EDUCATING GENERATIVE DESIGNERS IN ENGINEERING

Dr. Zhenghui Sha (PI)[1], Dr. Molly Goldstein (Co-PI)[2], Dr. Onan Demirel (Co-PI)[3], Dr. Charles Xie (Co-PI)[4], Dr. Darya L. Zabelina (Co-PI)[5]
John Clay[1], Xingang Li[1], Elisa Koolman[1], Nalin Varma[1]

[1] University of Texas at Austin, [2] University of Illinois at Urbana-Champaign,[3] Oregon State University,
[4] Institute for Future Intelligence, [5] University of Arkansas

PROJECT GOALS

To **define**, **implement**, and **disseminate generative design thinking**, a new form of design thinking, to **facilitate the teaching and learning of generative design**.

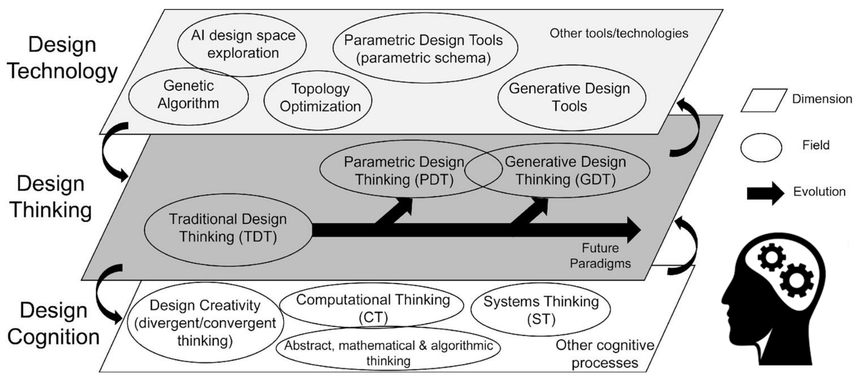
RQ1: *Theoretical perspective*: What are the **essential elements** of **generative design thinking** that students must acquire in order to work effectively at the human-technology frontier in engineering?

RQ2: *Practical perspective*: To what extent and in what ways can the project products **support the learning** of **generative design** as indicated by students' gains in generative design thinking?

RQ3: *Affective perspective*: To what extent and in what ways can **artificial intelligence** affect the **professional formation** of engineers shown by changes in interest and self-efficacy in engineering?

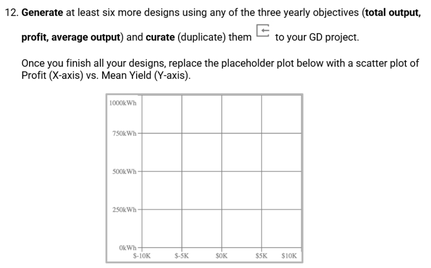
MAJOR ACTIVITIES (2019-2024)

Activity 1: Investigation on the relationships between traditional engineering design thinking, parametric design thinking, and related design thinking concepts to seek an operational definition of Generative Design Thinking.



Evolving Design Thinking Model: With this model we will examine the influence of technology development on the formation of design thinking, the cognitive processes and personality traits associated with each design thinking concept, and the design methodologies implementing the corresponding design thinking concept. We are conducting a systematic literature review to provide an in-depth understanding of GDT and a clarification of the obscure boundaries between the many design thinking concepts.

Activity 2: Development of curriculum documents to teach traditional, parametric, and generative design concepts, and refinement of an open-ended design problem for human-subjects data collection of students' learning and design behavior.


12. **Generate** at least six more designs using any of the three yearly objectives (**total output, profit, average output**) and **curate** (duplicate) them to your GD project.

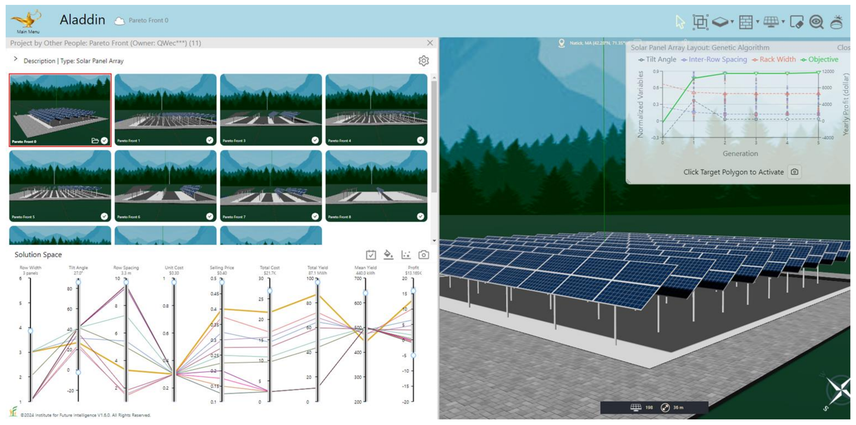
Once you finish all your designs, replace the placeholder plot below with a scatter plot of Profit (X-axis) vs. Mean Yield (Y-axis).

13. Compare your six (or more) new designs with your six (or more) old designs. Did you discover any new non-dominated designs? Are there any old non-dominated designs that have now become dominated?

(Top) An example of a practice example from the Generative Design curriculum chapter. Curriculum activities were created by the researchers with Aladdin and prompted students to use solar energy design to reinforce concepts covered via text, e.g., visualizing and comparing designs along the Pareto Front.

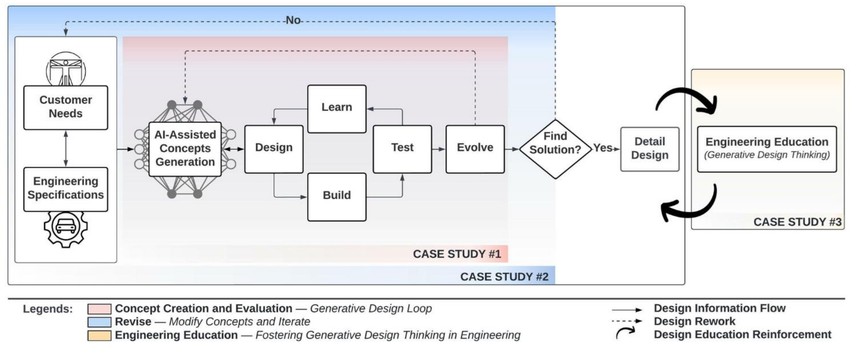
(Below) The environment for the open-ended design problem in Aladdin. Students are asked to use the empty plot to optimize multiple solar energy design objectives (profit and energy output) using traditional, parametric, and/or generative design approaches at their own discretion.

Activity 3: The design and development of Aladdin, an open-source computer-aided generative design and engineering software, with the goal to support the learning and teaching of generative design.



Aladdin is a web-based CAD platform that is reimagining design in the age of AI by implementing generative design in the fields of architectural engineering and renewable energy engineering. It allows researchers to explore the new human-technology frontier of AI in engineering design, especially how design thinking evolves with the paradigm shift of AI-based generative design. The platform provides an alternative to commercial software that fosters independent research in engineering education. Aladdin enables multi-objective solution space visualization for the user to compare a portfolio AI generated and/or human-created designs.

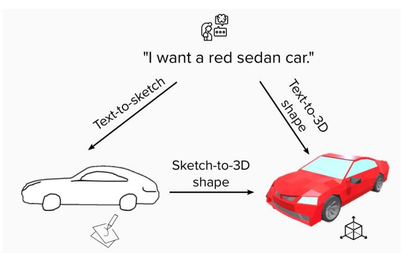
Activity 4: Developed a Human-Centered Generative Design Framework to support the role of humans in GD and inject human factors early in the design process for rapid and approximate concept generation and evaluation.



Visualization of the conceptual GD-based human-centered design framework. Through two case studies, Human-Centered Generative Design (HCGD) shows promising outcomes for improving the GD workflow by incorporating human-factors (e.g., ergonomics) with computational design.

Activity 5: Exploration of data-driven methods for the realization of generative design in support of software development.

A systematic literature review on methods for deep learning of cross-modal tasks (DLCMT)



Cross-Modal Tasks	Article
Text-to-3D shape retrieval	2
Text-to-3D shape generation	6
Text-to-sketch generation	4
Sketch-to-3D retrieval	19
Sketch-to-3D generation	18
Cross-modal design integration	5

Opportunities:
- *Incorporate human inputs for human-supervised generative design in design search, design creation, and design integration*
- *Democratization of product design*
- *AI-based pedagogical tools*
- *Immersive design environment*

Challenges
- *Datasets : engineering performance and manufacturability*
- *Complex system design*
- *3D representations*
- *Generalizability*

SIDI LAB | DISCOVER MORE
System Integration & Design Informatics Laboratory

Activity 6: Design and implementation of curriculum modules based on existing generative design technologies offered by Fusion 360 in collaboration with our industrial partner from Autodesk Inc. Data collection and analysis of students' learning data collected using the Fusion 360 based generative design lab modules.

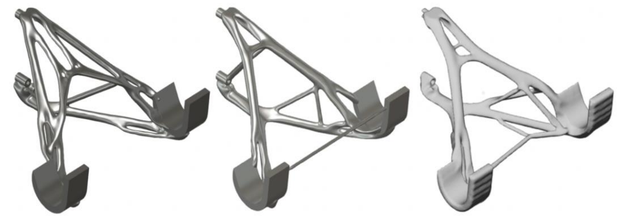


Figure 5a: Design 1, Stainless Steel *Figure 5b: Design 2, Aluminum* *Figure 5c: Design 3, ABS Plastic*

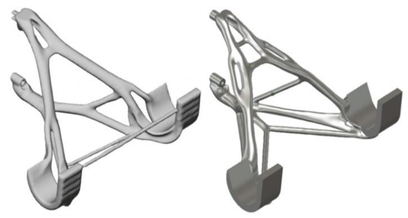
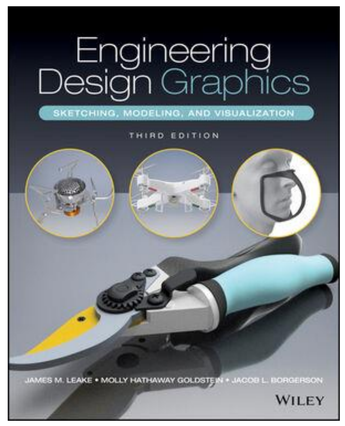


Figure 5d: Design 4, ABS Plastic *Figure 5e: Design 5, Aluminum*

~800 students *used the materials developed in an introductory design and graphics course at UIUC.*



We are broadly disseminating these GD techniques to other institutions by including them in co-PI Goldstein's engineering design graphics textbook, "Engineering Design & Graphics 3rd Edition," released in March 2022. In this book, we include a new chapter on CAD Solid Modeling to details a generative design workflow.

PUBLICATIONS

1. J. Clay, X. Li, O. Demirel, M. Goldstein, R. Jiang, C. Xie, D. Zabelina, Z. Sha, "**Thinking Inversely in Engineering Design: Towards an Operational Definition of Generative Design Thinking**," The 130th ASEE Annual Conference & Exposition, Baltimore, MD, June 25-28, 2023.
2. E. Koolman, J. Clay, X. Li, R. Jiang, M. Goldstein, C. Xie, O. Demirel, Z. Sha, "**A multi-case study of traditional, parametric, and generative design thinking of engineering students**," Eleventh International Conference on Design Computing and Cognition (DCC), July 8-10, 2024, Montreal, Canada. Paper accepted.
3. X. Li, Y. Wang, Z. Sha, "**Deep-Learning Methods of Cross-Modal Tasks for Conceptual Design of Product Shapes: A Review**," Journal of Mechanical Design, volume 145, issue 4, pp: 041401 (20). (2023).
4. C. Xie, "**Beyond Solar Cookers: Modeling and Designing Concentrated Solar Power as Engineering Projects in Physics Classrooms**," Phys. Teach. 61 (6): 447–452. (2023).
5. A. Brown, M. Goldstein, J. Clay, O. Demirel, X. Li, Z. Sha, "**A Study on Generative Design Reasoning and Students' Divergent and Convergent Thinking**," Journal of Mechanical Design, volume 146, issue 3, pp:031405 (10). (2024).
6. H. O. Demirel, M. H. Goldstein, X. Li, & Z. Sha, "**Human-Centered Generative Design Framework: An Early Design Framework to Support Concept Creation and Evaluation**," International Journal of Human–Computer Interaction, 1-12. (2023).
7. X. Li, M. H. Goldstein, O. Demirel, Z. Sha, "**Exploring Generative Design Thinking for Engineering Design and Design Education**," 2021 ASEE Midwest Section Conference, Virtually hosted in Fayetteville, AR, Sep. 13-15, 2021.
8. J. Leake, M. H. Goldstein, J. Borgerson, **Engineering design graphics: sketching, modeling, and visualization**. J Wiley & Sons. Third Edition. (2022).

Scan to see more project information, including: the full EDGE Curriculum; a full list of project publications; and researcher contact information.

ACKNOWLEDGEMENT

This material is based upon work supported by the National Science Foundation under Grant No. 2207408.