Generative Design in Engineering Research and Education Workshop

May 22nd - 24th, 2024, Boston, MA

Hosted by the SiDi Lab and PTC Inc. for the NSF-funded ***Educating Generative Designers in Engineering*** *project.*

Workshop attendees at PTC Inc.'s headquarters. *See the final page for a list of attendees.*

Workshop Organizers

Dr. Zhenghui Sha
University of Texas at Austin

Dr. Jordan Cox
PTC, Inc.

Dr. Molly H. Goldstein
University of Illinois UC

Dr. Charles Xie
Institute for Future Intelligence (IFI)

Layne Scherer
American Association for the Advancement of Science (AAAS)

Dr. Onan Demirel
Oregon State University

Industry Collaborators

ptc

Institute for Future Intelligence

Workshop Summary

by J. Clay

The Generative Design in Engineering Research and Education Workshop was recently held in collaboration with researchers from the multi-institutional EDGE project (Educating Generative Designers in Engineering; based at the University of Texas at Austin) and industry partners PTC Inc. at PTC's headquarters in Boston, MA (see the website for more information, workshop organizers, and a list of project publications). The major goals of the NSF-funded EDGE project are to define, develop, and disseminate educational materials for *generative design thinking*, the most recent evolution of design thinking, which considers how the addition of generative AI (e.g., data-driven generative design, topology optimization, large language models (LLMs), etc.) to the engineering design process changes the role of the human designer and their cognition.

In total, 17 attendees representing 11 institutions joined for a range of presentations and discussions on topics related to the application of generative artificial intelligence (AI) algorithms in engineering design. The workshop proposed three goals:

1. First, to discuss best practices in teaching generative design and generative AI in engineering;
2. Second, to exchange ideas on the development of curriculum for teaching generative design; and,
3. Third, to promote collaboration between stakeholders in industry and academia to stimulate cutting-edge developments in generative design research and education in engineering.

The first day of the workshop began with a keynote introduction from project PI Dr. Zhenghui Sha (UT-Austin) on the workshop goals and EDGE project background, and was followed by an Industrial Session which consisted of two speakers from PTC (Dr. Jordan Cox and Chris Gromek) and one speaker from the Institute for Future Intelligence (IFI; Dr. Charles Xie). Attendees were treated to an inside look at and hands-on demonstration of Onshape, PTC's generative design software platform; this was followed by an overview of Aladdin, IFI's open-source, web-based computer-aided design (CAD) software which enables generative AI solutions for solar-energy structures and was developed as a key contribution of the EDGE project. All were invited to a reception and complementary dinner.

The following day featured four lectures on topics regarding industrial applications of generative design (Chris Gromek, PTC), generative design thinking (two lectures: John Clay, UT-Austin; Vinayak Krishnamurthy, Texas A&M), and inclusive design for equity and diversity (Layne Scherer, AAAS).

Workshop attendees were then divided into three groups for a Roundtable Discussion on the best practices for educating future designers about the use of generative AI in engineering design. Groups attended three sessions and discussed the same set of eight questions (see the full list below) regarding the key skills that students of generative design must learn, and how to best teach these skills. Each forty-minute session prompted the groups to answer the questions in the context of one of three levels of engineering courses: introductory, senior, and graduate level. Additionally, each session had a non-rotating moderator to take notes and facilitate inter- and cross-group communication, who then gave a summary presentation on the key themes debated throughout the sessions.

Day 2 Roundtable Discussion Questions

1. What are the core competencies of working with generative design (GD)?
2. What aspects of GD shall be taught?
3. What type of GD tools are needed?
4. How to use GD tools effectively?
5. How can GD skills and ideas be taught?
6. How can they be integrated into classical curricula?
7. What type of projects or lectures would be required?
8. What are the technological and logistical needs to effectively implement your proposed lessons in teaching GD?

Two major themes arose throughout the discussions to answer these questions. The first theme was manifested through three sets of generative design core competencies across three education levels. Student designers being introduced to engineering design with generative AI should be educated on the fundamental concepts required to understand and work with these techniques, including (but not limited to):

- How to translate qualitative design goals and manufacturing requirements into a quantitative framework that an AI algorithm can “understand” and aid the human in solving;
- How to simply communicate the advanced mathematical techniques executed by the AI to team members, clients, or supervisors; and,
- Identifying when a traditional, human-driven design process is preferred to the use of generative AI.

- Additionally, students should be taught basic skills of CAD, the fundamental concepts of mechanical engineering, and a basic proficiency in programming in the courses between their introductory and senior-level courses.

Senior-level design courses should teach students more advanced concepts related to the design space, including:

- Understanding boundary conditions and how to computationally represent them;
- Fostering a sense of geometrical intuition about what is feasible in application;
- Building experience in visualizing, prototyping, and analyzing design concepts (and the underlying math); and
- An understanding of the Pareto frontier and multi-objective design optimization.
- Additionally, students must be able to apply the knowledge of these concepts via an advanced proficiency with an understanding of computational design tools and their limitations.

Finally, graduate student designers should become intimately familiar with the intricacies of generative AI and computational design methods, including a burgeoning expertise in:

- Numerical methods,
- Programming, data science, and basic statistics;
- CAD and 3D modeling;
- Teamwork; and,
- Critical thinking when solving design problems and when reading GD literature.

Best practices for teaching these identified core competencies comprised the second major theme. Project-based learning (i.e., assigning students design projects to complete) is a key pedagogical technique across engineering design curricula and a promising space for teaching students how to understand and utilize new design methodologies based on generative AI. The focus of introductory level engineering design course projects should be twofold: first, to build experience in traditional design processes, in which all key decisions are made and manually executed by the human designer, so that the student appreciates and more fully comprehends the generative AI-based paradigm shift. Second, students should be prompted to use generative AI to re-design artifacts to design problems that they previously solved with traditional methods; ideally, multi-objective design problems which prompt student designers to consider systems level interactions across variables as they generate and choose between alternative, non-dominated solutions.

Once the key differences between human-driven and AI-driven design processes have been established, senior level engineering design capstone projects using generative AI should represent the multidisciplinary, team-based nature of designing solutions to real-world problems in the workplace. This experience can be built upon in graduate courses which incorporate the element of programming personalized AI systems to optimally solve highly specific and/or technical design problems.

Workshop attendees were treated to a personal tour of PTC's product portfolio in their Customer Experience Center (CXC).

Attendees began the third and final day of the workshop with a guided tour of PTC's Customer Experience Center (CXC) to provide a close-up look at their wide portfolio of cutting-edge products. The tour was followed by a second Roundtable Discussion which impelled the same three groups from the previous day to develop a research agenda for generative design topics via a discussion with two goals: first, to identify the key gaps in generative design research; and, second, to identify specific goals and research questions for addressing these gaps. Group discussion was divided across three categories:

Generative AI in Engineering Design Research Agenda

1. Design Principles and Theories

- **Design Cognition.** The addition of generative AI to design changes the design process and the cognition that underlies it. This fundamental change in the role of the designer opens the space for a wide range of research questions related to how GD changes the cognitive processes that designers engage in, including:
    - **Research Questions.** What core competencies distinguish expert designers from novice ones, and how can we teach novice designers these skills to build expertise?
    - Are there any potential negative effects on human cognition when sharing the design process with generative AI, and if so, what are they?
- **Design Processes.** Traditional, human-driven design processes and workflows must be reconsidered in light of generative AI. Important topics for researchers to explore include:
    - **Research Questions.** What is the effect of generative AI on design workflows? How does this affect the resources that are spent on design (e.g., time and money) in relation to the added quality of the final output? How do new design workflows affect student learning?
    - Where in the design process should generative AI be used? What is the role of generative AI at different levels of the design process, e.g., at a lower level when designing individual pieces vs. during the higher-level integration of these pieces into a system?
- **Design Education.** The paradigm shift brought by generative design methodologies must be reflected through updates to existing engineering design curricula and the creation of new education materials. Additionally, there is a lack of professional development for faculty to learn the concepts and skills necessary to teach GD. Education research should address the following:
    - **Research Questions.** What prerequisite skills and concepts must students acquire to effectively grasp and work with GD? For educators, how large is the gap between their existing knowledge and what is needed to effectively teach these skills and concepts to the next generation of students? How can we bridge this gap, what resources are required, and what can each of the stakeholders (researchers, educators, practitioners, *and students*) provide?

2. **Design Techniques and Data Collection/Analysis Techniques**
    - **Data Ethics, Laws, and Policy.** Generative AI algorithms require a vast supply of data to train the networks for creating novel solutions, and the importance of the following ethical data use considerations will grow in direct proportion with the spread of generative AI:

- **Research Questions.** What is the origin of the data that is used to train AI models, and who owns it? How does training data affect the output of the algorithms, e.g., does it introduce bias to the design process? Who owns (or is credited for) solutions created by AI? How can engineers and developers participate in policy making on the use and regulation of AI?

3. **Design Applications**
   - **Application Equity.** Generative AI offers groundbreaking potential to change society and our daily lives for the better. However, the unequal distribution of these benefits may perpetuate previous inequalities instead of overcome them. To address these issues, researchers should consider:
     - **Research Questions.** How are communities and individuals affected by the proliferation of GD techniques? How can researchers and educators shape these effects towards the greater benefit of stakeholders outside of industry and academia? Finally, how can we educate those without the relevant technical expertise to understand, accept, and benefit from the increasing role of AI in society?

Outfitting engineering design workflows with generative AI has only recently begun and offers a fertile ground for a variety of research topics. The authors and attendees of the Generative Design in Engineering Research and Education Workshop hope that the insights generated from the discussions may inspire researchers and developers in academia and industry to focus their efforts on these and related topics as generative design methodologies mature.

Workshop Attendees

listed alphabetically

In-person

- Jessica Barbera, PTC Inc.
- Dr. Dylan Bulseco, Institute for Future Intelligence (IFI)
- Dr. Wei “Wayne” Chen (Day 1 attendance), Texas A&M University
- Dr. David Christensen, Utah Tech University
- John Clay, UT-Austin
- Dr. Jordan Cox, PTC Inc.
- Dr. Ethan Danahy, Tufts University
- Dr. Michael Davis, Northern Virginia Community College
- Dr. Onan Demirel, Oregon State University
- Xiaotong Ding, Institute for Future Intelligence (IFI)
- Chris Gromek, PTC Inc.
- Katelynn Havener, PTC Inc.
- Andriy Kashyrskyy, Institute for Future Intelligence (IFI)
- Dr. Vinayak Krishnamurthy, Texas A&M University
- Dr. Christopher McComb, Carnegie Mellon University
- Dr. Matthew Mueller, PTC Inc.
- Layne Scherer, American Association for the Advancement of Science (AAAS)
- Dr. Zhenghui Sha, UT-Austin
- Dr. Charles Xie, Institute for Future Intelligence (IFI)
- Dr. Juan Zheng, Lehigh University

Virtual

- Shuichi Fukuda, Keio University
- Dr. Molly H. Goldstein, University of Illinois Urbana-Champaign
- Aaron Hanai, Kapi‘olani Community College
- Dr. Xingang Li, UT-Austin (at the time); The University of Melbourne (current)
- Dr. Alison Olechowski, University of Toronto
- Dr. Darya Zabelina, University of Arkansas