The Aladdin Platform for Design Research and Education

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Workshop on Generative Design
PTC Headquarters, 121 Seaport Blvd, Boston, MA 02210
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IFI is a small non-profit research and development organization
funded by National Science Foundation and National Institutes of Health.

Platform & Domains

Platform Features

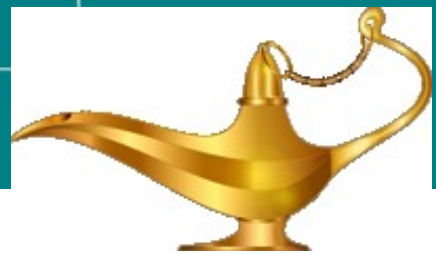
Engineering Domain 1: Building Design and Energy Modeling

- Integrate CAD and CAE into a single system
- Support generative design (cloud computing not required)
- Focus on renewable energy and energy efficiency
- Provide a data logger for capturing user interactions with software (for education research)

CAE → (Feedback) → CAD

Goal: Minimize feedback generation time to speed up design iteration

No need to do toolchaining using scripts, creating a closed feedback loop to guide students.



Aladdin, a Web-based CAD/CAE program developed by IFI with NSF grants, is an open-source platform for design research and education.

Freely available at: https://intofuture.org/aladdin.html

Engineering Domain 2: Concentrated Solar Power Design

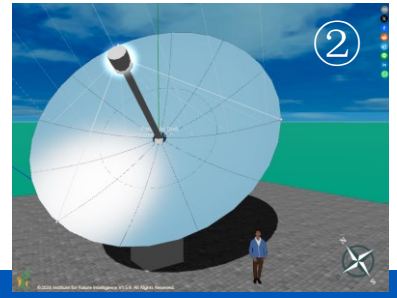
①

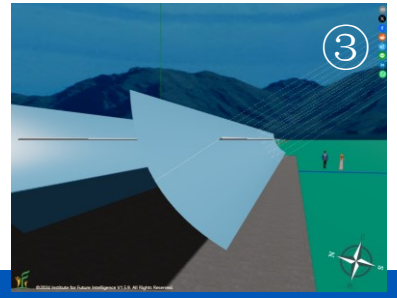
An extremely high-dimensional design problem that cries for AI's help!

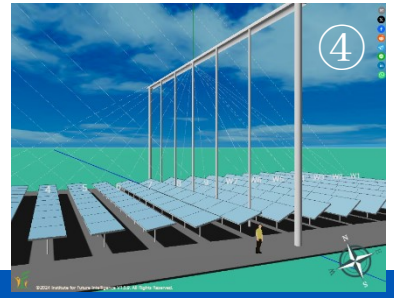
All the four CSP configurations are supported:

① Solar power towers ② Parabolic dishes

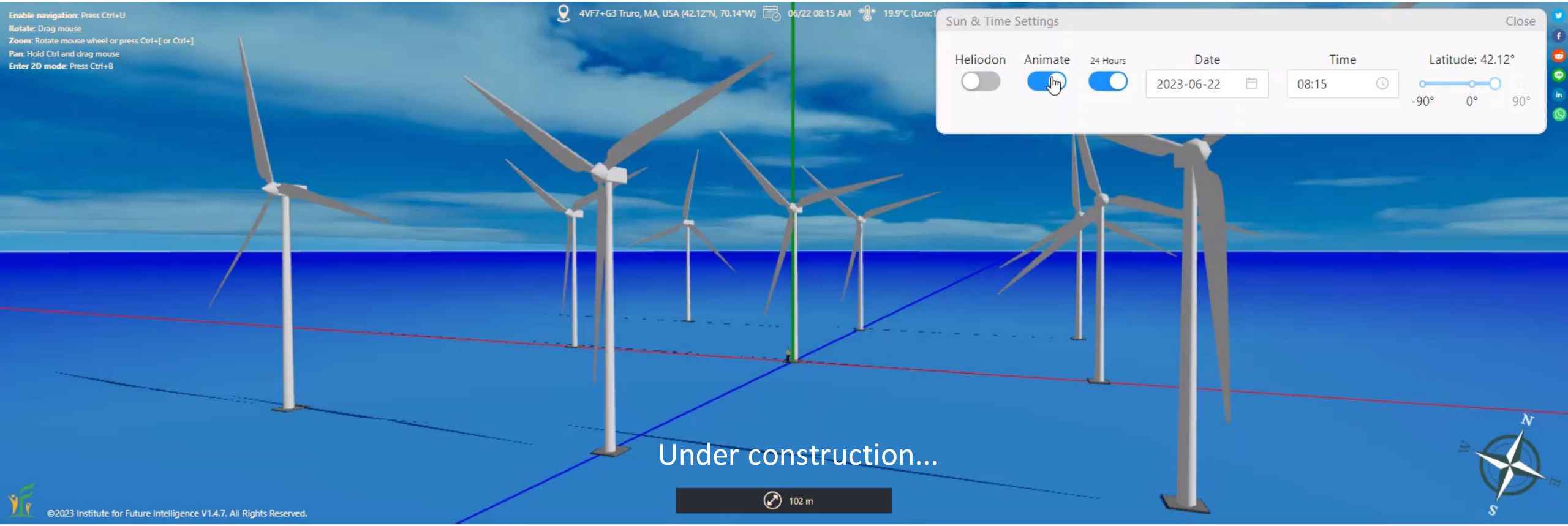
③ Parabolic troughs ④ Linear Fresnel reflectors







Engineering Domain 3: Wind Farm Design



The reason to focus on these domains (especially for the K-12 schools):
Renewable energy is a favored context of engineering education due to the importance of climate change and energy independence.

Validation

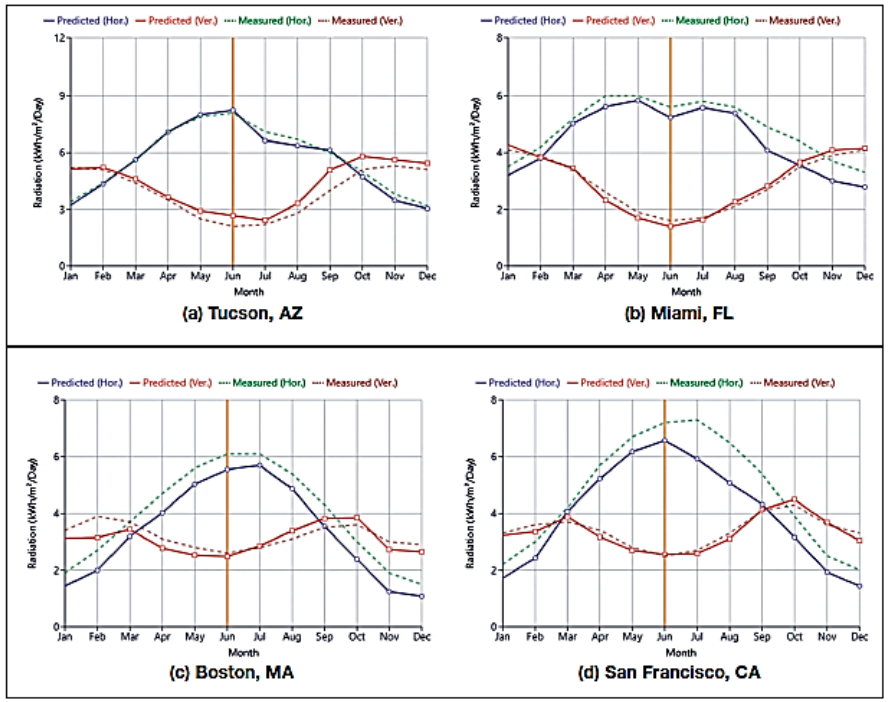
Real-World Photos

Aladdin Models

Structural modeling (CAD)

How accurate are Aladdin's solar energy simulations?

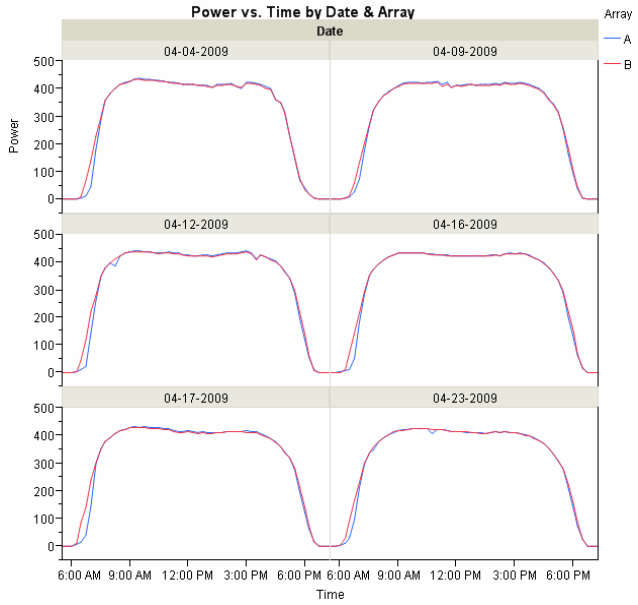
A comparison between the predicted and measured solar radiation intensities for four U.S. locations: Horizontal and vertical (south-facing) sensors



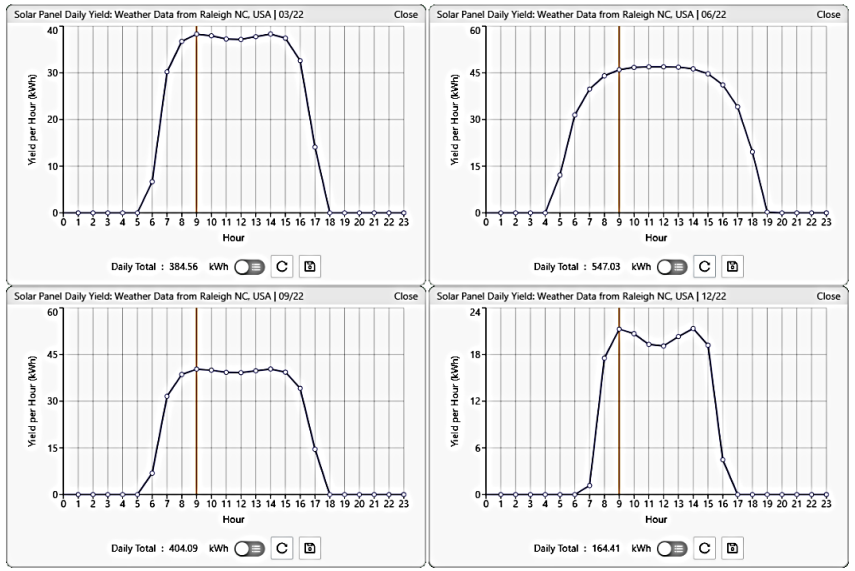
Aladdin predictions agree with other tools:

- **PVWatts Calculator**, U.S. National Renewable Energy Laboratory (NREL)
- **Photovoltaic Geographical Information System (PVGIS)**, the Joint Research Centre of the European Commission

Marzouk, O. A. (2022). Land-Use competitiveness of photovoltaic and concentrated solar power technologies near the Tropic of Cancer. *Solar Energy*, Vol. 243, pp. 103-119, https://doi.org/10.1016/j.solener.2022.07.051



Real-world data (spring) Cary, North Carolina, USA



Aladdin results (four seasons)

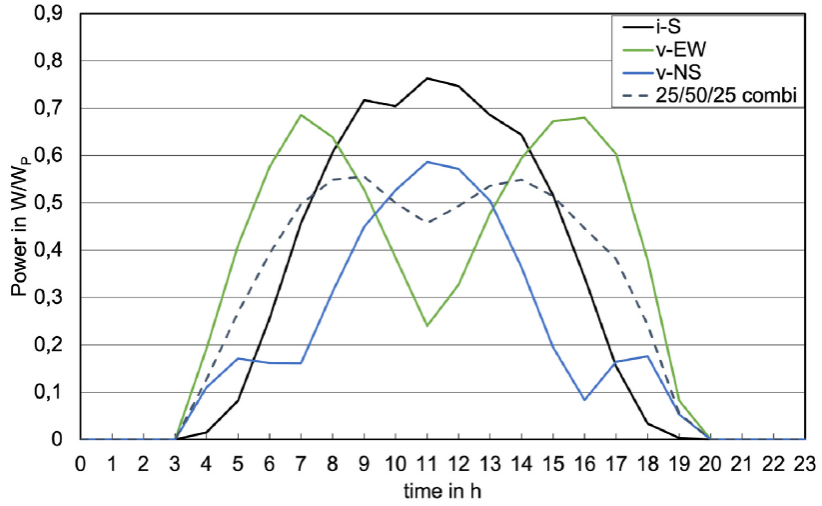
A "surprise" in the pattern of hourly outputs of monofacial solar panels driven by horizontal single-axis trackers (HSAT) – a small dip at noon in the output curve in some seasons.

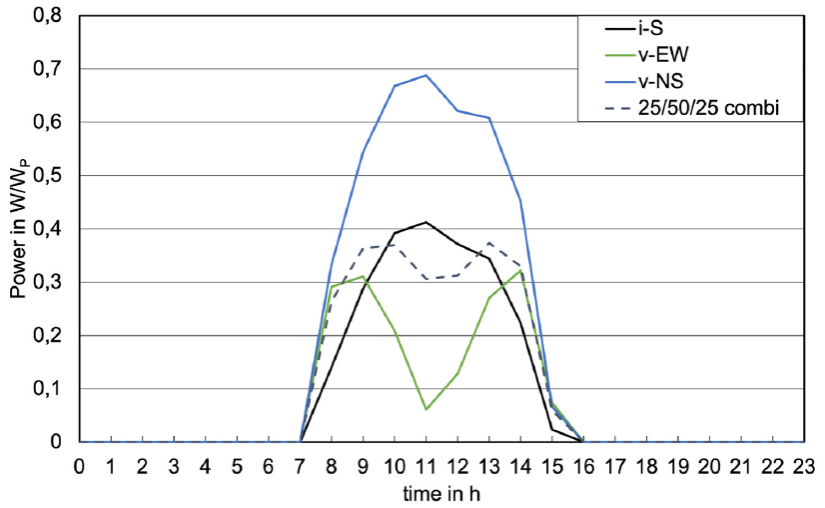
Functional modeling (CAE)

Bifacial solar panel results

Real-world data from vertically-installed bifacial solar panels in Germany.

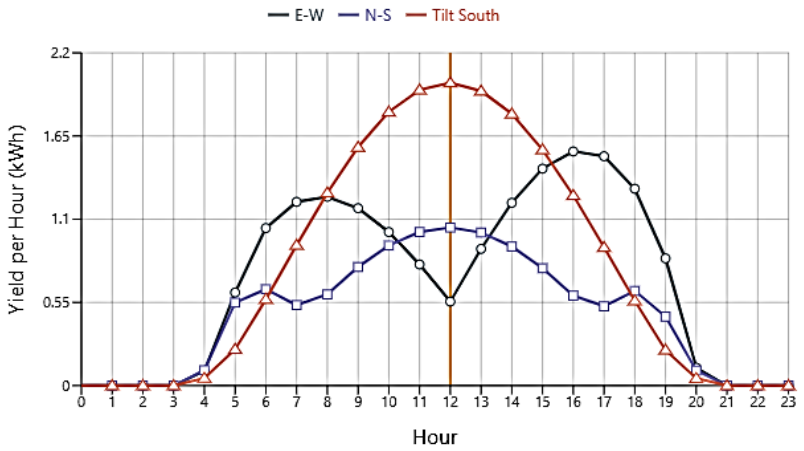
Source: Reker, S., Schneider, J. & Gerhards, C., *Solar Energy*, 2022

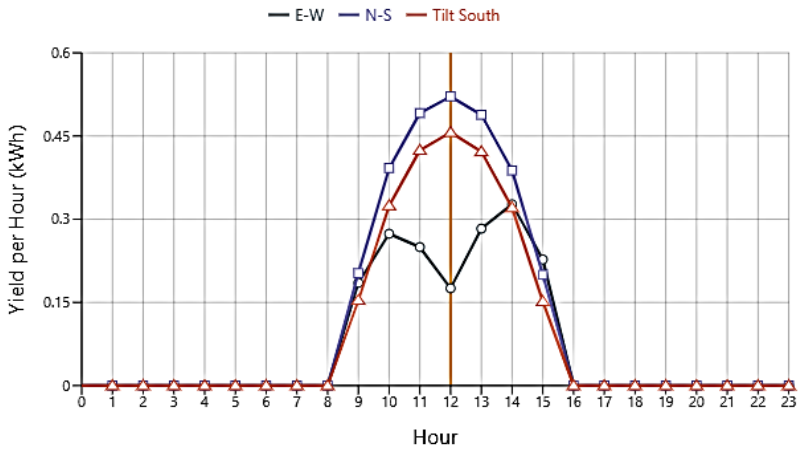




Calculated results for vertically-installed bifacial solar panels in Germany.

Source: Aladdin



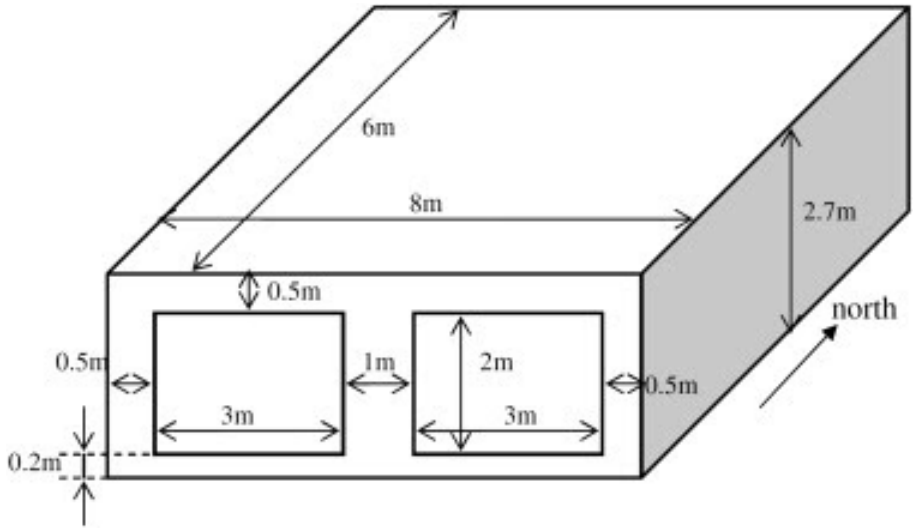


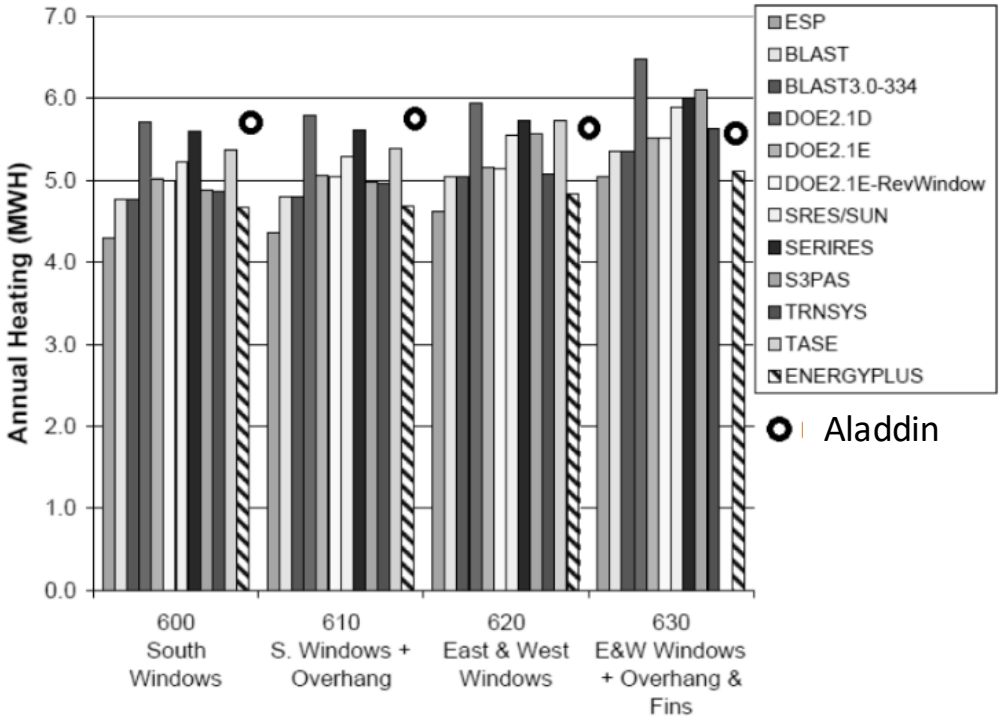
Functional modeling (CAE)

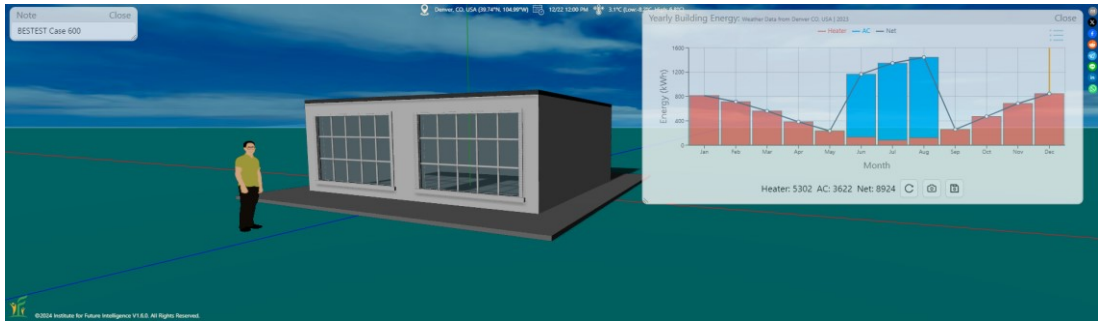
Note: These graphs only show a qualitative agreement. The y-axis units and design parameters are different.

How accurate are Aladdin's building energy simulations?

Aladdin's building simulation was validated independently by **Warsaw University of Technology** based on U.S. DOE's Building Energy Simulation Test (BESTEST).







A comparison of Aladdin's results with other energy modeling software

Gajewski, R. & Pieniążek, P. (2017) Building energy modelling and simulations: qualitative and quantitative analysis, *MATEC Web of Conferences 117*, 00051, https://doi.org/10.1051/matecconf/201711700051

Functional modeling (CAE)

AI

Vision

Why Name It Aladdin?

In Arabic folklore, Aladdin is a tale that features a magic lamp able to generate whatever its owner wants. In the field of design, AI has somewhat realized the fairytale — designers only need to specify what they want, and AI would bring their wishes to life.

Evaluating the Objective Function Through Numerical Simulation

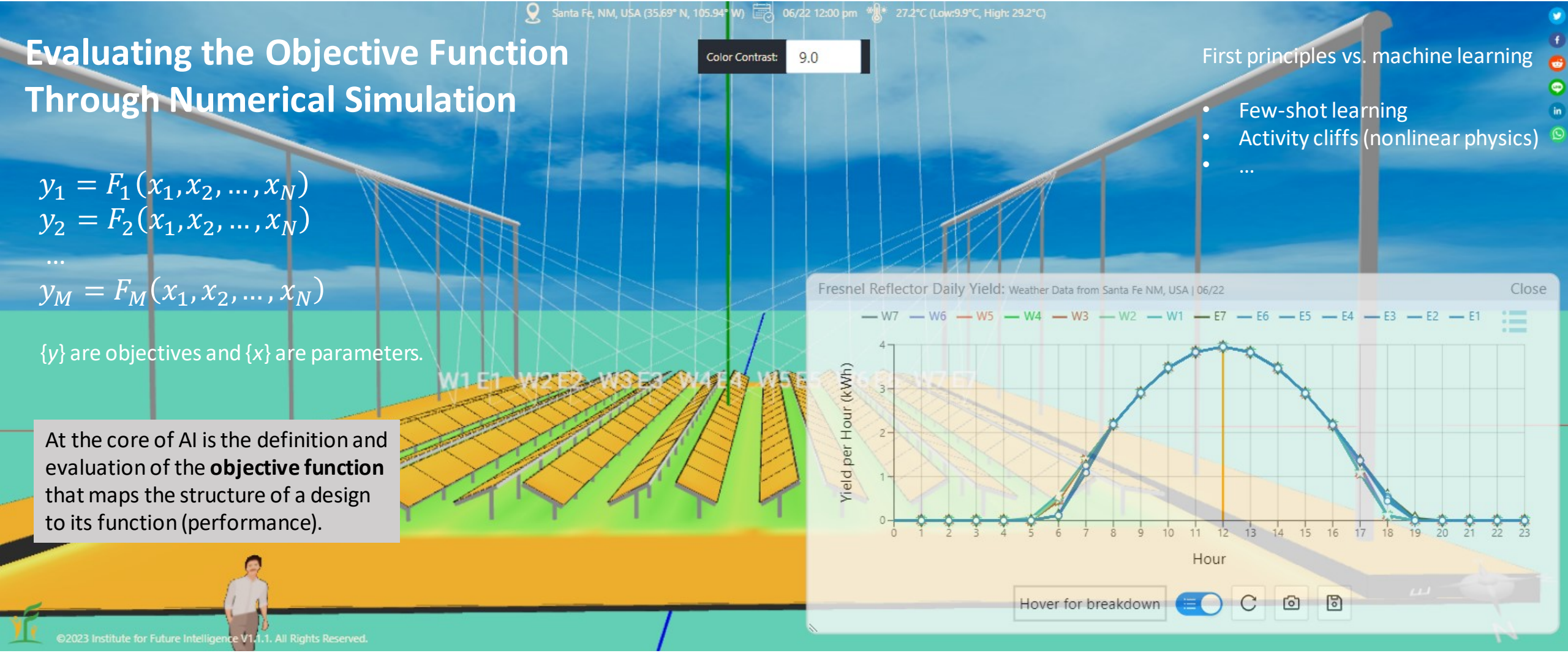
$$y_1 = F_1(x_1, x_2, \dots, x_N)$$
$$y_2 = F_2(x_1, x_2, \dots, x_N)$$
$$\dots$$
$$y_M = F_M(x_1, x_2, \dots, x_N)$$

$\{y\}$ are objectives and $\{x\}$ are parameters.

At the core of AI is the definition and evaluation of the **objective function** that maps the structure of a design to its function (performance).

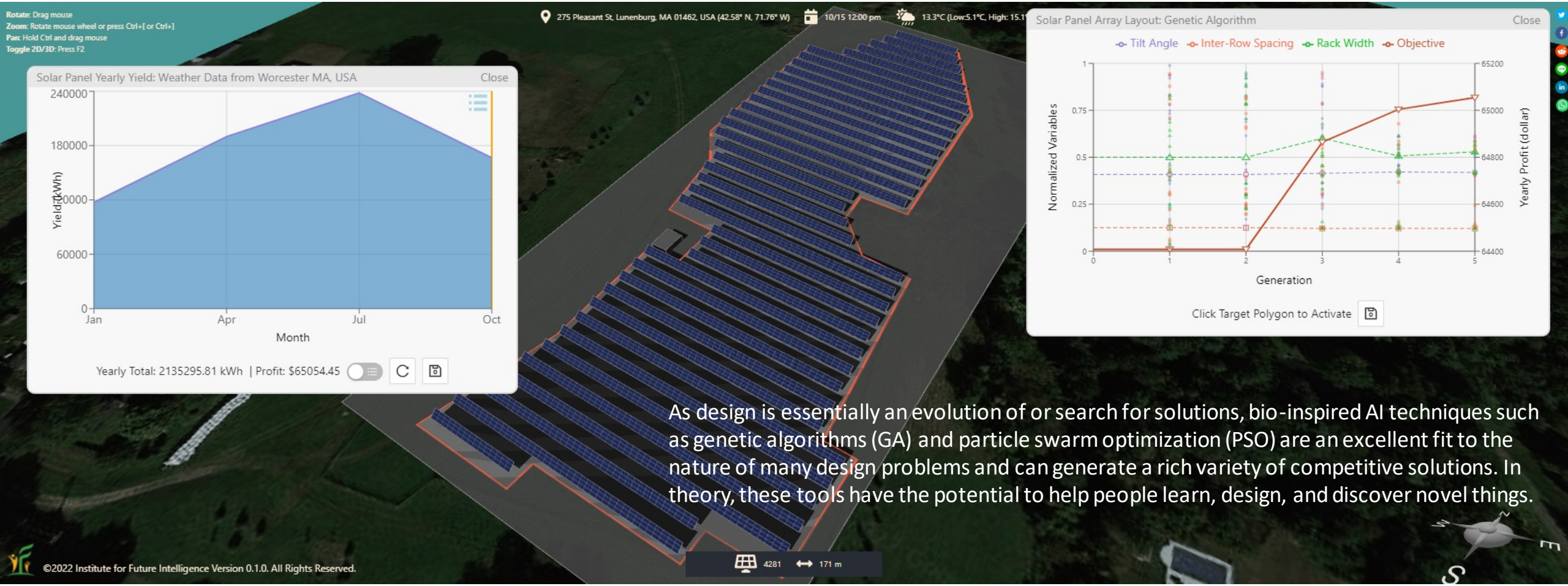
First principles vs. machine learning

- Few-shot learning
- Activity cliffs (nonlinear physics)
- …



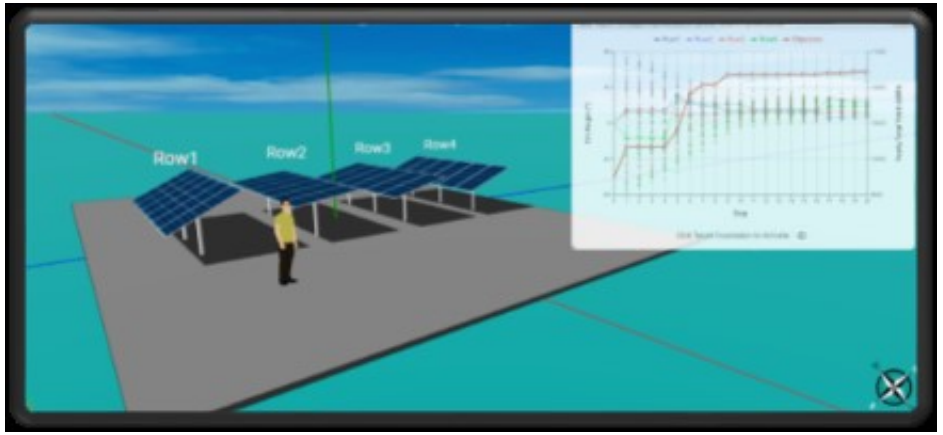
An objective function in Aladdin has no closed form and must be evaluated through numerical simulation of energy flow based on discretized time and space (e.g., solar radiation and heat transfer on a building envelope in a diurnal cycle). Only a geometric change larger than a step length in a spatial dimension can result in a difference in the objective function. **This spatial resolution sets the sensitivity of generative design.**

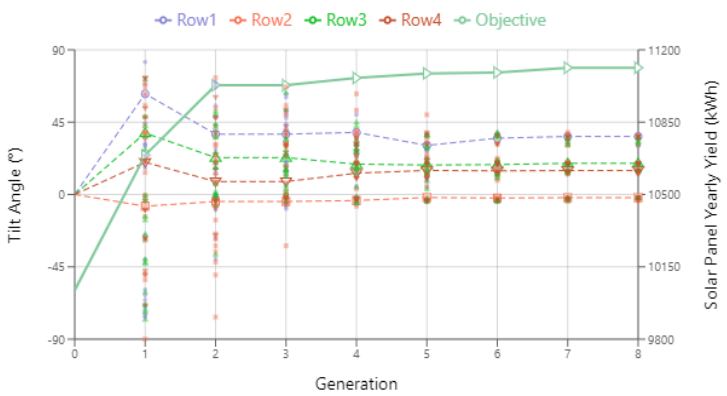
Evolutionary Computation for Engineering Optimization



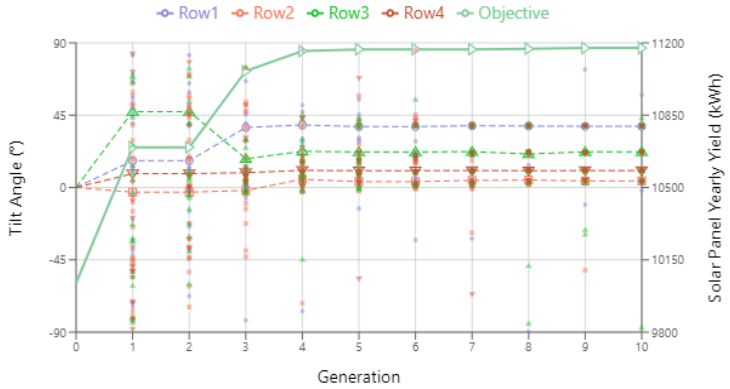
Example: Design a photovoltaic (PV) solar farm for a land area in an arbitrary shape that can make the target profit while meeting all the constraints

Transparency and Explainability: Visualizing AI in Action





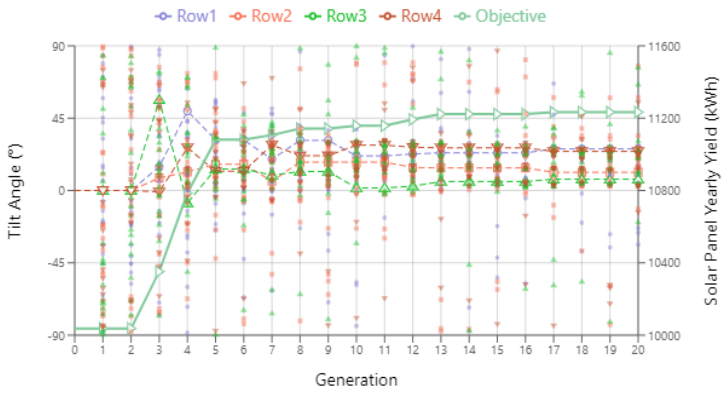
Mutation rate: 0



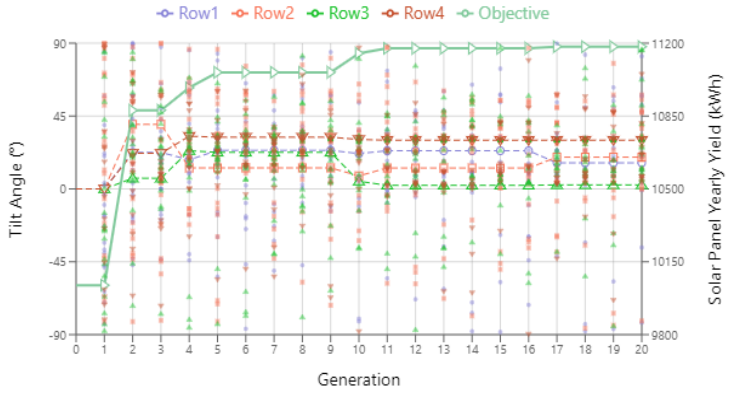
Mutation rate: 30%

Opening the black box of AI

Aladdin visualizes the design space explored by genetic algorithms with a mutation rate of 0, 30%, 70%, and 100%, mimicking different degrees of divergent design thinking of humans.

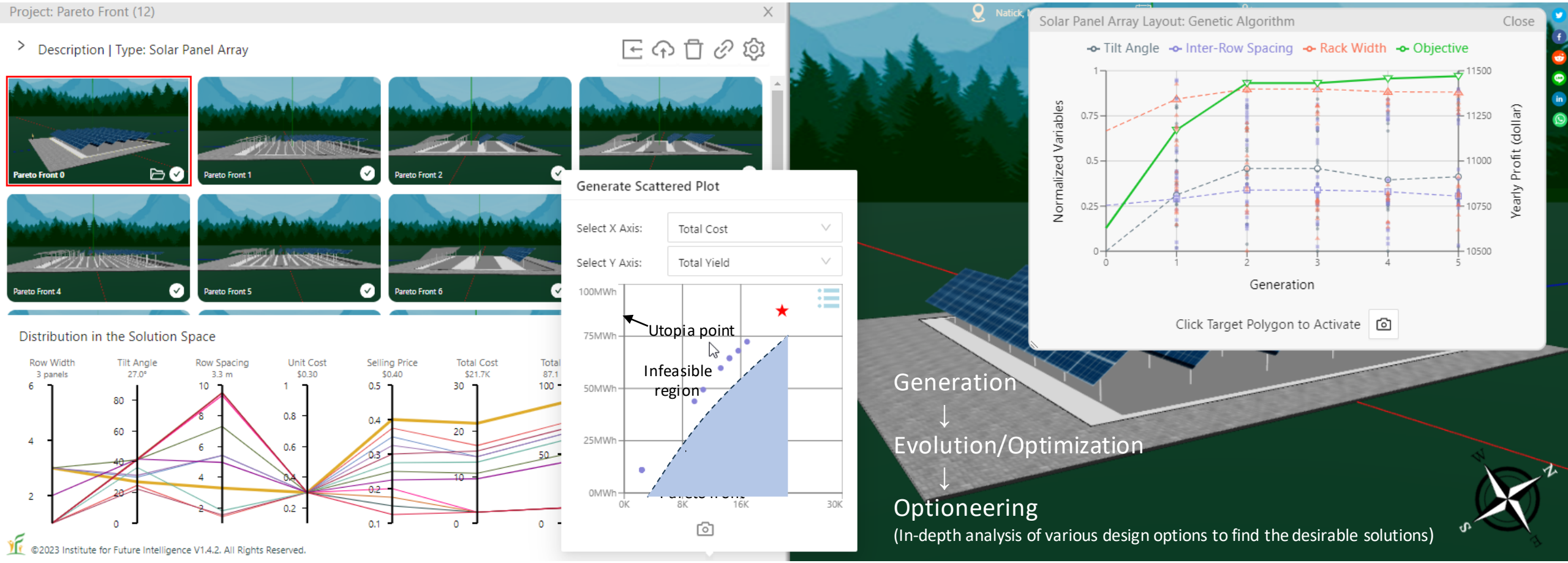


Mutation rate: 70%



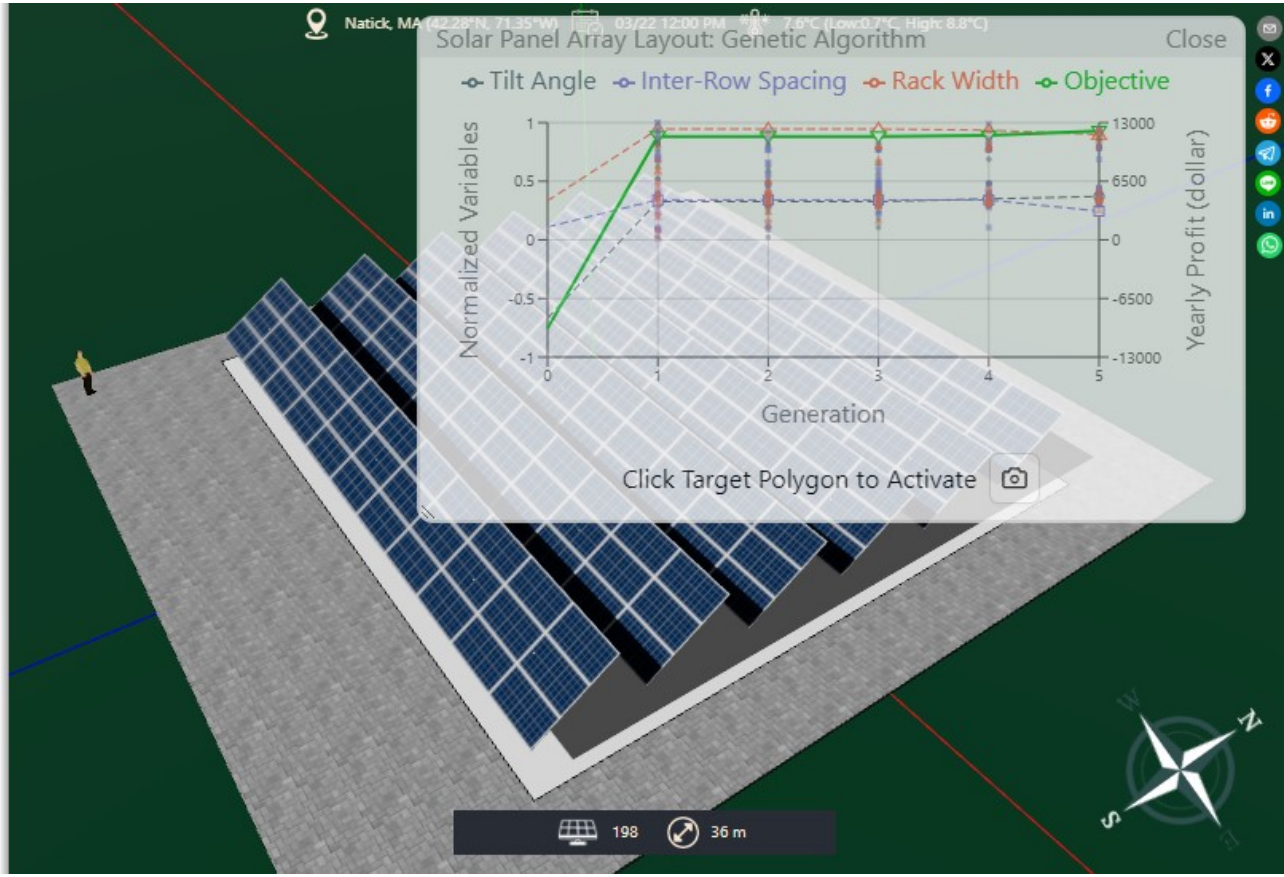
Mutation rate: 100%

Generative Design: From a Few to a Lot



From traditional design to generative design, the role of an engineer is transformed from a designer into a curator.

Optioneering: Engineers as Data Scientists

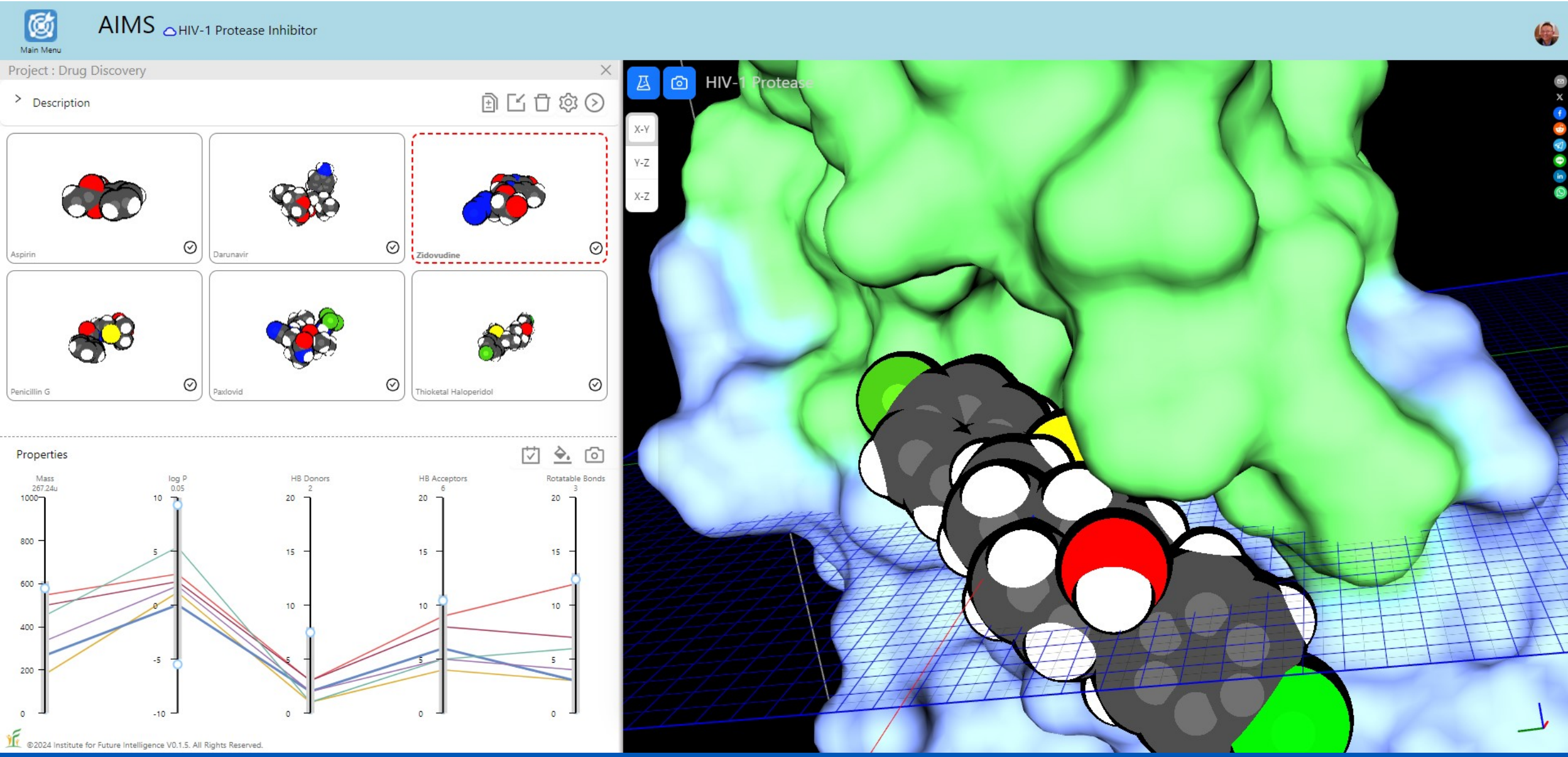


Interactive visual analytics is needed for designers to mine desirable solutions from many options generated by AI.

Aladdin supports linking, brushing, sorting, filtering, and more.

Our Work in Other Fields

Drug Design: Artificial Intelligence for Molecular Sciences (AIMS)



Thank you for your time!

Acknowledgements