GENERATING GAUDÌ: AI AND CREATIVITY IN DESIGN

RYAN WU

The tapering pillars soar over the entrance, leaning away from the modernist Passion Facade of the Sagrada Familia. Blending natural hyperboloids with angular sculptures and organic columns, it is one of the greatest construction projects ever undertaken, a symbol of Barcelona and the incredible artistry of its architect, Antoni Gaudí. A work spanning three centuries, construction began in 1882 on the cathedral, which manages to appear modern and distinctive even alongside the 21st-century skyline its construction cranes stand amidst. One of the most unique features of the cathedral's design is its vaulted ceiling, held aloft by a forest of columns that change from polygonal to round along its length, branching and curving both for the engineering purpose of withstanding horizontal loads in a unique structural system while artistically emulating a tree canopy (Schnepp 569). The columns create a fascinating combination of the natural world replicated in stone, solving a structural problem while simultaneously converging upon an organic muse. The cathedral has been described as "one of the most original and bizarre church buildings in the world," and its "transfigurations of the Gothic" as "alternately disorienting, beautiful, and startling" (Schnepp 567, 568). Yet, the distinctions of this unique piece of architecture may not remain so for long.

Driven by the data revolution of the information age, new tools are providing engineers and architects with the ability to create parts, buildings, and structures that would otherwise have been unthinkable with traditional design practices. The technique is known as generative design: engineers provide manufacturing, cost, and material constraints to an AI which then optimizes for each given parameter using a complex algorithm to balance the constraints while ensuring the final product meets all specifications. Though the procedure itself sounds mundane, the results that are created are instantly distinctive, bearing a high degree of detail and an organic appearance resembling that of ligaments or spiderwebs. Loads are not distributed via the standard geometric beams and bars of traditional design but rather complex webs of tapering strands, connecting the component while also remaining structurally sound and greatly reducing mass (Agkathidis 17). Creations of similar algorithms have even been used by designers as works of art, like an AI-designed chair launched by Philippe Starck during Milan design week 2019 (Jordahn). Much like Gaudí's groundbreaking vision of hyperboloidal curves and branching columns, the creations of generative design appear both familiar and unnatural, blending practical use and artistic liberty in a way that defies the imagination. Even in appearance, the designs bear a striking resemblance: data-driven engineering products approach Gaudí's vision through the same natural inspirations without ever being explicitly shown the various muses which inspired the architect.

Yet, this correspondence raises an uneasy question, one which researchers have contended with since computers were invented: Can a program ever be truly creative? This question is further complicated by generative design in particular, as the program is never explicitly judged or rewarded based on the creativity or artistry of its product but rather a set of practical manufacturing goals. The unique and unconventional solutions it provides to these problems would be considered creative if imagined by any human engineer, but unlike the engineer, the program does not know what "creative" means. As such, this raises the question of whether creativity is necessarily intentional, or can it be an emergent property of sufficiently advanced problem solving. In evaluating operational definitions of creativity, which are not skewed by inherent anthropocentrism, generative design itself appears no different from any other data processing assessment produced by a thinking human or machine. Like a spreadsheet taking in a row of numbers, the algorithm of generative design simply makes observations and creates outputs in the same way an artist might be influenced by aesthetic features in their environments and experiences. Therefore, in the absence of finer distinctions of what types of data input are required to produce a creative result, there appears to be no reason why generative design algorithms are *not* creative, though the element of determinism raises technical and philosophical questions regarding the degree to which prediction and methodology are involved in a determination of creativity or originality. In answering such questions, one gains a greater understanding of the human creative process and, most importantly, the ways these developing technologies can be harnessed to complement human ability.

A basis for tackling these definitions of creativity will be provided by professor of cognitive science Margaret Boden. Many attempts at defining creativity rest upon anthropocentric and poorly defined concepts of "intuition" and "inspiration," which Boden contends are not conducive toward a more scientific or psychological understanding of the term (Dartnall 4). She instead defines three types of creativity: "combinatorial," "exploratory," and "transformational," which seek to categorize creative thought in relation to extant ideas and the conceptual domain in which those ideas exist (Boden 348). While combinatorial creativity only produces new amalgamations of ideas previously posited, exploratory creativity yields novel ideas in the domain, and transformational creativity alters the domain completely. In this sense, both Gaudí and generative design programs are transformationally creative, adding new dimension to the solution space through wholly novel ideas that challenge established heuristics of design. Metamorphosis is a theme in Gaudi's design—from natural to geometrical forms, and also through the permutations of a theme or motif. In his branching columns and the fine webbing of a generatively designed joint, unexpected and surprising results are found which defy the limits of conventional engineering, hinting at something truly transformational (Thomas 68).

However, Boden's definition assumes knowledge of the extant conceptual domain, which is purposefully not the case for *de novo* design optimization programs or other "creative" algorithms. One such program is AlphaGo Zero, which was an AI solely trained by competing against different versions of itself in the classic board game *Go*, having only been taught the rules of the game. Unsupervised machine learning in this sense therefore must be transformationally creative under Boden's definition, regardless of the actual product, simply by virtue of not knowing the span of accepted or historical strategies prior to creating a solution. Clearly, further nuance must be added to this model of creativity to better explain these algorithms.

Dartnall expands upon Boden's definition by hypothesizing that creativity cannot merely be about combinations and existing ideas, instead focusing on the *ex nihilo* process of creation (43). Particularly since these inspirational moments are difficult to characterize in humans and result in completely new *not* combinational results, Dartnall's definition aligns closely with the experience of generative design algorithms. In humans, he hypothesizes, creativity emerges from experience in the outside world, and the process of creation redescribes these subconscious memories into conscious thoughts and mental states, which are then realized in the form of "creative" actions. In terms of conscious creation, these moments of inspiration must thus *make something out of nothing*, since the *something* previously existed only in a fragmentary and subconscious form. With regards to generative design algorithms, Dartnall's definition provides an actionable starting point for evaluating creativity due to the process of *ex nihilo* creation and the way it closely mirrors *de novo* machine learning algorithms. Functioning on a high level, these algorithms derive heuristics and strategies only from the governing laws of the problem it tries to solve.

However, Dartnall's definition introduces a new concept which Boden did not rely upon to define creativity: methodology. The connection between methodology and creativity may appear obvious. After all, just like how a recreation of a Van Gogh painting from an assembly line is completely unlike the original work in terms of creative talent, the method of "thinking" for AI should also be relevant within the consideration for the true creativity of its product. Yet, the introduction of methodology also means that creativity is a trait that can only be attributed to the *creator*, and cannot be properly determined from a product alone. This is a problematic concept in the context of AI since the black-box nature of the software makes analyzing the process of creation difficult. The organic curves and ligament structures made by generative structural design may appear unnatural and surprising to the human eye, as the Sagrada Familia strikes visitors as "bizarre" (Schnepp 567) and "fantasmagorical" (Thomas 65), but is the former truly creative?

Boden discusses these concepts of methodology in the form of four "Lovelace Questions" posed by Lady Lovelace in the 19th century in response to the computing machine of Charles Babbage (Dartnall 31). The fourth question is the critical one in this context: Can computers really be creative, or will they only *appear* creative due to the work of a human programmer? The degree of control an AI has over its own decision making is instrumental in assessing creativity, a notion echoed by professor emeritus of history Arthur Miller who makes the distinction between symbolic and neural network AIs. He defines the former as AIs governed by the rules of Boolean logic, with innate programming determining boundaries and outlines for its eventual products, while neural networks synthesize concepts in "experimental and unpredictable" ways (Miller). Critically, in the case of neural networks, "the work springs from the machine itself without any human intervention" (Miller). From that perspective, Miller argues that neural networks fulfill the *ex nihilo* condition of creativity and satisfy the fourth Lovelace question, though not in the same way that Dartnall describes. The AI is missing the process of human redescription since there are no "subconscious" experiences for it to capture in the form of inspiration. Rather, Dartnall's redescription is remolded in the form of heuristics derived from training data, providing the muses and patterns the algorithm explicitly, rather than subconsciously, tries to emulate in its own creation. Thus, the fact that the products of neural networks are not just amalgamations of its training dataset indicates that there must be *something* transformative occurring within the neural networks. That *something* is creative redescription, in a new form.

However, unlike neural network AIs, generative design poses a unique quandary for the fourth Lovelace question. The technique has been used with great success to optimize for constraints weighted already by designers, such as balancing work style, natural light, and other factors in the design of Autodesk's new offices in Toronto (Souza). Do these constraints then also limit the creativity of the final work, having been subjected to the "programming" of the outputs of the algorithm? Andy Clark of the University of Sussex argues that it does, as most neural networks can only apply their "understanding" of a problem domain within the domain itself, and not translate it to other analogous concepts (Dartnall 66). For example, a generative topology optimization algorithm may "discover" a catenoid curve as the optimal solution to designing an arch, but it cannot generalize that knowledge to recognizing other catenoid curves or understanding *why* the curve is a general solution to these types of problems in the same way Gaudí could as an experienced architect. This challenges Boden's definition of creativity relative to a concept in a solution space: how can a concept be transformative in a solution space without the concept itself ever being identified clearly? To Clark, this is an example of the "generality constraint," which stipulates that a true creative system must be able to derive "high-level abstractions" from the training data it is presented—that it needs to not just learn but *understand* (Dartnall 78). Clark's interpretation implies that modern generative design is only creative at a surface level, presenting an appearance of deeper understanding while not being able to conclude heuristics regarding the subject it attempts to design. Since the conclusions drawn by the algorithm only pertain to the specific set of constraints or solution space it was provided with, Dartnall's process of redescription and abstraction of latent understanding is not demonstrated by modern generative design.

However, Clark and Dartnall's definitions could also be cast as anthropocentric: is forming a deeper understanding and synthesizing concepts into a higher-level abstraction necessarily the only way to be creative? In examining this question, it is instrumental to not only look at the projects of AI, but also those of humans. British mathematician Marcus du Sautoy introduces the role of algorithms in art via a quote by jazz teacher Mark Levine:

> A great jazz solo consists of:
> 1% magic
> 99% stuff that is
> Explainable
> Analyzable
> Categorizable
> Doable (qtd. in Du Sautoy 200)

Though the origins of human creativity are difficult to describe, the primary component of many creative works is not. Transformational creativity, as Boden describes it, still exists within the context of the rules governing the work of art—Levine's 99%. To assess whether a design is creative, it is not equitable to punish an AI for that 99%, the rigid constraints so derided by Clark within which the solution is found, simply because humans do exactly the same thing. Du Sautoy goes further: quoting German mathematician Georg Nees in a response to artists who didn't believe an algorithm was capable of recreating an individual's painting style, he says, "Sure, I will be able to do this . . . Under one condition, however: you must first explicitly tell me how *you* paint" (118). In this, he indirectly responds to Dartnall's emphasis on methodology, highlighting how human creativity is even more of a black box than that of neural networks. After all, Dartnall's definition of creativity as a redescription of the subconscious experience is only a theory, and a likely untestable one with present technology. Who, then, is to say whether anything is truly creative if the processes underlying creativity could not be understood by humans?

Ironically, those same AIs which challenged human creativity may be the ones capable of rebuilding a definition of the concept itself. Du Sautoy concludes Nees' story in a description of a project to recreate a Rembrandt painting via AI, describing the algorithms used as "new tools to dig around inside the [black box] and to find new traces of patterns" (122). He argues that if humans are not able to identify what makes a great work of art great, AI might be able to do so. This concept is embodied in Ian Goodfellow's Generative Adversarial Network (GAN), which uses two dueling neural networks to competitively improve both an artistic AI and the understanding of the work of art or ground truth it seeks to emulate, such as a realistic human face or a style of painting (Giles). One neural network seeks to create the piece while the other seeks to discriminate between "real" and computer-generated works. The product of such an arrangement is not just an AI that can emulate art, but also another that can effectively find the distinguishing qualities of a genre or artist—the 1% which Levine described as "magic." This concept is just as true of generative design engineering, where the analysis of AI-created designs challenges "what [engineers have] seen in the past and what they believe to be true," as described by Frank DeSantis, a VP at Black and Decker (*Harvard Business Review*). In this sense, the hidden biases and inclinations which make emulated work discernable to a GAN or human engineering distinct from generative design are the same type of constraints that Clark describes as prohibitive to real AI creativity. Just as the artificial limitations of weight optimization and the laws of physics reduce the solution space for an AI, so too do the irrational preferences, internal subjectivities, and corporeal limits of human designers.

A step inside Gaudí's workshop in the basement of the Sagrada Familia makes this surprising distinction clear. Without simulation or 3D modeling software, the architect constructed the catenoid curves of his masterpiece via strings and bags of sand, simulating lines of force with how gravity naturally arranged the arches and spires of the strings and mirroring them to derive the structure of the cathedral's supports (Thomas 66). The models are works of art in their own right, yet they show that even Gaudí had his preferences and constraints. His solution domain was limited by the technology of his time, and his vision functioned within the strict rules he set for himself in terms of structural design. Still, those restrictions never took away from the majesty of the final product, instead contributing to his distinct style and creative imprint. Such is the goal for creative AIs as well, only they are unburdened by the physical and mental limitations of the human artist.

Nonetheless, AI need not only expose human imperfection in the domain of true creativity. With the versatility of a human mind and the analysis of a machine one, creative work can be done that is both transformational and methodologically unique, satisfying both Boden and Dartnall's definitions for creativity. Garry Kasparov, the Russian chess grandmaster who famously lost versus IBM's Deep Blue algorithm, argues that the competitive aspect of the human-AI race is the least important of all. As "human time scales and human capabilities are rendered practically insignificant compared to accelerating technological progress," development in the ethics and use of AI should not focus on whether humans can beat them, but what happens when we inevitably lose (Kasparov 299). As such, the language of contest only serves to forestall the inevitable need to understand, work with, and improve AI as it is Sisyphean to try to fight progress and "hold on to the dying status quo" (301). What then, when AIs truly are creative? What more will we understand of art, of science, of our own minds? When the next Sagrada Familia is built with algorithms designed to artistically emulate nature while balancing engineering constraints, we will gaze at the ornate vaults and columns and understand more about the original.

WORKS CITED

Agkathidis, Asterios. *Generative Design*. E-book, Laurence King Publishing, 2015.

Boden, Margaret A. "Creativity and Artificial Intelligence." *Artificial Intelligence*, vol. 103, no. 1–2, Aug. 1998, pp. 347–56, doi:10.1016/S0004-3702(98)00055-1. Accessed 4 July 2022.

Dartnall, Terry, editor. *Artificial Intelligence and Creativity: An Interdisciplinary Approach*. Kluwer Academic, 1994.

Du Sautoy, Marcus. *The Creativity Code: Art and Innovation in the Age of AI*. E-book, Harvard University Press, 2019, https://doi.org/10.4159/9780674240407. Accessed 4 July 2022.

Giles, Martin. "The GANfather: The Man Who's given Machines the Gift of Imagination." *MIT Technology Review*, 21 Feb. 2018. https://www.technologyreview.com/2018/02/21/145289/the-ganfather-the-man-whos-given-machines-the-gift-of-imagination/. Accessed 22 Mar. 2021.

Jordahn, Sebastian. "Philippe Starck, Kartell and Autodesk Unveil 'First Production Chair Designed with Artificial Intelligence.'" *Dezeen*, 11 Apr. 2019, https://www.dezeen.com/2019/04/11/ai-chair-philippe-starck-kartell-autodesk-artificial-intelligence-video/. Accessed 22 Mar. 2021.

Kasparov, Garri, and Mig Greengard. *Deep Thinking: Where Machine Intelligence Ends and Human Creativity Begins*. E-book, PublicAffairs, 2017.

Miller, Arthur I. "Creativity and AI: The Next Step." *Scientific American Blog Network*, 1 Oct. 2019, https://blogs.scientificamerican.com/observations/creativity-and-ai-the-next-step/. Accessed 22 Mar. 2021.

Schnepp, Jessica. "The Catholic Grotesque: Antoni Gaudí's Sagrada Familia and Flannery O'Connor's Wise Blood." *English Studies*, vol. 100, no. 5, 2019, pp. 564–77, https://doi.org/10.1080/0013838x.2019.1610240. Accessed 4 July 2022.

Souza, Eduardo. "How Will Generative Design Impact Architecture?" *ArchDaily*, 23 Apr. 2020,https://www.archdaily.com/937772/how-will-generative-design-impact-architecture. Accessed 4 July 2022.

"The Next Wave of Intelligent Design Automation." *Harvard Business Review*, June 2018,https://hbr.org/sponsored/2018/06/the-next-wave-of-intelligent-design-automation. Accessed 22 Mar. 2021.

Thomas, Derek. *Masters of the Structural Aesthetic*. Springer Singapore, 2018. https://doi.org/10.1007/978-981-10-5445-7. Accessed 4 July 2022.

RYAN WU, '24EAS was born and raised in Queens, New York, and is currently majoring in Mechanical Engineering with minors in Applied Math and Electrical Engineering. He is a member of the Columbia rocketry and formula racing teams, with

additional interests in diplomacy and energy policy. In his free time, he could be found designing in the makerspace and reading sci-fi and history.