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GANism: When AI Rethinks the Borders of Architecture. The Cases of ArchiGAN and Deep Himmelb(l)au

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Abstract

This paper aims to shed light on the challenges and limitations of GANism in contemporary architectural design. It focuses on two specific experiments carried out using different generative adversarial networks (GANs): ArchiGAN by Stanislas Chaillou, on the one hand, and Deep Himmelb(l)au by Coop Himmelb(l)au, on the other.This research is based on an in-depth literature review on the use of artificial intelligence in architecture today, at the dawn of the digital era. It also includes a visual analysis of photographic and videographic documents drawn from conferences and academic publications.ArchiGAN (2019), developed within the framework of a master's program at the Harvard Graduate School of Design, is an AI tool based on the Pix2Pix model, enabling the generation of various interior design configurations. It proposes a dynamic distribution of rooms, partitions, and structural elements (columns, load-bearing walls, etc.), thus adapting the space to multiple dwelling scenarios. By contrast, Deep Himmelb(l)au (2019), an experimental initiative conducted within the Coop Himmelb(l)au office, explores the acceleration of the architectural design process by employing a variety of GANs to reinterpret some of the firm's emblematic projects.How does GANism influence the creative process in these two projects? What kinds of spatiality, functionality, and aesthetics emerge from these computational approaches? What future awaits architecture as a discipline in the face of the growing power of generative tools? What lessons and perspectives do these experiments open up for contemporary architectural and artistic creation?.

Keywords: *Architecture, Aesthetics, Latent Space, GANism, Generative Adversarial Network (GAN).*

Introduction

The term *border*, derived from the former adjective *frontier*, literally means "to be neighboring" or "to face," referring to the idea of interaction, transition, intermediate passage, but also confrontation between two distinct territories, whether terrestrial, maritime, or aerial. While the notion of territorial separation was not foreign to ancient societies, the first documented use of the term *border* dates back to the thirteenth century, in connection with the emergence of topographic maps [1]. The term truly became established at the end of the Middle Ages, at the moment when the modern state was being formed, founded on the assignment of boundaries [2]. From that point on, the border came to designate the confines of the state [3]: its territorial limit [4], its edge, its line of demarcation, and, by extension, the very expression of its power [1]. It thus contributes, among other things, to the production of territory around itself [ibid.].

In the social sciences, the notion of the border goes beyond its strictly political and geographical dimension. It can be understood, on the one hand, as a space of separation and differentiation between social groups, thereby generating relations of symbolic or material domination [5]; and, on the other hand, as a zone of contact, circulation, and hybridization between distinct territories, cultures, and identities [6]. From this dual perspective, borders appear both as places of difference, danger, misunderstanding, or constant challenge [1], while simultaneously constituting spaces of transformation and metaphor par excellence [ibid.].

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Today, the notion of the border extends beyond its territorial materiality to include other dimensions and other fields, notably the digital realm, which we propose to explore in this contribution. It also invites us to rethink the question of limits, to interrogate the crossing toward the “beyond,” and to adopt a fundamentally critical stance in order to broaden our worldview and our knowledge. “This is undoubtedly where the principal heuristic value of borders lies” [1].

In the following sections, we propose to examine the theme of the digital border. To this end, particular attention will be paid to artificial intelligence in architecture, notably through the technique of Generative Adversarial Networks (GANs), considered as a form of co-creativity between humans and machines—what may be termed a “synthetic” creativity [7]—designed to transcend the limits of natural creativity. This form of creativity, specific to AI, can be described, according to Boden [8], as “combinatorial,” “exploratory,” and “transformational.” It nevertheless differs from human creation, which is generally imbued with emotion, sensitivity, and intuition. It is precisely in this difference that the interest of artificial creativity lies: by complementing human creativity, by exploring its limits—sometimes at the edge of the precipice—and by surpassing certain of its horizons, AI opens the way to new aesthetic and conceptual challenges in architecture.

Artificial intelligence was first introduced into the collective imagination through cinema in the 1930s, before being formalized as a scientific discipline in the mid-1950s. It is defined by *Le Petit Larousse* as “the set of theories and techniques implemented with the aim of creating machines capable of simulating human intelligence” [9]. Several perspectives from the scientific literature are added to this definition. As early as the 1960s, Marvin Minsky conceived AI as a “general problem-solving machine” [10], relying in particular on trial-and-error processes analogous to those of the biological brain. Herbert A. Simon, for his part, viewed it as “a field of research aimed at making a computer behave intelligently according to human standards” [11], while Hector Levesque defined it as a discipline that “studies intelligent behavior in computational terms” [12]. For Pallanca and Read, artificial intelligence encompasses all the sciences and technologies that make it possible “to imitate, extend, and/or augment human intelligence through machines” [13]. Margaret Boden, meanwhile, asserts that AI enables computers “to perform the same tasks as human minds” [14]. Finally, for Nils J. Nilsson, AI aims at the “mechanization” of human intelligence [15]—a choice that would allow machines not only to imitate it, but to rival it, to the point of calling its very limits into question.

To grasp the deeper meaning of artificial intelligence, it is necessary to retrace its history. The paternity of this notion is generally attributed to the British mathematician and logician Alan Turing, notably through his famous “Turing Test,” proposed in 1950. In his article *Computing Machinery and Intelligence*, he raises the now-celebrated question: “Can machines think?” [16]. He describes an experiment in which an individual interacts blindly with two entities—a human being and a machine—and must determine, solely on the basis of their responses, which one is human. If the machine succeeds in passing itself off as a human, it is then considered “intelligent.” A few years later, in 1956, the term *Artificial Intelligence* was officially introduced during a seminar organized at Dartmouth College in the state of New Hampshire, devoted to the theme of “thinking machines.” That same year, the first computer program to be described as artificial intelligence, *Logic Theorist*, was developed by Allen Newell and Herbert Simon. Capable of proving 38 of the 52 theorems of *Principia Mathematica* by Whitehead and Russell, this program represented a remarkable breakthrough at the time.

This marked the beginning of an initial period of enthusiasm, characterized by a proliferation of research and projects addressing a wide range of themes. Such was the intensity of this excitement that Herbert Simon predicted as early as 1958 that machines would become world chess champions within the following ten years. Although this prediction was only realized forty years later, it nonetheless proved visionary: in 1997, *Deep Blue*, IBM’s supercomputer, defeated the world champion Garry Kasparov. Other spectacular advances soon followed. In 2012, GAN-type algorithms won the ImageNet competition, an international contest in image recognition. Then, in 2016, the *AlphaGo* algorithm developed by DeepMind defeated the Korean master Lee Sedol at the game of *Go*, widely regarded as infinitely more complex than chess. In its wake, numerous other champions—both in Go and in various video games—were in turn defeated by artificial intelligences endowed not only with immense computational power, but also with extraordinary endurance.

Although still in its early stages, the art world is already being profoundly transformed by the emergence of artificial intelligence, particularly through Generative Adversarial Networks (GANs). These have given rise to a movement that some refer to as GANism, a term proposed by François Chollet, a researcher and AI engineer at Google. GANism paves the way for a new generation of creators—or forgers—of an art and, by extension, an architecture described as “AI.” It refers to a distinctive aesthetic resulting from a “fruitful collaboration between human intervention, the involuntary creation of artificial intelligence, and the artist’s selection” [17]. Today, an increasing number of artists, architects, and creators are turning to these neural networks, which are based on an algorithmic duel between the true and the false. By imitating the functioning of natural neurons, these systems assert themselves as a form of “transhuman” aesthetic expression—that is, one that transcends the traditional boundaries of human creation. These neural networks also constitute, among other things, a rapidly expanding field of research within artificial intelligence.

GANs are not only capable of recognizing and distinguishing iconographic content within large datasets of trained images, but also of generating entirely new creations. The results achieved so far are impressive, far exceeding our creative expectations and raising, among other issues, complex questions surrounding copyright. Among the most striking examples of AI-generated creations is *Paul the Robot*, a portrait-drawing machine designed in 2011 by the French artist Patrick Tresset as part of his doctoral research. The machine automatically produces burlesque drawings endowed with genuine artistic value, recalling in certain respects the mechanical sculptures of Jean Tinguely. In a different register, Trevor Paglen’s work *Adversarially Evolved Hallucinations* presents a series of images “hallucinated” by an AI, reinterpreting themes such as magic, demonology, or divination through strange surreal représentations. One may also cite the *Artificial Intelligence Creative Adversarial Network* (AICAN), presented by SCOPE Miami Beach in 2018. This deep learning program, trained on hundreds of thousands of images drawn from the history of art, generates ultra-contemporary pictorial works that draw inspiration from past styles while proposing a legitimate aesthetic inquiry.

Other significant projects employing GANs further testify to the rise of this technology within the field of contemporary art. Among them, *Portrait of Edmond de Belamy*, created in 2018 by the Paris-based collective Obvious, stands as one of the most emblematic examples. Trained on a corpus of approximately 15,000 paintings from different periods in art history, the work offers a stylistic amalgam whose unsettling appearance evokes, according to some observers, the canvases of Francis Bacon [18]. However, it “remains devoid of the ephemerality that characterizes the artist’s gesture,” as Shauna Jean Doherty notes in this regard [19]. That same year, Sofia Crespo presented *Neural Zoo*, a series of images generated by other types of GANs based on biological and microscopic patterns. These hybrid compositions suggest imaginary life forms, situated halfway between science and speculative fiction. Another emblematic project is *Memories of Passersby I* by Mario Klingemann. This interactive installation, composed of two generative screens, reinvents artificial human portraits in real time, inspired by photographs dating from the seventeenth to the nineteenth centuries and adapted to the artist’s sensibility. In a different vein, *UUmwelt* by Pierre Huyghe, presented at the Serpentine Gallery in London in 2018, offers a series of immersive images generated from data derived from a human subject’s brain activity. The work explores the tenuous boundary between mental perception and artificial creation, blurring the distinctions between psychic interiority and visual representation. Finally, the data paintings of Refik Anadol illustrate the capacity of GANs to transform architectural space into a sensory experience. Among the most notable are *WDCH Dreams* (Los Angeles, 2018), *Machine Hallucinations* (New York, 2019), and, more recently, *Living Architecture: Casa Batlló*. This latter work, a video mapping projected onto Gaudí’s iconic façade, mobilizes various GANs trained on visual archives of the building, as well as on real-time climatic data. The result is a spectacular nocturnal street art performance, orchestrated through a dynamic symphony of light, color, and sound.

Architecture, like digital art, has recently been added to the growing list of fields engaged by artificial intelligence. Works situated at the boundary between human creation and semi-autonomous computational systems testify to an unprecedented techno-aesthetic effervescence. Among them, the *Daedalus Pavilion* by Ai Build stands as an emblematic example. This architectural installation, 3D-printed and constructed by robots programmed using AI, was presented at NVIDIA’s GPU Technology Conference in Amsterdam in 2016. It illustrates the ability of machines to produce complex structures with remarkable precision. Other initiatives, such as *Spacemaker AI* and *XKool Technology*, also launched in 2016, position themselves as “invisible assistants” [20], aiming not to replace the architect but to enrich and support the design process. In a similar vein, Patrik Schumacher’s *Agent-Based Parametric Semiology* project, developed in 2017, explores—through a combination of GANs and multi-agent simulations inspired by life processes—the possible interactions between the spatial organization of a hypothetical architecture and the social behaviors it is likely to generate.

The year 2019, in particular, marked several architectural experiments involving GANs. The project *Machine Perceptions: Gaudí + Neural Networks* is expressed through the confrontation of photographic images of the Sagrada Família with landscapes of natural forests, thus generating an unprecedented visual hallucination. From another perspective, the work *Deep Himmelb(l)au* aims to accelerate the architectural design process by crossbreeding images from previous projects by the firm Coop Himmelb(l)au. Also in 2019, *ArchiGANs*, a master's thesis by Stanislas Chaillou at the Harvard Graduate School of Design, proposed an algorithmic model capable of generating various spatial reconfigurations for existing apartments. That same year, at the Bi-City Biennale of Urbanism and Architecture, the neural network *AI-chitect* was presented, capable of transforming schematic sketches into standardized architectural drawings. At the intersection of technological design and social critique, *Can the Subaltern Speak?* by Behnaz Farahi questions the external threats faced by Iranian women. Also produced in 2019, this work features a sophisticated mask adorned with nine pairs of eyes, endowed with an artificial intelligence capable of generating a language in Morse code.

Materials and Methods

Within the framework of this research, we focus on two significant works: *ArchiGANs*, designed by Stanislas Chaillou in 2019, and *Deep Himmelb(l)au*, developed by Coop Himmelb(l)au in the same year. Our methodology is based on a cross-sectional and critical analysis of these two projects, highlighting their aesthetic and technological dimensions, and examining in particular the role of Generative Adversarial Networks (GANs) in the architectural creation process. This approach is situated within a qualitative and descriptive framework, structured around several axes. First, a graphical analysis based on the examination of images derived from the works. Second, a descriptive study through the exploration of spatial and aesthetic interpretations provided by official and academic sources. Finally, a videographic analysis, relying on the extrapolation of online video recordings (webinars, conferences) documenting the design processes, simulation stages, and creative intentions of the designers.

The objective of this research is to propose a critical synthesis articulating the aesthetic and architectural dimensions of the analyzed works, while opening up a series of questions. How does the technique of Generative Adversaire Networks (GANs) manifest itself in these projects? What role does artificial intelligence—and more specifically GANism—play in architectural design processes? What kinds of spatiality, aesthetics, and works emerge from these computational systems? What future is taking shape for architecture and for art more broadly in a context of human–machine co-creation at the frontier of the digital? Finally, what challenges, limits, and risks accompany this new form of collaboration between AI and the architect?

Results and Discussion

I. *ArchiGAN* by Stanislas Chaillou

Stanislas Chaillou is a French architect and researcher specializing in artificial intelligence (AI). He obtained a Bachelor's degree in Architecture from the École polytechnique fédérale de Lausanne (EPFL) in 2015, followed by a Master in Architecture from the Harvard Graduate School of Design (GSD) in 2019, where he developed the *ArchiGAN* program. His career has been distinguished by several awards: in 2017, he received the American Architecture Prize on two occasions, and in 2018 he was awarded the Architecture MasterPrize, an international distinction recognizing innovation and creativity in architecture. Stanislas Chaillou has also collaborated with several internationally renowned architectural firms, including Adrian Smith & Gordon Gill (Chicago), Shigeru Ban Architects (Tokyo), Flux.io (San Francisco), and Helix.RE (London). In March 2020, he contributed to the organization and presentation of the exhibition *AI & Architecture* at the Pavillon de l'Arsenal in Paris. In parallel, he pursues an active career as a lecturer and researcher and has published several books, including *Artificial Intelligence at the Service of Architecture* (2021) and *Artificial Intelligence and Architecture: From Research to Practice* (2022). Since 2020, he has held the position of Data Scientist at Spacemaker AI (Autodesk), a cloud-based collaborative platform that leverages AI to optimize the early phases of architectural projects, particularly land acquisition and valuation. The tool aims to facilitate interdisciplinary collaboration and generate design alternatives [21]. More recently, he co-founded Rayon, a Paris-based startup dedicated to developing a new generation of digital tools for architectural design.

ArchiGAN is an artificial intelligence program developed as part of a Master in Architecture in May 2019 [Figure 1]. This project extends a nearly two-hundred-page thesis entitled *AI + Architecture: Towards a New Approach*, which explores the potential of Generative Adversarial Networks (GANs) for architectural creation and for assisting architects throughout the design process [22]. Freely available online, this document adopts a data science–based methodology and applies it to the architectural field, seeking to demonstrate how AI can enrich the discipline.

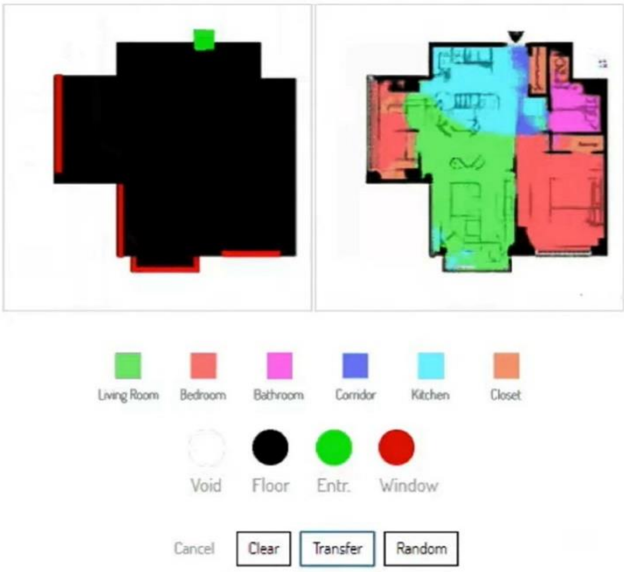

Figure 1: Graphical interface of the *ArchiGAN* program.

Chaillou's thesis is structured around three main chapters. First, it situates the emergence of AI in architecture within a historical perspective, considering it as the culmination of a logical evolution of the discipline. He traces its genealogy from research on modularity in the 1920s, through the development of computer-aided design (CAD) systems in the 1970s, and the rise of parametric design in the late 1990s, leading, in his view, to the current era of artificial intelligence. The second chapter, entitled "Generate," describes the organization of the *ArchiGAN* program as a sequenced algorithmic pipeline. Chaillou outlines three stages: a first algorithm responsible for generating the building footprint, a second dedicated to the distribution of spaces within this footprint, and a third focused on the detailed layout of the plans.

The third chapter of Chaillou's thesis, entitled "Qualify," deepens the experimentation by defining six metrics considered essential for facilitating user navigation through the program: footprint area, spatial orientation, wall thickness, functional program, connectivity, and circulation. At the end of each stage, the user is invited to intervene by selecting the solutions deemed optimal, which then serve as the basis for the subsequent phase. In this sense, Chaillou interprets the interaction between the user and the algorithm as an illustration of the "gray box" principle formulated by Andrew Witt [23]. Unlike the "black box" model, characterized by the absence of control over the process, the "gray box" establishes a constructive dialogue between human and machine, allowing artificial intelligence to assist and enrich the architectural design process.

ArchiGAN was developed on the basis of Generative Adversarial Networks (GANs). Introduced in 2014 by Ian Goodfellow, then a doctoral candidate at the University of Montreal [24], GANs constitute a machine learning technique based on an unsupervised approach, that is, without direct human intervention. In this framework, the machine receives raw, unlabeled data and must train itself to acquire general knowledge through observation in order to generate relevant representations.

The operation of GANs relies on the competition between two artificial neural networks. The first, known as the generator, acts as a "forger," producing counterfeit data that closely resemble the original data from a latent space constructed on the basis of a large training dataset. The second, the discriminator, plays the role of a "critic," tasked with distinguishing real data from generated data. This antagonistic mechanism, structured as a continuous feedback loop, draws on the concept of a zero-sum game developed in game theory, in which the gain of one player corresponds to the loss of the other [25]. The term *adversarial* thus conveys the idea of direct confrontation, a kind of head-to-head battle [26].

Over the course of training, the generator is by learning from its own errors and becomes increasingly "intelligent". Its role is to produce ever more convincing visual forgeries capable of deceiving the discriminator. During the initial iterations, the results are crude and easily detected. However, as the machine's training progresses, the quality of the generated data becomes increasingly refined. Eventually, the generator is able to produce samples so convincing that the discriminator fails to distinguish the real from the fake. At this stage, the two networks reach an adaptive equilibrium—known as Nash equilibrium—resulting in the production of extremely realistic images [Figure 2].

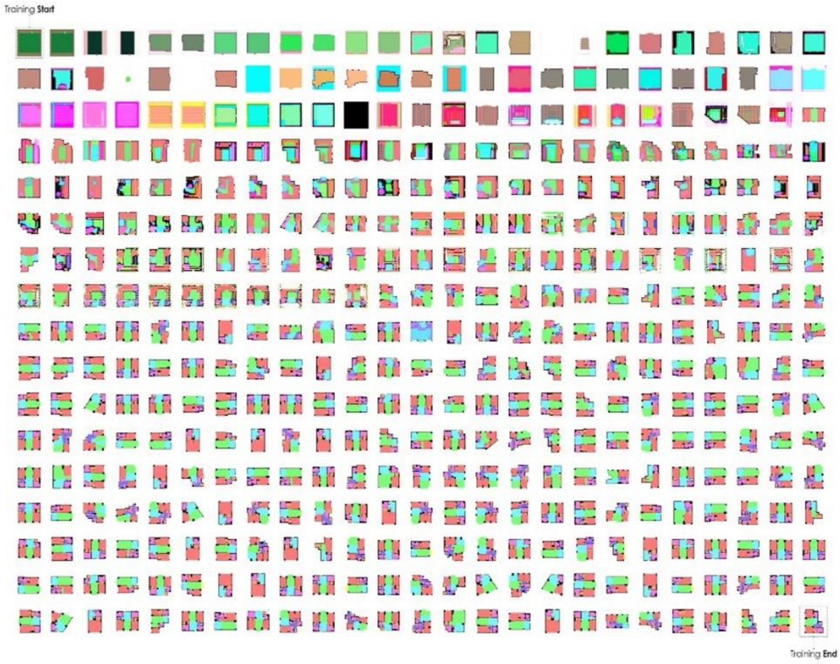

Figure 2: Learning sequences of the *ArchiGAN* program.

Since their invention in 2014, GANs, in their basic configuration known as VanillaGAN, have undergone significant development. Numerous variants have emerged, giving rise to a wide range of applications, including image synthesis, super-resolution, style transfer, and image restoration. Applications can also be found in artistic generation [27], architectural optimization [28], tumor detection in medical imaging [29], as well as malware identification in cybersecurity [30]. In this context, the *ArchiGAN* program relies on a specific GAN model: Pix2Pix. The latter is a particular variant of Conditional GANs (cGANs), proposed by Mirza and Osindero in 2014 [31]. In the Pix2Pix model, the machine's generation is conditioned by additional information provided by the user. Designed for image-to-image translation tasks, Pix2Pix learns to generate correspondences between different visual representations—such as building façades, as illustrated in the publication by Isola and colleagues [32]—thus opening the way to potential architectural applications.

In his thesis, Stanislas Chaillou emphasizes that *ArchiGAN* is part of a broader continuum of generative AI programs dedicated to architecture and based on the Pix2Pix model. Among these is the work of Weixin Huang and Hao Zheng, presented in the proceedings of the 38th ACADIA Conference [33]. The authors employ a Pix2PixHD network to perform high-quality image-to-image translation, enabling both the recognition of architectural drawings and the generation of apartment plans. Through a chromatic coding system, the AI produces spatial layouts according to the program and the position of openings specified by the user. A similar approach is pursued by Nathan Peters in his thesis defended at the Harvard Graduate School of Design in 2018 [34], where the Pix2Pix model is used to generate spatial distributions for modular houses from a given footprint. Finally, research conducted by Nono Martinez at the same institution [35] proposes an AI program entitled *Sketcher*, capable of transforming a simple user-drawn sketch into representations of remarkable artistic quality.

The core objective of the *ArchiGAN* program is to ensure that the machine can develop a form of spatial "intuition," enabling it to predict floor plans [28]. To achieve this result, Stanislas Chaillou trained a Pix2Pix model using a dataset comprising more than seven hundred apartment plan examples [ibid.]. The process is structured into three successive phases, within which the user intervenes to select the necessary elements that then serve as the basis for the next stage. The first phase consists in training the algorithm to generate the building footprint from a given plot [Figure 3]. To this end, Chaillou relied on a large collection of footprint configurations, notably GIS (Geographic Information System) data from the city of Boston [ibid.]. The second phase aims at generating a variety of apartment plans derived from the footprint defined by the user, including the position of the main entrance and the location of windows [Figure 4]. Finally, the third phase is devoted to interior layout: the algorithm proposes a furniture arrangement based on a color code indicating the programmatic distribution of spaces, as well as on information provided by the user regarding partitions and openings [Figure 5]. These three stages are grounded in a close interaction between human and machine, considered fundamental to the design of the *ArchiGAN* program. Each phase requires approximately sixteen hours of algorithmic computation [36]. While the initial training sessions yield imprecise results, the AI succeeds in developing a genuine form of architectural "intuition" after approximately 250 iterations [22].

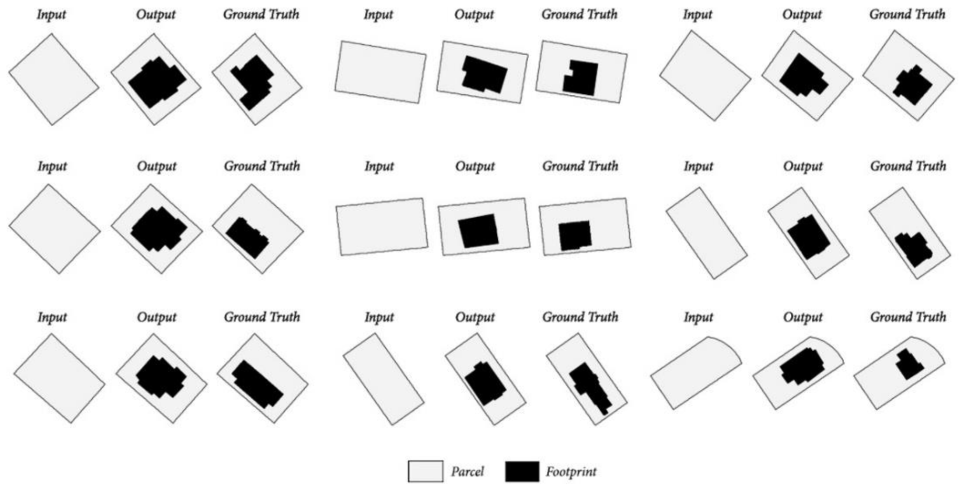

Figure 4: First phase of the *ArchiGAN* program

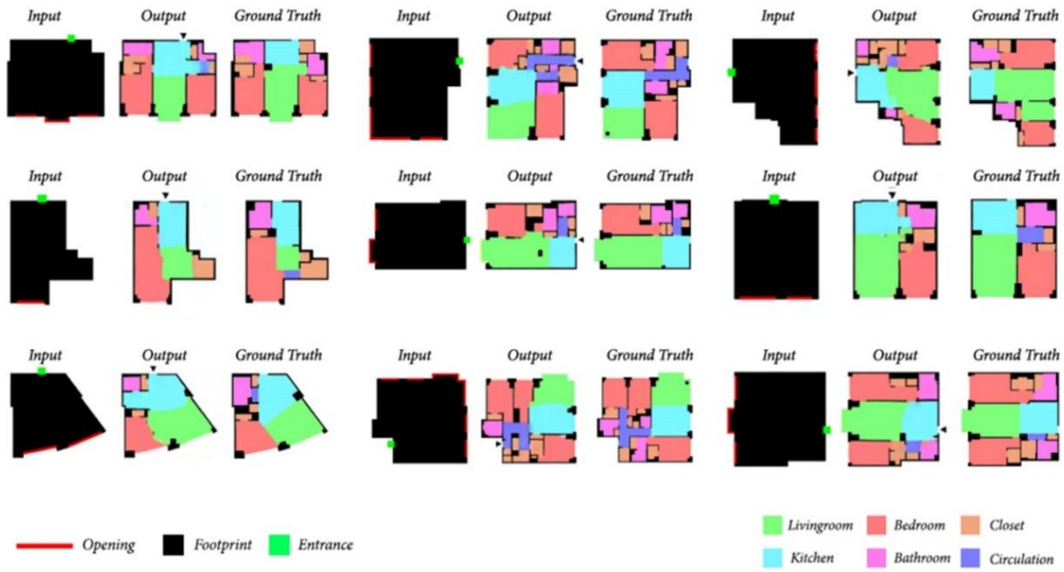

Figure 4: Second phase of the *ArchiGAN* program.

Figure 5: Third phase of the *ArchiGAN* program.

Another significant aspect of the *ArchiGAN* program concerns the transfer between different architectural styles. From this perspective, Stanislas Chaillou explores how the deep learning process of the Pix2Pix model can generate plans adapted to four different American styles: Baroque, row housing, the Victorian country house, and the Manhattan-style housing unit [Figure 6]. At the end of the training process, the AI is able to assimilate the geometric logic specific to each of these styles, revealing, according to the author, a set of functional rules defining their particular spatial organization [22]. The generated plans thus illustrate different layout configurations depending on the style selected by the user. To further investigate this process, Chaillou designs an experimental pipeline allowing the visualization of the transfer from one style to another [Figure 7]. This device demonstrates that the transformation performed by the algorithm goes far beyond mere graphic styling: it affects the internal structure of the plan itself [ibid.]. In this sense, training on different architectural styles endows *ArchiGAN* with the capacity to function as a critical "mirror," revealing the historical mechanisms of architecture and inviting them to be reconsidered [ibid.].

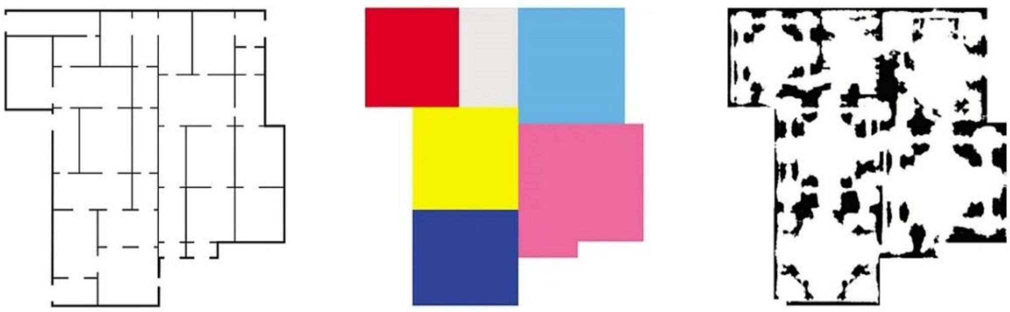

Figure 6: Style transfer generated by the *ArchiGAN* program.

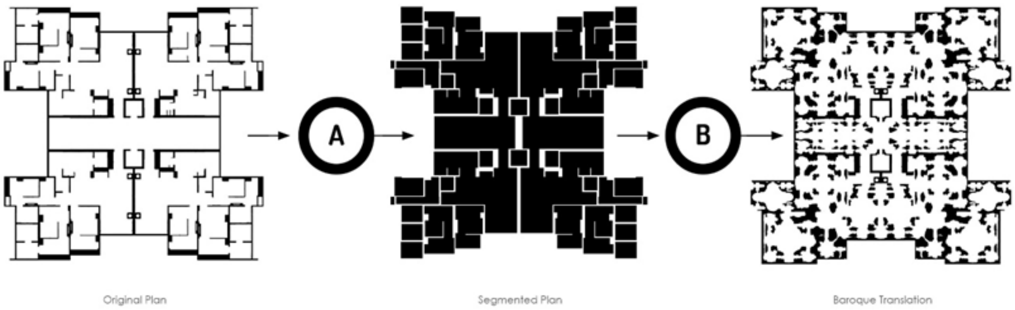

Figure 7: Style Transfer Process.

In order to refine the solutions generated by the artificial intelligence program and make them more engaging for the user, Stanislas Chaillou defines a set of metrics. These are presented in the third chapter of his thesis, which he refers to as the “Qualify.” These metrics allow the user to avoid any confusion during navigation by offering the possibility to filter, explore, and compare the plans generated by the machine. They are represented as search trees: the solution currently being consulted occupies the center, while its variants unfold along the neighboring branches. Through these metrics, Chaillou seeks not only to reinforce the “generative” character of the tool, within a “gray box” logic, but also to establish a flexible dialogue between humans and machines.

The first metric, referred to as “footprint,” relates to the outline of the generated plan. It consists in analyzing the shape of the perimeter and translating it into a histogram in order to facilitate comparison between multiple solutions and to inform the user’s choice. The second metric, the “program,” defines the internal organization of the plan according to the uses assigned to the spaces. The various functions are distinguished by color codes and represented in the form of bands, allowing their distribution to be immediately grasped. The third metric, “orientation,” focuses on the arrangement of interior spaces and, in particular, on the placement of openings in relation to natural light. For each plan, Chaillou provides an orientation diagram that enables comparison. The fourth metric, designated as “thickness and texture,” concerns walls and partitions, which the author refers to as the “fat of the plan” [ibid.]. It visualizes the thickness and geometry of walls and highlights stylistic differences: a Baroque building, characterized by thick and irregular walls, produces a graphically dense and crenellated plan, whereas a modernist architecture in the manner of Mies van der Rohe is distinguished by thin, rectilinear partitions. Thickness histograms complement this analysis by offering an intuitive visualization. The fifth metric, “connectivity,” addresses the relationships between the different spaces and is represented by an adjacency matrix documenting the connections between rooms. Finally, the sixth and last metric, “circulation,” examines the organization of movement flows within the plan. It is represented by a wireframe diagram or “skeleton,” which can then be related to other similar diagrams.

A significant lecture by Stanislas Chaillou, published on the Dailymotion platform in 2020, presents several film sequences illustrating the functioning of *ArchiGAN*. It was delivered within the framework of the exhibition *Artificial Intelligence and Architecture*, held at the Pavillon de l’Arsenal in Paris in February and March 2020. From the eighth minute onward, Chaillou’s presentation shows a series of machine-generated images projected in accelerated motion: a training sequence of chromatically coded architectural plans evolving from the crudest to the most elaborate [Figure 8]. The earliest iterations are limited to very simple abstractions, composed of one or two colors, insufficient to be interpreted as actual plans. Over the course of training, however, the models gain in precision, develop chromatic nuance, and begin to evoke architectural forms—“forms of intuition capable of assisting the architect” [36], “estimates,” or “suggestions intended to feed the design process” [37].

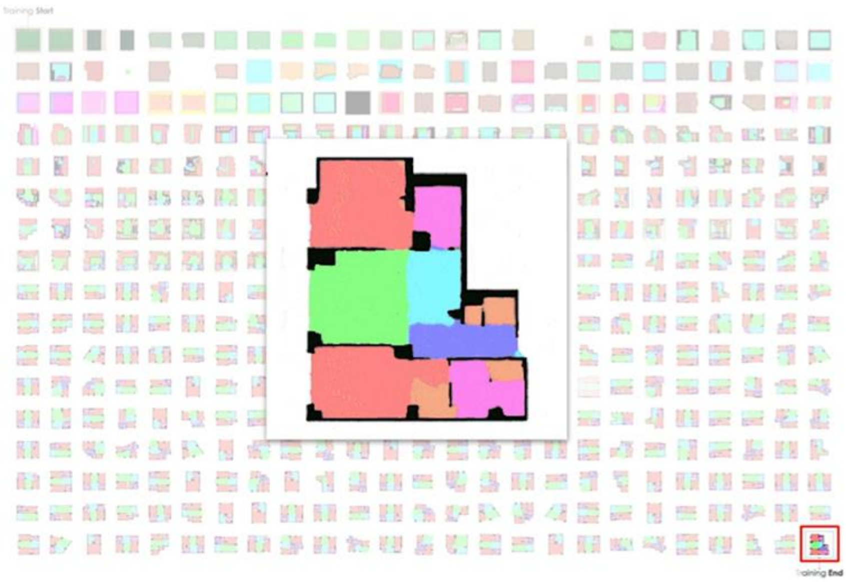

Figure 8: Training of the *ArchiGAN* program.

A second sequence, visible from the eleventh minute and fifty seconds, illustrates the metamorphosis of four distinct footprint prototypes (rectangular, circular, complex), whose interior layouts become increasingly precise and refined as training progresses [Figure 9]. A third sequence, accessible from the twelfth minute and thirty seconds, translates this logic of transformation into a chromatic animation referring to the notion of functional program [Figure 10]. Although these first three videos demonstrate the potential of generative AI in supporting architectural practice, they do not yet stage a genuine human–machine interaction. It is only from the fourth sequence, visible from the thirteenth minute and ten seconds onward, that an interactive interface of the *ArchiGAN* program appears: by drawing the shape of the plan as well as the position of the main entrance and windows, the user instantly obtains, with a single click, a possible spatial distribution, enriched by a chromatic coding indicating the functions of the apartment and its furniture [Figure 11].

Figures 9 & 10: Generation of different building footprint shapes.

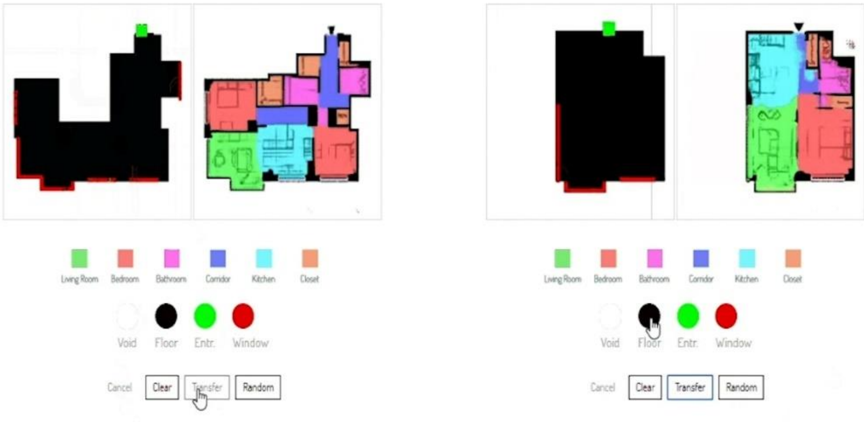

Figure 11: Human–Machine Interaction

Although the strength of the *ArchiGAN* program lies in its degree of architectural imagination and its ease of use, it nevertheless presents several limitations that open up perspectives for future research. On the one hand, the automatic generation of floor plans requires high-performance computing hardware as well as a substantial training time, factors that must be integrated into the design process. On the other hand, this generation does not take into account the continuity of load-bearing elements, which is nevertheless essential to architectural design. Furthermore, the graphical rendering of the produced solutions, based on the Pix2Pix model, remains of limited quality, generating blurred details, particularly in interior layouts. Finally, the raster format of the renderings does not lend itself to direct use by designers, who are generally accustomed to working with vector-based drawing tools.

***Deep Himmelb(l)au* by Coop Himmelb(l)au**

Emerging in the wake of Viennese Actionism, Coop Himmelb(l)au is an architectural firm founded in 1968 by Wolf Prix, a Viennese architect, Helmut Swiezinsky, an architect of Polish origin, and Michael Hölzer, an Austrian architect. Wolf Prix, the firm's principal director, is an emblematic figure of Deconstructivism and an active member of several architectural institutions. Michael Hölzer and Helmut Swiezinsky remained members of the agency until 1971 and 2001 respectively. The name Coop Himmelb(l)au chosen by these architects is a German wordplay meaning "to build the sky," incorporating, among other meanings, Himmelbau, referring to "sky blue," which explains the parentheses surrounding the "l" in Blau.

Coop Himmelb(l)au achieved paradoxical recognition through its intervention on a rooftop in the Austrian capital for the design of a law office, which earned the firm an invitation to the landmark exhibition Deconstructivist Architecture organized at the Museum of Modern Art in New York in 1988. This exhibition brought together a small group of architects described as "deconstructivists," who sought to produce buildings capable of establishing a critical distance between architecture and the meanings inherent to it. Another spectacular project is Open House, designed for an elderly Austrian psychoanalyst who wished to spend his final years in Malibu, California. It is noteworthy that the first sketch of this house was produced with closed eyes, hand-drawn "like a seismograph" [38], recalling certain forms of automatic drawing practiced by Dadaists and Surrealists during the 1920s and 1930s [39]. The unsettling imbalance of the spaces in this house generates a sensation of slipping, instability, and dramatization that "causes the relationship to reality to implode in the name of heterotopia" [40]. Working in a "state of semi-consciousness" [41], Coop Himmelb(l)au appears to seek to "oppose the vital function of aesthetics to the leaden dogma of profitability" [42]. Projects as daring as the East Pavilion of the Groningen Museum in the Netherlands (1994), the Seibersdorf Research Center in Austria (1995), the Media Pavilion of the Sixth Venice Architecture Biennale (1996), and more recently

BMW World, the European Central Bank in Germany, and the Musée des Confluences in France, testify to an unprecedented distortion of our habitual sensory perceptions.

The works of Coop Himmelb(l)au have consistently adopted a visionary approach that integrates computational advances and emerging technologies. For Wolf Prix, architecture must open itself to the possibilities offered by artificial intelligence, which he regards not merely as a simple "tool," but also as a "collaborator" capable of enriching creativity [43]. This ambition nonetheless raises certain ethical concerns, particularly among critics such as Timnit Gebru, who describes AI systems as "stochastic parrots": "parrots because they repeat the [information] they were trained on; stochastic because they rely solely on probabilities" [44]. Conversely, Prix sees AI as an unknown potential, comparing it to the feathers of a dinosaur developed by nature without knowing they would one day enable flight. According to him, artificial intelligence is the tool that would allow "architects to fly" [45]. It is within this spirit of openness and exploration that *Deep Himmelb(l)au* emerged—an unprecedented research project at the intersection of architecture, professional practice, and artificial intelligence [Figure 12]. This experimental project, as its name suggests, employs deep learning techniques to teach the computer how to interpret, design, and extend the agency's creativity based on images of its past projects [46].

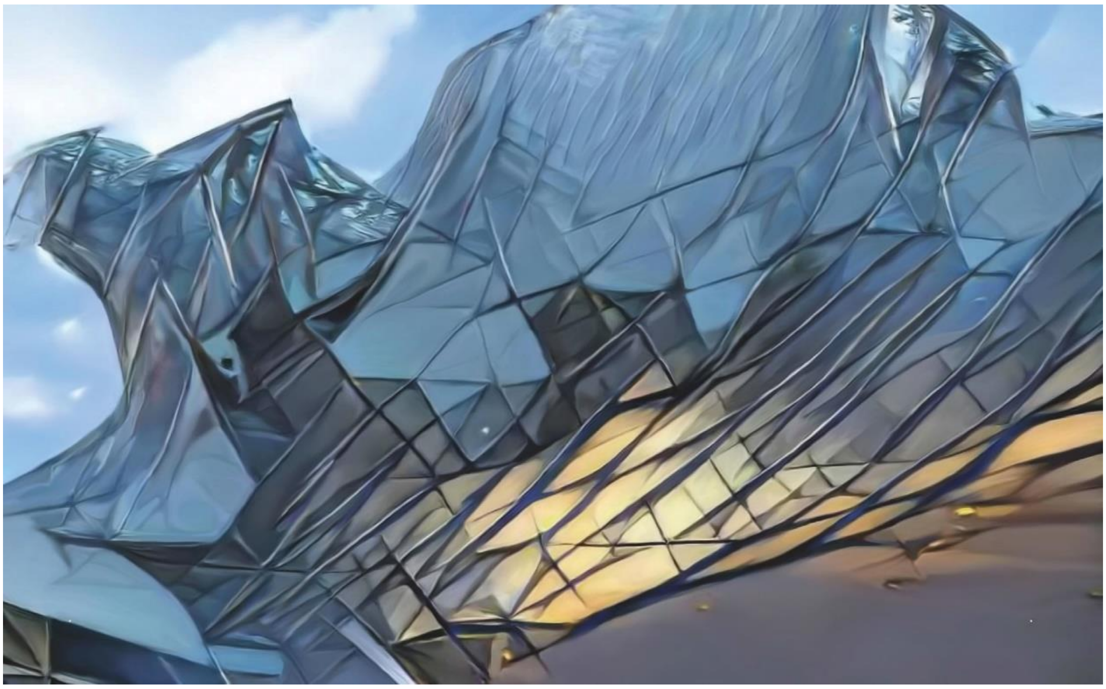

Figure 12 : Animation generated by the Deep Himmelb(l)au program.

Generative Adversarial Networks (GANs), presented in the previous chapter, constitute a subfield of artificial intelligence aimed at extracting and automatically generating knowledge from massive volumes of data projected into latent space. They draw inspiration from the functioning of the human brain, reproducing—with remarkable fidelity—its mechanisms of learning, prediction, and decision-making. Within the framework of the *Deep Himmelb(l)au* project, CycleGAN-type neural networks were primarily employed. Whereas the *ArchiGAN* project relied on the Pix2Pix model, CycleGANs were used here to generate stylized architectures, reinterpreting and extending the distinctive aesthetic of the Coop Himmelb(l)au firm. This process enabled the production of striking visualizations, merging the agency's architectural identity with the creative potential of generative algorithms.

The generative networks employed in *Deep Himmelb(l)au* follow an operational cycle similar to that of the *ArchiGAN* project, but are based this time on a corpus of images drawn from the agency's previous projects, spanning nearly fifty years of production and preserved in both analog and digital archives [Ibid.]. These archives include hand-drawn sketches, scale models, photographs, 2D drawings, 3D models, and construction details. The GANs used in *Deep Himmelb(l)au*, structured around the iterative process opposing generator and discriminator, do not merely recognize and distinguish the iconographic content of an image dataset: they also create new architectural spaces. Each network of nodes is trained to grasp the semantics of the analyzed data and the underlying compositional rules, in order to produce new images without requiring human supervision [20]. The result is not a simple replication of the agency's former projects, but rather an amalgamation—a genuine “augmentation of the design process” [47]—developed from hundreds of thousands of data points introduced into the system during training. This gives rise to a spectacular cinematic immersion within an imaginary landscape populated by hallucinatory architectural forms, reminiscent of the characteristic aesthetic of Coop Himmelb(l)au [ibid.].

Deep Himmelb(l)au is a collaborative team effort bringing together Wolf Prix and Karolin Schmidbaur on the conceptual side, Daniel Bolojan and Elfatiha Eleni Basela for the computational aspects, and Karolin Schmidbaur for the research component. This work explores the potential of GANs to produce a semantic structure intrinsic to the formal language of Coop Himmelb(l)au. It should be emphasized that *Deep Himmelb(l)au* currently represents the most advanced research in artificial intelligence applied to architecture, particularly in its ability to explore three-dimensionality through supervised learning models other than CycleGAN. Moreover, the project has been recognized by DigitalFUTURES, an architecture-focused platform that annually organizes a series of scientific activities related to the latest technologies in computational design and fabrication, including artificial intelligence.

The *Deep Himmelb(l)au* program is based on a network of nodes designed from several GAN models, themselves grounded in the dialectic between generator and discriminator. These interconnected GANs iteratively and incrementally interpret the agency’s earlier projects. They are organized around three thematic axes: Gestalt, organization, and technique [ibid.]. The first, Gestalt, addresses the formal dimension of architecture and relies on image generation. The second, organization, focuses on the functional dimension by leveraging the training of models based on plans and sections. Finally, the third, technique, addresses technological aspects, particularly in relation to environmental issues.

The *Deep Himmelb(l)au* program offers several modes of architectural generation. First, it appears as a cloud of miniaturized images, bringing together the agency’s various projects and thereby constituting a visual mapping of its latent space [Figure 13]. Certain regions of this space correspond to specific aesthetics that are easily identifiable by the user, which facilitates engagement with the program. Selecting a precise region of the cloud makes it possible to generate an animation, whether in the form of a two-dimensional representation, fixed in plans and sections, or a three-dimensional projection producing hallucinatory perspectives and volumetric simulations. In addition, the program offers the possibility of generating new variants of architectural images based on textual prompts [Figure 14]. The user enters a description, in a manner similar to *Midjourney* or *DALL-E*—popular artificial intelligences dedicated to translating textual prompts into coherent graphic representations [48]—in order to obtain building proposals corresponding to the statement, ranked according to text–image likelihood ratios. Finally, the program integrates a third component that allows the user to model physical mock-ups, digitize them, and then evaluate their environmental performance [Figure 15].

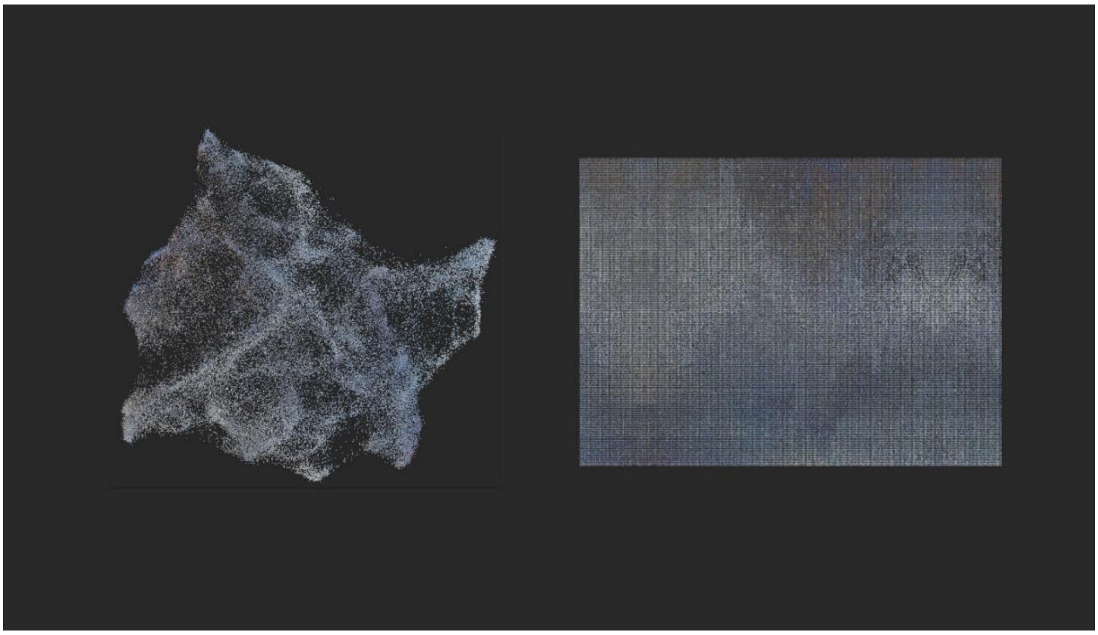

Figure 13: Latent Space of the *Deep Himmelb(l)au* Program.

Figure 14: Example of 2D Image Generations

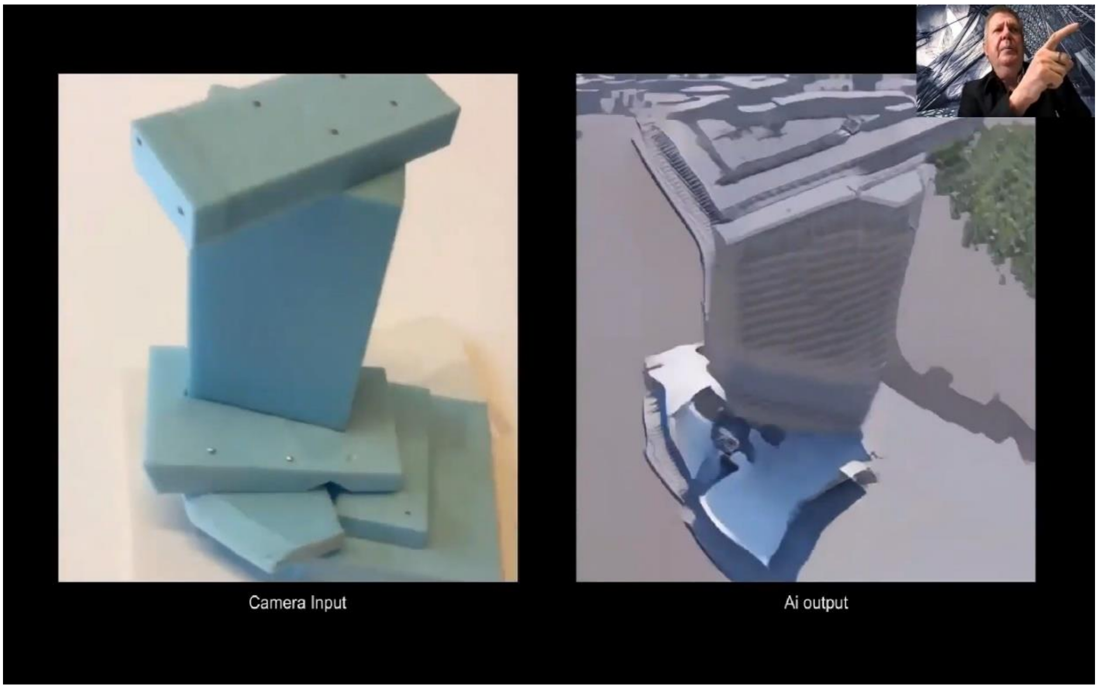

Figure 15: Generation of 3D Images

Deep Himmelb(l)au manifests itself through a series of videos disseminated online. The first—and most striking—video, with a duration of one minute and forty-seven seconds, was published on 4 June 2020 on the Vimeo platform as well as on the agency's website. It presents a 3D simulation with subtle tonal variations, immersing the viewer in a promenade around a constantly transforming building, thus generating new spatial interpretations [Figure 16]. The aesthetic of this sequence is inspired by a metaphorical entanglement of the agency's landmark projects, such as the UFA Cinema Center (Dresden, 1998), the JVC New Urban Entertainment Center (Mexico City, 2001) and BMW Welt (Munich, 2007) In this simulation, the ceiling—alternately constructed and fixed, then absent and dissolved—vanishes beneath a succession of visual superimpositions that intersect and deform, thereby altering the architectural lines of the building.

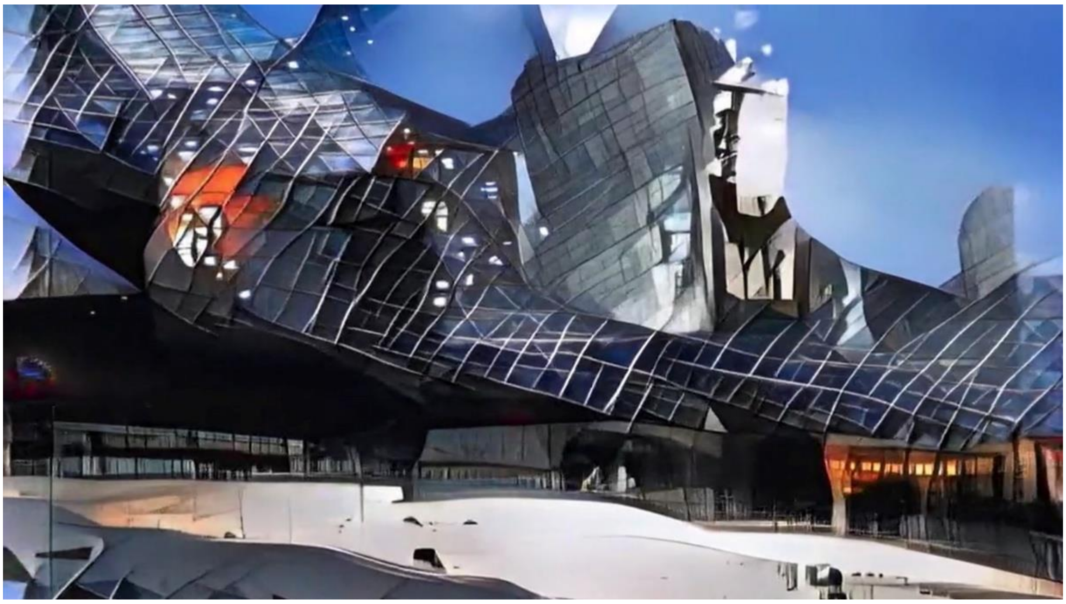

Figure 16: Image generated by the Deep Himmelb(l)au program.

The second video, approximately one minute in length and uploaded on 18 October 2019 to the agency's website and YouTube channel, proposes an accelerated trajectory around buildings with blurred contours in perpetual metamorphosis [Figure 17]. This animation appears to refer to a proposal for a port redevelopment competition in the Crimea region of Russia, a project mentioned by Wolf Prix during a videoconference in 2021. Its distorted, at times even crushed, aesthetic evokes the paintings of Francis Bacon, particularly *Portrait of Michel Leiris*. The animation also incorporates formal reminiscences of projects realized by the agency, such as the Dalian Conference Center (China, 2011), the European Central Bank (Frankfurt am Main, 2014) and the Musée des Confluences (Lyon, 2014).

Figure 17: Image generated by the Deep Himmelb(l)au program.

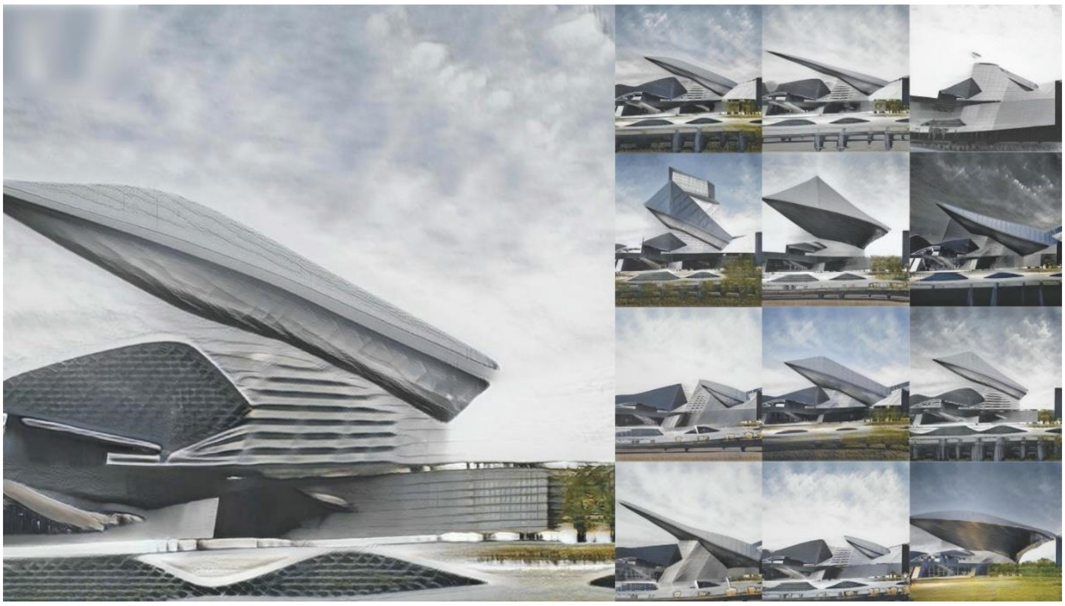

Figure 18: Image generated by the Deep Himmelb(l)au program.

The third video, lasting approximately ten seconds, appears from the fifty-ninth minute of a lecture entitled *The Project Himmelblau*, delivered at the FAU School of Architecture on 23 February 2021. It also circulates on social networks, particularly Facebook. Dating from 2021, this sequence presents the conceptualization of a convention center associated with a hotel complex, dominated by an inclined roof with exaggeratedly knotted and protruding forms [Figure 18]. This metaphorical roof—oscillating between bulging volumes and deployed surfaces—hollows and expands to evoke a domed carapace. Enhanced by sophisticated material effects, it leaves a singular impression on the observer, tinged with strangeness and even surrealism.

The programming of *Deep Himmelb(l)au* mobilizes a variety of generative adversarial network (GAN) models, enabling it to perform complex conceptual tasks. CycleGANs, which occupy a predominant role, are distinguished by their ability to establish correspondences between two different visual domains without requiring aligned image pairs [49]. They make it possible to extract, within the latent space of the AI program, the aesthetic characteristics of images previously used for training and to synthesize them, thereby generating coherent stylistic transformations. StyleGANs, for their part, offer refined multi-scale control over image style manipulation and achieve a level of realism such that it often becomes difficult to distinguish synthetic images from their real counterparts [50]. Pix2Pix models, analyzed in detail in the previous chapter, condition image generation on input data [51]. In this context, they ensure image-to-image transformation while preserving the iconographic characteristics of the source data. By combining these different models, the algorithmic approach of *Deep Himmelb(l)au* provides artificial intelligence with a significant advantage for complex tasks such as the conversion of two-dimensional spaces into three-dimensional spaces, self-learning, and the synthesis of multiple digitized représentations [52].

Deep Himmelb(l)au opens up new architectural perspectives while remaining faithful to the morphogenesis of Coop Himmelb(l)au, rather than evolving in a traditional manner from experiences and creative practices accumulated over fifty years of existence. Despite the heterogeneity of the agency's formal language, *Deep Himmelb(l)au* succeeds in creating unique works of art that are coherent with the agency's predominant style, thereby pushing the boundaries of architecture and the digital realm. These creations affect the invention of architectural aesthetics and challenge our very definition of the discipline, without fully relinquishing control of the design process to artificial intelligence [43]. AI-assisted creation, although incapable of accessing human consciousness or emotion, sometimes exceeds our own cognitive capacities, generating ethical concerns for some and leaving others in a state of skepticism.

Engaged, from its earliest works, in an “open process” receptive to technological innovation [46], the creative approach of the agency Coop Himmelb(l)au initially relied on a seismographic and intuitive sketching practice, rich in meaning and open to interpretation. With the advent of digital tools, this graphic practice—originally manual and analog—gradually gave way to parametric models, making the manipulation and control of complex geometries more accessible. Photogrammetry subsequently facilitated the measurement and reproduction of physical models, followed by the introduction of robotic arms and additive manufacturing, which broadened the scope of formal experimentation. These technologies were complemented by computer-aided manufacturing, as well as digital simulations and animations, enabling an increased temporalization of space and its representation.

In continuity with this openness to the “other”—whether technological or conceptual—the agency’s recent engagement with deep learning and artificial intelligence, as observed in the *Deep Himmelb(l)au* project, appears as a hybrid and retrospective synthesis of the technologies progressively integrated into its practice. This approach oscillates between a poietic dimension rooted in creativity and a technological dimension oriented toward computational experimentation. Since their emergence in the architectural field in the 1990s, digital tools have been embraced by Coop Himmelb(l)au not as conceptual substitutes, but as instruments of amplification, spatial optimization, and, in certain cases, automation. Within this framework, human–machine co-creation reaches a level of performance that may exceed the boundaries of human creation, giving rise to an architecture that is both oriented toward the future and deeply anchored in the agency’s own history.

Conclusions

We have explored two forms of *GANism*, that is, two approaches to architectural creation assisted by deep learning techniques based on neural networks and situated at the frontier of the digital realm. In the first case, AI instantaneously generates the interior layout of an apartment—with the possibility of stylistic transfer—based on a building footprint sketched by the user, having been trained on thousands of plan models previously embedded in its latent space. In the second case, it reinvents plans, perspectives, and 3D models in the style of the firm Coop Himmelb(l)au, relying on an archive corpus accumulated over nearly fifty years.

The work *ArchiGAN*, developed within the framework of a Master in Architecture, presents itself as a kind of digital “Aladdin’s lamp,” capable of generating and predicting furnished plans with a simple mouse click. *Deep Himmelb(l)au*, by contrast—born from a utopian exploratory initiative within a renowned international architectural practice—offers a deconstructivist, and even parametric, immersion nourished by its distinctive aesthetic language. The creativity of both projects lies in the ability of GANs to learn, interpret, and generate intuitive and unprecedented works, pushing back the boundaries of human creation—and particularly those of “digital architecture”—while simultaneously supporting architects in the design process.

Both works highlight two distinct design approaches. Stanislas Chaillou’s work, limited to the Pix2Pix model, results in a two-dimensional generation of architectural space within the framework of a fluid human–machine dialogue. Wolf D. Prix’s approach, by contrast, mobilizes a variety of collaborative GANs—including CycleGANs, StyleGANs, and Pix2Pix—to explore three-dimensionality and even generate architectures from textual prompts. In both cases, the algorithms are trained on vast banks of digitized images, mimicking certain aspects of the human brain’s behavior. They anticipate visually striking graphic outcomes by making intuitive architectural decisions and demonstrating an unsupervised visual sensitivity.

The creative challenge raised by these cases depends on numerous parameters: the size and quality of the images used for training, iconographic recognition processes, available computational power, the diversity of GAN models employed, and the quality and format of the generated outputs. Although GANism is capable of producing architectural forms that surpass human imagination, this approach remains unaware of its own capacities and continues to develop without clearly defined limits. At this stage, it appears primarily as a technology of assistance or suggestion, acting as a prosthetic extension in the service of the architect.

Artificial intelligence nonetheless opens new creative frontiers, both in physical space and in cyberspace, extending beyond our current horizons and constituting a new experimental territory increasingly embraced by architects. However, this expansion calls for minimal regulatory frameworks grounded in rules. Without such regulation, it would be illusory to anticipate the future of inhabited space solely through the lens of artificial intelligence—particularly systems of memory inspired by the human brain.

In light of the emergence of GANs, several questions remain open. What form might architecture take, and how far might its creative boundaries extend? How should the role of machine learning within the design process be regulated? Should moral and ethical rules be introduced into the knowledge transmitted to algorithms in order to guide their learning? Should their use be subject to specific permits or authorizations? Finally, what type of architecture do we wish to see emerge in this new context? These questions invite a deeper reflection on the role of GANs—and more broadly of artificial intelligence—in the future of architecture, as well as on the boundaries of the digital in the transformation of the architectural discipline.

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Data Availability

All data generated or analyzed during this study are included in this published article. Further inquiries can be directed to the corresponding authors.

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