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Steering into the Skid

Arbitraging Human and Artificial Intelligences to Augment the Design Process

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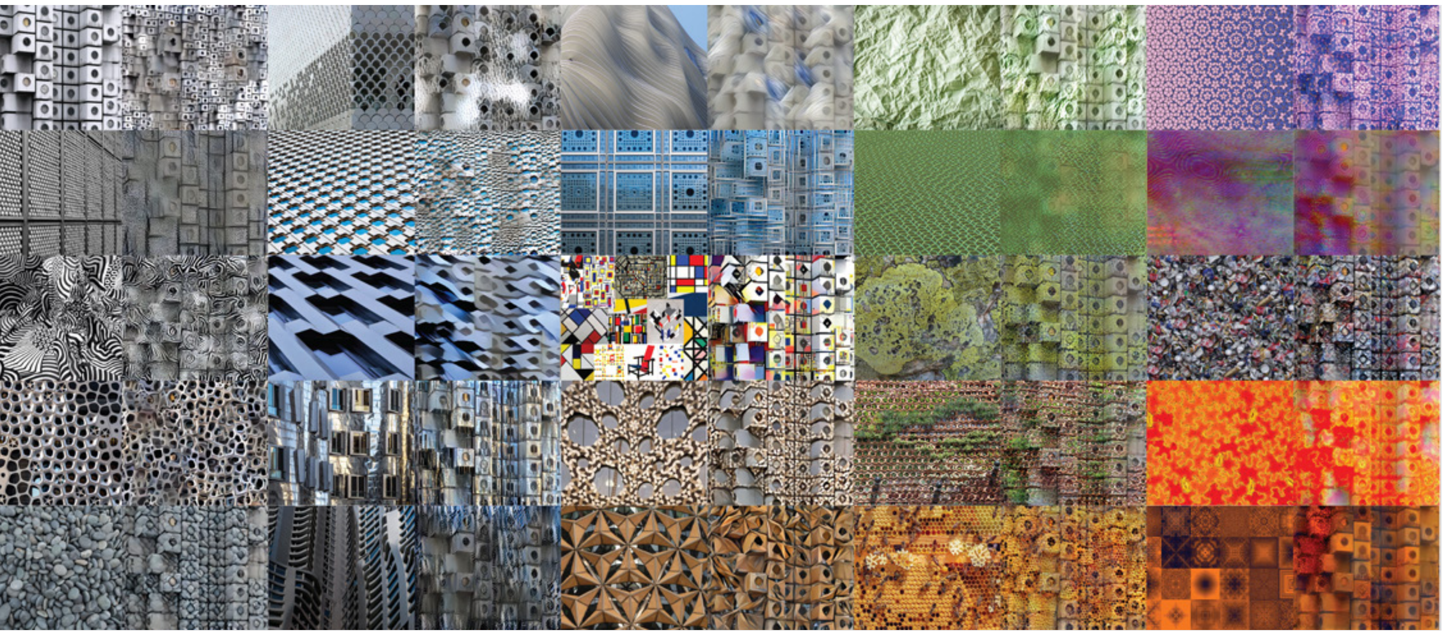

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1 AI style transfer onto Kurokawa's Nakagin Capsule Tower (shown top left). Each subsumed style requires a few minutes of human endeavor and, superficially at least, illustrates the beguiling ease with which AI tools can be co-opted for the design process.

ABSTRACT

What if any perceived risks of lost authorship and artistic control posed by a wholesale embrace of artificial intelligence by the architectural profession were instead opportunities? AI's potential to automate design has been pursued for over 50 years, yet aspirations of early researchers are not fully realized. Nonetheless, AI's advances continue to be rapid; it is an increasingly viable adjunct to architectural practice, and there are fundamental reasons for why the perceived "risks" of AI cannot be dismissed lightly.

Architects' professional role at the intersection of social issues and technology, however, may allow them to avoid the obsolescence faced by other roles. To do this, we propose architects responsively arbitrage an ever-changing gap between maturing AI and mutable social expectations—arbitrage in the sense of seeking to exercise individual judgment to negotiate between diverse considerations and capacities for mutual advantage.

Rather than feel threatened, evolving architectural practice can augment an expanded design process to generate and embed new subtleties and expectations that society may judge contemporary AI alone as being unable to achieve. Although there can be no road map to the future of AI in architecture, historical misevaluations of machines and our own human capabilities inhibit the intertwined, synergistic, and symbiotic union with AI needed to avoid a zero-sum confrontation. To act myopically, defensively, or not at all risks straitjacketing future definitions of what it means to be an architect, designer, or even a professionally unaligned creative and productive human being.

INTRODUCTION

The threat of technology to the survival of humanity, through gray goo, stray biological agents, rogue and ravenous universal constructors, and even malevolent artificial intelligence (AI) features large in science fiction. This paper responds to a more modest and perhaps more actual proposition: AI has the potential to usurp the architect's role in architectural practice. This proposition—whether made implicitly or explicitly—is of course not new. The possibility of machines to automate design has been pursued for over half a century (Burry 2020). Aspirations of early researchers such as Frazer and Gero are yet to be fully realized; nonetheless, there have incontestably been two main developments: increased ease and efficiency of modeling, drafting, and detailing; and a degree of automation in the evaluation and generation of design possibilities as options (Grobman, Yezioro, and Capeluto 2010). This paper focuses on the latter and its possible conflict with the architect's traditional creative role. It is presented as a theoretical argument motivated explicitly around architects' evolving practice.[1] It sets out first to establish a theoretical framework for AI-enabled design computing and some perceived potential risks to architectural practice, and then to analyze how architects may respond with continuing their professional relevance in mind. Our research has been informed by ongoing practical work insufficiently advanced to be reported here; in its place we refer to real-world examples where appropriate.

AGENCY IN DESIGN COMPUTING

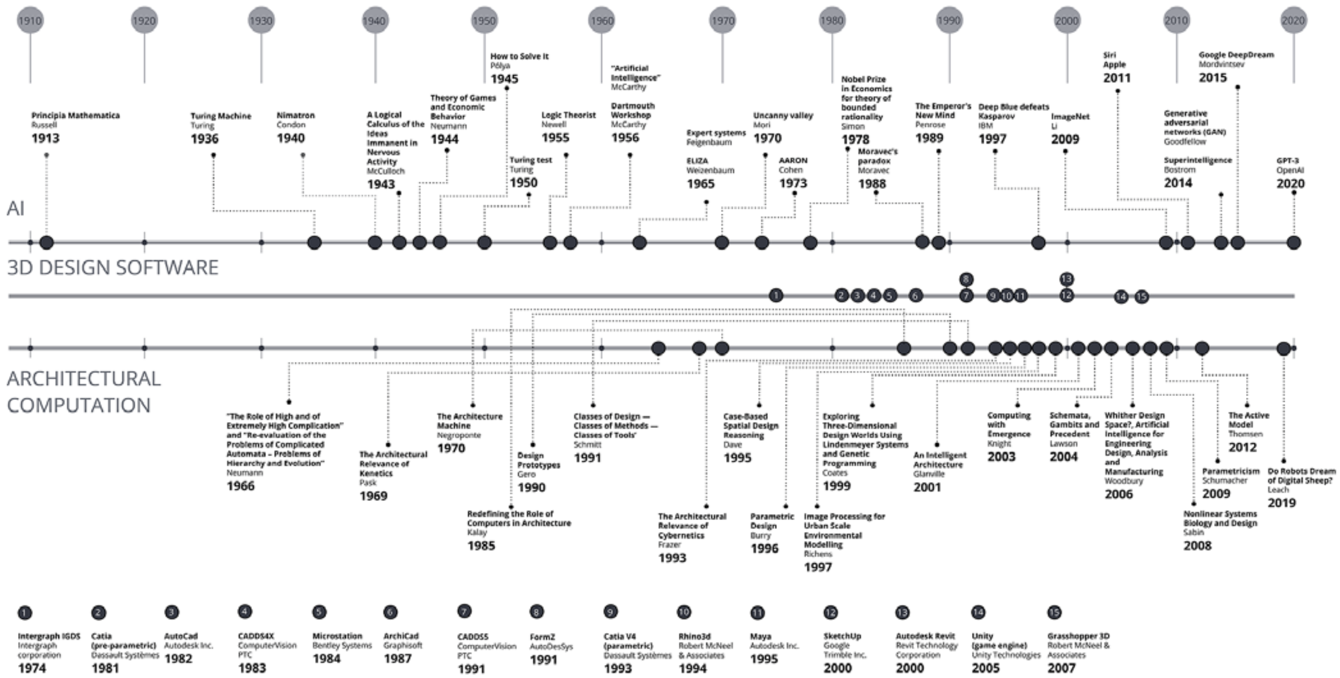
Certain datapoints in the history of design computing plot a trajectory of the machine's increasing agency. Algorithmic thinking and explicitly detailed relationships in design have existed since Moretti's 1960 exhibition of models of parametrically designed stadia, and arguably earlier, with Gaudí's evolving parametric design strategy for his final design of the Sagrada Família Basilica (1914–1926) (Frazer 2016). In itself, this approach may not seem to be a great threat to the traditional role of the architect. Its reliance on a designer formalizing "rules" of relationships is perilously close to the top-down nature of expert systems that was a contributing factor to the failures of early AI seeking to replicate those aspects of human intelligence (HI) that are not easily formulated as "if-then" statements (Haenlein and Kaplan 2019).

Cross (1999) observes that the human designer engages in an exploratory and rhetorical process as they argue for an outcome that is progressively developed against "both known goals and previously unsuspected implications." AI methods in design computing such as evolutionary computation display recursive navigation of multidimensional solution spaces, and can drive a design proposition to peaks of optimality, or at least solutions that may acceptably fit a designer's assumptions (Besserud and Cotten 2008; Carpo 2019; Dutta and Sarthak 2011). The machine in this sense of exploration may add to a search for a range of possible design outcomes, beyond any traditional notion of a singular design outcome (Leach 2018). Evolutionary computing and allied methods are still essentially directed optimization tasks; the process may determine relationships in its inner workings but the designer must still formalize rules of what is 'good'. Moreover, the bounds of the solution space are statically set to those determined by the designer and the machine does not recognize Cross's "previously unsuspected implications."[2]

Artificial neural networks (ANNs) have been in development since the 1940s but rallied in 2015 when Google's AlphaGo beat a world champion player at the intractable game of Go, and progress has subsequently been rapid (Haenlein and Kaplan 2019). The first paper on generative adversarial networks (GANs) was published by Goodfellow et al. (2014) as recently as 2014, and GANs are currently posited as one of the most promising AI technologies for design (Leach 2019). In just a year, generative-built environment design, albeit simply the composition of bedroom scenes, through use of a GAN was demonstrated (Radford, Metz, and Chintala 2015). AI is now a viable adjunct to architectural practice (Leach 2019; Watanabe 2017). In this, the architect moves into a new mode of control through providing example and precedent rather than the formal setting of relationships and bounds.

A CLOSING GAP BETWEEN AI AND THE ARCHITECT'S TRADITIONAL CREATIVE ROLE

Current AI is not superintelligence and its capabilities are still limited (Kaplan 2016). AI in the design workflow is composed of discrete, often-disconnected AI tools that are developed for specific contexts, projects, and stages, and there is still no unified "Architectural Artificial Intelligence" (AAI) (Mrosla, Koch, and von Both 2019). Given the scope and complexity of architectural practice, such an AAI may be an indispensable step to a greater autonomous role of AI in architecture (even if that step would be a threat to the architect's traditional creative role). An AAI would require near-human (or high) level AI (HLAI) capabilities. HLAI may be far off, but could be in place within the lifetimes of today's graduating architects. In a 2016 survey of AI experts asked to consider when "unaided machines can accomplish every task better and more cheaply than human workers," HLAI was given an even chance of occurring within 45 years, and a 10% chance of occurring within



2 Step changes in AI, architectural computation, and 3D design software.

9 years (Grace et al. 2018).[3] Such HLAI need be created only once; unlike a fledgling architect, an HLAI for design would be mechanically duplicable (Cassimatis 2012). A threat of AI matching HI design performance, despite the intractable nature of architectural practice, should not be dismissed by architects.

There has been a historical lag between development of AI and its adoption in architectural practice (Fig. 2). Aspirations in early and even current AI have exceeded scientific and technical capabilities (Cassimatis 2012; Haenlein and Kaplan 2019). Early visions for design computing were perhaps too ambitious and may have suffered from overreach. Perhaps architectural problems are inherently more tractable to modern AI techniques than rule-based approaches such as expert systems.[4]

Despite those historical insufficiencies of capacity and currency, AI is increasingly used in architecture. Experts see the pace of overall AI development to have accelerated in recent years (Brundage et al. 2018; Grace et al. 2018). It is notable that a 2011 RIBA survey report on the "Future for Architects" makes no mention of AI, and the respondents' greatest perceived threats to the architects' profession were judged to come from human parties (Jamieson et al. 2011). Architects are approaching a narrowing of the divide between AI and HI capabilities in architectural practice.

Where may architects be today in relation to AI? Carlopio (1988) expands Friedmann's three phases of automation to accommodate the perspective of the worker. First, dependent machines serve as labor-saving devices, yet as technology advances, these move from simply aiding us to undertaking the bulk of the work. Second, machines have become "labor-enslaving" devices: the worker now assists the machine but may derive little intellectual stimulation in the exchange. Third, machines enter a "labor-replacing" phase: the machine supplants the human in producing actual work. The human may be liberated to new levels within the organizational structures and spared hazardous, tedious, or degrading jobs; however, workers may be devalued, displaced, and undermined in their expertise. With respect to AI, contemporary architects may just be in the first phase and progressing towards the second.

How might this progression continue—what happens if Carlopio's three phases are adopted to design computing? In the first level, design computing is dependent on the architect. Decisions made by the computer are understandable and explainable, for they are the proximate outcome for the relationships and constraints set by the architect themself. The architect is in control, and the computer undertakes little if any exploration or creation of "novelty." In the second level, design computing becomes autonomous in the internal mechanism of its production or the "how" of its decision-making. Decisions show a level of novelty or surprise, and the derivation may not be explainable. The architect is at risk of being devalued unless they can use the output to augment their own creative process. In the third level, design computing becomes autonomous in its agency. The computer is able to exploit new opportunities and take advantage of or incorporate subtle and nuanced context. The architect may potentially be replaced in significant parts of the design process within traditional architectural practice.

VULNERABILITIES OF THE ARCHITECT'S TRADITIONAL CREATIVE ROLE

Of course, architecture is not as simple as plowing a field or operating a loom, and AI replacing the architect's creative role could seem fanciful, especially to those "many architects" who suggest upcoming AI would modify architecture "only marginally" (Morel 2019). Nevertheless, to discount a risk of AI to architectural practice in the face of a long history of machines impinging on the domain of human work is a variation on Lewis's "chronological snobbery" (Lewis 1955). There are no special protections offered to architects by mere dint of being the ones privileged to occupy the fleeting present. Furthermore, there are fundamental reasons why the traditional role of the designer may be threatened by AI developing in a social context outside the architects' typical practice.

Architectural practice has many areas that can be readily formalized in computer models extensible to creative exploration; indeed, given a key facet of architecture is clearly communicating the output of a building's design process so that it may be logically constructed, this statement verges on the axiomatic. Such work is rapidly becoming mainstream: in 2008, for example, SOM undertook highly exploratory work using genetic algorithms; in 2020, Autodesk released Generative Design for Revit to the mass market (Autodesk 2020; Besserud and Cotten 2008). Already there is a significant corpus of training examples on which AI models may be developed and, with BIM, the library of increasingly nuanced precedents is growing every day. There is also the opportunity for this process to be self-sustaining: platforms such as Generative Design will be able to gather metadata of practitioners' interactions, leading to an ecosystem of improved approaches. Frazer (1995) proposed the concept of an "extended architect" in which architects are needed "to guarantee a rich genetic pool of [progenitor] ideas, the role of the mass of imitators would be more efficiently accomplished by the machine." The architect as the progenitor of ideas now need not explicitly seed the genetic pool. Furthermore, AI can exploit even small datasets of precedent (Newton 2019).

Many aspects of the architectural solution space are extremely subjective and have no solution that can be proven to be optimal through any reasonable process; the search is one of satisficing that accounts for idiosyncrasy and whim. Watanabe (2017), for example, notes the different meanings architects may see "good form" to have. The subjectivity is implicit in Frazer's assertion that the design process may often be without a definitive goal and that a creative leap may seem self-evident only in hindsight: "By the time the problem has been defined, it has been solved. Indeed, the solution is often the very definition of the problem" (Frazer 2002). Jansen notes the "vastness of the multidimensional [solution] spaces involved" and that within them remote alternatives arise from "radically different roots" and, consequently, are not simply comparable (Frazer 2002). However, the subjectivity of the relative value of a design outcome introduces vulnerabilities for architecture.

Architecture is vulnerable with regard to furnishing design itself as a 'manufactured' product; many AI techniques increasingly excel at this type of navigation of inexact solution spaces. This is seen in both evolutionary computing that may find a "good enough form" from a vast array of alternatives, or in contemporary ANN techniques such as GANs that, in their training, collect subtle patterns within their latent space for regurgitation and sifting on demand (Dutta and Sarthak 2011, Radford et al. 2015).

Architecture is vulnerable with regard to design as a product to be "sold." Just as an architect may ascribe their own meaning to "good form," so too can the client base that pays for their architectural services. Alternatively put, the architect's product is exposed to price sensitivity if the person on the street sees little practical distinction between good architecture (as defined by architects) and wholesale building design. For evidence, consider the expanding acres of McMansions in wealthy developed countries. In 2017, Dan Rockmore of Dartmouth College proposed a Turing test in creative arts to determine if machine outputs can be distinguished from the creative works of humans (Mrosla et al. 2019). We suggest the bar is much lower if the judge is barely paying attention. In a world of open-source images and ideas, and in which generative AI techniques exist that demonstrate at least superficial novelty, this may be unsound ground on which to risk asserting the profession's ongoing viability.[5]

Watanabe (2017) states that "people [not machines] are the only ones that can create an image that does not yet exist." Yet creativity inherently transforms precedent, and Hofstadter (in Liu 2000 via Minsky) noted "making variations on a theme is the crux of creativity." In Csikszentmihalyi's model of creativity, the individual transforms extant cultural information, and the products, once sieved by society, become nucleation sites for further creativity (Liu 2000). Art, design, or cultural output is always rooted in what has gone before (even if that prior art is not considered to be a precedent in any traditional or formal sense). Such works are permutative transformations of the creators' past experiences and the subtle, pervasive, and essential process of drawing out and reinforcing of pattern and relationship (the beginnings of this are clear in Google's DeepDream); to view this statement alternatively, any "image" created that truly does not already exist would be entirely unrecognizable, in a literal sense, as art, architecture, or indeed anything else.[6]

In this general context Leach (2018) proposes that humans might essentially misperceive the nature of their "genius." We extend this to propose there is a prevalent and general misunderstanding of how people should relate to AI, and this nearsightedness aggravates risks to the architectural profession.

TOWARDS A CULTURAL REALIGNMENT

Accurately forecasting the future is difficult, including of AI (Haenlein and Kaplan 2019; Tetlock 1999). The historical response to AI's advances has been to shift the goalposts to redefine its capabilities continually as not true intelligence (Minsky 1958).[7] This defensive posture, ostensibly protecting the status of HI, may be a losing strategy: the ultimate outcome may be a very narrow definition of what it means to be a designer.

Once matching human performance at a task, AI can now exceed the performance of the most capable human, and any task performed by natural intelligences can fall victim to AI (Brundage et al. 2018). The use of AI need not become a zero-sum game if essential differences of AI and HI are appreciated and thus exploited so as to not redefine the practice of architecture per se, but rather reorient its focus and capability. To enable this, architects need to reassess AI's role that tends to have been miscast through historical bias against machines that arose from their procedural origins. Ethnocentrism in human society prioritizes the ingroup along with perceptions of superiority and preferential attitudes toward its behaviors and mores, with negativity displayed toward the outgroup (Bizumic and Duckitt 2012). Might such bias exist in relationships with the machine, and hence frustrate the greatest potential of the collaboration? To illustrate, people's demands of machines are very different from those made of the human peers with whom they work: perfection is assumed from machines and their outputs are taken to be therefore canonical in this regard (Dyson 1993; Garibaldi 2019). Indeed, Simon observed HI itself is "not correct or optimal in many situations" (Cassimatis 2012). HI divergence from optimality and correctness may be a compromise essential to human-level intelligence (Cassimatis 2012). Human experts themselves do not obtain 100% efficiency; it should not be unreservedly expected of the intelligent machines with which people work (Garibaldi 2019).[8]

Despite these prejudices, there are still essential differences between the capabilities of HI and AI in design. Mathematician Richard Hamming questioned whether evolution has confined human thoughts to certain avenues preventing access to otherwise "unthinkable thoughts" (Morel 2019). Morel extends this to assert the task of the architect is not to duplicate existing accomplishments with design computing; it is rather to pursue a "fully new form of architectural intelligence that we humans are unable to conceive," and that machines "shall logically give birth to a kind of architecture that is also beyond our usual capacities." Similarly, Cross (1999) asserts, "So rather than just emulate human abilities, some of our design machines should also do things that designers cannot do."

Yet there are matters machines cannot hope to understand, even if they may see further than us in certain areas. Writing on the problem of explaining the mechanism of consciousness, cognitive scientist Chalmers (1995) defined "easy" problems of consciousness—"susceptible to the standard methods of cognitive science"—distinguishing them from "hard" matters of subjective experience. The easy problems are susceptible to AI, being matters of response to input, information integration, and output of an internal state. For the "hard" problems, AI cannot (yet, if ever) embody *qualia*;[9] it can never feel an internal response to the architecture it might create, or experience being part of the social and cultural context that leads to it. Here, Watanabe's (2017) assertion computers do not "dream" would be apt. Machines must instead rely on an ersatz description of what humans sense, vicariously passed on by the designer as best as they are able, given that many designers are unable to articulate as a methodology how they design, even to themselves. But a challenge of automating creativity is to generate novelty that makes sense (Frey 2019). Machines, without their own experience of reality, and relying on utility functions "specified by the human designer" that "may not be perfectly aligned with the values of the human race," have the potential to optimize "highly undesirable" solutions (Russell 2014).

Nor can machines experience the motivations that drive architects to design. A desire for social relevance or making an original, meaningful contribution, for example, is widespread among architects (Jamieson et al. 2011). There is little point directing AI to the tasks humans excel at and enjoy, and for which the need for social connection is not easily replaced (Cross 1999; Kaplan 2016).

A cultural realignment could aid Vinge's (1993) "greater merging of competence." In this, early aspirations for AI to facilitate "intelligence amplification" and "symbiotic association" have the potential to be realized. Engelbart (1962) describes a collaboration of intelligence amplification that "will exhibit more of what can be called intelligence than an unaided human could; we will have amplified the intelligence of the human by organizing his intellectual capabilities into higher levels of synergistic structuring." Licklider (1960), in his seminal article "Man-Computer Symbiosis," saw the potential for computers to "facilitate formulative thinking as they now facilitate the solution of formulated problems" and cooperative action between humans "without inflexible dependence on predetermined programs."

ARBITRAGING A CONTINUING GAP

Counterintuitively, a closer, more equitable collaboration between AI and HI could progressively exploit their differences to the benefit of the architectural profession.

Architectural practice is a complex process that is composed of tasks crossing many domains (Mrosla et al. 2019; Veit 1987). Frazer (2016) notes "architecture does not address trivial problems" and identifies the inherent incongruity of applying algorithmic procedures to complex architectural considerations. Contemporary AI is (in the main) used to free up people to do other work, not displace them (Davenport and Ronanki 2018). Furthermore, Kaplan (2016), an expert on the economic and social effects of AI, observes tasks, not jobs, are automated and that the most vulnerable jobs involve unvarying workflows and well-defined objectives. Kaplan continues that those workers participating in diverse pursuits, response to dynamic goals, or real engagement with human emotion are at much lower risk, and may become more productive through AI.

Technology continually eliminates professions, such as traditional white-collar roles in customer service, while increasing production and reducing employment (Rotman 2013). Simultaneously, it leverages collective intellect to bring new endeavors into professional reach, and the demands of society itself shift in accordance with the affordances of technology. Expectations and visions of technology themselves shape its role and direction, and are particularly significant in those uncertain moments of early innovation (Borup et al. 2006). AI, as a potential replicant of HI, in its complex, continual evolution within responsive, changing society, may be in a persistent state of novelty.

We propose that as the generality of AI increases, even to the point of HLAI, architects can generate and embed new subtleties and expectations of outcomes that society will judge AI unable to achieve. Not only will the goalposts shift; architects may also change the very rules of the game at halftime. Architects are therefore challenged to arbitrage the gap between the actuality of AI and fluid, dynamic social expectations.

Effectively exploiting that gap as arbitrage requires an ongoing assessment incorporating a focus on what AI is today and its immediate challenges while keeping the architects' longstanding agility to respond to the pressures and opportunities. This includes what AI may create for society and architects' own sociotechnical role. We propose three initial alignments for the architect that, as AI progresses through our described three levels of design computing development, may help avoid the trap of Carlopio's third phase: as *architechs*, *arbiters*, and *shamans*.[10]

Architech

The architect may be "master builder" of those physical structures and spaces people inhabit and, as *architech*, be master builder of the AI frameworks that will complement their designs. This essential role is identified by Koh (2017) and others. We add the proposition to the discussion that AI does not yet excel at formulating reasoning that is elementary to humans, such as cause and effect (Knight 2020). The architect-in-the-design-loop can provide this understanding and as well accommodate cultural nuance (Burry et al. 2019; Woodbury et al. 2017).

This alignment is appearing increasingly in architectural practice. The Living, a design studio and research arm of Autodesk, used AI-driven generative design for the architectural space planning of a new office (Nagy et al. 2019). The generative design process was placed explicitly within before and after stages in which HI established the design concept and refined the AI outcome to meet other criteria. Their workflow employed a multiobjective genetic algorithm exploring a solution space of six metrics of employee preferences and spatial qualities to create 10,000 designs. Data analysis tools were used to reduce that pool to HI-manageable size and themselves generated insights. By clustering design types, patterns of performance against metrics could be visualized, and insights into the design problem and potential design strategies uncovered. Rather than offering a single best design, the outcome was a set of high-performing designs demonstrating trade-offs between metrics that could be reviewed by human designers in consultation with stakeholders, leading to a final design.

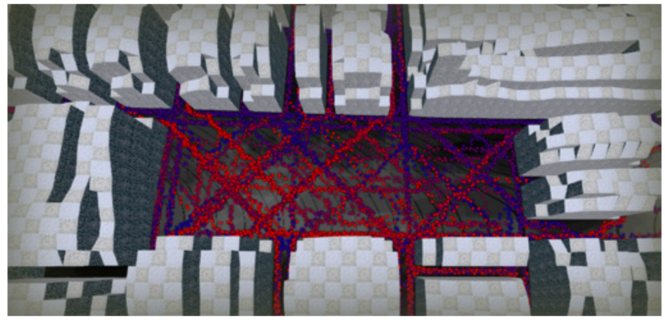
Use of ANNs to predict meeting-room usage for space planning at WeWork demonstrated similar outcomes (Phelan et al. 2019). Although the AI prediction could outperform HI, its real value was to leverage AI evaluation of past project performance to enable the designer to exploit their HI to adjust their response on current projects.

Arbiter

The architect is responsible for the consequences of what they create (Karakiewicz 2020). The architect as *architech*—and thus in control of what AI in architectural practice achieves—would hence have a social obligation to arbitrate how it is applied. AI operating alone can produce undesirable outcomes. It has no moral conscience. Biased training data and other flaws can produce outcomes from the downright prejudicial to simply underwhelming in accommodating diverse needs (Weyerer and Langer 2019). Directing AI towards fair solutions is nontrivial. There are risks in bottom-up and top-down solutions such as "personal choices" and "law enforcement" (Etzioni and Etzioni 2017). A free market risks the tragedy of the commons, and narrow interests may lead to ramifications even when the intent is just, such as occurred when IBM released an image dataset to aid development of fairer facial recognition scraped without permission from social media (Hao 2019). Conversely, legislating in a changing situation is rife with unanticipated consequences (Merton 1936). Could society therefore rely on a "reasonable architect" test to decide the essential bounds of AI in built environments through fostering a culture of reflection, professional responsibility, and collective oversight? Just as The Living, as one example of this trend, adapted AI processes to capture and accommodate group and individual employee preferences for distraction, daylight, and amenity accessibility, it will need to be the architects themselves who guard against any overstep, as already evident with AI-generated solutions permeating the practice of architecture.

Shaman

AI's reasoning can be opaque (Leach 2018). In response, architects can interpret black-box AI outputs to provide meaning to incorporate into their design process. This explication is not machine-like translation, for it is not dealing with a functional mapping but instead maps preferences, emotions, intuition, and biases: at a higher level, the architect could design the rich narratives around AI contributions to the design process. Furthermore, just as architects analyze immutable aspects of site and draw on the uncontrollable context, cannot architects treat opaque AI input as something relatively fixed but still to be exploited? Architects could move to a mode of practice in which they—almost as architectural narrators or *shamans*, channel and placate the whims and wants of the AI world—acting as interpreters of the AI recommendations.



3 Generative design of public space solar amenity.

In our own work in progress on the potential role of AI within design computing, we have observed a need for this realignment. Shadow modeling that can track locations of obstructing building geometry, for example, enables iterative refinement of building envelopes in response to shading outcomes (Kimm 2020). Through extending that work as a tool to produce generative designs for public space with optimal overshadowing, solutions can be sought that preserve a given minimum of solar amenity throughout the year (Fig. 3). Although the AI-generated designs are high-performing with respect to pedestrian experience of sun and shade, the spatial and temporal distribution of sunlit areas is not intuitive nor necessarily that which a designer fully exploiting their HI would produce as their design preference. The architect who chooses to use such results must, within their design response, interpret and translate their benefit to the client and public alike, and meeting a shading performance of itself might be insufficient.

CONCLUDING REMARKS

That AI is increasingly undertaking creative "thought" once considered the unique preserve of HI, even if faux, is indubitable. Ultimately, AI may supersede architectural HI on any practical metric, albeit ones naïve or just plain mercenary. With appropriate foresight, the architect's distinctive role in the nuanced synthesis of social and emotional understanding with emerging technology may allow them to sidestep the obsolescence AI may visit on certain roles in other professions. The three initial alignments we identify—*architech*, *arbiter*, and *shaman*—are facets of the same response: the future avant garde architect may need to exploit AI in order to offer new value to their innate skills. The complex interplay between evolving AI and developing expectations of society allows for a capability reciprocity in which the future architect arbitrages between architectural AI and architectural HI to construct a chain of new value models for both clients and broader society alike.

The motivating threat of AI to the architect's traditional creative role may seem as fanciful to some as the sci-fi dystopias outlined in the introduction above. Whatever the future of AI-enabled architectural practice, there will be architects who will be able steer into the skid of forced adaption to imposed change and, looking back on the looming challenges of AI, proclaim, "I got it right." Yet, if such examples are relatively few and thinly scattered across the vast body of practice (or the solution space of architectural practice phenotypes), would architects as a profession have performed with any greater prescience than the insentient metaheuristic of a genetic algorithm?

NOTES

1. There is not a lot of writing in AI in architecture at the right level to meet the requirements of this research and the ambitions of the authors, and therefore many sources may not address architecture directly.
2. The neat separation of the design computing levels given here is due to simplification for the sake of discussion within the available space; for illustration of fuzziness between levels, see for example work in AI that combines genetic algorithms and deep learning.
3. Cassimatis (2012) discusses a "cognitive substrate" in which our intelligence (and as applied to the myriad challenges of the modern world) arose from an essential mental toolkit that met the very-different social and spatial needs of our forebears. Might solving the essentials of design computing, and therefore producing such a cognitive substrate for design, lead to a massive leap in design computing AI?
4. There may be presumptions at play in which computers are more powerful than they actually are, data sets found to be more elusive than anticipated and often either incomplete or thwarted by missing components from the data set itself, and algorithms less effective in real application than in experiments. Underlying this in design might be creatives investing a sci-fi belief in capability unable to fundamentally understand how AI "works" and what really is at stake.
5. Frazer's extended architect might lie between the second and third of our proposed design computing levels. A point here is that Frazer made these apposite observations 25 years ago—a demonstration of the length of time this level of technological osmosis can take.
6. Therefore making critical assessment difficult using the critics' usual criteria: if we are to judge how well the rules have been broken, we need to have a set of rules to begin with.
7. Minsky comments, on perceptions of creativity being "some kind of 'gift' which simply cannot be understood or mechanized," that the "weakness of the advocate of inexplicable creativity lies in the unsupported conviction that after all machines have been examined some items [unique to HI] will still remain on the list."
8. The *weak anthropic principle* in cosmology states we observe a "comfortable" universe as one is necessary for our sentient existence to arise. In perceptions of human "genius," there may be corresponding subjectivity: on a population scale, the means to judge our achievements can only be the same minds that create them. There is an exact one-to-one equivalency of the minds that produce and the minds that judge. Furthermore, crude analogs of the processes that created HI are used in AI; that contemporary outcomes are inferior does not preclude success.
9. The *Stanford Encyclopedia of Philosophy* characterizes *qualia* as "the introspectively accessible, phenomenal aspects of our mental lives" (https://plato.stanford.edu/entries/qualia/).
10. The etymology of *shaman* is from *saman* of the Tungusic language group of eastern Siberia and Manchuria and from there potentially Sanskrit. It is not related to the suffix *man* of English (Laufer 1917).

REFERENCES

Autodesk. 2020. "Generative Design in Revit now available." https://blogs.autodesk.com/revit/2020/04/08/generative-design-in-revit/.

Besserud, Keith, and Joshua Cotten. 2008. "Architectural Genomics." In *ACADIA 08: Silicon + Skin: Biological Processes and Computation, [Proceedings of the 28th Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA)]*, Minneapolis, MN, 16–19 October 2008, edited by A. Kudless, N. Oxman, and M. Swackhamer, 238–245. CUMINCAD.

Bizumic, Boris, and John Duckitt. 2012. "What Is and Is Not Ethnocentrism? A Conceptual Analysis and Political Implications." *Political Psychology* 33 (6): 887–909.

Borup, Mads, Nik Brown, Kornelia Konrad, and Harro Van Lente. 2006. "The Sociology of Expectations in Science and Technology." *Technology Analysis & Strategic Management* 18 (3–4): 285–298.

Brundage, Miles, Shahar Avin, Jack Clark, Helen Toner, Peter Eckersley, Ben Garfinkel, Allan Dafoe et al. 2018. "The Malicious Use of Artificial Intelligence: Forecasting, Prevention, and Mitigation." https://maliciousaireport.com/

Burry, M. 2020. *Digital Architecture*. London: Routledge.

Burry, Mark, Camilo Cruz, and Geoff Kimm. 2019. "Avoiding the Color Gray: Parametrizing CAS to Incorporate Reactive Scripting." In *Urban Galapagos*, edited T. Kvan, and J. Karakiewicz, 137–154. Cham: Springer.

Carlopio, Jim. 1988. "A History of Social Psychological Reactions to New Technology." *Journal of Occupational Psychology* 61 (1): 67–77.

Carpo, Mario. 2019. “The Natural Logic of Artificial Intelligence, or What Genetic Algorithms Really Do.” *Philosophy Kitchen Extra: Journal of Contemporary Philosophy* 6 (2): 123–129.

Cassimatis, Nicholas L. 2012. “Human-Level Artificial Intelligence Must Be an Extraordinary Science.” *Advances in Cognitive Systems* 1: 37–45.

Chalmers, David J. 1995. “Facing Up to the Problem of Consciousness.” *Journal of Consciousness Studies* 2 (3): 200–219.

Cross, Nigel. 1999. “Natural Intelligence in Design.” *Design Studies* 20 (1): 25–39.

Davenport, Thomas H., and Rajeev Ronanki. 2018. “Artificial Intelligence for the Real World.” *Harvard Business Review* 96 (1): 108–116.

Dutta, Kamlesh, and Siddhant Sarthak. 2011. “Architectural Space Planning Using Evolutionary Computing Approaches: A Review.” *Artificial Intelligence Review* 36 (4): 311–321.

Dyson, Esther. 1993. “Biology Is Destiny in Computers, Too.” *Computerworld*, January 18.

Engelbart, Douglas C. 1962. *Augmenting Human Intellect: A Conceptual Framework*. SRI Summary Report AFOSR-3223: Prepared for Director of Information Sciences, Air Force Office of Scientific Research, Washington DC, Contract AF 49(638)-1024. https://www.dougengelbart.org/content/view/138.

Etzioni, Amitai, and Oren Etzioni. 2017. “Incorporating Ethics Into Artificial Intelligence.” *The Journal of Ethics* 21 (4): 403–418.

Frazer, John. 1995. *An Evolutionary Architecture*, London: Architectural Association.

Frazer, John. 2002. “Creative Design and the Generative Evolutionary Paradigm.” In *Creative Evolutionary Systems*, 253–274. Burlington: Morgan Kaufmann.

Frazer, John. 2016. “Parametric Computation: History and Future.” *Architectural Design* 86 (2): 18–23.

Frey, Carl Benedikt. 2019. *The Technology Trap: Capital, Labor, and Power in the Age of Automation*. Princeton: Princeton University Press.

Garibaldi, Jonathan M. 2019. “The Need for Fuzzy AI.” *IEEE/CAA Journal of Automatica Sinica* 6 (3): 610–622.

Grace, Katja, John Salvatier, Allan Dafoe, Baobao Zhang, and Owain Evans. 2018. “When Will AI Exceed Human Performance? Evidence from AI Experts.” *Journal of Artificial Intelligence Research* 62: 729–754.

Grobman, Yasha Jacob, Abraham Yezioro, and Isaac Guedi Capeluto. 2010. “Non-Linear Architectural Design Process.” *International Journal of Architectural Computing* 8 (1): 41–53.

Haenlein, Michael, and Andreas Kaplan. 2019. “A Brief History of Artificial Intelligence: On the Past, Present, and Future of Artificial Intelligence.” *California Management Review* 61 (4): 5–14.

Hao, Karen. 2019. “IBM’s Photo-Scraping Scandal Shows What a Weird Bubble AI Researchers Live In.” *MIT Technology Review*, March 15. https://www.technologyreview.com/2019/03/15/136593/ibms-photo-scraping-scandal-shows-what-a-weird-bubble-ai-researchers-live-in/.

Jamieson, Claire, Dickon Robinson, John Worthington, and Caroline Cole. 2011. *The Future for Architects?* London: Royal Institute of British Architects.

Kaplan, Jerry. 2016. “Artificial Intelligence: Think Again.” *Communications of the ACM* 60 (1): 36–38.

Karakiewicz, Justyna. 2020. “Design Is Real, Complex, Inclusive, Emergent and Evil.” *International Journal of Architectural Computing* 18 (1): 5–19.

Kimm, Geoff. 2020. “Actual and Experiential Shadow Origin Tagging: A 2.5 D Algorithm for Efficient Precinct-Scale Modelling.” *International Journal of Architectural Computing* 18 (1): 41–52.

Knight, Will. 2020. “If AI’s So Smart, Why Can’t It Grasp Cause and Effect?” *Wired*, March 9. https://www.wired.com/story/ai-smart-cant-grasp-cause-effect/.

Koh, Immanuel. 2017. “Inference Design Machine and 'Infinite' and 'Recombinant' Series.” In *Computational Design*, edited by N. Leach and P. Yuan, 291–296. Shanghai: Tongji University Press Company Limited.

Laufer, Berthold. 1917. “Origin of the Word Shaman.” *American Anthropologist* 19 (3): 361–371.

Leach, Neil. 2018. “Design in the Age of Artificial Intelligence.” *Landscape Architecture Frontiers* 6 (2): 8–20.

Leach, Neil. 2019. "Do Robots Dream of Digital Sheep?" In *ACADIA 19: Ubiquity and Autonomy [Proceedings of the 39th Annual Conference of the Association for Computer Aided Design in*

Architecture (ACADIA)], Austin, TX, 21–26 October 2019, edited by K. Bieg, D. Briscoe, and C. Odom, 298–309. CUMINCAD.

Lewis, Clive Staples. 1955. *Surprised by Joy, the Shape of My Early Life*. London: Geoffrey Bles.

Licklider, Joseph CR. 1960. "Man-Computer Symbiosis." *IRE Transactions on Human Factors in Electronics* 1: 4–11.

Liu, Yu-Tung. 2000. "Creativity or novelty?: Cognitive-Computational Versus Social-Cultural." *Design Studies* 21 (3): 261–276.

Merton, Robert K. 1936. "The Unanticipated Consequences of Purposive Social Action." *American Sociological Review* 1 (6): 894–904.

Minsky, Marvin L. 1958. "Some Methods of Artificial Intelligence and Heuristic Programming." In *Proc. Symp. on the Mechanization of Thought Processes,* 3–28. London: Her Majesty's Stationary Office.

Morel, Philippe. 2019. "The Origins of Discretism: Thinking Unthinkable Architecture." *Architectural Design* 89 (2): 14–21.

Mrosla, Laura, Volker Koch, and Petra von Both. 2019. "Quo vadis AI in Architecture? Survey of the Current Possibilities of AI in the Architectural Practice." In *Architecture in the Age of the 4th Industrial Revolution*, 45–54. Porto: eCAADe/SIGraDi.

Nagy, Danil, Damon Lau, John Locke, Jim Stoddart, Lorenzo Villaggi, Ray Wang, Dale Zhao, and David Benjamin. 2017. "Project Discover: An Application of Generative Design for Architectural Space Planning." In *Proceedings of the Symposium on Simulation for Architecture and Urban Design*, Toronto, Canada, 22–24 May 2017, edited by Michela Turrin, Brady Peters, William O' Brien, Rudi Stouffs, and Timur Dogan, 59–66. SIMULATION COUNCILS.

Newton, David. 2019. "Deep Generative Learning for the Generation and Analysis of Architectural Plans with Small Datasets." In *Architecture in the Age of the 4th Industrial Revolution*, 21–28. Porto: eCAADe/SIGraDi.

Phelan, Nicole, Daniel Davis, and Carl Anderson. 2017. "Evaluating Architectural Layouts with Neural Networks." In *Proceedings of the Symposium on Simulation for Architecture and Urban Design*, Toronto, Canada, 22–24 May 2017, edited by Michela Turrin, Brady Peters, William O' Brien, Rudi Stouffs, and Timur Dogan, 67–73. SIMULATION COUNCILS.

Radford, Alec, Luke Metz, and Soumith Chintala. 2015. "Unsupervised Representation Learning with Deep Convolutional Generative Adversarial Networks." arXiv preprint. arXiv:1511.06434.

Rotman, David. 2013. "How Technology Is Destroying Jobs." *Technology Review* 16 (4): 28–35.

Russell, Stuart. 2014. "Of Myths and Moonshine." *Edge*, November 14. http://www.edge.org/conversation/jaron_lanier-the-myth-of-ai.

Tetlock, Philip E. 1999. "Theory-Driven Reasoning About Plausible Pasts and Probable Futures in World Politics: Are We Prisoners of Our Preconceptions?" *American Journal of Political Science* 43 (2): 335–366.

Veit, Franz S. 1987. "Design Augmentation in the Architectural Practice." In *Principles of Computer-Aided Design: Computability of Design*, edited Y. Kalay, 337–347. Chichester: Wiley-Interscience.

Vinge, Vernor. 1993. "Technological Singularity." In *VISION-21: Interdisciplinary Science and Engineering in the Era of Cyberspace,* 30–31. Cleveland: NASA.

Watanabe, Makoto. 2017. "AI Tect: Can AI Make Designs?" *In Computational Design*, edited N. Leach and P. Yuan, 69–75. Shanghai: Tongji University Press Company Limited.

Weyerer, Jan, and Paul Langer. 2019. "Garbage In, Garbage Out: The Vicious Cycle of AI-based Discrimination in the Public Sector." In *Proceedings of the 20th Annual International Conference on Digital Government Research*, 509–511. Dubai: ACM.

Woodbury, Robert, Arefin Mohiuddin, Mark Cichy, and Volker Mueller. 2017. "Interactive Design Galleries: A General Approach to Interacting with Design Alternatives." *Design Studies* 52: 40–72.

IMAGE CREDITS

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