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For the first time in human history, more than half the population of the Earth now lives in cities. At the same time, cities are being transformed, often in dysfunctional ways, especially due to endless sprawl. The explosion of urban populations worldwide is now a common topic of concern. Cities are reevaluating smart growth strategies while seeking sophisticated transportation solutions to unprecedented levels of congestion. Meanwhile, energy and material resources continue to be depleted at an accelerated rate, inspiring a host of conservation programs and environmental reforms initiated by both the public and private sectors.

Architecture is currently undergoing one of the most fundamental and unprecedented shifts in its history, both in the eyes of its makers and its users. Given the newfound awareness of humanity’s undeniable impact on the health of our planet, coupled with the fact that buildings use roughly half of all resources, a new challenge has arisen that architecture must address.

For as long as we can remember, architects have attended to the fundamental qualities of function and form in their work. Create an edifice that is practical as well as beautiful, we were told, and you have succeeded. However, this simple recipe is no longer sufficient. We know architecture should not merely be a collection of attractive and pragmatic objects that suck large amounts of resources, serve the needs of relatively few people for relatively short periods of time, only to be demolished and injected into the great human waste stream. We now need more from architecture. In addition to function and form, architecture must be imbued with foresight.

Architectural Foresight

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Foresight does not simply consider ways to make a building last longer, although durability can be an important component of sustainable thinking. Foresight respects the future health of the environment and the lives of individuals beyond the targeted occupants. Foresight considers the entire ecology of material and energy resources that comprise a work, including their origins and their life after demolition. Foresight contemplates the welfare of the individuals affected by the work, from the building inhabitants to the laborers who manufactured the building materials, perhaps thousands of miles away. Foresight shapes architecture that, like life itself, produces as well as consumes, reincorporates all of its waste, and maintains an ecological footprint in balance with the requirements of its context. Foresight in architecture necessitates a fundamental understanding of the present and future material flows harnessed by building construction and product manufacturing. It is therefore imperative for architects to become more knowledgeable about material resources at both local and global scales. Today, major material shifts are occurring in the domains of energy, resources, and technology, all of which promise profound changes to our physical environment. An understanding of the coming challenges, as well as potential positive solutions to these challenges, will allow architects to lead, rather than follow, the change ahead.

**Energy and the Demise of the First Machine Age**

We cannot consider the human-made world without regarding the resources used to mine, manufacture, transport, construct, and distribute its physical components. History has shown us the extent to which various civilizations have been shaped by their energy resources, and how complacency in the face of dwindling supplies has led even the greatest empires to collapse.¹

We may face such a moment today. The international scientific community has suggested we may be nearing the brink of inestimable change, defined by the point at which half the Earth’s supply of crude oil has been tapped (peak oil), soon to be followed by the same halfway mark for natural gas. The term *peak* doesn’t mean the world will run out of oil; it is simply the point at which accelerating demand meets decelerating supply, a simple law of economics based on limited resources. No one is certain what the outcome will be, but the upheaval of international markets may be the least of our worries.

We are, after all, the great-great-grandchildren of the petroleum era. We may think of ourselves in futuristic terms, and claim to represent the information-age society, yet virtually every aspect of our lives is still defined by the extraction of fuels from fossils.

**Our Energy Diet**

How did we decide to unleash the energy stored, over billions of years, beneath the Earth’s surface as our primary fuel source? It comes as no surprise that humankind will exhaust fossil fuel supplies in a mere blink of the time required to store them. Should we not seek energy sources that may be harnessed “live,” in which the rate of depletion never surpasses the rate of storage? Could we not emulate real-time natural models for daily energy use (such as photosynthesis), and save long-stored supplies for peak or emergency uses?

Clearly, the energy use of society has increased exponentially since the dawn of technology. Today, the annual energy diet of the average American is gluttonous indeed; it amounts to the equivalent of 8,000 pounds (3,636 kilograms) of oil, 4,700 pounds (2,136 kilograms) of natural gas, 5,150 pounds (2,340 kilograms) of coal, and one-tenth of a pound (45 grams) of uranium.³ The United States is home to less than 5 percent of the global population, yet consumes 25 percent of the world’s energy.⁴ Not surprisingly, rapidly developing nations, such as China and India, desire greater energy shares. But at what cost? Approximately two billion people worldwide lack access to electricity or power.⁵ How do we justify such a massive disparity in energy accessibility today?

**Energy Regime Change**

An answer may reside in the form assumed by our current energy establishment, in which a centralized, hierarchical model, represented by a few large companies, dictates the energy outlook of most of the developed world. Unlike the Internet, which is a massively distributed information network, the fossil fuel regime more closely mimics the form of the early, inefficient, centralized telephone network. Our current energy network has not changed much since the industrial revolution.
American economist Jeremy Rifkin suggests our future energy milieu will closely resemble the Internet in its structure, open access, and lack of centralized control. The nonprofit organization Solar Electric Light Fund, for example, empowers developing communities with stand-alone power-generation systems and safe sources of nighttime illumination, demonstrating that the third world can improve its living standards without dependence on traditional energy networks. In communities with established energy distribution, the combination of high fossil-fuel costs, increased performance in renewable energy technologies, and local incentives, such as rebates and reverse-metering, point to a future comprising self-propagating, semiautonomous networks that share energy over shorter distances than traditional power grids. These networks will be messy and complex, encouraging creative trading partnerships between neighbors seeking to optimize power use while avoiding peak loads.

While much of today’s alternative energy buzz focuses on “off the grid” strategies, these tendencies are really the desire for freedom from centralized power models. In reality, rather than energy independence in stand-alone situations, we should seek energy interdependence via new models, since power reliability, effectiveness, and use options will likely be superior in a new energy web. The propagation of wireless energy technologies using electromagnetic resonance to convey power over short distances without cables or batteries will facilitate this interdependence.

Like wireless communication networks, wireless power will lead to freedoms and security vulnerabilities, resulting in the development of sophisticated access protocols as well as concerns about the effects of low-level radiation on the body.

**Creative Conservation**

As energy costs continue to escalate, conservation measures will likewise intensify. In a 2008 exhibition at the Canadian Centre for Architecture examining architecture’s response to the 1973 oil crisis, curators Giovanna Borasi and Mirko Zardini remind us of the stark conservation measures mandated by many nations after the OPEC oil embargo, including designated car-free days and imposed curfews on business and nighttime illumination. Given the price of a barrel of oil quadrupled in a little over one year, it comes as no surprise such drastic strategies were implemented.

While the 1970s oil crisis was largely a politically motivated maneuver orchestrated by Arab nations after the peak in United States’ oil production, today’s crisis relates to the imminent peak in global oil production. In other words, the physical limitations of a natural resource have led to our current situation. While this distinction poses a much larger threat to our current energy status quo, there is hope the change will occur more gradually than during the 1973 oil crisis. More time would mean more creative conservation solutions could be developed.

Some of these solutions will likely come from the study of how nonwestern cultures relate to matters of energy consumption and conservation. The Japanese, for example, believe in conditioning bodies versus space. The focus on heating and cooling people—via high-tech devices, such as infrared-sensing heating, ventilating, and air conditioning (HVAC) systems, or low-tech means, such as increased ventilation in summer, or portable, electric devices in winter—results in considerable savings compared with typical energy use in the United States. This strategy also allows increased natural ventilation, meaning buildings in Japan often have healthier interior environments.

Creative solutions for energy conservation will also include renewed scrutiny of lighting strategies. After all, artificial illumination is used in many circumstances when free daylight exists outside. It is precisely
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because buildings are largely constructed with opaque, light-reducing materials, deep floor plates, and inadequate penetrations, that artificial illumination is so widely required during daylight hours. Artificial lighting not only consumes energy and materials, it adds to the heating load of buildings. However, a new generation of sunlight-delivery systems offers a solution. The Parans Solar Lighting system, manufactured in Sweden, uses fiber-optic technology to deliver sunlight via rooftop magnifying units to remote “skylights” located deep within a structure. [Fig. 02] Tokyo-based Material House’s Mirror Duct system functions similarly, reflecting ultraviolet-free light with highly efficient mirrors far inside interior spaces. The delivery of reflected sunlight within building interiors can increase occupant health and outlook, as natural diurnal cycles are reinforced by variations in light levels and coloration. Moreover, interior, daylight-delivery strategies can support plant growth while mitigating mold development in wet areas. These kinds of natural strategies should help architects remember the critical role daylight played in defining space, long before interior conditions could be modified by the flick of a switch.

Growing Materials

Ending our addiction to fossil fuels will also require the development of new alternatives to petroleum-derived products. Bioplastics, for example, will replace traditional plastic with polymers developed from various agricultural products. Corn-derived polyactic acid (PLA) has already replaced a significant percentage of petroleum-based plastic packaging in the consumer market, and wood fibers from rapidly renewable plants like kenaf may be incorporated with PLA to produce sturdier, longer-lasting products such as cell phone shells, laptop casings, and automobile body parts. [Fig. 02] Many bioplastics also possess properties superior to traditional plastics, such as biodegradability, shape-memory capabilities, and 100 percent horizontal recyclability. Like biofuels, however, bioplastics production raises the ethical dilemma of appropriating food substances for other uses. Using agricultural products to provide energy or create new consumer goods rather than feed people will likely be one of the great controversies of the current century.

Reducing energy embodied in materials will also be an important strategy for mitigating our petroleum dependency. Since the discovery of fire, humankind has used heat extensively in the manufacture of materials. Despite the fact material production methods have become increasingly sophisticated over time, we still use the “heat, beat, and treat” method of manufacture, employing great amounts of heat, pressure, and processing to synthesize stuff from natural resources. The result is that our constructed environment is largely “cooked.” Constructed from concrete, wood, steel, brick, glass, and so on, the buildings and cities that
surround us retain the record of the vast quantities of expended energy required for their existence. However, there is an alternative model that promises to reduce or eliminate this embodied energy, as well as redefine conventional manufacturing methodologies. Biomimicry, or biomimetic design, looks to natural principles for inspiration and guidance. In terms of fabrication, nature creates many materials—some of them many times stronger than our best performers—using biochemical methods. Mimicking these processes means growing materials rather than manufacturing them.

Rethinking Resources
I once saw a bumper sticker that read “If you ever had enough, would you know it?” This simple phrase delivers a sobering blow to our consumption-based zeitgeist. Although it is uncomfortable to contemplate, we need to consider: Would most of us, given the chance, live up to whatever living standard we were afforded, no matter how luxurious or prodigal in nature? Don’t we all seek more than we currently have? But how many bedrooms do we really need? How many cars, computers, or calories, for that matter?

The point here is not to instill guilt, but to encourage awareness about what resources fulfilling lives truly require. Until recently, there have been few means for determining an individual resource-allocation standard, so it is no wonder, in a throw away economy, we have rarely considered such a notion. However, researchers are developing an increasingly accurate picture of our ecological footprint.

Scientists now tell us that we exceeded the world’s ability to sustain our current lifestyle during the late 1980s, at which point we began using natural resources faster than the rate of replenishment. According to the World Wide Fund for Nature’s 2004 Living Planet Report, society’s ecological footprint outstripped the globe’s capacity by twenty percent in 2001.

Citing a recent United States Geological Society study, American environmentalist Lester Brown informs us that we will exhaust known stores of several metals, including lead, copper, iron ore, and aluminum, vital to construction and other industries, within the next two to three generations. Although recycling efforts have accelerated, virgin materials are still being harvested at an alarming rate. Metals aren’t the only substances being rapidly depleted; timber extraction is also highly controversial, with the near disappearance of old-growth forests worldwide via uncontrolled land development and deforestation.

What will the world be like when virgin materials become too expensive, difficult, or controversial to harvest or extract? The average building today relies upon a great quantity of these resources for its construction. Faced with these facts, we can easily imagine a future in which industry has completely reengineered its handling of material resources. After all, there seems to be no other choice.

Coming to Terms with Waste
As if resource extraction isn’t bad enough, we must also consider its evil twin: waste. Homo sapiens is the only species that creates what may be truly considered waste (matter that is difficult to reincorporate into the natural cycle). We create waste coming and going, creating and destroying, preserving and dismantling. The construction industry is the most wasteful, with 136 million tons of construction debris generated annually in the United States.

Not the least of our concerns is the waste produced in the form of greenhouse gases resulting from industrial processes and construction activities. The embodied energy present within new products and materials also indicates proportional amounts of carbon dioxide released into the atmosphere during their manufacture. Concrete is responsible for 7 to 10 percent of global carbon dioxide emissions, making it the third largest contributor to global warming after transportation and power-generation.

Dematerialization
Predictably, the relative resource consumption levels of materials are being carefully examined, resulting in less-substantial products that perform similar to or better than their predecessors. From the Stone Age to today’s era of advanced fibers, there has been an accelerated thinning of materials. The recently developed synthetic fiber Zylon, for example, possesses approximately twice the tensile strength of steel and twice the tensile modulus of Kevlar, not to mention unprecedented lightness and fire resistance. Common materials like concrete are also being
transformed via lower-embodied-energy cements and lightweight high-performance aggregates, generating products with half the weight, better thermal resistance, and similar strength to conventional concrete.\textsuperscript{16}

One of the results of this trend is that, in general, architectural cladding has become thinner and more complex over time. If we were to graph the thickness of the wall over time, we would witness the emergence of an accelerated trend line, from the stone walls of Egyptian temples to modern curtain wall structures. The wall cavity has also become more intricate, with multiple layers of materials designed to perform a variety of functions, including solar radiation mitigation, moisture protection, and insulation.

Another intriguing development concerns dematerialization, in the form of increased light- and view-transmittance in architecture. Optical-fiber-embedded, light-transmitting concrete, for example, conveys significant levels of illumination and crisp shadows through a medium historically associated with solidity and opacity. \textsuperscript{[Fig. 04]} High-alumina and corundum ceramics likewise yield strikingly transparent materials with high strength, hardness, and wear resistance. Aerogel-infused building panels make light transmittance possible within insulated, fire-resistant cladding systems. These technologies indicate a compelling, potential future for architectural illumination and point to the dissolution of a clear boundary between the wall and the window in architecture. As light- and image-conveying materials become endowed with “wall-like” properties related to structure, thermal performance, and fire resistance, we will continue to witness the deopacification of the wall.

\section*{Renewal}

Materials are also being studied for their potential to lead second lives, rather than be disposed of as waste once they have served their originally intended purpose. The escalating buzz surrounding the environmental movement, accompanied by trends like the self-described Lifestyles of Health and Sustainability (LOHAS) market segment, highlights a newly emerging, aesthetic predisposition. Personal products and accessories made with reused content increasingly garner positive status due to the more meaningful message carried by “recycled chic” versus the generic consumerism of luxury brand-names.

This movement informs us that trash can be transformed into art, a fact that alters the problem from how many resources do we need, to how creatively can we use the resources we have? When the least wanted materials are incorporated into the most desirable products, we realize the power of design. However, the waste challenge is significant enough to merit not only product-level solutions, but also applications at architectural and infrastructural scales. Manufacturers have begun to fabricate building surfaces containing high percentages of repurposed waste, such as solid-surface countertops made completely of household, high-density polyethylene (HDPE) containers, and translucent wall panels made of fused waste glass from building construction sites. Alternative architectural practices—exemplified by operations such as Rural Studio, ZEDFactory, and the Office of Mobile Design—likewise demonstrate that design can be just as much a creative form of reconnaissance as synthesis, because the act of seeking out salvage materials for reuse in construction can often yield promising and highly unexpected design results, while using fewer virgin resources and diverting existing material from the waste-stream. In this way, an architecture generated through salvage may impart deeper meaning than one comprising virgin resources.

Another important factor related to waste is the production of material byproducts, such as volatile organic compounds (VOCs) that degrade environmental quality. While much attention has been paid recently to reducing the VOC levels in materials such as carpet, paint, and sealants,
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another trend promises to upend conventional strategies for improving air quality. Using the photocatalyzing properties exhibited by compounds like titanium dioxide, new cements, such as used in Italcementi’s TX Active concrete, and paints, such as Reben, have been formulated to reduce ambient air pollution in the presence of sunlight. Rather than simply degrading environmental conditions less than their conventional peers, these products improve them. [Fig. 06] Considering the unprecedented levels of pervasive pollutants now present throughout the globe, this trend promises to play a much-needed role in remediating the environment.

The Living Machine

When Silicon Valley pundit Kevin Kelly talks about technology, he personifies it as a global-scale entity with its own desires and predispositions. Technology wants to increase its own ubiquity, power, accessibility, and replicability, he claims.17 When we look at trends in technology—charting computational power against time, for example—a parabolic arc emerges indicating the consistent acceleration of technological development. After four decades, we are witnessing the perpetuation of Intel cofounder Gordon Moore’s observation that computational density doubles within a given unit of time. However, what happens when change occurs too fast? What will it be like when the gentle curve approaches a vertical line—when Moore’s Law becomes Moore’s Wall? For example, how will we respond to technologies that advance every second at a rate that used to require a month? Environmentalist Stewart Brand, inventor Ray Kurzweil, and others describe this moment, called a singularity, as a point at which the old rules change and we enter a new epoch defined by a completely new set of circumstances.18

It is clear a significant transformation is taking place within the fields of design and architecture resulting from the dramatic influx of new materials and technologies. Influential thinkers in fields as diverse as biomedicine (Francis Crick), philosophy (Manuel De Landa), and economics (John Young) point to a new materialism brought about by advances in science and an increasing awareness of humankind’s physical influence on the Earth.

In the spirit of Kevin Kelly, author of Out of Control, one could imagine technology has become aware of its effect on the planet and is adapting accordingly.19 Traditional models of technology position it in contrast to nature, but as technology becomes increasingly sophisticated the lines begin to blur. The nanoscale experiments occurring in laboratories, the endeavor to map and manipulate life’s genetic code, the development of parallel computing and complex networks, and emerging biomimetic technologies and manufacturing processes, all point to the gradual merging of the mechanical with the biological. If technology is, in fact, now becoming conscious of resource limitations, perhaps it will work more in concert with nature than against it. For example, cleanup efforts are being conducted in China’s rivers, Kelly states, not only for health reasons, but also because silicon chip manufacturers require clean water.20 Closed-loop manufacturing processes, which operate more like natural models than industrial-era methods, have been shown to make efficient use of materials, significantly reduce or eliminate waste, and create economic success.

Smart Technologies

One of the most environmentally friendly developments in building technology is the capability to monitor and regulate energy and resource consumption. Since the beginning of the industrial revolution, widespread consumption of cheap energy from fossil-fuel sources has promoted waste; today, however, rising energy costs encourage conservation
measures, and building-integrated, resource-monitoring technologies can prove economically viable over time. For example, Stephen Gage and Will Thorne have proposed a collection of facade-roving robots, called “edge monkeys,” that monitor energy use by checking windows, regulating blinds, monitoring thermostats, and even signaling building occupants regarding their own energy consumption. [Figs. 06–09] Less technologically sophisticated approaches include building-integrated daylighting systems with photo sensors, automated operable louvers, and dimmable lighting controls. These technologies make design a spatiotemporal affair: interactive systems like these have the ability to influence form directly, and are therefore like architectural editors, continually tweaking and adjusting the performance—and aesthetics—of architecture.

This persistent transformational quality is, after all, more like life itself, and the architect’s role shifts from that of a musician playing a fixed performance to that of a director orchestrating a collection of diverse, semiautonomous players. As today’s material revolutionaries coax technology toward a more diverse, complex, and specialized future, we are witnessing the mechanical age shift into the biomimetic age. Although current examples emulate living systems in terms of form or performance, future materials will also emulate life in their fabrication, and products will be grown rather than manufactured.

**Material Frontiers and the Architect**

During previous material epochs, humankind privileged the development of particular materials over others, such as the focus on metallurgy in the mid-twentieth century. We now live in a time in which all material frontiers are being explored at once. Materials science advances are unprecedented in their number, diversity, and distribution. With regard to construction materials, we only have to pick up a recent design industry journal to see the extent to which manufacturers are scrutinizing and retooling their product lines. Increased awareness concerning changes in energy, resource allocation, and technology has led to a veritable explosion of creative material solutions, and these solutions are increasingly taking cues from natural systems. The establishment of distributed, semiautonomous, renewable-energy communities; the trajectory toward closed-loop fabrication and the creative transformation of waste into
art; as well as the increased sophistication, diversity, and interactivity of technology, all highlight a positive trend toward biomimesis, albeit at an early stage.

In this brave new world for architecture, architects must place as much emphasis on research and teaching as they do on practice, because the complexities of future challenges and the expertise required for new solutions leave us no other choice. Tomorrow's architect will possess a thorough grounding in materials science, the mechanics of industrial ecology, and advanced environmental building practices. She will be a vigilant student of technology and its future directions, incorporating innovative techniques, products, and systems as appropriate, in order to push the boundaries of architecture. Moreover, the future architect will also be actively engaged in the public realm, creating profound connections with leaders in other fields and advocating the power of design through far-reaching, collaborative endeavors. In this way, tomorrow's architect may act as a catalyst, releasing the creative potential inherent within all people for the betterment of the physical environment.

Let us not forget change is imminent. Clearly, serious consideration of issues relating to material flows and processes in architecture will be essential. There has never been a better time for architecture to live up to its full potential and demonstrate its value to all. The future is here, and every one of us has a stake in it.

NOTES
9. Ibid.