IN SERVICE 10 SOCIETY STRATEGIC VISION FOR

CIVIL AND ENVIRONMENTAL ENGINEERING

Department of Civil and Environmental Engineering University of Michigan





INTRODUCTION

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This is undoubtedly one of the most exciting times to be in the profession of civil and environmental engineering. We deal with the design, construction and operation of large-scale infrastructure systems while advancing solutions supporting stewardship of environmental systems. Fundamentally, our profession advances the economic prosperity and quality of life of our society. More than any other engineering discipline, we are in service to society advancing the common good.

Today, the field is at a major crossroads; how we proceed will define us for the remainder of this century and beyond. Technological change is occurring at a breakneck pace, offering a wealth of new tools and methods that will transform our approaches to solving problems. Powerful new sensing technologies and computational platforms are creating opportunities to monitor and model the performance of built and natural environments with unprecedented fidelity, and are shedding new light on pathogens in the environment that threaten public health. These emerging approaches are critical given the massive global challenges now confronting our society including climate change, rapid urbanization, natural hazards, global income disparity and aging infrastructure.

In 2010, our department published *Building on our Legacy: Strategic Directions for the Future*, a strategic plan that has informed our investments and growth over the past decade. The plan centered on expanding upon our legacy as a pioneer in science and engineering, by investing in new research and education programs necessary for the field to tackle emerging challenges that were certain to affect our society. The strategic plan especially emphasized a systems perspective, underscoring the importance of the interconnectivity between the components, processes and technologies associated with built infrastructure and natural systems. Nearly ten years later, after making significant progress in implementing our 2010 plan, we are proud to offer an updated vision and new strategic plan that will better position our profession as the scientific, technological and business leader forming multidisciplinary teams required to tackle the complex societal grand challenges ahead. Through a process that engaged our faculty, staff, students, alumni and partners, we have identified five strategic directions that will inform our future growth:

- *Human Habitat Experience* focuses on how members of society experience our engineered solutions to advance new approaches to system design that aim to enhance user experiences.
- *Shaping Resource Flows* explores the analysis and control of resource flows within our habitat to minimize their negative impacts on the environment and public health while achieving equitable resource management.
- *Adaptation* advances new approaches to adapting the design and operation of infrastructure systems to ensure societal sustainability and resiliency in the face of dramatic global changes.
- *Automation* pioneers new sensing and control methodologies needed to automate the design, construction and operation of the built environment while enhancing the efficiency and resiliency of infrastructure systems.
- *Smart Infrastructure Finance* examines new financing instruments for public and private infrastructure investment including new approaches to monetizing infrastructure data.

Our new vision recognizes that our discipline's leadership is urgently needed today. It is essential that our discipline remain the leader in advancing the data-driven frameworks our field will rely on in the future. This leadership is not only critical to managing the risk of domain encroachment by those lacking our hard-earned expertise but is increasingly integral to recruiting the best and most diverse students to enter our profession.

The rapid development of technology in the profession demands our curricula evolve just as fast, if not faster. We are responding to the urgent need to empower graduates with modern curricula; our program is committed to offering not only the technical tools but also the entrepreneurial mindset and notions of social responsibility necessary for them to emerge as the thought leaders of the future, working at the forefront of the profession.

For us to truly advance the state of our discipline, it is also essential that we test new technologies and methods at fullscale in realistic operational environments, and that we engage the public. We are breaking down traditional barriers between laboratory and field to accelerate research into practice by forming new partnerships with industry, government and other stakeholders. Our research is increasingly forming "living laboratories" where we can leverage these new partnerships to validate new frameworks at scale.

Now more than ever, our profession must embrace our role in service to society. The future is undoubtedly bright for civil and environmental engineering, and we are excited by the opportunity to lead the way.



OUR MISSION

Michigan Engineering provides scientific and technological leadership to the people of the world. We seek to improve the quality of life by developing intellectually curious and socially conscious minds, creating collaborative solutions to societal problems, and promoting an inclusive and innovative community of service for the common good.

Civil and Environmental Engineering at the University of Michigan strives to serve society by enriching habitats and sustaining resources. We leverage our diverse community of scholars to expand the boundaries and accelerate the impact of our profession.



THE LANDSCAPE

The profession of civil and environmental engineering finds itself in a complex landscape that will strongly influence how it can address the grand challenges facing society. This landscape is defined by dimensions of society, business and technology.

SOCIETY

The well-being of society and its inhabitants has been central to the field of civil and environmental engineering since its earliest origins. Inarguably, the advancement of civil infrastructure systems and improved stewardship of the environment have drastically raised societal standards of living across the globe. Looking to the future, our profession will be challenged by dramatic global shifts in population, climate and income distribution. Today the world's population is 7.6 billion, but it is projected to approach 10 billion by mid-century. Rapidly increasing urbanization has shifted more than half of the world's population into large cities. Continued population growth and urbanization will require well-designed infrastructure to ensure current standards of living can be maintained without compromising environmental quality or public health.

In developed countries such as the United States, aging infrastructure and reduced infrastructure spending are making it more challenging to protect public well-being and retain public trust in infrastructure. With population growth rates largest in emerging economies, societies in these economies will be especially challenged in meeting their infrastructure needs. These communities may also have greater risk exposure to the effects of climate change due to having fewer resources to prepare and adapt to changing climatic conditions.

BUSINESS

Economic growth is inherently tied to the infrastructure that supports the prosperity and security of society. Challenges such as climate change and urbanization could threaten future growth if infrastructure and the environment are strained. Hence, growth of the global economy will inevitably require innovation in all aspects of the infrastructure business. Inadequate longterm investment in infrastructure in many leading economies puts additional pressure on growth. In response, civil and environmental engineers need to find new and improved solutions to address these challenges and ensure infrastructure remains an engine for societal prosperity. The 20th century saw tremendous innovation in the profession to ensure the safety of the public. Today, we are expected to go beyond designing for safety and prescribe higher performance levels for our systems. To do so, civil and environmental engineering firms today crave tech-savvy professionals that have the capacity to conceptualize innovative ideas that shape the future. We need solutions that are technically sound, scientifically innovative and technologically current, yet also financially viable.

Traditional financing strategies based on a combination of debt and equity are insufficient to address the emerging financial needs associated with infrastructure renewal and expansion. As private financing plays an increasing role in infrastructure, a pressing challenge will be how the profession continues to uphold its leadership role in promoting social good.

TECHNOLOGY

A wave of emerging technologies will make the field of civil and environmental engineering the epicenter of societal innovation. The profession is already beginning to embrace the technological innovations originating from other domains including computing, sensing, DNA sequencing and synthetic biology, just to name a few. For example, a new generation of connected devices promises to make our habitats more responsive and adaptive. Computational power continues to grow, enabling modeling and data processing at previously unimaginable scales. Connected vehicles will transform the transportation landscape, while robots will build the cities of the future. Beyond information technology, new nanomaterials, membrane technologies, and sequencing methods will transform how we learn and respond to our toughest environmental challenges.

Civil and environmental engineers will become much more than mere users of these technologies. A new generation of civil and environmental engineers are beginning to seize the opportunity to lead the development and meaningful implementation of these technologies by relying on their deep domain expertise in the built and natural environment.

SOCIETAL GRAND CHALLENGES

Urbanization

Energy Security

Resource Scarcity and Preservation

Climate Change

Natural and Human-

induced Hazards

Living in Extreme

Environments

Aging Infrastructure and Next

Generation Infrastructure Needs

Education and Science Outreach

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GUIDING PRINCIPLES

Throughout its history, the University of Michigan has made high-impact technological contributions that have revolutionized the field of civil and environmental engineering. The Department of Civil and Environmental Engineering is globally recognized for its impact in water quality engineering and biotechnology, advancing the field of soil dynamics, pioneering design principles that enhance the safety of civil engineering structures, developing more sustainable construction materials, introducing sensors for infrastructure monitoring, and advancing the field of construction engineering and management as a science, among many more.

Looking ahead, the department will continue to tackle grand challenges that now confront our society by leading the pursuit of technological solutions while training the future leaders of industry. To achieve this mission, we will seek to expand the very identity of civil and environmental engineering to ensure our profession remains at the vanguard of emerging solutions. Three core principles serve as the foundation of our outlook and have strongly influenced our selection of strategic directions.





INTERSECTION OF SYSTEMS

Although there are still important scientific contributions to be made in many of the primary areas of the profession, we believe that future breakthroughs will emerge by understanding the "true system" that our habitat represents. Our habitat is fundamentally shaped by the interdependencies that exist among many domains, including people, natural and built environments, and cyberinfrastructure. First and foremost, what we do as a profession is centered on people and their experiences within this complex habitat system. Exploring how people and communities operate and prosper in their environments while focusing on how communities can be resilient to disruptors must be the primary goal when addressing current and emerging societal challenges.



EXPANDING OUR IDENTITY

Over the last century, our profession has established the core scientific principles that inform our approaches to environmental stewardship and infrastructure resilience. While the pursuit of scientific advancement will remain a defining feature of our profession, it is imperative that we broaden our pursuits by translating the technological advances from other fields to yield novel solutions geared toward habitat optimization. We must also lead the way in innovative implementation and validation of the solutions to ensure the best interests of society are served.



RAPID INNOVATION

Societal grand challenges are significant and urgent—they demand an acceleration of the innovation process to quickly move solutions from concept to deployment. We will actively work with all stakeholders to accelerate the conversion of scientific advances into engineering practice, modernize public policies that impede adoption, and educate the next forward-thinking engineers who will build and expand these new approaches in service to society. It is vital that our entrepreneurial spirit remain unencumbered to create the new business models that will be necessary to drive solution adoption while also ensuring our profession remains properly rewarded for its innovation.

HUMAN HABITAT EXPERIENCE

STRATEGIC DIRECTION HUMAN HABITAT EXPERIENCE

The built and natural environment frames the human experience; it facilitates human social interactions, enables movement of people from one point to another, and provides us with the air, water and food we need to flourish. Habitats are a cornerstone of our well-being as a society. With growing urbanization, the built urban environment will continue to be pivotal in human lives. The increasing importance of infrastructure in the human experience means that civil and environmental engineers will work closely with social sciences, public health and anthropology to enhance the experiences of humans in their various habitats.



We will work to enhance the human experience by promoting interdisciplinary designs that are based on close collaboration with the public. Developing new ways to empathically listen to residents will be critical in order to understand how people experience their built environment and how the infrastructure can subsequently adapt to improve and complement this experience. We will also improve the fundamental understanding of how habitats impact the human experience, including human decision-making and trust in infrastructure. Our focus must be on forming habitats with low water and carbon footprints so that these experiences are sustainable for future generations.

This human-centric focus requires an informed public, empowered to improve their built infrastructure and land, air and water resources. We will lead the way in educating and engaging the public in how infrastructure is used to the benefit of people, and we will educate the next generation of civil and environmental engineers to apply interdisciplinary principles in their infrastructure design.

(Left) University of Michigan researchers are designing novel, nonintrusive methods to monitor and control the quality of the built environment for improved health and well-being of building occupants. Here, U-M researchers inspect a robotic platform that monitors and maps air temperatures and air quality to facilitate automatic control of building heating, ventilation and air-conditioning systems.

(Right) Smart cities will have dense sensor networks deployed throughout our built environment. To truly enhance the habitat experience, citizens must derive benefit from the data these networks will produce. Our researchers are exploring how cities of the future can use their data to empower all city stakeholders by working with Detroit youth in deploying urban sensors.

Air pollution is the world's biggest environmental health risk, with

MILLION DEATHS

worldwide in 2012 attributable to ambient air pollution.

From 2000 to 2015, the global number of people without at least basic sanitation provision increased from 567 million to

MILLION. 5 5

By 2050, the number of people living in extreme poverty in urban communities worldwide, already close to 1 billion, could rise to



FRAMING THE HABITAT EXPERIENCE

Detroit, Multiple

INCLUSIVE MOBILITY

Researchers are working closely with underserved communities to study how their voices can be incorporated into designing next-generation public transit systems that are more responsive to their mobility needs. Improvement in the mobility of citizens can translate directly into improved access to employment, healthcare and education.

UNDERSTANDING MICROBIOMES

Our urban water system contains multiple complex microbial biomes that play important roles in human health and water infrastructure integrity. Researchers in CEE are studying the linkages between water and human microbiomes so that water infrastructure can be managed to maximize function and protect human and environmental health.



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TAKE A DEEP BREATH

Diseases transmitted by air can spread rapidly from person to person; some, like swine flu or avian flu, can even spread from animals to humans. Sterilization of ventilated air, for example using the non-thermal plasma device developed by U-M researchers seen here, can help prevent the spread of airborne pathogens.

SENSING STRESS

University of Michigan researchers are exploring methods to improve human mobility within the built environment, with particular focus on vulnerable individuals such as the elderly and people with physical disabilities. Here, a U-M graduate student discusses the use of wearable sensors that can help determine where elderly populations experience stress when interacting with infrastructure to determine what interventions could alleviate that stress.



THE WATER EXPERIENCE

Water quality and availability shape how people experience and value water. Through close collaborations with researchers in the disciplines of ethnography and epidemiology, U-M researchers are exploring how people experience the engineered water system and how water ultimately impacts nearly all aspects of their life.



SHAPING RESOURCE FLOWS

STRATEGIC 2 DIRECTION 2 SHAPING RESOURCE FLOWS

Resources and their flows are vital for sustaining the well-being and prosperity of society. These resources are finite, and their distribution across the planet and its communities is uneven. The imbalance in resource flows is widely believed to be a root contributor to global warming. Fortunately, the global and regional systems that civil and environmental engineers envision, design and build are ideally positioned to alter the flow of resources to create more sustainable habitats. We are reimagining how to manage resources, implement new scientific approaches, design innovations, develop business models and create more equitable access to resources in ways that disrupt the modus operandi. In this way, the efforts of civil and environmental engineers will create efficient resource utilization and sustainable resource management.

We are rapidly moving from a single-use mindset to a circular mindset around use and management of resources. Materials previously classified as waste, such as municipal and industrial waste, can be safely repurposed for use by other sectors of the economy or other communities. New approaches to capturing and managing all sources of fresh water, such as urban stormwater, can combat water scarcity and provide greater water security. Rich nutrients can be extracted from urine and used to produce fertilizers for food production. Carbon dioxide emitted by industrial processes, including in the creation of infrastructure materials, can be collected and sequestered in built infrastructure.

Novel approaches to managing resource flows require new ways of thinking and interacting with stakeholders and society, who are the ultimate managers, consumers and also producers of resources. We are using the principles of co-design and community engagement to share knowledge in ways that result in user engagement and conservation-minded behavior.



Like many other human wastes, source-separated urine is rich in valuable resources, namely nitrogen and phosphorus. Our researchers are developing new technologies to collect urine and convert it into fertilizer. We also seek to understand and address the infrastructure and societal barriers to capturing nutrients from urine.



gallons of stormwater went down the drain in California, enough to supply 1.4 million households for a year. In the next ten years, U.S. local governments will spend over

SBOO BILLION to replace 1.6 million miles of aging water infrastructure. On average, everyone uses **KILOS** of resources

extracted from earth every day—metal, fossil energy and minerals. If you live in the western world this number is much higher—up to 57 kilos of newlymined minerals per day.

SHAPING RESOURCE FLOWS

BY-PRODUCTS AS RESOURCES

Flying, ground-based and underground sensors can be used to monitor and optimize the generation of biogas from the degradation of municipal solid waste. The biogas is then used for energy production for the communities in the grid. Such new approaches, that are now possible with next-generation sensors and computational performance models, change the paradigm of by-products from hazards to be contained to resources to be harvested.



MAKING WAVES

Ocean wave energy constitutes a tremendous, untapped resource for utility-scale power in the United States. However, the development of devices to harness this resource is an enormous challenge. Not only must such devices be able to survive the harsh conditions encountered during storms and hurricanes, but they must also be equipped with sophisticated control systems that maximize the amount of energy they harvest from random waves. At the University of Michigan, researchers are collaborating with a number of commercial wave energy device developers to better understand control system design for these devices and to maximize energy output.

RESOURCE CYCLES

The way we harvest and leverage resources is constrained by how we initiate the infrastructure design process; it is influenced by "the way things have always been done." We are re-envisioning the value of wastewater, stormwater, solid waste and even waves as resources by exploring disruptive and transformative approaches to achieve efficiencies in resource harvesting. Here, a University of Michigan researcher works with a system that achieves resource recovery through energy offsets, enabled by sensor-mediated control.





LOCK IT DOWN

University of Michigan researchers are finding ways to sequester carbon in manmade materials, such as engineered cementitious composites or "bendable concrete" as shown here. The resulting product not only locks away carbon that would otherwise enter the atmosphere, but also has mechanical properties that may be superior to traditional concrete.

ADAPTATON

STRATEGIC 3 ADAPTATION



(Above) Flooding in densely populated areas has remained the costliest natural hazard of all weather-related events in terms of fatalities and material costs. Past events are clear harbingers of what is yet to come: estimates indicate that the number of people residing in the flow path of high-risk floods will double (from one to two billion) within two generations. CEE researchers are developing new computational methods to characterize floods at high resolution and quantify uncertainty in order to better understand and predict floods.

(Opposite page) The Amazon rainforests are highly biodiverse and play a critical role in global water, energy and carbon cycles. With no general consensus over rainforest vulnerability to the increasing drought frequency in the region, CEE researchers traveled to the Amazon to collect data on how trees respond to global climate changes.

Adaptation is essential to any species' survival. Some animals change their coloring to blend with their environment. Others migrate to find more favorable climates as environmental conditions change. Humans are no different—we too need to adapt to external stressors such as climate change, urbanization, evolution of technology or resource scarcity. We must enhance our adaptive capabilities to be better prepared to understand, respond to, and/or mitigate the pressures of constantly evolving global demands.

Climate change, continued sea level rise and overpopulation require the adaptation of infrastructure to ensure its continued safe, reliable and economic operation now and in the future. Understanding how natural systems adapt in a changing human environment will help us understand how to live sustainably. Understanding resiliency of cities to evolving environments will inform decision-makers regarding where and how to optimally adapt in the short term (to specific events or hazards) and the long term (lifetime). Adapting transportation infrastructure to facilitate the deployment of automated vehicles will transform future mobility systems. This fundamental need for adaptive resilience can only be met through the development of new models, theories, technologies and materials that bring a multidisciplinary and systems-level perspective to engineering.

The need to understand the adaptation of the systems on which we depend will transform engineering education. Modeling of engineering problems that rely on solitary principles will be replaced by an encompassing view of systems where interconnectedness and multidisciplinarity are central.





In 2017, floods in South Asia killed



Natural hazards in the United States caused



Global sea levels have risen
200
in the last century, including more than
7
cm in the last 25 years.

ADAPTING TO MEET NEW CHALLENGES

ENGINEERED NATURALLY

Fish passage is an integral part of the civil infrastructure and energy grid. For too long, fish ladders were designed only with engineering constraints in mind, and biological consequences were ignored. Now, to help render our infrastructure sustainable, engineers are working with biologists and ecologists to better understand and quantify the interplay between fish species and flow conditions within these structures, leading to a "natural" design of fish ladders.





DYNAMIC ADAPTATION

Humans dynamically adapt to their evolving surroundings. This fundamental aspect of humanity is crucial to the successful long-term understanding and estimation of the resilience of communities to major natural hazards. Our researchers are enabling a new understanding of the ability of societies to respond to natural disasters and adapt to major perturbations by investigating community-level resiliency, which involves not only infrastructure resiliency, but also a human-centric dynamic adaptation assessment at the community level.

NEXT-GEN RESILIENCE MODELING

Extreme natural hazards, such as severe earthquakes and hurricanes, are among the most destructive forces to impact the built environment. Long-term adaptation of communities to such destructive forces requires the estimation of their resilience. Our researchers are developing a new generation of computational tools and models that will enable optimal strategies for supporting community resiliency to extreme natural hazards.





INSPIRED BY ORIGAMI

University of Michigan researchers are exploring origami-inspired structures that can morph into multiple new geometries to adapt their orientation, physical characteristics and function. Building components with multiple stable states could retrofit and adapt structures for ever-changing design requirements. Large-scale reconfigurable and deployable structures such as sea walls, bridges and shelters could be shared within a community and be used to reduce the impacts of natural disasters, and expedite recovery after the event.

AUTONOMY

STRATEGIC 4 AUTONOMY

The concept of autonomy has already generated a significant amount of public interest. From thermostats to robotic vacuum cleaners, autonomous technology is already permeating our daily lives. For civil and environmental engineering, autonomy encompasses the use of artificial intelligence, data, materials and robotics to revolutionize the methods of design, construction and operation of the built environment and the management of resources. Autonomy is transforming conventional infrastructure to smart infrastructure, allowing for robust decentralized infrastructure systems. It is reshaping our mobility systems and catalyzing new mobility services and business models. Rapid developments in other engineering fields are opening doors for new levels of autonomy in civil and environmental engineering. Automated vehicles interacting with instrumented highways, adaptive water and energy utilities that respond to changing demands, exoskeleton-empowered skilled workers capable of exceeding human endurance, and autonomous robots and equipment performing dangerous tasks involved in constructing civil infrastructure are now all within the realm of realization. The evolving proliferation of autonomy in civil and environmental engineering promises the emergence of new career opportunities that require a workforce with the skills to confidently apply new technologies across civil and environmental engineering domains. This necessitates a broad, multidisciplinary education in civil and environmental engineering that also trains future students in interdisciplinary areas related to computer science, data analytics, control, economics and business.

> (Left) Vehicle automation will revolutionize urban and rural mobility, and support a range of uses, from sole vehicle ownership to shared ownership, ridership and subscription services. The University of Michigan is not only the pioneer in the development and testing of automated vehicles, but also a leader in investigating the implications of vehicle automation on the design and operations of mobility services and systems.

> (Opposite page) University of Michigan researchers are designing and building new robots that can adapt to rugged and unstructured conditions, and can work collaboratively with human coworkers to perform a wide variety of repetitive and physically-demanding construction tasks. Here, a U-M researcher inspects a joint-sealing robot that adaptively performs work by self-programming its motion based on the encountered workspace geometry.



Widespread use of autonomous vehicles could eliminate

of all car accidents in the United States, prevent up to \$190 billion in damages and health-related costs each year and save thousands of lives. Cities around the world could spend as much as **TRILLION**

on smart tech over the next 20 years. The number of robots per worker is expected to

INCREASE 4 BY 2025.

REACHING NEW LEVELS OF AUTOMATION

CONNECTIVITY & AUTOMATION

Vehicle automation holds the potential to substantially improve traffic safety, facilitate mobility and reduce traffic congestion, fuel consumption and emissions. Our researchers investigate how to leverage vehicle automation and connectivity to transform traffic control, facilitate truck platooning and create innovative shared mobility services. Researchers also examine the implications of vehicle automation on highway infrastructure, urban land use and environmental justice.

MAPPING HAZARDS

Advances in automation are expected to dramatically change the way we design, construct and monitor geoinfrastructure systems to enhance their resiliency. CEE researchers are already using Unmanned Aerial Vehicles (UAVs) and land robots to better understand the impact of natural disasters on infrastructure by characterizing the surface and even the subsurface conditions at levels that were not previously feasible. Here, a UAV inspects a landslide following the 2016 Kaikoura earthquake in New Zealand.



HUMAN-IN-THE-LOOP DESIGN

The exponential growth in computing power at the disposal of engineers and scientists is resulting in models that produce massive sets of data. Technologies for automated mining of this data are crucial if the full potential of high-fidelity computation is to be unleashed. Our researchers are developing tools for automated human-in-the-loop data mining through virtual reality.





INFORMATION FLOW

By combining the flow of water with the flow of information, smart water systems have the potential to transform how water resources are managed on a real-time basis. Here, CEE researchers are deploying open source wireless sensors on a surface water system in Michigan. The data are used by local municipalities to manage the ecology of the stream and inform infrastructure investments.

SMART INFRASTRUCTURE FINANCE

STRATEGIC 5 SMART SNART SNART

(Below) The way we are financing infrastructure is stuck in the 20th century. But there are new ways to finance infrastructure systems – if you know where to look.

(Opposite page) Civil and environmental engineers will need to be trained in digital assets, information valuation and project finance models of the future. We are leading partnerships with the Business, Law and Policy Schools at U-M to holistically address the technical, business and social implications of future infrastructure design approaches. Public investment in infrastructure systems in the U.S. has tapered off, while demand for high-performing, high-capacity and resilient systems has grown. Current levels of public funding are far below what is needed to maintain, improve and expand system capacity to accommodate future demand and avoid the economic costs and inefficiencies associated with underperforming systems. In order to deliver on our mission of serving the public good, we need alternative financing mechanisms. Intelligent infrastructure, data analytics based on information derived from infrastructure, and the integration of performance data with financing mechanisms offer new opportunities.



Modern infrastructure is connected and automated through sensors and computational approaches that help us better understand the performance of these smart systems. Roads and bridges, water and energy systems, buildings and industrial operations—all are being designed to become more adaptive, responsive and resilient. The data generated in this information-driven approach can bring in new investors, attracted by the information efficiencies and value of the infrastructure and the premiums they can get if the infrastructure exceeds performance targets.

Smart infrastructure financing models can also democratize access to quality systems across income disparities. Traditionally, the credit rating of a municipality determines what they (and thus the people living there) have to pay to obtain investment. This tends to disadvantage lower-income communities, which often have lower credit ratings. Smart infrastructure financing has the potential to offset this disparity, since it does not depend on credit ratings only. Rather infrastructure performance and the value of the data derived from the infrastructure are largely uncoupled from credit ratings. With smart infrastructure financing, investors can access new cash flows and equity value from the data markets, not just fixed interest payments from the municipality. In this way, some of the debt burden is taken off the taxpayers.

These ideas are percolating in the finance world and require an understanding of the actual infrastructure. Civil and environmental engineers have a wealth of expertise to bring to the table. Our deep domain knowledge in designing smart infrastructure systems that are in harmony with natural environments, our capacity to harness data and distill information through engineering models, combined with our direct involvement with the potential applications and needs facing communities across the globe, is central to the digital revolution of smart systems. By helping to develop standards and benchmarks, civil and environmental engineers will enable the responsible and equitable integration of smart infrastructure design with efficient financing models in service to society.

The 10-year infrastructure investment gap in the United States is

Sec Same



More than \$5 trillion a year is available for infrastructure financing, of which

\$1.4 TRILLION can't be invested because the right financial models don't exist. Infrastructure shortcomings will result in a GDP impact of



in the U.S. due to lost business sales, rising costs and depressed incomes.

CREATING NOVEL FINANCIAL MODELS

BUILDING BLOCKS

Blockchain models are changing the way that we think about storing, securing and transacting data. The University of Michigan is collaborating with blockchain companies and institutional investors to allow researchers to prototype new blockchain and tokenization applications in smart cities. We explore how they can be leveraged across industries to impact payment models, track information from distributed sensors, and design smart contracts to increase transaction efficiencies and inform new data-driven financing and business models.

A NEW WORLD OF WATER

Rapid urbanization and industrial development has exerted tremendous pressures on global water resources, estimated to affect \$145 trillion of assets under management. This new era requires novel approaches to valuing, allocating and funding water projects, in arid climates just as in the Great Lakes region. There is a massive opportunity to modernize water production and delivery through novel sensing and financial technologies to enable real-time water markets.



PREDICTING PERFORMANCE

The University of Michigan is a leader in creating and deploying sensors in our built and natural environments, giving researchers unprecedented insight into how infrastructure systems perform under environmental demands. The data generated are being explored to inform private investment strategies by predicting future performance of infrastructure. Additional means of monetizing sensed data from infrastructure are being advanced to assist asset owners with financing infrastructure maintenance.





PRICING INFRASTRUCTURE

Financing our nation's surface transportation infrastructure has become more and more challenging. Our researchers are investigating innovative ways to properly price the surface transportation infrastructure. Based on vehicle trajectory and occupancy, the data-driven fine-grained pricing paradigm is expected to not only ensure cost recovery, but also yield efficient use of facilities and influence mobility service providers to reduce empty trips and increase vehicle occupancy.

LEADING THE WAY

We are entering a pivotal and truly exciting era for civil and environmental engineering. We must seize the opportunity to expand our identity and keep pace with a changing world.

We have charted five directions to guide us in this effort. We will move swiftly and with resolve to ensure that all of our actions—big and small—are closely aligned with this strategic plan. Fostering a culture of diversity in our academic community will be integral to our success. This diversity of perspectives and experiences will drive innovation and creativity in our department.

We will push ourselves, and pivot as needed, to ensure that our fundamental discoveries surpass the needs of the communities we serve. We will refine and modernize our curricula to equip our students to be leaders and agents of change in their careers. We will invest in new research areas through new faculty and renovated laboratories. We will engage communities as equal partners in our research to work collaboratively toward real solutions.

We recognize that this is only the beginning of a journey, with much work to be done. As we implement our strategic vision, we will document our progress and share what we learn. We invite you to join us in this effort of serving society and the common good.

www.UMServiceToSociety.org





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The strategic planning process was a collaborative effort among all members of the Department of Civil and Environmental Engineering at the University of Michigan, with special effort from staff and faculty members of the Strategic Planning Committee.

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