EDUCATING DESIGNERS FOR GENERATIVE ENGINEERING (EDGE)

Executive Summary

Prepared by:

Dr. Zhenghui Sha	zsha@austin.utexas.edu
Dr. Darya L. Zabelina	dlzabeli@uark.edu
Dr. Molly H. Goldstein	mhg3@illinois.edu
Dr. Onan Demirel	onan.demirel@oregonstate.edu
Dr. Charles Xie	charles@intofuture.org
Xingang Li	xingang.li@utexas.edu
John Z. Clay	jzc298@utexas.edu

September 2nd, 2022

Executive Summary

The goals of this project are to **define**, **implement**, and **disseminate generative design thinking** to facilitate the teaching and learning of generative design at undergraduate levels.

To define generative design thinking, we proposed an **Evolving Design Thinking (EDT) model** to study the relationships between engineering systems thinking, parametric design, and computational thinking, as well as the relationships between their associated cognitive underpinnings, design theories, and technologies (Li et al., 2022. Exploring Generative Design Thinking for Engineering Design and Design Education). The EDT model illustrates the relationships among different design thinking concepts, as well as the relationships between these thinking concepts, design technologies, and cognitive competencies (see **Figure 1**). Literature review showed that a wealth of research has been conducted to understand the relationships between traditional design thinking and human cognitive competencies to better understand designers and aid them for better design. However, research on generative design has been primarily focused on developing efficient and effective design methods and tools. Little research has been conducted on understanding the essential cognitive constructs and competencies that form generative design thinking, and we plan to address this gap with our future research. By doing so, we hope to identify the basic constituents of design thinking in the generative design process.

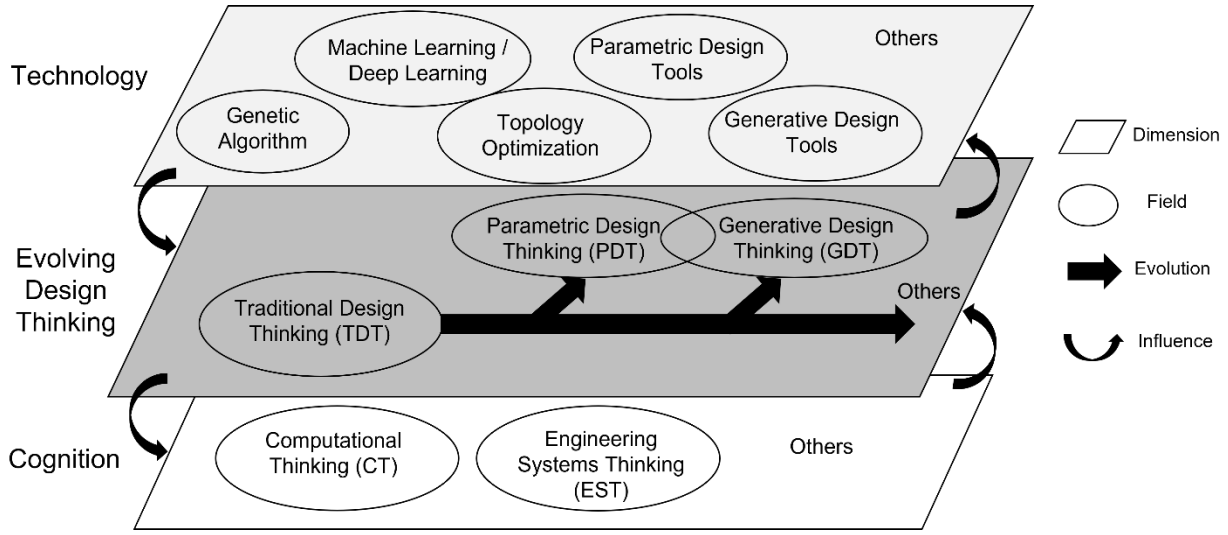

Figure 1: The Evolving Design Thinking (EDT) model (Li et al., 2022. Exploring Generative Design Thinking for Engineering Design and Design Education).

To implement generative design thinking, we have developed and released a preview of the **cloud-based, open-source CAD/CAE Aladdin software** for engineering design research and education. Aladdin has many features, including a virtual heliodon for visualizing the sun paths at different latitudes and seasons, modeling different types and sizes of trees, support for solar array design, and the use of Google Maps as an engineering design canvas. For generative design, we plan to build its AI engines based on evolutionary computation methods such as multi-objective genetic algorithms. Work has begun with building a kernel of genetic algorithms with various capabilities such as the local and global search for photovoltaic solar farm design and concentrated solar power design (see **Figure 2**).

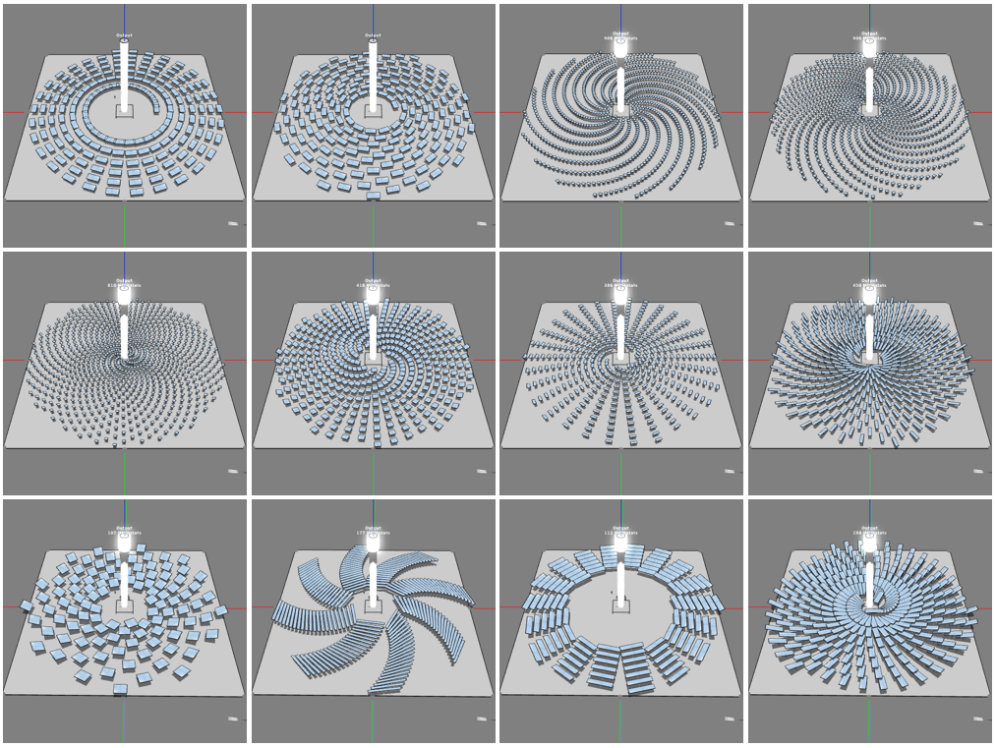

Figure 2. Generative design of concentrated solar towers using Genetic Algorithms.

To further implement generative design thinking, we have created **new instructional materials** using Autodesk's Generative Design software to support project-based learning of generative design, and collected and analyzed **students' learning data to study their generative design rationale** (Leake et al., 2022. Chapter 15: Simulation. In Engineering design graphics: sketching, modeling, and visualization). The new course module was developed to introduce students to the design process, including communicating design ideas generated through hand-sketches and produced in Fusion360. Students engage in the human-centered design process by completing

nine individual modeling assignments (MAs) in Fusion360. The final required assignment, MA9, served as an introduction to generative design and stress analysis. MA10, an extra credit assignment, investigated students' generative design thinking through how they approached an open-ended engineering scenario (see **Figure 3** for this design problem). During Year 2, 202 students completed MA9, and 18 students completed MA10. Work-in-progress results suggest that students are likely to cite rational reasoning in design decision-making between generative design solutions. When comparing their own sketches to the computer-generated solutions, students are still rational in their responses but might engage in intuitive and emotional thinking. The goal is to implement generative design rationale in the undergraduate classroom.

(a) Context for MA10, generative design extra credit assignment

(b) Three example solutions provided by the generative design engine in Fusion 360.

Figure 3: New course material developed in an introductory design and graphics course.

We have also developed **a new data-driven generative design approach** based on a new target-embedding variational autoencoder (TEVAE) neural network architecture, enabling students to generate 3D product shapes directly from their 2D sketches (Li et al., 2022. A Predictive and Generative Design Approach for 3D Mesh Shapes Using Target-Embedding Variational Autoencoder). This predictive and generative design approach for 3D shape generation in support of human creativity in the conceptual design of product shapes is built on the proposed (TEVAE) neural network architecture, which consists of two modules: 1) A training module with an E^2D network that has two

encoders and one decoder, and 2) An application module performing generative design functions (shape reconstruction, interpolation, random generation of new 3D shapes, and prediction). See **Figure 4** for more detail. By using the proposed approach to generate 3D car models, results showed that the method can learn two latent feature representations, one of which can generate a large number of novel 3D shapes, and the other one can predict 3D shapes purely based on the 2D silhouettes from user inputs.

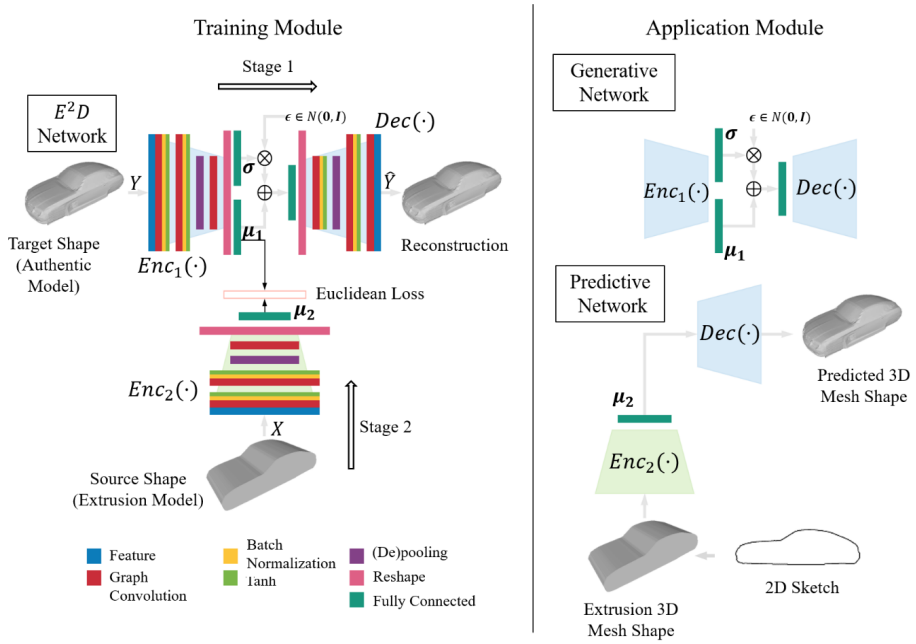

Figure 4: The proposed approach following target-embedding variational autoencoder (TEVAE) architecture (Li et al., 2022. A Predictive and Generative Design Approach for 3D Mesh Shapes Using Target-Embedding Variational Autoencoder).

To disseminate our findings on generative design thinking, we have shared the outcomes of our project to the community of both four-year colleges and K-16 engineering educators through various channels, including online education division, partner websites, conference presentations, and journal publications. Due to COVID-19, our intellectual output has been primarily disseminated through online means so far. We have published 1 journal article, have 3 potential journal articles under revision, review, or reparation, have published 7 conference papers, 6 conference abstracts and posters, 1 book chapter, and 1 doctoral dissertation. As the development of the generative design module in Aladdin becomes more mature, collaboration will begin with the participating colleges for the dissemination of the software and instructional materials.

Overall, our research has four broad impacts. First, the development of cloud-version Aladdin has demonstrated how **Aladdin is enabling engineering design of**

renewable energy solutions for everyone in the browser. Aladdin allows the designer to store their files on the cloud and open them later on any device, thus enabling engineering design of renewable energy solutions in the browser for everyone.

Second, the new data-driven generative design approach can **support students' decision-making in conceptual design**, and meanwhile, **supports the later development of generative design engines in our CAD software** in addition to the evolutionary computation methods, such as the genetic algorithms. The realization of this system will yield several additional benefits: 1) 2D-to-3D reconstruction process automation, thus saving labor and time for designers, 2) 2D sketches can be evaluated against the desired engineering performance in 3D form, ensuring that the designs that would have a better performance will not be ruled out too early when performance-driven decisions are not yet obtained, 3) Non-experts would not be discouraged to show their design ideas due to the lack of CAD experience or sketching skills, which may have significant educational implications for training novice designers, 4) Enterprises may use this system to enable user interface soliciting consumer preferences for design customization.

Third, our research to study students' generative design rationale has a potential impact on **teaching students' trade-off design decision-making**. Concepts such as design trade-offs or the elusive Pareto frontier might be effectively taught using generative design solutions and their visualizations.

Lastly, our work to develop the Aladdin software has the potential to generate a profound impact on the domain of design thinking study because it will **support the collection of standard and quality design behavioral data**, which are lacking in the field. The lack of research platforms that can be freely accessed and assessed is a major hurdle for design research, and is the cause of serious issues on research repeatability and reproducibility. The open-source commitment of the Aladdin platform will broaden its impacts.