MIT CSHub

MIT CONCRETE SUSTAINABILITY HUB

CSHub Annual Report

An Overview of CSHub Research and Activities in 2019

March 2020

2019: A Year in Review

MIT CONCRETE SUSTAINABILITY HUB

The MIT Concrete Sustainability Hub (CSHub) is a dedicated interdisciplinary team of researchers from several departments across MIT working on concrete and infrastructure science, engineering, and economics since 2009. The CSHub brings together leaders from academia, industry, and government to develop break-throughs using a holistic approach that will achieve durable and sustainable homes, buildings, and infrastructure in ever more demanding environments.

During 2019, researchers persisted in this mission, innovating novel solutions to old problems in the fields of resilience, infrastructure, and sustainability. Their efforts led them to give 31 presentations in 21 cities—two of which were before members of Congress. In total, they published 9 journal articles, including one in the Proceedings of the National Academy of Sciences. CSHub researchers also contributed to broader conversations of sustainability and resilience in national media outlets like *The New York Times*, *The Wall Street Journal*, and *USA Today*.

As well as being a productive year, 2019 was a transformational one for the Hub. In the fall, it inaugurated it's third 5-year phase of collaboration with its industry partners the Portland Cement Association (PCA) and the RMC Research & Education Foundation. In this new phase, the Hub will harness the technical innovations developed during its initial phases to engage the broader public. To do this, researchers will employ sophisticated tools such as crowdsourced data, artificial intelligence, and the latest tools of data science.

The momentum generated during 2019 will carry the Hub into this exciting new phase. This report outlines just some of the past year's achievements that have advanced the Hub's stature and will continue to propel it forward.

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Photo by Christopher Harting for the MIT Image Library

CSHub Research

By the Numbers

7 Journal Articles

8 Research Briefs

4 Topic Summaries

Photo by Wing Ngan of Ink Design Inc.

Exceptional research is the Hub's central focus and its stellar researchers make that possible. They hail from numerous countries across the globe but possess a singular vision–to develop research that facilitates a sustainable and resilient built environment. Their work spans three general research topics: pavements, buildings, and concrete science.

Buildings

CSHub buildings research focuses on materials, energy efficiency, and resiliency. This research takes a life cycle approach, quantifying the environmental impacts and costs of structures from the cradle to the grave. Such an approach is vital for stakeholders to understand the complete picture of their building's impact.

Buildings Life Cycle Assessment

The emissions generated during a building's construction account for just a portion of its total environmental impact. Capturing a building's full environmental footprint requires an investigation of every stage of its life—from materials extraction, operational life, and deconstruction. This approach is known as life cycle assessment (LCA).

In a research brief released in July 2019, CSHub researchers applied their LCA approach to the energy consumption of commercial buildings. The brief, "Meeting Greenhouse Gas Reduction Targets in the Buildings Sector", estimated the potential for changes in energy efficiency and concrete mixtures for office buildings to help meet greenhouse gas (GHG) reduction targets. Researchers found that by adopting the latest building codes to improve energy efficiency and employing 50% low-carbon cementitious materials in concrete mixes (such as blended cements or supplementary cementitious materials), GHG emissions from office buildings would decrease by 12% over 50 years.

Though building to these latest codes can significantly reduce emissions, much of the built environment operates at a lower standard of efficiency. To reduce the impact of existing structures, CSHub researchers proposed a model for targeted retrofits in a topic summary on urban energy consump-

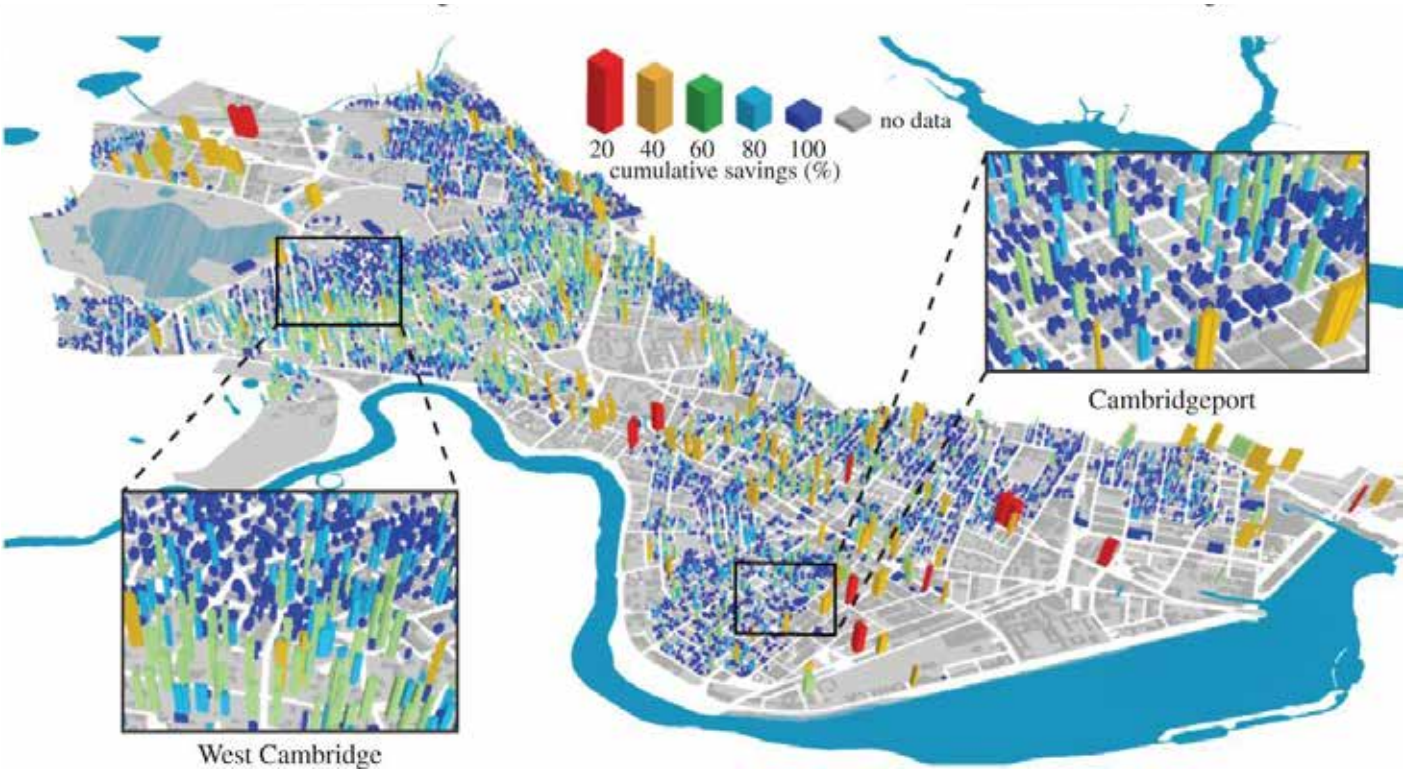

Fig. 1 The GIS map of buildings in Cambridge, MA, USA, with colors representing the retrofittability potential at the city level.

tion. They utilized gas bills, building footprints, and physical simulations to develop a model that would allow the City of Cambridge to retrofit only 16% of its building stock and see a 40% reduction in its overall gas consumption.

Buildings Resilience

When most think of a resilient built environment, they tend to think of structures capable of resisting hazards like hurricanes. But hurricanes are only one of many hazards threatening communities. According to the National Oceanic and Atmospheric Administration, heatwaves, not hurricanes, represent "the leading cause of weather-related deaths in the United States for the last 30 years."

Heatwaves are especially acute in cities, where the urban heat island effect (UHI) can exacerbate them. CSHub research seeks to predict and mitigate UHI—the phenomenon by which cities experience higher air temperature than their less-developed surroundings.

In a topic summary released in June 2019, researchers proposed a model that captures how the layout—or textures—of cities influence UHIs.

They found that cities with more ordered, grid-like textures can experience UHIs twice as severe as a city with a disordered layout. Unlike current methods, this city texture model can predict the severity of UHIs without the need for detailed

surface or air temperature data. Planners can then account for the UHI effect regardless of climate change's impact on future temperature levels. Ultimately, the aim is for stakeholders to employ this model to mitigate the impacts of UHIs by identifying vulnerable areas for retrofit.

Pavements

On average, pavements compose up to 44% of urban land area in America. This makes calculating their environmental footprint and costs vitally important. Just like with its buildings research, CSHub applies an LCA approach to capture these lifetime impacts.

Network Asset Management

More than ever, Departments of Transportation require a comprehensive estimation of their pavement network's lifetime performance and impact: According to the American Society of Civil Engineers, a fifth of the nation's highways have poor conditions while the backlog for their repair has risen to $420 billion.

In their April 2019 topic summary, CSHub researchers proposed a new pavement maintenance model for DOTs to overcome these hurdles. While conventional methods tend to employ rigid pavement management systems, CSHub researchers instead presented a more flexible approach. Their model considered uncertainty and incorporated a diverse set of paving strategies to decrease life cycle costs and emissions while also improving performance. To perform as well as the CSHub model, current methods would have to spend up to twice as much over 50 years.

Pavements Life Cycle Assessment

Since pavements are static, many assume that their environmental impact derives entirely from their construction. However, that is not the case. According to a CSHub case study, the use phase—or operational life—of a pavement can contribute up to 60% of its GHG emissions. Much of these emissions stems from the impact of a pavement on vehicle fuel consumption.

According to CSHub research, decreasing these use phase emissions may help contribute to reaching climate targets like the Paris agreement. In a July brief, researchers found that if Missouri increased its budget to past levels, cumulative savings would be equivalent to 1,000,000 passenger car trips of 58,800 miles each.

Crowdsourced Data

The United States has over 8.5 million lane miles of roads—the largest road network of any nation. But according to the ASCE, 20% of it is in poor condition.

To improve roads and reduce emissions, CSHub researchers released the Carbin app in early 2019. Using just a smartphone, Carbin measures pavement quality and its effect on fuel consumption while directing users to their destination.

The anonymous data users collect can then inform repairs that will help to improve roadways all over the world. By the end of the year, Carbin users had collected around 150,000 miles of pavement data in more than 20 countries.

Competition

In economics, competition plays a regulatory function in balancing supply and demand: as competition increases, the price for similar goods and services is expected to decrease. As transportation agencies search for new, cost-ef-

Fig. 4 A map of pavement data crowdsourced from across Greater Boston by Carbin users.

fective ways to preserve existing infrastructure, CSHub research shows how increasing inter-industry competition can offer them a way to more efficiently use their financial resources.

Concrete Science

Concrete is the world's most popular building material. It is therefore vital that it achieves the durability for which it is known. CSHub concrete science research focuses on two main mechanisms of deterioration in concrete that can lower its durability—freeze-thaw damage and the alkali-silica reaction.

Freeze-Thaw

As its name might suggest, freeze-thaw damage occurs when the water inside concrete expands as it freezes. The conventional understanding of freeze-thaw assumes that the damage originates from the pressure ice exerts directly onto cement. CSHub research conducted in 2019 has found otherwise. By simulating the freezing conditions within cement, CSHub researchers found that the salt trapped within the narrow layer of liquid water between the ice and cement may generate the pressure behind freeze-thaw damage. Their research was published in a March 2019 research brief and a paper in the *Proceedings of the National Academy of Sciences*.

Alkali-Silica Reaction

Alkali-silica-reaction (ASR) is a significant cause of premature concrete deterioration. While it has received extensive scholarly attention, questions remain about how the ASR gel can crack the concrete matrix. To develop a means of better understanding this gel, researchers at CSHub sought a basic understanding of it at the atomic scale.

Since ASR gel forms over several decades, it remains difficult to estimate its mechanical properties. In an April 2019 research brief, CSHub researchers proposed state-of-the-art atomistic methods to overcome the time-scale issue. This new method allows them to efficiently simulate the formation of these gels.

By the Numbers

7 MIT News pieces

6 stories in national outlets featuring CSHub research

CSHub Communications

Photo by Dominick Reuter for the MIT News Office

Though CSHub research regularly appears in scientific journals, its communications efforts ensure that this research is conveyed beyond the scientific community to key stakeholders and the public. Forms of communications material include MIT News pieces, videos, and infographics. In addition to this collateral, CSHub maintains strong connections with journalists in the national media and trade presses. The Hub's communications efforts during 2019 culminated in several placements in well-known outlets.

MIT News

MIT News communicates institute news and announcements to MIT faculty, staff, students and alumni as well as to the broader public. The pieces published in MIT News vary from public announcements to feature stories that draw the interest of media outlets from around the world.

MIT News is a key communications tool for CSHub. In total, CSHub published 8 MIT news pieces on a variety of topics, from network asset management to hazard mitigation. These stories have often proved instrumental in communicating CSHub research to the media.

In its next phase, CSHub will continue to utilize the resources of MIT News to ensure that its research has the greatest impact.

CSHub in the Media

Journalists from outlets around the world rely on CSHub researchers as trusted resources on issues of resilience, sustainable construction, and infrastructure science. This trust is reflected in the variety of major outlets that have featured comments from CSHub experts in the past year.

USA Today

As storm damage increases due to climate change and coastal development a demand has arisen for resilient infrastructure. Yet, many still do not know that resilience offers cost as well as safety benefits.

When interviewed for a piece in *USA Today*, CSHub's Executive Director Jeremy

Gregory explained these cost benefits.

"Over [a building's] lifetime, you spend more…on the repairs than on the initial construction costs," he said of construction in hazard-prone areas.

CNBC

The environmental impact of cement and concrete has become a heavily discussed topic. Much of that discussion has focused on reducing the embodied emissions of these materials.

Aesop's Fables, II
by Mark di Suvero
Located by MIT's Stata Center

Photo by Christopher Harting, September 2014

A number of companies have sought to reduce these emissions, developing increasingly low-impact cement and concrete.

In a video and accompanying article, *CNBC* discussed some of these innovations as well as the fundamentals of cement and concrete. Gregory was featured in both, explaining the barriers to adoption for these lower-emitting cement and concrete technologies.

Bloomberg

In the ASCE's most recent Infrastructure Report Card, America received a D+ rating. In an op-ed in *Bloomberg*, Gregory and PCA's Mike Ireland reiterated this pressing need for better infrastructure. Citing CSHub resilience and pavements research, they highlighted the environmental and cost benefits of building and paving more resiliently and urged members of Congress to act on the current infrastructure crisis.

Grist

As one of the premier environmental news sites, *Grist* is at the forefront of the conversations surrounding climate change and sustainability. In the fall of 2019, Grist's Maddie Stone contacted Gregory to better understand the environmental impact and the strategies aimed at reducing that footprint. Gregory's comments in Stone's November piece focused on the use of alternative fuels in cement production and the construction of more adaptable and durable buildings to lower the footprint of the built environment.

The New York Times

Since its release in early 2019, CSHub's Carbin app has grown rapidly. By January 2020, it had gathered several hundred dedicated users and collected over 200,000 miles of pavement data around the world. The app's growth garnered attention from *The New York Times*, which featured it and CSHub researchers in an article that became a Sunday Editor's Pick.

The Wall Street Journal

Low-carbon concrete has grown from a nascent technology to an increasingly viable tool for climate change mitigation. *The Wall Street Journal* chronicled this rise in a February 2020 piece that featured comments from Gregory. In the article, he explained the source of concrete's emissions and how carbon capture, storage, and utilization can reduce its carbon footprint.

CSHub Presentations

By the Numbers

31 Presentations in 21 Cities

2 Testimonies before Congressional Committees

1,600 attendees in total

Photo by Greg Gibson for The Bipartisan Policy Center

On a near-weekly basis, CSHub researchers present their work to the public–from the halls of MIT to the chambers of Capitol Hill. 2019 marked a particularly successful year for presentations, with invitations to speak at renowned venues.

National Press Club's Headliners Newsmaker Series

The first major presentation of 2019 was at the National Press Club's Review of the 2018 Hurricane Season on March 5.

CSHub's Gregory and NOAA's forecasting expert Gerry Bell participated in a discussion that focused on the effects of the 2018 hurricane season, the ongoing rebuilding process after the 2017 season, and how to prepare for future storms.

The event received attention in local media outlets in hurricane-prone communities throughout the South and Southeastern U.S.

Embodied Carbon in Buildings Conference

In the spring, CSHub hosted a major event in partnership with the Boston Society of Architects—the Embodied Carbon in Buildings Conference.

The conference convened several experts across the region to discuss sustainable construction. Gregory was one of those experts. In his presentation, he stressed collaboration in tackling the planet's climate crisis. "Change doesn't have to happen based on just technology," he noted. "It can also happen by how we work together toward common objectives."

House Committee on Energy and Commerce

In the Fall, Gregory returned to DC to discuss issues of resilience and sustainable construction.

First on his agenda was testifying before the Subcommittee on Environment and Climate Change of the Committee on Energy and Commerce. During the hearing, "Building a 100 Percent Clean Economy: Pathways to Net Zero Industrial Emissions," Gregory discussed the

role of concrete in sustainable development and strategies to reduce its environmental impact.

Bipartisan Policy Center

A week after his first testimony, Gregory returned to Capitol Hill to participate in the Bipartisan Policy Center's panel, "Reducing Natural Disaster Costs: Building Better and Stronger". In his conversation with Terry Dinan, a consulting economist from the Congressional Budget Office, he stressed long-term approaches to disaster mitigation.

"People [tend to] think in the short-term… [But] there are opportunities to change the norms we have associated with construction. Rather than viewing resilient construction as an alternative, and a premium, we need to think of it as the norm," he said.

Select Committee on the Climate Crisis

The next day Gregory testified once again before Congress, this time during a hearing hosted by the Select Committee on the Climate Crisis. During his testimony before the Select Committee, he discussed several strategies, including carbon capture, utilization, and storage, that could help the cement and concrete industries meet emissions targets.

La Grande Voile (The Big Sail)
by Alexander Calder
Located in MIT's McDermott Court

Photo by Dominick Reuter for the MIT News Office

The Road Ahead

From climate change to infrastructure crises, the next decade poses several urgent and interconnected problems. Through its singular yet interdisciplinary approach, CSHub is uniquely positioned to help guide the world's response to these pressing concerns.

In its next phase, the Hub will expand its scope, building on a robust foundation of research to investigate concrete's role in solving these economic, environmental, and social challenges.

In 2019, the Hub capitalized on this mission, beginning several projects that will drive its work over the next 5 years.

One of those projects is a report presenting novel solutions to durability concerns in concrete. The report, "A Scientific Investigation into Concrete Pavement Durability," developed in collaboration with the University of New Brunswick and Oregon State University, will provide a unified framework to improve the durability of concrete, as well as expand its functionalities, allowing it to conduct electricity and radiate heat.

Another Phase III project, Carbin, is now well underway. Through crowdsourcing, Carbin hopes to involve the public in conversations of infrastructure and climate change. CSHub researchers have already begun to collaborate with state departments of transportation and municipalities to best apply this data.

This kind of public engagement will prove key during Phase III. To sustain it, CSHub will develop numerous publicly-available online dashboards and design tools. The ultimate goal is to enable the public to better understand the broader impacts of infrastructure decisions as well as to equip practitioners and policymakers with the tools to develop sustainably and resiliently.

Though ten years have passed since the Hub's founding, its purpose—to achieve sustainable buildings and infrastructure in ever more demanding environments—remains more relevant than ever. With the inauguration of Phase III, CSHub will persist in this mission, developing breakthroughs that will inform the public of the road ahead.

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