

Philip F. Yuan · Mike Xie · Neil Leach ·
Jiawei Yao · Xiang Wang *Editors*

Architectural Intelligence

Selected Papers from the
1st International Conference
on Computational Design and Robotic
Fabrication (CDRF 2019)

 Springer

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Introduction

Introduction



Neil Leach and Philip F. Yuan

1 Introduction

A new movement is emerging. It is a movement that operates at the interface between advanced digital technologies and the built environment. It is a movement that involves some of the most talented and inspiring designers, fabricators, and theorists to have emerged in recent years. We call this new movement “*architectural intelligence*.”

But what exactly do we mean by architectural intelligence? Molly Wright Steenson has already used the term in the title of her book, *Architectural Intelligence: How Designers and Architects Created the Digital Landscape*.¹ In this historical overview, Steenson traces the contributions of four architects, Christopher Alexander, Richard Saul Wurman, Cedric Price, and Nicholas Negroponte, some of the key protagonists who helped to lay the foundations of the discourse of the digital in architecture.

This new movement, however, is not about the past. It is about the future. And it is not limited to a few individuals. It includes all those involved with the built environment. Nor is architectural intelligence limited to the digital. There are many other manifestations of architectural intelligence. Architectural intelligence is a global movement that embraces all forms of intelligence related to the design, fabrication, and use of the built environment. It straddles both practice and theory, material and

¹Molly Wright Steenson [1]. Makoto sei Watanabe has also referred to “*architectural intelligence*.” After describing a series of investigations into the potential uses of AI, Watanabe coins the term “AI Tect” to describe the role of an architect operating with AI: “Collectively they could be referred to as *architectural intelligence* (AI). The word AI Tect encompasses two meanings: *architectural intelligence and artificial intelligence*.” Makoto, Sei Watanabe, “AI Tect: Can AI Make Designs?” in Neil Leach and Philip Yuan (eds.) [2].

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immaterial, academia and the profession, and architecture and urbanism. But most importantly of all, it is a movement that straddles both east and west, north and south, bringing together some of the leading voices from across the globe.

2 Material Intelligence

There are many manifestations of architectural intelligence, and not all of them digital. Take *material intelligence*, for example. Materials belong to the realm of the material world, whereas computation itself is immaterial. A sand dune, for example, is an expression of *material intelligence*. And we must remember that alongside digital computation, there is also material computation. The sand dune “computes” its form through the interaction of wind on the particles of sand. The sand dune might look beautiful. But fundamentally its form is the result of material processes.

Indeed, any kind of morphogenesis is an expression of *material intelligence*. We can see morphogenesis at work in a soap bubble. If we were to dip a tube into liquid soap and blow through that tube, a bubble of soap film will be formed. A perfect sphere. The material “computes” its shape through a calculation based on internal and external pressures, surface tension, and so on. Frei Otto experimented with soap film to produce morphogenetic forms on which to base his designs for structures. Likewise, Antoni Gaudi famously suspended weights from strings to generate a catenary curve—the perfect form in tension that could be inverted to become the perfect structural form in compression.

Material intelligence, however, can be modeled computationally. Examples include structural engineering software, such as Ameba developed by Mike Xie or RhinoVault developed by Philippe Block illustrate.² The objective here is to simulate the structural behavior of form using digital tools so as to produce a structurally intelligent solution. We might therefore also include structural intelligence within the broader category of *architectural intelligence*.

Furthermore, architecture could also be transformed by new materials and their embedded new intelligence, such as those researched by Lyla Wu’s NEUNI Lab, or those applied in robotic printing. These new materials could draw our contemporary design discourse away from the traditional dialectics of tectonic and anti-tectonic, giving architecture a new form of production as well as a new form of *intelligence*.

²<https://ameba.xieym.com/>; <https://block.arch.ethz.ch/brg/tools/rhinovault>.

3 Swarm Intelligence

Alongside material intelligence there is *digital intelligence*.³ There are many forms of *digital intelligence*, such as *swarm intelligence*, a technique involving multi-agent systems could be understood as an early form of *artificial intelligence*.

In the book, *Swarm Intelligence: Architectures of Multi-Agent Systems*, *swarm intelligence* is described as follows: “The complex aerial choreography that unfolds through the motion of a flock of birds exemplifies the emergence of collective behavior. Underlying the coherent elegance and fluidity of the flock is a highly sophisticated form of *swarm intelligence* premised on the local interaction of individual agents that gives rise to a complex global behavior. The resultant order is not enforced from above, but emerges from the bottom-up interaction of the agents in the swarm. This model of complexity is increasingly being understood as the logic that underlies systems as diverse as flocks of birds, colonies of insects, human social networks and even the operations of a city. This distributed mode of formation has also begun to emerge as the methodological and conceptual basis for an array of generative architectural design strategies.”⁴

Within the field of architecture, *swarm intelligence* has become an important field of research. Educators, such as Alisa Andrasek, Jose Sanchez, Karl Chu, Paul Coates, Cecil Balmond, Roland Snooks, and Ed Keller, have explored the potential of using these systems to generate designs using processing and other multi-agent systems.

Swarm intelligence, however, is not only used to produce progressive designs, but it is also used to model behaviors. For example, the logic of slime mold—another aspect of *swarm intelligence*—has been used by The Living in the design of a panel for an aircraft, in collaboration with Autodesk.⁵ Likewise, in his essay in this volume Patrik Schumacher of Zaha Hadid Architects (ZHA) also explores the use of populations of “multi-agents systems” to simulate the potential behavior of occupants in buildings, with the eventual aim of informing and modifying the layout based on the simulated behavior of the agents.

Meanwhile, in his book *Emergence: The Connected Lives of Ants, Cities and Software*, Steven Johnson extends the logic of *swarm intelligence* to the entire city.⁶ For Johnson, the city operates as a dynamic, adaptive system, based on interactions with neighbors, informational feedback loops, pattern recognition, and indirect control. As John Holland notes: “Like any emergent system, the city is a pattern in time.”⁷ Moreover, like any other population composed of a large number of smaller discrete elements, such as colonies of ants, flocks of birds, networks of neurons, or even the

³*Digital Intelligence* was the title of an exhibition embracing advanced computational work by students of architecture from all over the globe. Neil Leach and Xu Weiguang (eds.) [3].

⁴Neil Leach and Roland Snooks (eds.) [4].

⁵Margaret Rhodes [5].

⁶Steve Johnson [6].

⁷John Holland, quoted in Johnson, p. 27.

global economy, it displays a bottom-up collective intelligence that is more sophisticated than the behavior of its parts. In short, the city also operates through a form of “*swarm intelligence*.”

4 Artificial Intelligence

With the development of more advanced forms of *artificial intelligence*, such as deep learning, we are witnessing something of a revolution in digital design techniques. In particular, Generative Adversarial Networks (GANs), invented by Iain Goodfellow in 2014, have opened up a new chapter in generative design. As Stanislas Chaillou comments:

‘Goodfellow’s research turns upside down the definition of AI, from an analytical tool to a generative agent. By the same token, he brings AI one step closer to architectural concerns: drawing and image production. All in all, from simple networks to GANs, a new generation of tools coupled with increasingly cheaper and accessible computational power is today positioning AI as an affordable and powerful medium.’⁸

Although GANs play a relatively insignificant role within the broader field of *artificial intelligence*, they have been responsible for opening up an extraordinary new range of possibilities for architectural design. In this volume, Chaillou himself writes about ArchiGANs, a new version of GANs that he has developed for architects. Indeed, such is the popularity of GANs, that Wanyu He, Hao Zheng, Daniel Bolojan, Matias del Campo, and Guvenc Ozel also write about them in this volume.

But *artificial intelligence* is not limited to the design of buildings. New *artificial intelligence* tools are being developed to monitor environmental conditions, such that we are seeing the increasing proliferation of *intelligent buildings*. These are buildings that rely on sensors, brains, and actuators to respond to their environmental conditions and to their users, and to optimize their environmental performance. These informational innovations extend to the individual home, where smart devices, such as the sensor driven, self-learning thermostat, NEST, have introduced energy-saving efficiencies.⁹ *Artificial intelligence* is also used for controlling temperature and humidity, monitoring sound levels, and checking the quality of water.¹⁰ We might therefore include *environmental intelligence* as a further category of intelligence. This refers not only to the research undertaken by researchers, such as Biayna Bogosian, who monitor environmental pollution levels using GIS data, AR, and drones, but also to the whole body of research into the behavior of a building within the environment.¹¹

Artificial-intelligence-based apps and technologies can be found throughout our cities. Tollbooths have been replaced by transponders and *artificial-intelligence*-based vehicle identification systems. Transportation tickets have been replaced by

⁸Stanislas Chaillou [7].

⁹<https://nest.com>.

¹⁰Anne-Sophie Garrigou [8].

¹¹<https://biaynabogosian.com/>.

digital tickets. Artificial-intelligence-based smart parking apps, such as Pixavia, have been developed that allow tracking of empty parking spaces.¹² Artificial-intelligence-based traffic apps, such as Wayz, have helped drivers to avoid traffic congestion. Social media apps can now be used to pay for taxis and other transportation services. Likewise, in some airports, facial recognition cameras have already replaced the scanning of boarding passes, while in China it is already possible to pay for goods in a supermarket using facial recognition. Alongside *intelligent buildings*, then, we need to recognize the emergence of *intelligent cities*.¹³

5 Extended Intelligence

Increasingly nowadays we are hearing references not to straightforward “*artificial intelligence*” but to “*extended intelligence*.”¹⁴ Ultimately, the issue is not about a competition between *artificial intelligence* and *human intelligence*, but rather a potential synergy between the two. We should therefore refer to “extended intelligence” [EI] whereby AI operates in tandem with *human intelligence*. As Joi Ito puts it:

“Instead of thinking about machine intelligence in terms of humans vs. machines, we should consider the system that integrates humans and machines—not artificial intelligence, but extended intelligence. Instead of trying to control or design or even understand systems, it is more important to design systems that participate as responsible, aware and robust elements of even more complex systems. And we must question and adapt our own purpose and sensibilities as designers and components of the system for a much more humble approach: Humility over Control. We could call it “participant design”—design of systems as and by participants—that is more akin to the increase of a flourishing function, where flourishing is a measure of vigor and health rather than scale or power. We can measure the ability for systems to adapt creatively, as well as their resilience and their ability to use resources in an interesting way.”¹⁵

There is no question that AI will have an enormous impact on architectural design, just as it will on almost every profession and discipline. However, we need to view AI not as an end in itself, but as a potential tool to enhance the capacities of human beings—a prosthetic extension to the human imagination. As such, AI can be understood as *augmenting the intelligence* of human beings.

¹²<https://www.parking-net.com/parking-news/pixavia/artificial-intelligence-smart-parking>.

¹³Alibaba has developed its City Brain Lab as part of the logic of *intelligent cities*. It claims that this now allows ambulances to arrive at their destination 7 min earlier on average, customers to check in and out of hotels in 30 s, and drivers to pass through any pay station in an average time of 2.7 s. Blog Post, “City Brain Now in 23 Cities in Asia,” *Alibaba Cloud Blog*, October 28, 2019, https://www.alibabacloud.com/blog/city-brain-now-in-23-cities-in-asia_595479.

¹⁴Anant Jhingran refers to a similar concept, “intelligence augmentation” [IA]. He notes, “AI makes machines autonomous and detached from humans; IA, in on the other hand, puts humans in control and leverages computing power to amplify our capabilities” Jhingran, Anant [9].

¹⁵Joiichi Ito [10].

6 Cyborg Intelligence

Andy Clark and David Chalmers take this even further, and claim that a tool can even become part of our “extended mind.”¹⁶ Indeed, it could be argued that we are all already cyborgs.¹⁷ Forget the romanticized notion of the cyborg—half human, half robot—that we see in the movies. A cyborg is simply a creature that depends on some technological device that serves as a prosthesis to its bodily operations. An ordinary walking stick is a prosthesis. But our increasing reliance on sophisticated digital prostheses—from cell phones, tablets, and laptops to robotic arms—is making us ever more cyborg-like.¹⁸ We have absorbed these external technological devices, so that they have become part of who we are. Indeed human beings are natural born cyborgs, as Clark has observed.¹⁹ For the human brain, as has often been observed, is plastic. It is constantly adapting to new tasks and challenges. And it is precisely our capacity to adapt quickly to new tools that allows us to become so cyborg-like.

Robotic fabrication, then, can be understood within the logic of the cyborg as a form of *cyborg intelligence*. With industrial robots as the revolutionary construction platform in the digital era, the architectural profession is experiencing a significant paradigm shift from traditional crafts and industrial reproduction to a new human–machine collaboration. Indeed, all robotic fabrication tools are an extension of the operations of the fabricator. As such, it is not as though we should make a distinction between manual craftsmanship and digital fabrication. Rather the whole of robotic fabrication can be understood as a form of cyborg craftsmanship. If, as Alberti claimed, “The workman is a tool in the hand of the architect,” so too the robotic arm is a tool in the hand of the architect, a cyborg-like extension to the architectural imagination.²⁰ We could therefore refer to the intelligent use of robotic fabrication technologies as *robotic intelligence*.²¹

Meanwhile, the new human–machine collaboration challenges traditional design authorship and questions the concept of creativity within the cycle of architectural design and construction. Through the reciprocal feedback loop between cloud computing and robotic fabrication, the building industry is beginning to exhibit a mode of collective production. The shared knowledge and new found creativity afforded by the robotic platform encourage a form of collective contribution. Through

¹⁶Clark, Andy, and David J. Chalmers [11].

¹⁷Amber Case, We Are All Cyborgs Now, *TEDWomen*, https://www.ted.com/talks/amber_case_we_are_all_cyborgs_now?language=en (2010, accessed 21 September 2019).

¹⁸Good design helps. It is easier to absorb an elegantly design device than an ugly one. And so too does ease of operation. Indeed it is interesting how intuitive gestures—swiping, clicking, cutting, and pasting—as part of the operations of our devices. For the role of design in assimilation, see Neil Leach, *Camouflage*, Camb., MA: MIT Press, 2006.

¹⁹Clark, Andy [12].

²⁰L B Alberti [13].

²¹In some cases, *robotic intelligence* employs *artificial intelligence* itself, such as AI Build in London, a company that employs AI to control their 3D printing technologies <https://ai-build.com/>.

open-ended mass production and mass customization, the built environment is developing its own distinctive processes of growth and reforming, as the collective creativity of various participants interacts in both the virtual and spatial dimensions to reach a new human-to-human collaboration.

7 The Future of Artificial Intelligence

In 2002, Bill Gates predicted that the first decade of the third millennium would be known as “The Digital Decade” in that, by the time that it comes to an end, the impact of the digital realm will have been so far-reaching that there will scarcely be any facet of human existence which will remain untouched by it.”²² Gates’s prediction proved largely correct.

In 2010, I predicted that we would not be using the term “digital” any more.²³ This would not be because we would stop using the digital, but for precisely the opposite reason. Almost everyone would be using the digital. For this very reason, the term itself would simply disappear. “Digital design” would simply become “design.”

To a large extent, then, this prediction has also proved correct. Just look at the way that we refer to drawings. Initially, when digital drawings first arrived, and when most drawings were hand drawings, we would simply call hand drawings “drawings,” and would call computationally drawn drawings “digital drawings.” These days, however, the term “drawings” is more or less synonymous with digital drawings, to the point that if we wish to refer to drawings drawn by hand we need to specify them as “hand drawings.”²⁴

What, then, will we call artificial intelligence in the future?

As *artificial intelligence* becomes more and more present, and begins to eclipse *human intelligence*, the logical step would be to reject the distinction between “*human intelligence*” and “*artificial intelligence*,” and refer instead simply to “*intelligence*.”

The irony here is that when John McCarthy originally coined the term “*artificial intelligence*” at the famous Dartmouth Conference back in 1956, he and others did not

²²Neil Leach [14].

²³“My own prediction is that by 2020 we won’t even use the word ‘computation’ because it will be everywhere.” On this see “Interview” in Leach, Xu Weiguo (eds.) [15].

²⁴Or take the example of the car. In the early days of cars, a carriage drawn by horses would simply be called “a carriage,” whereas it was necessary to specify a car—in other words, a carriage not drawn by horses—as a “horseless carriage.” Now it is automatically assumed that a car is the dominant form of transportation to the point that if we refer to a carriage drawn by horses we now have to specify “a horse drawn carriage.” By extension, we could imagine that once self-driving cars are introduced, we might likewise reach a threshold moment when the number of self-driving cars exceeds that of cars driven by humans. As such, another phase transition will be reached, whereby self-driving cars will simply be known as “cars” and what we now call “cars” will be known as “cars driven by humans” or perhaps “hand-driven cars.”

really like the term, as the goal was to achieve *genuine*—rather than *artificial*—*intelligence*.²⁵ But it appeared to be their only option, so they stuck with it. Interestingly, many of the central figures in *artificial intelligence* are more interested in how the brain works than in developing artificial intelligence itself. In 1946, Alan Turing, before the term *artificial intelligence* had even been invented, Turing confessed: “I am more interested in producing models of the action of the brain, than in the practical applications of computing.”²⁶

Interestingly, Geoffrey Hinton, another luminary within the world of *artificial intelligence*, initially studied physiology: “I wanted to know how the brain worked.”²⁷ Likewise, Demis Hassabis, who has a PhD in neuroscience and is CEO of the artificial intelligence company, DeepMind, does not refer to *artificial intelligence*, but simply to “*intelligent systems*”: “Our ambition in DeepMind is to build *intelligent systems* to help find solutions that can learn to solve any complex problem... Put another way, we want to use it to solve everything else.”²⁸

Soon, we can predict, *artificial intelligence* will simply become intelligence.²⁹

8 The Future of Architectural Intelligence

What then will be the future of *architectural intelligence*?

Architectural intelligence has established an agenda that looks set to influence the future of the discipline for some time to come. It demarcates what is essentially a whole new approach to architectural design and fabrication. In effect it charts out a new domain where architectural production is being informed increasingly by the introduction of *intelligent* modes of operating. These intelligent ways of operating are not intended to replace human operations, but rather to augment and supplement them. In fact, just as the invention of artificial intelligence was originally meant to form a symbiosis with human beings, so should architectural intelligence as well.

But—looking further into the future—what will happen as *architectural intelligence* grows in popularity and becomes persuasive, so that every architectural system becomes intelligent? Surely, at that stage, the whole “*architectural intelligence*” movement will have canceled itself out. It will have become so universal that it would not mean much any more. At that point, surely, *architectural intelligence* will simply become “*architecture*.” In the future, all architecture will be *intelligent*.

²⁵N J Nielson [16].

²⁶Alan Turing, Letter to William Ashby, 1946. The W. Ross Ashby Archive. <https://www.rossashby.info/letters/turing.html>.

²⁷Geoffrey Hinton interviewed by Martin Ford, in Martin Ford [17].

²⁸Demis Hassabis and Fan Hui [18].

²⁹Indeed, we might need to introduce a new category “*human intelligence*” to refer to the lower level form of intelligence of human beings.

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Rethinking Intelligence

What About Humans? Artificial Intelligence in Architecture



Antoine Picon

Abstract Artificial intelligence is about to reshape the architectural discipline. After discussing the relations between artificial intelligence and the broader question of automation in architecture, this article focuses on the future of the interaction between humans and intelligent machines. The way machines will understand architecture may be very different from the reading of humans. Since the Renaissance, the architectural discipline has defined itself as a conversation between different stakeholders, the designer, but also the clients and the artisans in charge of the realization of projects. How can this conversation be adapted to the rise of intelligent machines? Such a question is not only a matter of design effectiveness. It is inseparable from expressive and artistic issues. Just like the fascination of modernist architecture for industrialization was intimately linked to the quest for a new poetics of the discipline, our contemporary interest for artificial intelligence has to do with questions regarding the creative core of the architectural discipline.

Keywords Automation · Artificial intelligence in architecture · Human–machine interaction

Envisaged from a humanist perspective on architecture, the main problem raised by the introduction of artificial intelligence in the design process has to do with the roles that the humans will play in a few decades from now in this process. What if artificial intelligence was soon to become a pervasive reality in architecture? What type of agency would humans retain once computers have taken over many tasks that they still carry out today?

Before addressing this question, let me begin by an apparently naïve question. Why is it that we want so much to automate not only fabrication but also large

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parts of the design process itself? Why is it that we are gradually passing from a discourse on robots to a discourse on artificial intelligence in architecture? After all, one could wonder whether automation will truly happen in our field. Human labor comes still cheap compared to the machinery needed if we want to automate significantly the building industry. This is even truer of the design process. Young architects are not that expensive compared to the sophisticated machines that would be needed to replace them. Starting from this question will allow me to unpack a number of dimensions not currently discussed in the field of digital architecture.

1 Automation, from Myth to Reality

The truth is that automation is not an entirely rational enterprise. It is all the more unavoidable that it is rooted in something that extends deeper than rational calculation, something that has to do with the recognition that there are forces in the world that go far beyond the usual factors that shape our ordinary actions and productions. How to be plugged into these forces was a question that the Surrealists had tried to raise through their practice of “*écriture automatique*,” automatic writing.

The reason I am mentioning the Surrealists is not only because of their use of the notion of automatic writing and more generally automatic creation as a way to go beyond ordinary artistic production in order to tap into more fundamental forces such as those that move the unconscious. Among their disciples was a young intellectual who was later to become one of the major Post-War French sociologists, Pierre Naville. Naville worked on automation in the industry. But while doing empirical work on what was happening on workshops floors, he remained sensitive to the lesson that the Surrealists had taught him.

He famously declared in an influential essay entitled *Vers l'Automatisme Social, Towards Social Automatism*, published in the early 1960s: “I am not far to believe, despite the violent rejections that it often provokes, that automatism represents an archetype as ancient and radical as our sense of symmetry or cycle, that it touches something intimate in us, a vibrant chord of our creative power, that it has to do with enchantment, with our will to power, and many other impulses that moves us, starting from our unconscious” [1].

For Naville, automation was ultimately about this general pursuit of automatism as an archetype. It had to do with the quest for a spontaneity usually reserved to natural phenomena and beings. It was an attempt to make nature do, by itself, through machines harnessing its power, what humans wanted it to do. It appeared as a Promethean quest that could never be fully satisfied by our technology, as sophisticated as it could be, for it possessed a foundational and even mythical character.

Envisaged from this point of view, automation corresponds to something far more fundamental than the ambition to improve efficiency. It has to do with the desire to create something that can rival nature, living beings in particular. Another way to put it is to say that automation has to do with the desire to animate matter, to surround



Fig. 1 William Blake, Elohim Creating Adam, circa 1805

oneself with artificial creatures that seem endowed with something akin with life. There are multiple legends and works of fiction that illustrate the enduring character of this theme, think of Pygmalion, the Golem, or Frankenstein (Fig. 1).

From the start, robots were inheritors of this tradition. Like their mythical predecessors, they were situated on the fringe where the distinction between the natural and the artificial becomes blurred. Published in the 1880s novel by the Symbolist French writer Auguste Villiers de l'Isle Adam, *L'Ève Future*, *The Future Eve*, is characteristic of this blurring. The artificial woman featured in the novel gradually awakes to a life very similar to the human one. Similarly, in Fritz Lang's *Metropolis* the robot seems endowed with a vibrant life that allows her to impersonate a human. The question of the relation between robots and life has of course known a new development with artificial intelligence and deep learning, but our fears of an artificial form of life challenging our alleged superiority as "real" human beings has remained unchanged. In many fictions, beginning with *Metropolis*, robots seem endowed with almost diabolical powers.

The potentially diabolical dimension of robots offers a convenient transition toward a fundamental aspect of animation: its ambiguous, transgressive, and finally potentially sinful character. For, at least in the Western tradition, it is only God or the gods who can animate. This is what God does when he creates man and woman



Fig. 2 Animated Modernism: The La Tourette priory by Le Corbusier completed in 1961

in the Genesis. For humans to animate appears as a transgression that can easily lead to catastrophe. Think of the series of unfortunate events that follow the animation of the Golem or Frankenstein.

Let me now turn to architecture. The discipline has a both intimate and complex relation to the question of animation. On the one hand, it tries to animate matter so that it can address humans, as if it was about to speak. This expressive power was traditionally entrusted to ornament. But ornament was not alone to fulfill this function. Composition played also a role in the capacity of architecture to address humans, to enter in relation with them akin to a sort of dialog. On the other hand, animation has to be incomplete; otherwise, it appeared as transgressive (Fig. 2).¹

For a very long time, architecture had to do with animation, but its animation left almost entirely aside the question of automatism and automation. The discipline was in quest of an immobile animation. It was very different in that respect from other domains, from technology in particular with its multiple machines in motion.

Now, it is striking to observe how what has happened in the past decade or two can be characterized as a dramatic shift in the relations in between architecture and animation. With the rise of digital culture and the extended use of computers and robots in architecture, animation has become inseparable from the question of automation. Following what I said earlier, such a transformation can be interpreted not only as a technological revolution but also as a reactivation of powerful mythical

¹On animation in architecture, see Spyros Papapetros, *On the Animation of the Inorganic: Art, Architecture, and the Extension of Life* (Chicago: The University of Chicago Press, 2012), Antoine Picon, *La Matérialité de l'Architecture* (Marseille: Parenthèses, 2018).



Fig. 3 Fabio Gramazio and Matthias Kohler, robotic arm in operation, 2008

forces. This mythical character explains probably why the relation between automation and architecture is complex and even contradictory. Part of the power of myths lies in their capacity to host contradictory dimensions, just like dreams (Fig. 3).

Automation in architecture is an unfolding process. So far, the most salient phenomenon has been the development of digital fabrication with laser cutters, milling machines, 3-D printers, and, of course, robots. With their multiplication, one has observed the rise of interrogations regarding the possibility to automate entirely the construction process, just like what has happened in the automobile industry.

At this stage, it is possible to go even further and imagine that we could very well be on the eve on a new wave of automation, the automation of design tasks proper with the rise of artificial intelligence. This is what I will mostly discuss in the rest of this article.

2 Big Data, Machine Learning, and Architectural Conversation

Under what condition is the development and use of artificial intelligence possible in architecture, in the design process in particular? Let me begin by evoking some of the basic conditions that will need to be fulfilled in order to have truly intelligent machines.

The first condition is to have gathered sufficiently large quantity of data enabling machines to learn from precedents in architecture, landscape architecture, urban design, and urban planning. A number of designers are currently exploring what this perspective may entail concretely. At Harvard Graduate School of Design, Andrew Witt is among them. His researches on the possible use of big data are emblematic of the issues raised by the development of big data related to buildings, landscapes, and cities.²

In architecture, if machines ingest large enough databases of types, tectonic details, and ornaments, one may reasonably suppose that they will be able to produce designs of their own. What will these design look like? They may combine elements that we don't usually associate, such as Baroque compositions and modernist details, for instance.

Should this scenario become true, two questions would immediately arise. First, will we be able to understand how machines reason? It is not only a matter of being able to picture how algorithms actually function. The elements on which the machine base itself may differ profoundly from ours. Where we see floors, walls, ceilings, and roofs, the machine may choose a different way to organize its reading of buildings. Among humans, there are already differences between the way buildings are understood because of linguistic nuances and technological variations. The French word "poutre" corresponds, for instance, both to the English terms beam and truss, which means that entities that are of the same nature for French builders belong to distinct categories for their English-speaking counterparts. Think of how disconcerting the elements of construction produced by machine deep learning could be from what humans ordinarily recognized as the fundamental components of the building industry. We are already observing significant differences between the way they tend to see cities from a radical perspective than ours. They tend to observe, for instance, clouds of data or rather traces of geolocated events that have become big data after being recorded (Fig. 4).

Surely, the distance between our intuitive grasp of objects and phenomena and methods following entirely different premisses predates the invention of the computer. The diffusion of calculus during the eighteenth century was accompanied by a very similar interrogation on the relevance of the new mathematics pioneered by Newton and Leibniz since they were so far away from the geometric reasoning that had dominated since ancient times. What took place upon the course of a few decades was a dramatic realignment of human intuition, which enabled scientists and engineers to build coherent and above all operative mental images of how calculus did actually operate.

Will humans be able to produce similar mental images enabling a better understanding of machine procedures of deep learning? Theorist and historian Mario Carpo doubt it [2]. Contrary to him, I personally believe that this be the case for specialized professionals of code, the contemporary equivalent of early-19th scientists and engineers confronted with the Intricacies of Calculus, who will be able to imagine how computers operate. But since design and coding are very probably going to remain

²See the project showcased on his website, "Certain Measures," <https://certainmeasures.com/>.



Fig. 4 “Conversation” between a Buddhist monk and a robot at Longquan Temple, near Beijing

separate activities, except in some specific cases, a new question arises. Should we force machines to work with the same type of elements than those we manipulate day after day in design? Should machines be obliged to combine floors, walls, and ceilings, instead of the elements that deep learning might have led them to identify? This would make machines easier to understand, but it might be the same token deprive them of any genuine creative power. With computers following our ways to understand buildings, we will soon have machines which will be able to produce tolerably good Baroque churches of modernist villas instead of producing hard to imagine combinations of elements of an unknown nature. But is it what we really want? The building industry may not have the same hesitation. After all, it has been feeding for centuries on libraries of established types and patterns. However, this might not be the optimal way to mobilize computation in design. Kostas Terzidis has, for instance, advocated to respect the fundamental “otherness” of computers in order to fully take advantage of their creative potential [3].

Now, the previous discussion revolves around a central issue, that is, the way we will communicate in the future with machines or, to put it in a slightly different light, how to have a true architectural conversation with it. It is worth remembering at this stage that the architectural discipline is actually based on a series of conversations between architects and clients, architects and entrepreneurs, and entrepreneurs and labor, to name only a few. For the funding fathers of Italian Renaissance architecture like Leon Battista Alberti or Daniele Barbaro, this conversational character was the most fundamental aspect of the discipline [4]. From such a perspective, the main challenge raised by artificial intelligence in architecture lies in the difficulty to reach a sufficient level of understanding of machines to be able to associate them in productive manner to the conversation. This will prove extremely difficult if machines are too different from us, but forcing them to mimic us may lead to the symmetric pitfall of making them not interesting enough to deserve consideration.

3 The Automation of Design and Fabrication

At this stage, it seems plausible to assume that machines will soon be able to do more and more. It seems also plausible to assume than in most case we will force machines to consider elements and to follow rules that are somewhat similar or at least compatible with those that we have adopted in architecture and the building industry. Theorists like Karl Chu may dream of a completely alternative mode of design, but the industry will probably not be as open to this possibility.³

Until recently, one assumed that automation would impact only poorly qualified jobs. This might not be the case. Architecture will be probably among the most severely hit disciplines. The reason for this high degree of vulnerability is that architecture is among the formalized of all the arts. The mechanical part is stronger than in other domains, and hence the traditional position of the discipline on the threshold between art and technology. The very use of orders and proportions by the Vitruvian tradition seems already to be calling for automation, as Mario Carpo has convincingly argued in his essay *The Alphabet and the Algorithm* [5].

The early-19th project of Durand to codify design procedures could constitute an even clearer forerunner of the reflections on the possibility to use intelligent machines to design. British Architect Cedric Price's approach to projects like Generator seems also to announce an era of active machine involvement in design. One might be thus tempted to establish a genealogy leading from Durand to Price and from Price to contemporary machine learning.

It is almost certain that we are heading to an era of active machine involvement in design. This era had been announced by many proponents of early computer-in-architecture culture. It was, for instance, a key belief of the researchers led by Nicholas Negroponte in the Massachusetts Institute of Technology Architecture Machine Group, the ancestor of the Media Lab [6].

Retrospectively, the period during which computers and robots were mere tools will appear as a parenthesis in a long march toward a true cooperation between man and machine. Again, it is not sure that intelligent design machines will reason like humans. This means that as important as their intrinsic power to produce design solutions will be, their capacity to have a conversation with us will prove crucial. Negroponte's Architecture Machine Group had a clear vision of the necessity to be able to truly enter into a dialog with the computer. This is the reason why it gradually turned to questions of interface, thus giving birth to the Media Lab.

Intelligence will not be limited only to design proper. Construction will also be impacted. So far, robots are no more than mechanical slaves. One may imagine that they will acquire some autonomy. We might then see the emergence of disagreements between these various forms of artificial intelligence. Design could very well remain a conversation. But between whom remains undecided. Besides humans and computers, robots might have a role to play in such a conversation, especially if we

³See, for instance, Chu, Karl, "Metaphysics of genetic architecture and computation," in *Constructing a New Agenda: Architectural Theory 1993–2009* (New York: Princeton Architectural Press, 2010), 427: 431.

try to follow John Ruskin advocacy of the rights of labor to be associated to the creation of any form of collective work. Aren't they about to become the new labor force of our digital age?⁴

Before dealing with what could still remain the human responsibility in this transformation, let me say a word about some professional changes that this evolution will accelerate. Some of these changes have already intervened with the diffusion of digital tools. While thousands of books and articles have been devoted to the development of digital architecture, it is surprising to observe how little is currently written on that matter.⁵

The first striking feature of what has happened in the design profession is the consolidation of practices. Giant firms are no longer the exception. The rise of artificial intelligence in architecture may increase further this phenomenon. Indeed, it requires substantial investment in hardware and software that may not be accessible to small- and middle-sized structures.

In these extended practices, there is a risk of rapid obsolescence for designers because of the rapid evolution of a more and more demanding technological environment. Will the future of the profession concern mostly designers in their 20s and 30s, like what has happened in many sport disciplines?

Finally, one observes a profound redefinition of authorship with the rise of more collaborative and networked forms of authorships.⁶ This tendency will be accentuated by the cooperation with machines. What will mean being an author in dense networks comprising not only humans, but also computers and robots? Bruno Latour's Actor-Network Theory offers only very partial answers to this interrogation [7]. It leads to the more general question of what could remain specifically human in the future of design that I have sketched. It is not an easy question to answer. One may of course play the humanist and invoke the monopoly of humans on genuine creation. But is this attitude sustainable? We are already seeing texts written by computers, paintings produced by them. These creations are not yet brilliant, but nothing indicates that there are asymptotic limits to what machines can achieve (Fig. 5).

4 What About Humans?

What will remain specifically human in a design process suffused with artificial intelligence? The question is complicated by the fact that since we invent machines, there is something partly mechanical in the way we think. This mechanical dimension of human thought obsessed French eighteenth-century philosopher Denis Diderot, the Chief Editor of the *Encyclopédie*. It was the source of his interest for the mechanical

⁴See on this theme Antoine Picon, "Free the Robots!", *Log*, n° 36, Winter 2016, 146: 151.

⁵We have tried to address the subject in Wendy Fok, Antoine Picon, eds, *Architectural Design*, "Digital Property: Open Source Architecture," vol. 86, n° 5, 2016.

⁶For an example of a more collaborative form of authorship, see Philip F. Yuan, *Collaborative Laboratory/Works of Archi-Union and Fab-Union* (Hong Kong: Oscar Riera Publishers, 2018).



Fig. 5 Iris van Herpen with Jolan van der Wiel and Marjan Colletti, *Quaquaversal* centrepiece, Musée d'Histoire de la Médecine, Paris, 2015. A spectacular example of distributed authorship

arts to which he devoted a large part of the *Encyclopédie*. For Diderot, to describe a machine as he did with a knitting machine was synonymous with trying to address the question of what is mechanical in the human mind. Indeed, he assumed that we can design machines only insofar that we think like them [8] (Fig. 6).

If we are partly resembling machines, what is unique to what we bring to the design process? An immediate answer lies in the fact that we are still endowed with a much more generalist form of intelligence than machine. The path leading to computers able to successfully compete with the all-purpose brain that we possess is still ahead of us. But let us assume for the sake of the argument that we will be confronted to much more powerful and general forms of artificial intelligence in the near future: what could remain then the exclusive competence of humans?

Two factors must be taken into account at this stage. First, we have an embodied intelligence. Our conceptions and experiences of the body have proved eminently variable from one period and a civilization to another, but to be human is to have a body through which our brain and the awareness of who we are structure themselves. The findings of contemporary neurobiologists like Antonio Damasio tend to support this hypothesis [9]. The lack of embodiment, in the intimate sense I just referred to, represents a real limitation of robots and artificial intelligence.

Second, because we have a body, we have emotions that mix the purely physical and the mental. Memory and most of our cognitive functions blend in a very similar way the physical and the mental. Such an interaction is what produces the human relevance of objects and actions as well as this series of echoes in each other minds that we call meaning. It is telling that for a very long time, architecture was interpreted as what happened to buildings when they were able to connect with us through some

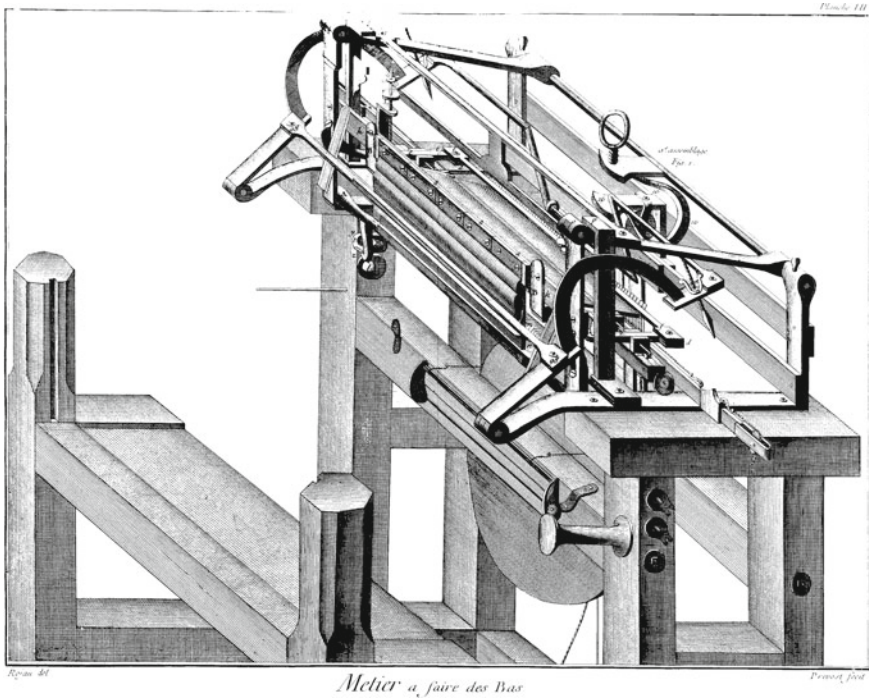


Fig. 6 Knitting machine described by Denis Diderot in the Encyclopédie

affinity with our body. The five orders of the Vitruvian tradition found, for instance, their legitimacy in the analogy between their proportions and those of the human body. More generally, the symbolic is very often connected to our body.

I would personally assign to the humans the task to decide what truly matters, to choose among a range of possible solutions produced by the machine what seems the most relevant to humans. In other words, this entails a shift from tactics to strategy, from the how to the why. This shift has already begun to happen with the diffusion of digital tools, with the rise of parametric design, in particular, that may produce and infinity of solutions. In that latter case, the real decision-making has to do with selecting what are the right questions. Again, the why seem to become more important than the how.

From this perspective, architecture becomes a question of choice, something akin to a form of action. Machines produce while humans perform, while they make choices that have to do with how the physical and the symbolic are actually co-emergent.

The interaction between the physical and the symbolic is what makes possible dwelling, or inhabiting, in the sense popularized by Martin Heidegger in his seminal text “Building Dwelling Thinking” [10]. Machines can occupy a space, but humans have the relatively unique capacity to inhabit it. Making choices about inhabiting