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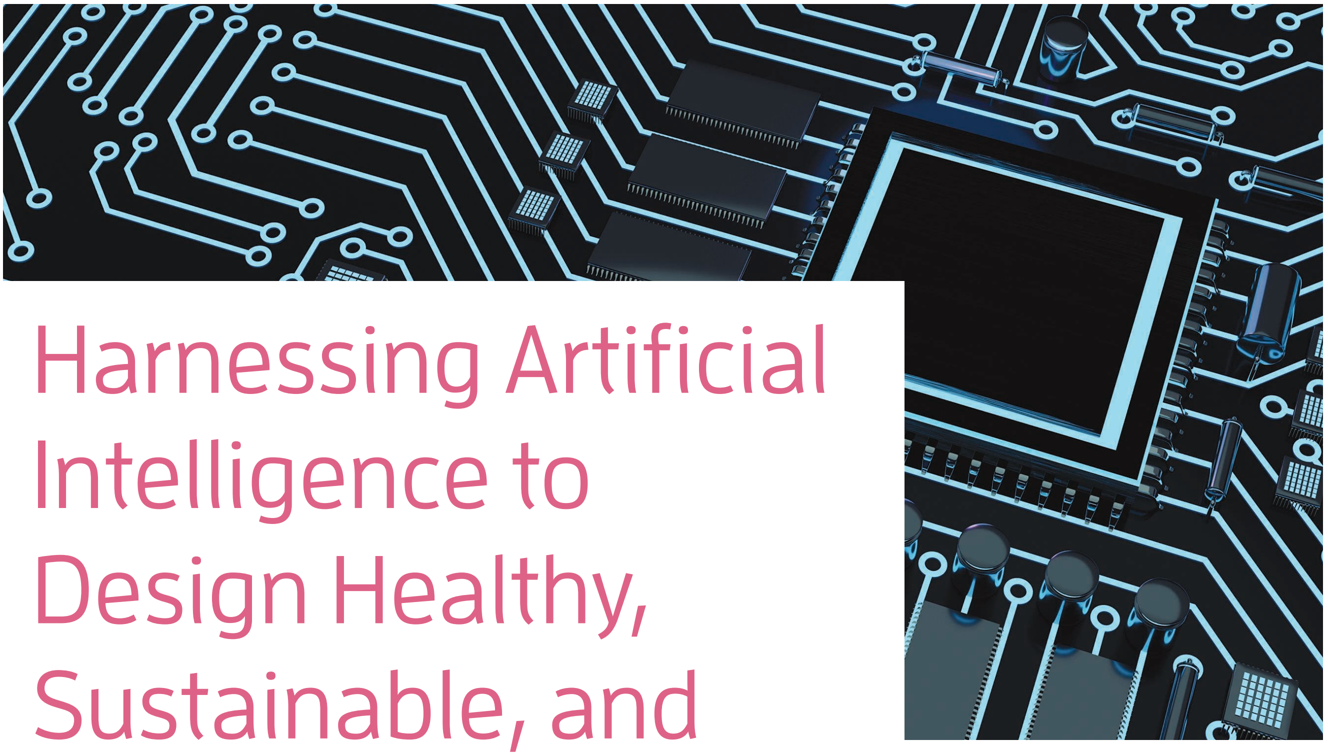

Harnessing Artificial Intelligence to Design Healthy, Sustainable, and Equitable Places

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Modern machine learning and artificial intelligence (AI) have revolutionized many disciplines but have only minimally impacted the practice of architecture. We discuss design challenges that architects face, illustrate how AI can meet them, and describe three areas where progress is needed to ignite the AI revolution in architecture.

Our term for the designers of computing systems, *architects*, is derived from the far older profession of designing the structures and places that occupy our world. Today's architectural firms are avid consumers of computing technology, from powerful CAD systems and building models to sophisticated urban simulations. However, while modern machine learning and artificial intelligence (AI) techniques have revolutionized many disciplines, they have only minimally impacted the practice of architecture.

Architects of the built environment need to do more than ever. It is no longer sufficient for buildings and places to meet Vitruvius' rubric: *firmitas, utilitas, et venustas*—strength, utility, and beauty. Now architects must also respond to a broad range of environmental, social, and community concerns. Designing even

Digital Object Identifier 10.1109/MC.2021.3134422
Date of current version: 14 February 2022

a single-family home today requires attention to climate change, pollution, the carbon footprint of every material used in construction, fair labor practices throughout the building supply chain, affordability, racial equity, and the development of healthy communities—in addition to all of the usual demands of the client and regulatory agencies. An explosion of information and data on all of these issues now influences every step in the design process and simultaneously threatens to overwhelm the people running that process. How can the architects of our built environment meet the demands of this new class of design goals without losing sight of their less-quantifiable aspiration to create inspiring and captivating buildings?

Designing great buildings has always been a "wicked" problem—one defined by imprecise goals, incomplete knowledge, deeply interconnected subproblems, and the need to continuously make best-guess tradeoffs (https://en.wikipedia.org/wiki/Wicked_problem). Instead of right or wrong answers, wicked problems require us to think in terms of better or worse solutions and rely on professional judgment and experience to point us forward. In a recent op-ed (https://www.archpaper.com/2021/02/op-ed-tackling-bidens-climate-change-challenge-artificial-and-human-intelligence/), we discussed a wicked problem tucked within President Biden's year-one legislative agenda on climate change (https://joebiden.com/climate-plan/)—a call to create the innovative technologies needed to build "zero net energy buildings at zero net cost." Owing to the cross-disciplinary nature of the problem and its resistance to traditional design methods, we argued that architects could leverage AI as a tool to supplement human intelligence and help find novel solutions.

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Today's architects already work routinely with digital tools to design, manage, and construct projects. At the center of this work is a technology known as *building information modeling* (*BIM*), which enables an architect to create a detailed, 3D representation of her design that behaves, digitally, like a real building. That model can then be used to predict the energy performance, daylight usage, and even the cost of the project before it is built as well as generate drawings and images to help explain the project to the client. With BIM as a base, architects can create vast amounts of digital information about their projects with tools that simulate a building and predict how it might operate in reality—everything from the amount of carbon needed to power its lighting system to the number of people who might occupy a particular space at a particular time. The builder can use that same model to price the project, order materials, coordinate labor in the field, and sequence construction. The BIM simulation lives on after construction as a digital tool that can be used by the building owner to operate the property and monitor its performance. BIM has established a common platform for architects, engineers, consultants, and contractors to develop and analyze building projects with robust analyses driven by explicit 3D modeling, well-understood relationships, and conventional types of digital simulation.

Contemporary AI approaches are fundamentally different from traditional BIM-based analyses. While BIM allows designers to model individual structures in significant detail, the machine learning algorithms used by today's AI systems identify patterns and correlations that are implicit in massive pools of data and then use those patterns to make predictions about specific instances. Crucially, the patterns that AI systems discover from large sets of design data can far exceed the power of the handcrafted building data models and simulations that are encompassed by BIM. These patterns capture subtle but authentic regularities across thousands of individual features and millions of examples, surpassing what humans can encode or even effectively explain using traditional models and rules.

Modern facial recognition systems illustrate this well. Rather than having programmers explicitly identify and model all the graphical elements relevant to recognizing faces and then write computer code that recognizes specific faces as unique combinations of these elements, AI systems process millions of images to learn distinguishing facial patterns for themselves. Continuous feedback and retraining allow the AI system to perform with increasing accuracy. Yet, the way that specific machine-learned parameters encode facial features to allow identification of any one face remains a mystery that, so far, is extremely challenging to explain in intuitive terms. This AI process is reminiscent of how humans learn to identify faces. No one explicitly teaches us how to recognize our friends. Our brains independently learn to do this task automatically and reliably based on experience gathered at a very young age, and yet the details of our own ability to recognize faces are a mystery. As with AI, we cannot satisfactorily explain how we do it, even to ourselves.

The basic property that characterizes modern AI is that machine learning algorithms are able to extract subtle patterns and correlations from large data sets without requiring an expert to explicitly model all of the detailed relations among the elements of such data sets. For example, AI might help uncover a deep connection between certain design choices and patient health outcomes to create more effective hospitals or exploit complex patterns between space and light to identify designs that would best support a socially vibrant public square.

While modern AI has gained little traction in the building industry to date, it is on track to provide a powerful path to extend and complement the detailed modeling capabilities of BIM and support architects in understanding tradeoffs that are not apparent from traditional digital-model representations of a design. A variety of innovative digital tools available in recent years has amplified architects' capabilities to create, depict, analyze, and communicate their design ideas (https://www.architecturalrecord.com/articles/15409-continuing-education-artificial-intelligence). Many such tools extend the data and power of BIM models, but they are targeted at single designs rather than leveraging a broad array of data compiled from many projects. AI improves on this by identifying patterns implicit in hundreds or even thousands of individual designs to help architects effectively respond to subtle and difficult-to-model design concerns. Just as AI has revolutionized how we design our drugs and drive our cars, it can uniquely help architects create inspiring and beautiful buildings that also respond to our desire for equity, justice, health, and community—issues that are at the forefront of the architectural profession today.

APPLYING AI TO THE DESIGN OF PLACES

AI can make it possible for architects to resolve vastly more complex design agendas than they are able to today. It will do this by rapidly analyzing huge amounts of data to generate options for design teams to consider and refine, just as Spotify or Netflix do when they recommend music or movies we might like. In architecture, AI can accelerate the design process to find and evaluate options that are likely to satisfy a complex set of design requirements across a variety of programmatic and qualitative domains. Finally, AI can integrate with advanced simulation technology to help architects assess the effectiveness of various design solutions aimed at satisfying the diverse demands of a building project.

While AI may be a disruptive technology, it cannot fully automate the work of design, any more than BIM "solved" architecture.

Of course, solving complex—even wicked—problems such as "zero net energy buildings at zero net cost" through design involves evaluating the human costs of tradeoffs and judgments, tasks that humans still do far better than algorithms. So while AI may be a disruptive technology, it cannot fully automate the work of design, any more than BIM "solved" architecture. Used properly, AI can give architects mastery of complex agendas by revealing insights based on otherwise impossible-to-recognize patterns and solutions, while preserving the ability of architects to focus on understanding human needs, applying creativity, and developing artistry.

In the near future, architects may employ AI to help with a broad range of challenges. To offer a clearer idea of what this might mean, following are three scenarios involving different project scales and levels of complexity.

BETTER EDUCATION

The first example is an elementary school in a suburban community designed to exemplify best practices in education, sustainability, and racial and economic diversity. In November 2020, the *Public School Review*, a widely used platform that provides free, detailed profiles of American public schools and their surrounding communities, highlighted 10 major challenges facing these institutions—including addressing social and health issues. But this information offers architects and educators only limited help in identifying the cause-and-effect relationships between critical elements in school design and desired outcomes, such as reduced absenteeism, higher test scores, and more parental engagement.

In this example, AI can work as an architect's assistant by leveraging large databases of BIM elementary school models along with regional health and testing data to surface new and promising configurations that best correlate a range of holistic, qualitative objectives. By broadening the scope and increasing the depth of the architect's understanding of the design problem, such assistance can help create schools that work better for students, faculty, and staff.

BETTER HEALTH OUTCOMES

A second scenario examines a larger, more complex project: a regional hospital with inpatient and outpatient care, a full range of departments (obstetrics, oncology, emergency, cardiac, renal, pulmonary, and so on), and both research and clinical facilities. Not only is this project larger and more expensive than the school, but it must resolve the often-competing needs of its different user groups: patients, visitors, medical professionals, and support staff.

New AI tools can review continually evolving data on patient-stay durations, medical procedure recovery times, and hospital-borne infections to find critical patterns and then apply this knowledge to help architects design the hospital. By revealing the underlying connections between design and outcomes—such as the relationship of building configuration to reduced hospital stays, better utilization of expensive medical equipment, and reduced carbon footprint—AI can establish an evidence-based process for architecture. It can also provide validation for design decisions, allowing architects to explore strategies that might not seem promising at first glance. And AI systems can be continually updated with new data sets and the latest studies.

BETTER COMMUNITIES

The third example involves the master plan for an urban neighborhood that proposes a holistic strategy for commercial mixed-use buildings, residential construction, infrastructure improvements, and public open space. By encompassing not only individual buildings, but also the interactions among them within the larger context of streets, parks, and occupants, the plan must accommodate a degree of complexity that challenges any existing technology. It requires coordination at multiple scales: from the building materials used to solar orientation, from landscaping to transit facilities, from safe bicycle routes to issues of affordability and diversity. By finding correlations across the relevant data, AI can help architects and planners evaluate complex decisions, make myriad tradeoffs, and project how individual pieces will fit together to support a vibrant community.

These data will be provided by today's smart city technologies, which collect vast amounts of information on traffic, pollution, open space usage, crime, energy consumption, and all kinds of other urban functions. If all of this information could be brought together, it could be used to train algorithms to discover patterns and offer insights on complex environmental, social equity, population health, and community governance issues that can't be found using traditional planning methodology. Those same AI tools could periodically update the master plan with new insights as the project moves forward over time, keeping it relevant as the community develops and plans evolve. As the AI systems learn more from these large data sets, they can begin to simulate and predict to help planners and architects shape a healthier and more sustainable future.

Each of these three imagined scenarios offers a window into the realm of possibilities that can leverage AI to correlate complex agendas that span a range of social, health, and environmental issues central to human progress and a healthy planet.

AI can also help architects expand the scope and value of services they provide to clients. Armed with the latest software, firms can engage with clients earlier in the process—providing advice, for example, on real estate decisions and programming. At the other end of the process, AI can help architects use data gathered on a completed building's performance in terms of energy use, water conservation, indoor air quality, and user comfort to manage a property for a client, a service not normally assumed by architects, but one that could be attractive to some.

Ultimately, AI is a tool of empowerment, giving architects the space to do what they do best: develop innovative ideas and new solutions. AI will allow them to focus on the poetics of a project, not just the pragmatics. AI has tremendous potential to advance the practice of design to more reliably create places and buildings that respond to national priorities for equity, justice, health, and community—and leverage the built environment to bolster our values across all strata of society. There are three areas where progress is needed to bring about this future:

1. *The promise of AI to improve architecture depends on the ability of these algorithms to learn from massive assemblies of information about design, construction, and building operation*. Data are the fuel for AI and analysis. Compiling these data, though, is beyond the capability of any single firm or group of firms in the design industry, or even leading professional associations like the American Institute of Architects. There are complex and difficult issues surrounding creation of such a data resource, including ownership, access, privacy, data bias, social equity, data assurance, labeling, governance standards, and protection. We envision a built environment data trust, overseen by a distinguished oversight board, which would aggregate as much building design data as possible. Such a resource will ignite the AI revolution in architecture.
2. *AI can allow designers to create far better performing buildings while reducing their environmental and energy footprints, improving the health of people who use and live near them, and leveraging the built environment to address a broad range of social and economic issues*. These impacts and the processes needed to achieve them will first be explored in architecture schools and leading architecture firms. We envision a set of innovative pilot programs aimed at using AI and information in the built environment data trust to drive AI forward for architectural design. This effort should include public–private partnerships with leading architecture firms, universities,

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construction companies, real estate developers, and building owners to ensure that technical advances can be quickly applied to real-world projects. Working together, such partnerships can enable the multitrillion-dollar design and construction market to take transformative steps to operate with greater efficiency and create communities that are healthier and more environmentally sustainable.

3. *Each of us recognizes the excitement that can be generated when like-minded people come together*. We look forward to an increasing number of workshops and conferences addressing AI's impact on the built environment. They will involve researchers, technologists, practitioners, developers, financiers, and government officials, all seeking to identify innovative ways of using data and AI to design and build sustainable, resilient, and healthy places for the 21st century.

A powerful tool tends to change its user. AI is a revolutionary technology that can transform the American practice of architecture in deep and positive ways and shape a healthy and sustainable future for the world we live in. ◼

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Digital Object Identifier 10.1109/MC.2022.3142837