the flagella of humble bacteria. While a “nanocar” might not seem particularly useful for humans at first glance, the remarkable architectural versatility of molecular machines has the potential to enable a wide range of functions. Suggested applications range from tiny robots for site-specific drug delivery to smart materials in sensors.

It is exciting to imagine the possibilities of applying these and other technologies in medicine, as we approach the capability of designing systems at the very same scale as the marvelous nanoscale processes that animate biology and may malfunction in the case of disease. Technological development and the process of design is often circuitous. Original ideas good enough to be pressed into service are rare and precious. However, we have advanced considerably from the times of relying solely on serendipitous accidents of the kind that surely must have pervaded the first manufacture of glass of the kind used for the Lycurgus Cup. Though the world of the nanoscale has always surrounded us, the lenses that allow us to peer into it reveal phenomena that are beautiful and challenge us intellectually. The rise of the concept of nanotechnology is largely a product of this significant shift in how we view and interact with the world. Observation at this scale raises the possibility of enlightened design and empowers us to both envision and develop future technologies.
potable water for a rapidly growing population? Would turning cyborgs help us stay unaffected by air pollution in densely populated cities and help us live on saline water? There is agreement that many of us have already become cyborgs. Any human with a pacemaker can be considered a cyborg. Here, turning cyborg is a response to cardiac problems. It is a prosthesis to make one’s own life agreeable despite health issues. It is a common fix, but not desirable. Why would we not want to stay in good health and preserve our earthly environment as our default human habitat in the first place?

While Clynes’ and Kline’s vision would have made architecture in space obsolete, the discipline of architecture itself challenged the existence of man in the more recent past. The arrival of the internet and new software tools catalyzed the colonization of cyberspace, moving attention away from the physical domain and thus dematerializing the agenda of architecture. Would humankind soon live in cyberspace? Mankind could not adapt quickly enough and, eventually, there was a pragmatic agreement that architecture would remain in the physical domain of reality. Neither the explorations of the nineteen sixties such as Hans Hollein’s architecture pill “Non-Physical Environment” from 1967 nor the short-lived hype surrounding virtual reality in the nineteen nineties have so far succeeded in virtualizing our built environment. The construction industry continued to be intensive in energy, labor and material, contributing to the growing necessity of having to become cyborgs.

Yet, the digital has started to inform and transform our mundane reality. In architecture, rather than being an agent for dematerialization, the digital has become a tool to describe the physical reality in new terms. The field of digital fabrication has established ways of how data can inform both physical material as well as space. The integration of sensors into the design and fabrication process allows for new control mechanisms based on real-world feedback. After decades during which architecture, following a modernist doctrine, was governed by mechanical processes and standardization, the digital and its communication protocols allow for the production of a new architecture linking back to a cybernetic architecture which protagonists such as Nicholas Negroponte, Cedric Price, and John Frazer envisioned decades ago.

The Optimized Palace
Revisiting their work, it is obvious that Cedric Price’s project for the Fun Palace aspires to function as a machine. Its drawings depict industrially produced elements, and some resemble a circuit plan for electrical wiring. Yet, Price conceived it together with Joan Littlewood, one of the important figures of modern theater in England. Like the Interaction Centre that Price later built in the London Borough of Camden, the Fun Palace was
conceived as a “university of the streets”, an alchemist’s laboratory for bringing the local community into contact with the arts, science and technology, pioneering the concept of architecture as a user experience.[2] Besides Littlewood, the English psychologist and cybernetician Gordon Pask was among the other significant contributors to the project. In 1965 he came up with a circuit plan to control the Fun Palace. This asked users about their preferences in order to compute the spatial configurations of the Fun Palace. With Littlewood and Pask on the team, the project exemplifies the negotiation between enabling participation, exploration, and free expression of the individual on the one hand and a computational regulation system on the other hand.

Seen from the perspective of today, where measuring user behavior to regulate the built environment has become common standard, the Fun Palace functions as an early cautionary tale. Pask’s plan defined unmodified people going in and modified people going out. Much in contrast to the name of the project, invoking unconstrained gaudy in tune with Swinging London, Pask’s initiative as a member of the cybernetics committee introduced a systematic approach of measuring and algorithmic moderation that suggests moderate freedom as an optimal solution in an “automated society”. [3] A vision that relates man and built artefacts in a single system. Pask’s plans remained an initiative – a controversial component of a much bigger project that, since it was never reduced to a single built work, continues to stimulate interpretations and thereby rejects the very notion of a reductive optimization.

**Toward a more Human Environment**

Across the Atlantic, Nicholas Negroponte and his Architecture Machine Group at MIT conceived a related project at model scale. SEEK exhibited as part of the Software Exhibition at the Jewish Museum in New York in 1970, consisted of a computer-controlled gantry system with a picker for moving blocks. Between the stacks of blocks lived a colony of gerbils representing the population of this cybernetic architecture environment. The system was tasked to learn from the unexpected behavior of the gerbils causing wreckage to the towers – or, put differently, to arrive at an ideal configuration. It did not quite work. However, the system integrated a computer vision system that was based on research by Marvin Minsky and Seymour Papert, two of the pioneers of artificial intelligence at MIT.

While Clynes and Kline meant to adapt the human being to an unsuitable environment by turning him or her into a cyborg, thereby making architecture or external machines ultimately obsolete, both Negroponte and Minsky shift the focus away from improving the human being and towards improving the machine by studying the human being itself. Seen from the perspective of the architect today, stacked identical blocks appear neither
particularly intelligent nor relevant as a contribution to a livable environment. For Minsky, however, the experiments of handling blocks stood at the core of his lifelong quest to understand human intelligence and, by transfer, to establish artificial intelligence. Minsky had experienced how they had struggled with the so-called Minsky/Papert eye to robotically copy a stacked arrangement of bricks. He wondered why a computer program would excel in solving “adult” calculus problems but would disappoint in a seemingly “childish” pastime. That is, he follows, because calculus is based on expert knowledge in one domain, while the task of stacking blocks involves many different categories of knowledge such as “shapes and colors, space and time, support and balance, and an ability to keep track of what one is doing”. Using the brick stacking as a fundamental example, he points out that “common sense” and “general competence” simply do not exist as primitive, disembodied faculties but are based on learning and knowledge. Common Sense is, thus, not a black box but instead something that can be studied, can be disentangled into different cognitive faculties all working together.

Digital Complexity, Material Simplicity
Half a century later, problems such as finding target objects based on edge detection, path planning and more broadly understanding context are still of concern in the field of robotics in architecture. Objects may today be of irregular shape - which makes everything a little more complicated - yet it appears reasonable to relate Minsky’s and Negroponte’s early experiments to the beginnings of our own investigation into robotic fabrication processes at ETH Zurich starting from 2005. As architects, our goal was to explore what the robotic arm can do for architecture as a discipline, rather than to just automate. Initially, it involved no machine learning - but we did learn. Moving slowly from accurate stacks of precisely rotated and placed bricks to the spatial assembly of linear elements, the rigorous analysis of architectural and constructive knowledge through the lenses of a robot defined our agenda. The opening of the Robotic Fabrication Laboratory in 2016 placed more emphasis on truly three-dimensional structures at building scale. Now able to build cooperatively with more than one robotic arm, parallel computed path planning for collision free trajectories was integrated. With the ability to build complex spatial geometries from simple elements, robotic joining methods, which have to account for tolerances, forces and material behavior, become more important. All this can happen at different scales, from the assembly of building elements to the assembly of whole buildings and down to the constitutions of the material itself. Jammed Architectural Structures demonstrates how loose gravel and ordinary string - each on its own without structural capacity - can be turned into a powerful building material with high compression strength.
Here, the information of the material through the robotic placement of circular string patterns transforms a heap into a seemingly archaic architecture. Heavy, yet temporal, the structure is fully reversible and can be returned to its mundane raw material.

**Our Intelligence, Our Machines**
The brief journey along some of the research we have been conducting underlines how we understand digital and robotic design and fabrication in architecture. Not as a new paradigm that exists independently from the long history of architecture and construction, but as an evolving system that integrates and extends existing traditional knowledge. It is a reformation rather than a revolution, which, in line with Minsky, considers complexity in architecture as arising from the integration of many, sometimes rather simple, processes into a comprehensive framework. If such framework is the future, we should ask what is and can possibly be inside this frame. Are we as human beings part of this framework – and if so, in which form? Can we only participate as “modified” people, as Gordon Pask envisioned the user of the Fun Palace?

Certainly, our knowledge based on reason, our evolving understanding of the world forms a basis for this framework. As Minsky argues, once there is an understanding of a phenomenon it can also be modelled into a digital process. Like “common sense”, he would reject the idea of “intuition” as some form of thing and instead see it as a wrapper for “the giant engines we’ve developed for understanding [...] which work so quietly, that they leave no traces in one’s consciousness”. [6] Strategically using the word “engine” for a process of the human mind, the spheres of the mind and the digital begin to blend. Consequently, the intuitive digital machine appears to be a reasonable outlook – all the more when comparing the state of today with the state almost fifty years ago when Negroponte published his seminal book *The Architecture Machine*. Today, machines have become very human in the sense of Negroponte’s understanding. They interface with humans, comprehend human touch and natural language, learn and have improved in understanding context. Associated concepts such as heuristics and hierarchical systems have moved the world of computation away from a binary world of true and false. The internet has turned software development into a collective effort that effectively harvests the intelligence of a global community. Computing power continues to get cheaper and quicker, and the advances of sensors allow for the control of agile, dexterous systems whether it is drones or robots.

Though Negroponte explicitly excluded automation from *The Architecture Machine*, the new levels of digital and robotic control have given rise to a race of automation that is gradually attracting more and more disciplines, including construction. Fueled by rapid ur-
ban growth in many parts of the world and a notorious reluctance of the construction sector to improve its productivity, automation and optimization are considered by many as the magic wand of architecture. With the human being as a user that is gradually digitized to become a discrete part of an architecture automation process from design to fabrication, is it then possible that at one point the architect will be made obsolete, replaced and rejected by a man-made mechanism ignorant of the complex nature of the human being?

Afterparty in the Fun Palace
Machines have become a part of us. They affect our behavior and our physical constitution. They regulate and expand our capabilities, trigger our fears and our optimism. It has become increasingly difficult to delimit their realm.

If we believe that artificial systems are truly rational, committed to reason and optimization, should we not simply step down and hand over control to preserve our own existence? Alternatively, should we reject such perfect regulation of the world in order to retain our human autonomy that comes with the freedom to question, modify, deviate from prevailing reason and rules? An author does not hesitate to choose the second option.

References