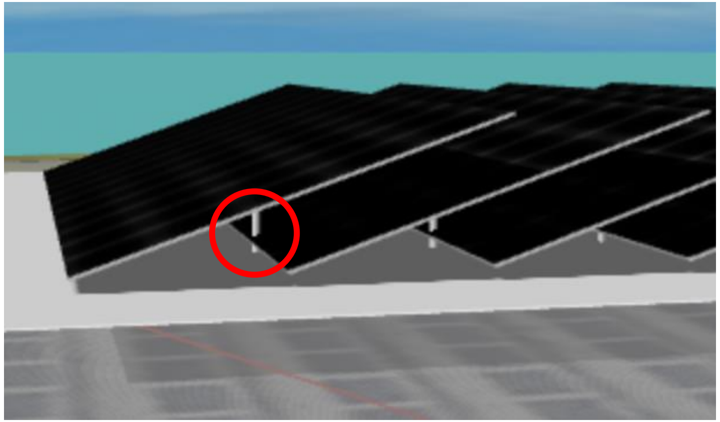
Practice Example: Solar Farm Design



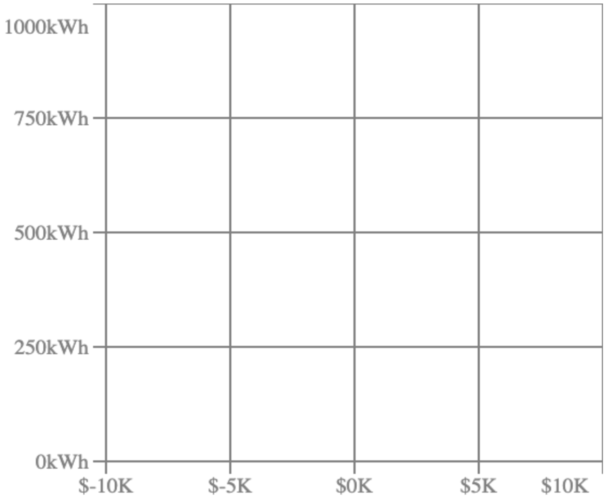


Visual inspection of the generated designs

The GD algorithm does not validate whether each generated design is physically feasible.

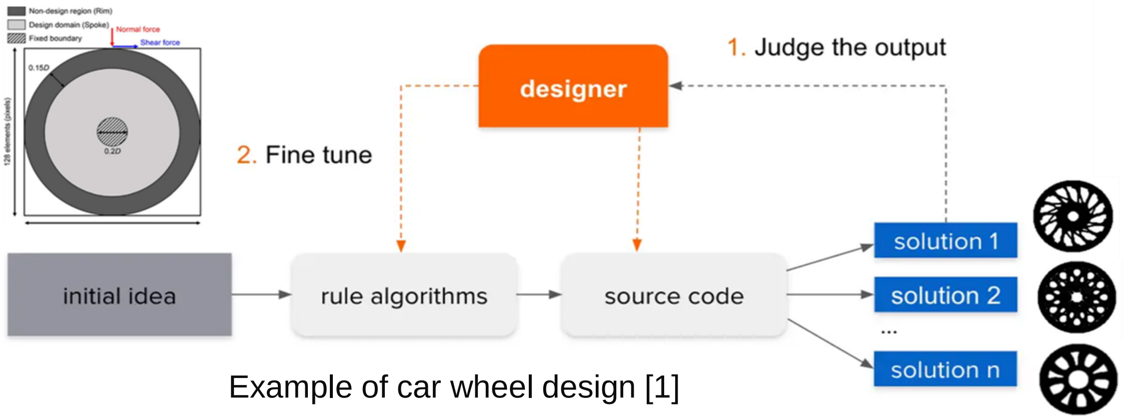
Practice Example: Solar Farm Design

You can also plot each design's performance according to the objectives (mean yearly output and profit). What effect does increasing one have on the other?



Iteration

In this step, the designer incorporates insights from the evaluation step, may modify the objective, and may adjust the constraints. By repeating this process and making adjustments to address any issues, a satisfactory solution can be reached.



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Practice Example: Solar Farm Design

To iterate the solar farm design, there are a few options:

- **Rerun GD with the exact same settings.** The genetic algorithm it uses involves a certain degree of randomness, so each run may generate different results.

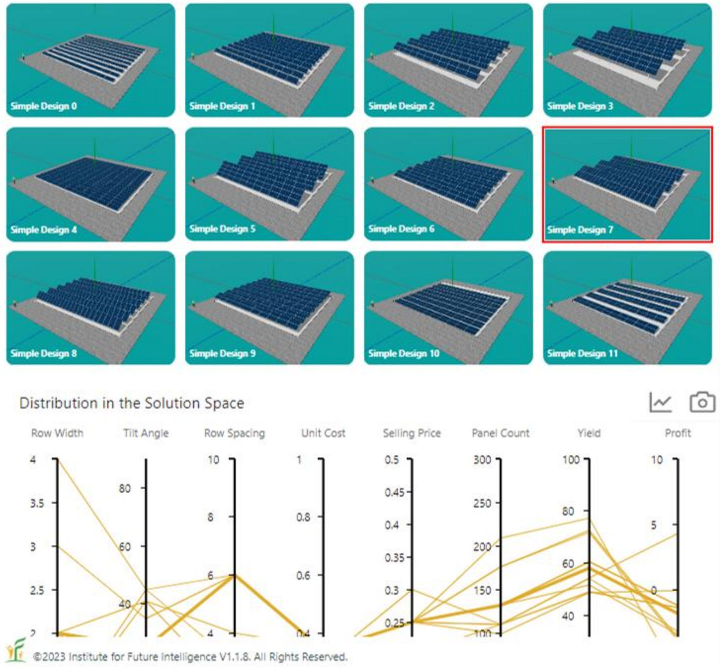
- **Change the design objective.** In addition to yearly profit and yearly average output, you can also set the objective to yearly total output.

- **Change the search ranges of one or more design variables.** For example, you can be more creative by searching in new areas in the design space (e.g., designs with wider rows), or be more efficient by avoiding certain areas (e.g., negative tilt angles).

Summary

Generative design is:

- the process of automatic design generations under defined objectives and constraints,
- exploring the design space automatically,
- evaluating multiple designs to make trade-offs, and
- iterating using insights from the evaluation stage.



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