Generative Design: Co-Creation Process Between Designer and Computational Thinking

Camilo Ayala-Monje, Universidad de los Andes, Colombia
Camilo Ayala-García, Universidad de los Andes, Colombia

The European Conference on Arts, Design & Education 2022
Official Conference Proceedings

Abstract
Generative design is a projective tool that allows designers and creators from other areas of knowledge to have applied innovation approaches. It is currently an emerging exploration process that integrates artificial intelligence and parametric design processes, consolidating itself as a milestone in the construction of alternative design proposals. This research analyzes the potential value of generative design in different fields; it presents and exemplifies the co-creation process between the designer and computational thinking, with six prototypes. It shows the product design process using this methodology and exposes the importance of these technologies. Generative design is recognized as a valuable opportunity for teaching and appropriation in academia because it allows to create products, evaluate, and optimize designs quickly, could generate more efficient processes and influences agile decision making to achieve higher performance throughout the design process. This research found that it is important for design students to know these tools, and to understand that, although they are very powerful, the human designer is and will be the one who makes the final decisions about the project, above the answers and algorithmic calculations that the parametric system gives. This research shows that this technology helps designers to face challenges in an era defined by the high degree of digitization, where it is increasingly necessary to create products that integrate with new technologies and human needs.

Keywords: Design Process, Generative Design, AI-Enabled Design, Genetic Algorithm, Evolutionary Algorithm

Introduction

Generative design is a tool that allows designers and creatives from other areas of knowledge to approach applied innovation. It is considered an emerging project exploration process that integrates tools such as artificial intelligence and processes such as parametric design. It is being considered also a contemporary milestone in the construction of alternative design proposals. It is important for the designer who is trained not only to know these tools and master them but to understand that, although they enhance the development of the project, it is and will be the designer who makes the final decisions about the project, above the algorithmic answers and calculations that the parametric system provides. Generative design has had important historical antecedents that have allowed the development of the technology. The first has to do with what happened in 1962, at the Lincoln Laboratory of Massachusetts Institute of Technology (MIT); when Ivan Sutherland developed the Sketchpad system, based on his doctoral thesis "A Machines Graphics Communications System" (Sutherland, 1962). This development lays the foundation for computer-aided interactive graphics systems, Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) (Llach, 2013).

Subsequently, there is an important advance in the production of algorithms capable of promoting multiple solutions autonomously based on predefined parameters (Bernal et al., 2015). Although there is a wide variety of evolutionary algorithms, the four most prominent types are genetic algorithms (Holland, 1975), evolution strategies (Rechenberg, 1973), evolutionary programming (Fogel, 1963), and genetic programming (Koza, 1992). From the practical point of view, several designers have concentrated on the development of projects with a significant load of parametric design, taking advantage of these algorithmic capabilities that enhance the design. In the field of generative evolutionary design, is important to highlight advances such as: a system of generation and evolution of three-dimensional construction models (Janssen et al. 2005), which describes a comprehensive framework for generative evolutionary design that varies in a controlled way. The Supporting product innovation using 3D shape grammars in a generative design framework (XI Tang, 2014) which concentrates mainly on the integration of 3D shape grammars with conceptual design knowledge in a generative design system. this framework helps the development of an advanced system for the exploration of design alternatives. The key problem that is identified is generating alternative designs that vary in a controlled manner. Within the proposed framework, the design process is split into two phases: in the first phase, the design team develops and encodes the essential and identifiable character of the designs to be generated and evolved. In the second phase, the design team uses an evolutionary system to generate and evolve designs that incorporate this character. This approach allows design variability to be carefully controlled.

Finally, we highlight the work of Joris Laarman, the Bone chair, developed from Adam Opel GmbH software, and is one of the first applications of topology optimization and generative design to have an impact on the furniture industry (Laarman, 1998).

Throughout the history of design, and in the revised literature, it is recognized that the use of computer systems does not imply the absence or replacement of the Designer, who is undoubtedly the decider in the development, creation, and innovation of any result (Narvaez, 2022).

Generative design has multiple definitions that have varied over time, responding to development processes. The present research considered what was stated by Lazzeroni, Bohnacker, Groß & Laub (2009) who define this technology as a cyclic process based on a simple abstract idea. The idea is applied to an algorithm and then translated into a source code, which in turn, produces a serial output through a computer. The output return through a feedback loop, allowing the designer to reinforce the algorithm and source code. This operation becomes iterative based on the exchange and feedback of information between the designer and computational thinking, allowing the designer to make better design decisions.

Unexpected phenomena such as the arrival of COVID-19 represented a series of tragic and unfortunate events, still, in the case of the implementation of parameterization in the design project, it was a factor of acceleration and cultural acceptance. While the entire material universe of our culture and economy had to face immense unexpected challenges, our computational infrastructure allowed us to advance very quickly in the acceptance of digitalization in the processes of project development. Those factors became relevant in a socio-economic context characterized by technological advances and with a high degree of digitalization. In academic terms, which are the basis of the development of this project, it became a fundamental axis, given that it was during the pandemic, where the project was developed, despite the limitations and with the support of parametric design.

Specifically, the processes of co-creation between the designer and computational thinking were addressed from six prototypes, with particular emphasis on the role of the designers and the value they have in the decision-making process supported by algorithms. This factor became a tool to exploit in academia, in teaching, and the implementation and appropriation of emerging technologies in the classroom. The generative design allows to create product proposals, evaluate and optimize designs quickly, enabling more efficient processes that affect agile decision-making by the designer. It Also provided greater performance throughout the design process, encouraging a change in the role of the designer in the project and his relationship with the technological tools at hand.

Methodology

The methodology used in this research was collaborative, iterative, and incremental, and was developed in three stages. The authors consulted to support the methodology affirm that performance-oriented generative design methods can produce stimulating concepts and solutions based on solid and rigorous models of design conditions and performance criteria (Janssen, Frazer, Tang, 2005). With generative methods, computational thinking becomes a design generator, in addition to its more conventional functions of copywriter, visualizer, data verifier, and performance analyst (Shea, Aish, & Gourtovaia, 2005). The above, considering the changes in the design of the manufacturing process through generative design, and the large percentage of participation in the morphological proposal made by artificial intelligence (Hyunjin, 2020). The research considers the case studies analyzed by Buonamici, Carfagni, Furferi, Volpe, & Governi, (2021) which offer a practical description of the workflow and experiment with a specific software system, Autodesk Fusion 360 ®. The software implements a generative approach to the realization of alternative solutions for a static structural design problem set by the designer. It examines and analyze the structure, finding completely unexpected geometric solutions (Nebot, Peña & López, 2021).

For the development of this project, we wanted that the integration between the designer's intention in the project and the computational algorithmic potentiation was simple, so the designer did not have to invest additional hours in software training. The software used in the study was Autodesk Fusion®, with the Generative Design module. At the time of execution of this research, the software had functionalities in development or beta state, such as experimental resolution algorithms, and geometrical displacement of limits (Autodesk, 2019). Such tools allowed us to enrich and explore the shape beyond the default possibilities presented by the software. The design process used the results of the CAD proposed models to delimit parameters and restrict objects with greater flexibility.

It was essential that the software had functions to allow the definition of criteria for its constant evaluation of the design processes. The tool has within its interface several visual evaluation possibilities that facilitated the co-creation experience. In the research, continuous evaluation was carried out, at all stages of the processes, generating the validation of alternatives to improve the design processes.

Methodological Model

The methodological model to which the present research is supported is the process evidenced by H. Bohnacker et al., (2009) in the book Generative Gestaltung. Modifications were made in the workflow making the process more dynamic, by adding five steps in the implementation of algorithmic rules. This allows the designer to gain control in the stage of definition and parametric modification. The methodology focuses on production, with a wide margin for academic reflection and naturalization of the design process in the classroom.

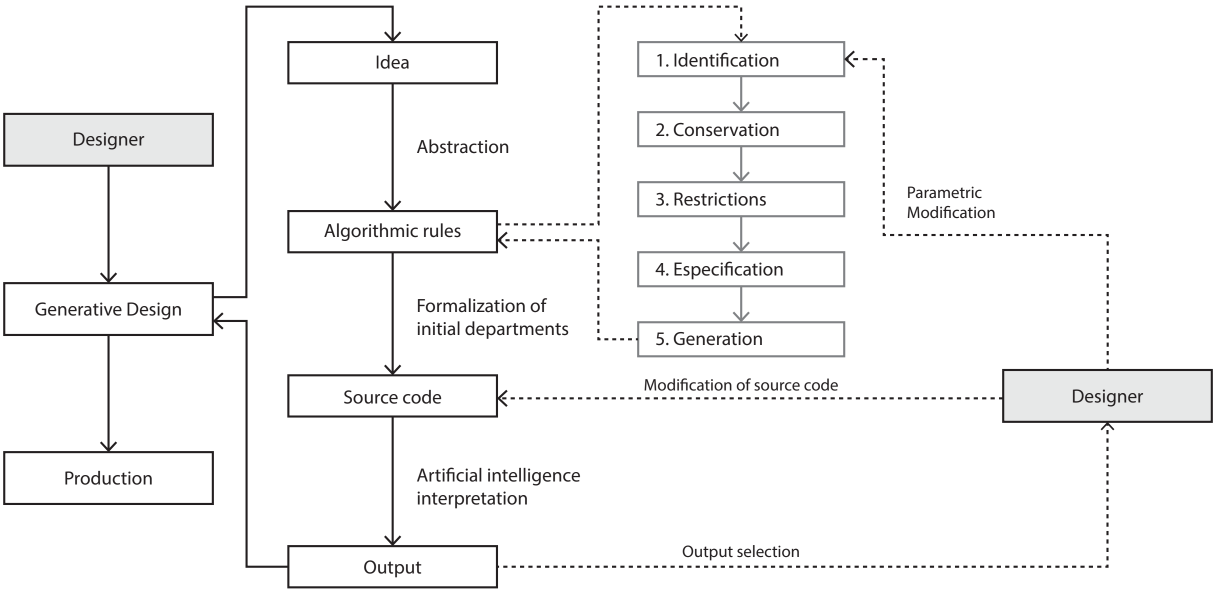

Diagram 1. Generative Design Methodology Based on Generative Gestaltung
(Bohnacker et al. , 2009)

The five steps in the implementation of algorithmic rules were proposed in conjunction with a series of questions to guide each of the steps and encourage the exchange and feedback of information between the designer and computational thinking.

Steps	Guiding questions for designers
1. **Identification:** it consists of recognizing the design problem that requires a parametric intervention.	- What is the goal of the design? - How do the pieces that make up the object interact? - What is the most relevant element to be intervened?
2. **Conservation:** Develop a basic CAD model that allows the software to understand the delimitations by conservation. What must be preserved from the geometries.	- What is the geometry that should be preserved? - How are the new elements generated and the geometry that was preserved related?
3. **Restrictions:** The software is delimited the space for generating constructive elements of the object.	- What are the constructive elements of the object? - What should be respected for these elements?
4. **Specifications:** Specifications, loads, details, manufacturing methods and materials are defined in the system so that the software can operate.	- What are the properties of the object components? - Do you have the technical tools to produce the object after the software calculates the specifications?
5. **Generation:** Execution and commissioning. On-cloud process of servers in hive to multiply the flow of processed data.	From the result the designer chooses the geometry - Should any parametric modifications be made? or would the element be ready for refinement?

Diagram 2. Five Stages in Implementation of Algorithmic Rules

Stages of the research

First stage / ***Sub-restricted Design***: the aim is to redesign an iconic modular object. For this purpose, the Eames Plastic Chairs DSW chair was chosen. At this stage, the constraint is flexible as only one part of the object is chosen to be redesigned. In this case, the most distinctive in the chair is the steel cross reinforcements. The restricted design allows the parametric software to feed the designer's decisions through the mathematical choices of possible alternatives, without a wide degree of freedom.

Second stage / ***Design Without Restriction***: In this stage, initial parameters based on a general morphology are used. Here the software can explore infinite results. Although it must respect elements defined by the designer, the number of calculations and results presented by the software increases in relation to the first stage.

Third stage / ***Restricted Dynamic Design**:* In this last stage, an iterative approach is used to generate similar project proposals in aesthetics and shape from similar initial parameters.

These stages help to evaluate the dialogue of co-creation between the designer and the parametric software to explore variations of a solution and thus, generate greater possibilities of transformation of the designed object. Although these possibilities could be obtained analogously, it would be a long and inefficient process within the project. The support of this kind of software in the amplification of finite possibilities of algorithmic calculations in a short time enhances the creative development within the project and allows the designer, according to his aesthetic, cultural, and project preferences, to make better decisions for the development of the project.

Results

The results of this research project demonstrate advances in the process of exchange and feedback of information between the designer and a computational entity. The computer software translates the information into a portfolio of alternatives that the designer can analyze and choose, to improve its design project. It is crucial to implement such an approach in academic spaces that integrates product development through CAD, as it prepares designers not only to improve their projects but also to construct a critical approach by not letting the computer software the final decision of a particular design direction.

First stage / Sub-restricted Design

In the first stage of the research, **called sub-restricted design**, a series of viable transformation alternatives were generated and suitable for the manufacture of the steel yarn of the Eames DSW chair. 490 possible forms were obtained from the inputs (Figure 1). For the resolution of this case, predefined materials were used in the system that can be used in additive manufacturing methods, for example, AISi10mg aluminum, AISI 304 stainless steel, and polymers such as PLA (Polylactic acid) or ABS (Acrylonitrile butadiene styrene).

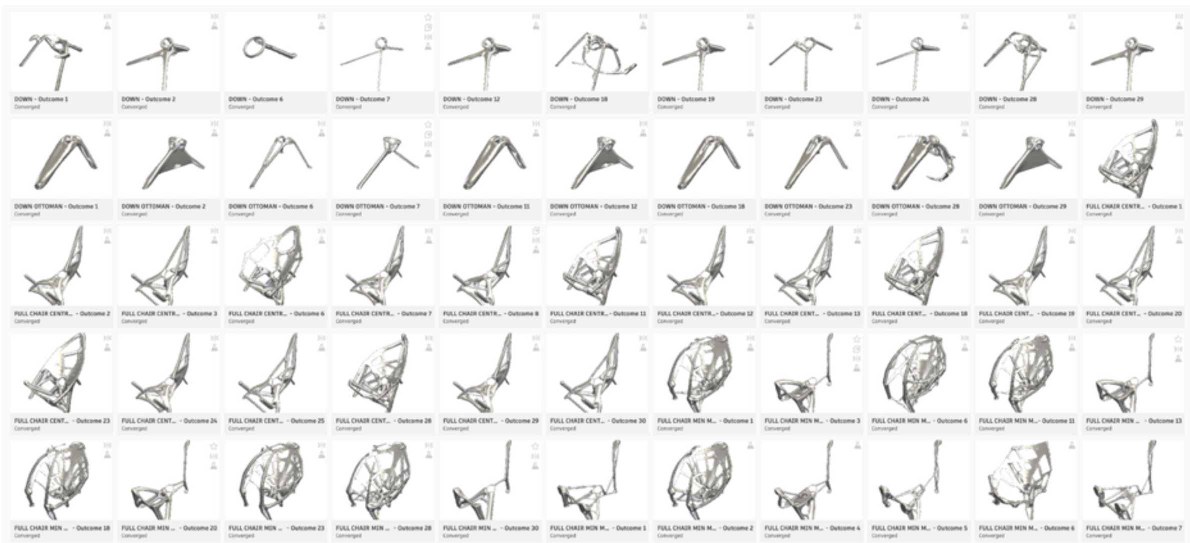

Figure 1. Generative design alternative interface, created with Autodesk Fusion®, Autodesk

For the first part, we generate two possible configurations under a non-restrictive additive manufacturing method, to be constructed with polylactic acid (PLA). This configuration showed potential in the autonomous topological creation with a lower volume structure as a replacement for the steel yarn of the original chair. A 3D visualization of the selected element is projected, together with the entire chair (figure 2).

Figure 2. Digital prototype of replacement of steel yarn for chair Eames DSW (Vitra, 2018)

In a second iteration, another configuration is generated with a stronger topological optimization process (Figure 3). A proposal that fits the parameters is co-created with the software and prototyped using additive manufacturing techniques of stainless steel AISI 304, considering high load capacities, resistance, and solidity.

Figure 3. Prototype replacement of steel yarn for chair Eames DSW (Drexler, 1973)

Although the software presents a significant number of options, it is the responsibility of the designer to make a curatorial process of them (Redshift, 2019). The final selection of the adequate piece for replacement lay exclusively on the designer´s criteria based on all suggestions presented by the software. In this case, the selection was made considering which piece suits both the structural and aesthetic points of view.

Second stage / Design Without Restriction

In the second stage, called **design without restriction**, two elements of a furniture object with completely different formal characteristics were generated through the methodology set out above. The Acapulco chair (figure 4), which is a common chair created by artisanal techniques, was taken as a morphological starting point. Thanks to its aesthetical language and simplicity in the use of materials, it has been elaborated with many different variations, spreading in the material culture of Latin America. As it has no copyright, official manufacturer, or original design blueprints, is on the market by a large number of producers with a high number of variations.

Figure 3. The Acapulco Chair, 2020

For this exercise, the chair, divided into two formal entities was given to the software to propose alternatives of variation (Figure 3). The results of the generative design process showed a wide formal richness in the proposals for each case, and the derivations were selected considering the feasibility projection in the manufacturing process analyzed by the software. The fulfillment of the initial parameters, especially those of tension, strength, and resistance were suggested by the computer software. The selection based on aesthetic criteria and cultural appropriation was the role of the designer. The results of the generation processes are closely related to the anatomy, and a large part of the shapes delivered by the software is highly organic (Figure 4 and 5). However, it was observed that some of the proposed solutions that technically achieve the desired requirements, maybe too unusual. Part of the co-creation process between the designer and computational thinking concludes with a classification and selection of the more attractive and feasible alternatives.

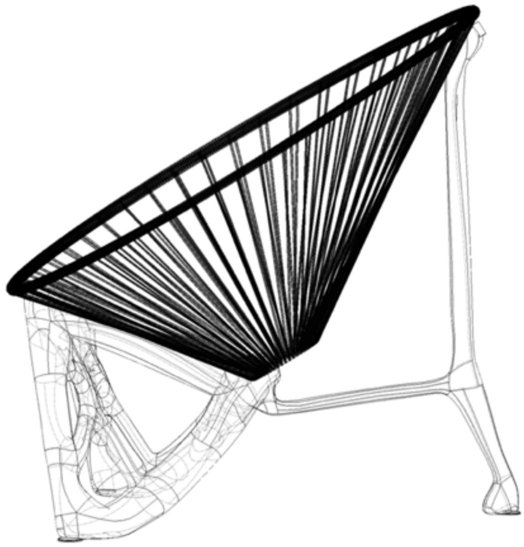

Figure 4 and 5. Traditional furniture re-purposed by the generative design methodology

Figure 6. Traditional furniture re-purposed by the generative design methodology

Third stage / Restricted Dynamic Design

In the third stage of the research called restricted dynamic design, two prototypes of furniture of the Ottoman chair type were generated. This element is born from the initial morphology of the chairs presented, designed as accompanying furniture. Is used to prove the same methodology, producing designs that can be part of the same object family and have reasonable similarities with those proposed above. The methodological application of the five steps, together with the similarity in the input parameters generated 522 options in total. Following the process of co-creation between the designer and computational thinking, two outputs were selected which fits with a high degree of similarity to the furniture project. The shape of the Ottoman chair is composed by three or four points of support to the ground. They connect to a plane that serves as a footrest or bench of the seat. The Ottoman proposals made in the research have simulated resistance properties, like their peer and can withstand a similar load.

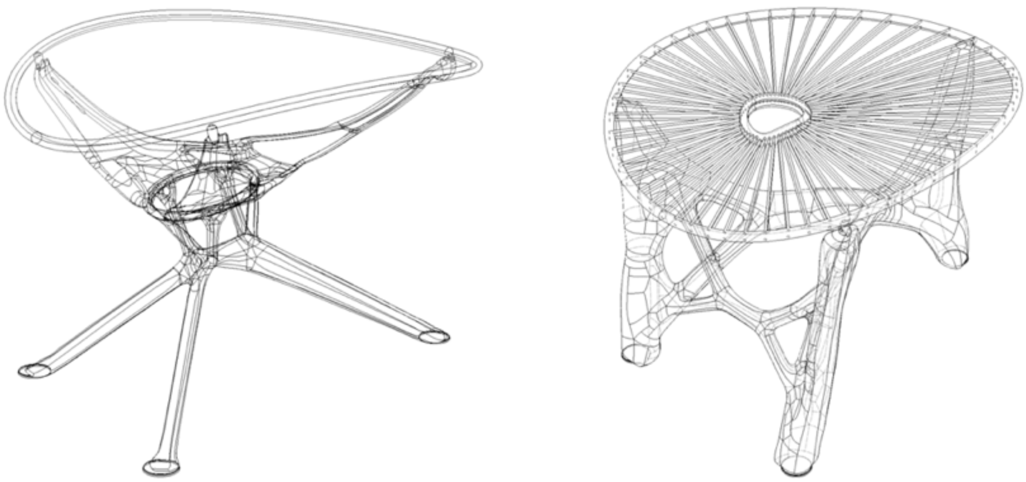

Figure 7 and 8. Ottoman furniture constructed by the generative design methodology

The previous process allowed us to verify the proposed methodology and infer that the software has the possibility of creating complex morphologies from a series of parameters given by the designer. The results obtained share formal, visual, and aesthetical elements of the whole project. The curatorial process to select the results produced by the software is the sole responsibility of the designer.

Figure 9 and 10. Ottoman furniture constructed by the generative design methodology

Figure 11. Rendered collection of furniture alternative 1

Figure 12. Rendered collection of furniture alternative 2

Discussion

In the methodology that is presented in this research, the active role of the designer in the conversation with computational thinking introduces a dynamic way to compose product development. We believe such a methodological approach must be taught in academic environments as it trains the designer not only in the use of state-of-the-art software but also in the decision-making process for the project. The advent of CAD software allowed in the past thirty years the development of new product language based on computational thinking. However, the decision of which shape, material, or finish is the best for the project cannot rely on the software. Instead, the designer should be responsible for the selection process based on suggestions presented by the computer.

It's important to know what these tools can do, as well as understand the limits of what they can't do in these early stages of implementation. The vision for the future of these systems, and the integration of more forms of artificial intelligence are extraordinarily promising, but there is a risk that expectations will be excessive. It is difficult, even impossible, to create an algorithm that allows a generative design system to consider the aesthetic sensibilities of a designer. This technology faces a truly sophisticated problem when trying to devise beyond the automatically generated shape. Generative design is remarkable at calculating a finite number of variables and generating a virtually infinite number of outputs, or formal proposals. That's more than what a human designer can do; however, it is still too early for this technology to propose autonomously because only humans can understand the complex cultural dimensions that design can contain. There is no doubt that, over time, generative design systems will be able to address increasingly sensible, and more human, conditions and considerations. They will become an essential instrument in the product design and development toolkit but will never replace human sensibility in the development of a project.

Exposing designers in academic environments to these technologies is fundamental to promoting critical thinking. Software capabilities increase faster each year. Still, is important that the designer does not accept all design improvements proposed by the software without critical analysis, further refining of alternatives, and a conscious final decision before manufacturing.

Artificial intelligence will be programmed, and self-programmed, better and better to understand the needs of users, and these in turn will be more skilled in the use of these tools. we hope it can never replace the designer.

Conclusions

The project described in this article shows iteratively the co-creation relationship between a designer and a computational tool of algorithmic thinking. The main focus of this research is on supporting the formative development of designers through the use of these systems. The different experiments carried out show the combined creative capacity between the designer's thinking and algorithmic thinking. It is important to highlight the importance of maintaining both models of thinking and not pretending that one replaces the other. As long as this symbiosis between the designer's capabilities and the mathematical enhancement of the tool is maintained, better projects will emerge in the future. That is why the academic training of the designer must be complemented with this type of tool and not replaced as it tends to be thought with the arrival of technological advances of this nature. The generative design will require new ways of thinking, it will force designers and creators from other areas of knowledge to evolve their development and production models. It is not only about learning new software, or some new functions in existing software; in many cases, the way of approaching a project must be addressed from the genesis. This is an invaluable opportunity for the academy to integrate new ways of approaching the project into its curricular structures, and to train designers with better tools to establish non-linear dialogues with new actors in the design process.

The dialogues that the human being establishes with technology are collaborative, iterative, and evolutionary. They allow the generation of knowledge, to acquire a greater relevance when these collaborations have the potential to change the forms of production, democratize knowledge, and expand the frontiers of human production. Generative design, as a process of co-creation between the human being and computational thinking, has a great projection, while the technological apparatus has maintained a constant evolution as time progresses; the development of artificial intelligence and the progressive evolution of neural networks are showing strong advances in the industry, promoting and naturalizing the adoption of these technologies in design processes.

Design projects can be formally enriched from topological generation systems using AI. However, one of the most important challenges facing this technology is cultural appropriation. Much of the forms delivered by the system are highly organic, however, incompatible with many of the morphologies that for decades have accumulated in the material culture of the different regions of our planet. Not all design languages can be solved in the same mathematical way, and this is a factor that parametric design does not yet take into consideration.

References

Arias, A., & Osorio, G. (2020). Albatros Create: an interactive and generative tool for the design and 3D modeling of wind turbines with wavy leading edge. International Journal on Interactive Design and Manufacturing, 14, 631-650.

Autodesk.com. (2020). Fusion 360. Obtenido de Cloud powered 3D CAD/CAM software for product design. https://www.autodesk.com/products/fusion-360/overview

Bernal, M.; Haymaker, J.; Eastman, C. (2015). On the role of computational support for designers in action. Design Studies. Volume 41, Part B, November 163-182.

Bohnacker, H. (2009). *Generative Gestaltung*. Mainz: Verlag hermann schmidt.

Buonamici, F., Carfagni, M., Furferi, R., Volpe, Y., & Governi, L. (2021). Generative Design: An Explorative Study. Computer-Aided Design and Applications, 18(1), 144-155.

Drexler, A. (1973). Charles Eames: Furniture from the Design Collection, the Museum of Modern Art, New York. New York: The Museum of Modern Art.

Fogel, D. B. (1995). "Evolutionary computation: Towards a new philosophy of machine intelligence." IEEE Press.

Fraile Narvaez, M. (2022). El diseño computacional: Un estudio de casos. Anales De Investigación En Arquitectura, 12(1). https://doi.org/10.18861/ania.2022.12.1.3216

Gu, Z., Xi Tang, M., & Frazer, J. (2006). Capturing aesthetic intention during interactive evolution. Computer-Aided Design, 38(3), 224e237. Doi:https://doi.org/10.1016/J.CAD.2005.10.008

Holland, J. H. (1975). "Adaptation in Natural and Artificial Systems." University of Michigan Press,Ann Arbor.

Hyunjin, Chun. (2020). A Study on the Change of Manufacturing Design Process due to the Development of A.I Design and 3D Printing. IOP Conference Series: Materials Science and Engineering. 727. 012010. 10.1088/1757-899X/727/1/012010.

Janssen, Patrick & Frazer, John & Tang, Ming. (2005). Generative Evolutionary Design: A system for generating and evolving three-dimensional building models. 35-45.

Janssen, Patrick & Frazer, John & Tang, Ming. (2005). Generative Evolutionary Design: A system for generating and evolving three-dimensional building models. 35-45.

Koza, J. R. (1992). "Genetic Programming: On the Programming of Computers by Means of Natural Selection." MIT Press, Cambridge, MA.

Laarman, J. (2015). Bone chair. Joris Laarman. https://www.jorislaarman.com/work/bone-chair/

Llach, D. C. (2013). Algorithmic Tectonics: How Cold War Era Research Shaped Our Imagination of Design. Architectural Design, 83(2), 16–21.

Rechenberg, I. (1973). “Evolutionstrategie: Optimierung Technisher Systeme nach Prinzipien derBiologischen Evolution.” Frommann-Holzboog Verlag, Stuttgart, Germany.

Shea, K., Aish, R., & Gourtovaia, M. (2005). Towards integrated performance driven generative design tools. Automation in Construction, 14(2), 253-264.

Sutherland, I. (1964). Sketchpad a man-machine graphical communication system. Simulation, 2(5), R-3.

Tang, Ming & Cui, Jia. (2014). Supporting product innovation using 3D shape grammars in a generative design framework. Int. J. of Design Engineering. 5. 193 - 210. 10.1504/IJDE.2014.062376.

Vitra. (2018). Eames plastic charis. Charles & Ray Earnes, 1950. Obtenido de Product: https://www.vitra.com/es-es/product/eames-plasticchair

Contact email: camiloayala@uniandes.edu.co
c.ayala954@uniandes.edu.co