WORKSHOP REPORT 3

Civic-Led Urban Adaptation Research Center

Developing a Digital Twin for Climate Adaptation

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HIGHLIGHTS

» The specification and therefore accuracy of New York City's basemap has not advanced in more than 20 years, limiting its utility for the ever-expanding climate change challenges and areas of responsibilities of city agencies.

» A major challenge to shared public data platform or a digital twin is how data is siloed in different public agencies throughout the city. When there is a climate change emergency, this inhibits the city's ability to respond quickly. The inability to share public data also creates additional costs for city agencies carrying out routine tasks.

» Public agencies expressed a universal desire to develop a platform for sharing data. The private sector has the capacity to help New York City develop a shared data system. For example, this capacity was demonstrated by combining multiple data sets to create a shared database of vaccine availability in the city during the pandemic.

» In addition to public agencies, New York City residents and civil society organizations also have data needs. Community members should be involved in designing any shared data platforms so these platforms can serve their needs.

» There remain unanswered questions about digital twins and climate adaptation: What level of complexity can be achieved that goes beyond current GIS systems? Who will be responsible for funding and maintenance? And ethical questions of individual privacy, liability, and security.

Workshop Reports contain preliminary analysis, findings, and recommendations. They are circulated to stimulate timely discussion and critical feedback and to influence ongoing debate on emerging issues.

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PROJECT OVERVIEW

The project is a one-year planning grant from the National Science Foundation (NSF) to develop a new Civic-Led Urban Adaptation Research Center (CIVIC-UARC) for New York City. The project brings together urban experts from across multiple disciplines and institutions, civil society organizations, and communities to support equitable, sustainable, and inclusive approaches to urban adaptation, assisted by innovative technologies. The team also engages NYC-based government agencies and private industry. Beyond creating new knowledge specific to New York City, the new Center aspires to produce useful research for cities across the U.S. that are grappling with climate change in the context of rising inequality and a legacy of environmental injustice. It will educate and train the next generation of investigators, change agents, and decision-makers working on just and equitable urban climate change adaptation. The work for the planning grant and the work of the new Center focus on three core research areas:

1. Adapting to Multiple and Cascading Climate Change Hazards and Risks

Effective, equitable, and timely adaptation planning requires a nuanced and comprehensive understanding of the hazards and risks associated with a rapidly changing climate. This research area, including a workshop on February 14, 2024, focuses on improving our understanding of how climate change hazards are spatially distributed across the city and how human behavior and activity, the urban built environment, and natural processes interact with one another. This research area is focused on multiple and cascading climate change hazards and the drivers of those hazards. The goal is to shed light on critical climate resilience challenges, with particular attention to pluvial and coastal flooding, urban heat and heat waves, and air pollution.

2. Climate Change Vulnerability and Community Capacity for Adaptation

An understanding of underlying community vulnerabilities and the capacity to respond to emerging climate threats is necessary for the equitable and effective allocation of climate adaptation resources. This report focuses on this research area and its associated workshop on February 15, 2024. Through them, the project team seeks to understand household and community capacity for care and climate vulnerabilities in two selected neighborhoods in New York City: Brownsville in Brooklyn and the Rockaways in Queens. The workshop drew on multiple data sources and existing vulnerability indices, but prioritized learning from residents' lived experiences and knowledge of sources of vulnerability and capacity.

3. Developing a Digital Twin for Climate Adaptation

Rapidly evolving digital technologies have the potential to support more coordinated and participatory urban interventions. This research area, including a workshop on March 15, 2024, examines the potential uses of a digital twin of New York City — a virtual representation of the city informed by live data streams from multiple sources — to support climate change adaptation. This workshop brought together panels of public sector and private industry experts. The aim is to create an open computational platform for decision-makers in the public and private sectors, researchers, civil society, and the general public to better understand climate-related issues and evaluate potential responses.

Image credit: Cornell Mui Ho Center for Cities

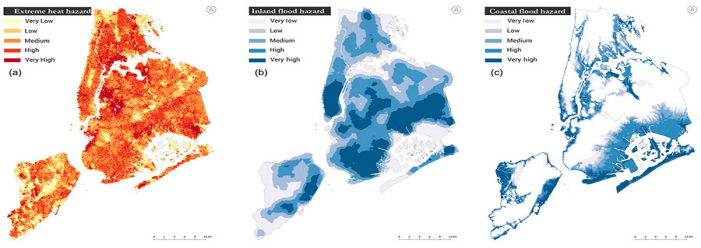

Image credit: Depietri, Dahal and McPhearson, 2018

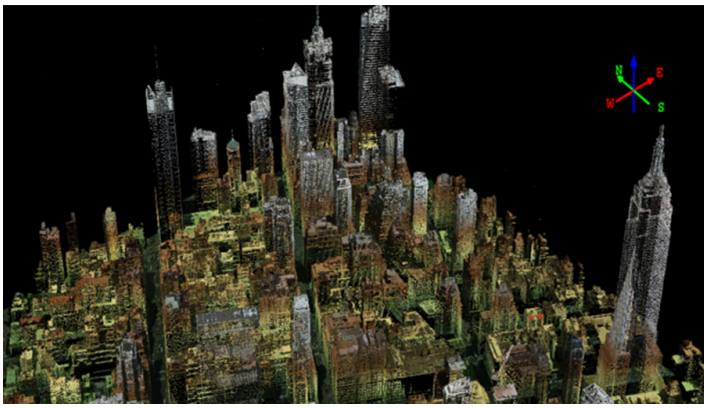

Image credit: Center for Analysis and Research of Spatial Information (CARSI Lab) at Hunter College – CUNY

WORKSHOP SUMMARY

A daylong workshop, "Developing a Digital Twin for Climate Adaptation in New York City," was held on March 15, 2024, at the Verizon Executive Education Center on the Cornell Tech campus on Roosevelt Island. It was hosted by the CIVIC-UARC Research Area Three team and discussed the potential of emerging digital technologies to support more effective and equitable climate-adaptation planning.

PARTICIPATION AND RECRUITMENT

The project team reached out to the invited participants through a variety of channels. As a first step, the project team contacted individuals already within the affiliated faculty's professional networks. With longstanding connections to leading experts in industry fields such as digital simulation, remote sensing, architecture and design, geospatial analysis, and urban planning, the CIVIC-UARC team brought together participants with a wealth of subject area knowledge. In addition, the project team identified potential municipal and industry participants by searching through the websites of critical public sector agencies and influential private sector companies.

The workshop included civil society and private sector representatives from: All Before Us, BetaNYC, RISE, Universe City NYC, The Waterfront Alliance, Arcadis, Esri, Fugro, MJ Engineering, Mott MacDonald, the Open Geospatial Consortium, Sanborn, Siemens, the Toyota Research Institute, and VHB. Public sector representatives attended from the Federal Emergency Response Management Agency (FEMA) and the following city departments: Metropolitan Transit Authority (MTA), City Planning, Environmental Protection, Finance, Health and Mental Hygiene, the Mayor's Office of Climate and Environmental Justice, NYC Emergency Management (NYCEM), the Office of Management and Budget, the Office of Technology and Innovation, Parks, and Transportation. Researchers from Cornell University, Hunter College - CUNY, and the United States Forest Service joined the workshop as well (Table 1). The participants did not receive any monetary compensation for their time.

Table 1 - **Types of Workshop Stakeholders**

Sector	Participants
Private industry	18
Research	28
Civil society	6
Public sector	16
Total participants	**68**

WORKSHOP PROGRAM

9:00 – 9:30 a.m. | Introductions and Objectives of the Day

Introduction of research team members and the concept of a digital twin. Explanation and background on the purpose of the proposed center on climate adaptation in New York City.

9:30 – 10:30 a.m. | Panel 1: Public Sector Use of Urban Tech for Climate Change Adaptation

A panel discussion about how NYC public organizations use technology to support planning processes and climate adaptation efforts, as well as pressing needs, areas of interest, and how digital twin technology could be leveraged to support participatory and inclusive climate-adaptation efforts.

10:45 – 11:45 a.m. | Panel 2: Understanding State-of-the-Art Digital Twin Technologies

A panel discussion about the "state-of-the-art" of digital twin technologies: their requirements, knowledge gaps, and potential for urban climate change adaptation work. Discussion of constraints, including ethical considerations and concerns associated with these emerging technologies and efforts to make them (and cities) more inclusive.

1:00 – 3:00 p.m. | Breakout Working Groups

Participants were divided into six groups, each led by a team member. The groups discussed one of three topics related to digital twins.

3:00 – 3:45 p.m. | Working Group Presentations, Summary, Next Steps, and Closing

PANEL 1: PUBLIC SECTOR USE OF URBAN TECH FOR CLIMATE CHANGE ADAPTATION

EXERCISE FORMAT & DESCRIPTION

Each panel began with a short presentation from each panelist. Afterwards, questions from moderators and audience members guided the discussions.

Panelists - Municipal Representatives
Michael Marrella (NYC DCP)
Carmela Quintos (NYC DOF)
Mallory Rutigliano (NYC OMB)
Melissa Umberger (NYCEM)
Roger Weld (NYC DOT)

Moderator
Sean C. Ahearn (CIVIC-UARC)

PANEL SUMMARY

Carmela Quintos (Assistant Commissioner of Property Valuation and Mapping, NYC Department of Finance) presented first on the NYC Tax Map and Property Information Portal. She introduced the topic and the history of the cadastre (a register of property showing location, value, and ownership for taxation purposes) in New York City, noting that as recently as 2008, only paper maps were used for property assessment. Ms. Quintos shared the work of her team at the NYC Department of Finance to develop the Property Information Portal, a software project that digitally records property within the city in three dimensions. Ms. Quintos discussed the challenge of directing her department towards more digital methods. She noted especially large barriers when attempting to harmonize disparate interagency datasets, such as between the departments of Finance and Buildings.

Mallory Rutigliano (Supervising Analyst, Environmental Sustainability and Resiliency Task Force, NYC Mayor's Office of Management and Budget) is part of the team responsible for New York City's climate budgeting. She shared that the practice of climate budgeting was pioneered in European cities such as Oslo, Norway, as a way to more thoroughly integrate climate-change planning into municipal practices and consider climate with other priorities. Ms. Rutigliano's team assesses the city's investments through the lens of climate impacts and focuses on annual budgeting efforts as well as longer-term plans. The team relies on digital tools for up-to-date information in order to evaluate past projects and to analyze and forecast the impact of future projects and initiatives toward climate goals. This work could potentially benefit greatly from the development of an interagency digital twin providing more, updated data on climate design.

Photo 1 - **Panelists from NYC DCP, DOF, OMB, EOM, and DOT addressed workshop attendees.**

Image credit: Cornell Mui Ho Center for Cities

Melissa Umberger (Executive Director of Risk Analysis and Recovery, NYC Emergency Management) builds and deploys a variety of analysis tools to understand the risks of climate hazards. She communicates those risks to residents and supports municipal agencies' decision-making based on these analyses, as well as supporting hazard recovery. Ms. Umberger highlighted several of these tools, including the Hazard History and Consequence Tool (a repository of past emergency events in New York City), and the Community Risk Assessment Tool (which allows citizens to submit addresses and receive information about the climate risks relevant to them). She shared that her team uses a "risk index" to rank hazards at the community and neighborhood level. This index helps to prioritize both emergency prevention and emergency response. Ms. Umberger's team also uses NYC311 data, a citizen service request line, to help better understand the local impacts of climate change. Ms. Umberger noted that a digital twin could support the city's response to emergencies.

Roger Weld (Chief Engineer, Transportation Planning and Management Division, NYC Department of Transportation) focused his comments primarily on the need for an extremely precise, survey-quality model of city morphology. Currently, no such survey-grade basemap exists for New York City; the existing basemap

has accuracies of +/- 22.5 cm, which is inadequate for his team's needs. Currently, his team uses orthophotos to ensure accurate placement of pavement markings used for traffic control in AutoCAD. Mr. Weld noted the challenge of mapping subsurface infrastructure, highlighting how survey resolution and control as a foundation for underground surveys could allow underground utility providers to control their data access and reference manholes and vaults identifiable on a digital twin survey as precision common reference.

Michael Marrella (Director of Climate and Sustainability Planning, NYC Department of City Planning) works on issues of zoning across New York City. Mr. Marrella underscored that clear and correct information is crucial for communicating zoning issues to the public. He noted that the Uniform Land Use Review is a public process it is also a political process. Appropriate public messaging is paramount for his department. Mr. Marrella remarked on the ethical challenges inherent in the creation of a digital twin. In his opinion, transparency is an important consideration. He insisted that if a digital twin is to influence decision-makers, the public needs to be informed about the details of this process. Mr. Marrella made the analogy between the refrain "show me your budget, and you'll show me your values" and new technologies like a digital twin, pointing out that the inclusion or exclusion of variables from this type of online platform would inevitably reflect the values of the individuals and institutions that created it.

Dr. Ahearn gave a brief history of the NYC basemap (NYCMap), which was created from a 1996 overflight of the city and directed by the Center for Advanced Research of Spatial Information (CARSI) at Hunter College. NYCMap had a resolution of 30 cm for the orthophotography with an accuracy of ~45 cm in 1996. Although the orthophotography resolution improved in the 2001-02 update to 22 cm and in 2004 to 15 cm with an accuracy of 23 cm in 2004, Dr. Ahearn noted that achieving the +/- 2 inch resolution of a survey-grade map with a digital model of the city would pose significant technical challenges. He noted that "survey-grade" implies a legal definition of parcels (i.e. the cadastre) and is different from the physical basemap (NYCMap). He summarized that while New York City was once in the global technological vanguard, it now lags behind other cities in the use of technology for governance. For example the specification for NYCMap has not improved in the 20 years since his CARSI lab turned over the responsibility for NYCMap to the City of New York. Dr. Ahearn sees the urgency of climate change as an opportunity to adopt better use of technology citywide.

The panel then engaged in open discussion. One audience member then asked if New York City needs one digital twin or many digital twins. Noting this tool would be a "symphony" of twins, which would influence and interact with each other twins in myriad ways and serve a variety of functions. Dr. Ahearn opined that these data streams and systems composing the digital twin would be mutually associated, creating new dynamics and outputs, and ultimately he raised the potential of this approach to model extremely complex interactions within the city. Mr. Marrella countered this vision, making clear his skepticism that a digital twin would ever be capable of making the types of predictions Dr. Ahearn suggested. In Mr. Marrella's view, system interactions are simply too complex to model with a digital twin of the city. This is a fundamental question: what level of complexity can be achieved using the digital twin framework that goes beyond what current GIS systems have accomplished, which is substantial.

Responding to a question about the most important challenges that would need to be addressed for a digital twin to be helpful, Ms. Quintos stated that an accurate basemap and data integration across departments would be the two biggest barriers to this outcome. A shared data infrastructure would streamline city operations, increase data quality, and save the city money by reducing duplicate data-collection efforts. Regarding a city basemap, Ms. Quintos noted that the Property Information Portal is currently the closest thing that the city has to an accurate basemap. She said that many departments would benefit from shared data: While DOT needs survey-grade accuracy to maintain and develop transportation infrastructure, Ms. Quintos' team needs this same information to adequately identify illegal buildings and errors in the tax map, and to automate data collection. She added that a shared data repository would save her department money by reducing the number of hours assessors have to spend in the field identifying errors in data.

Ms. Umberger added that her office would greatly benefit from an accurate basemap. Having an accurate digital surface model can help the city better understand flood risk from events such as Hurricane Sandy and inland flood events such as Post-Tropical Cyclone Ida, to better plan for future emergency response.

PANEL 2: UNDERSTANDING STATE-OF-THE-ART DIGITAL TWIN TECHNOLOGIES

EXERCISE FORMAT & DESCRIPTION

Each panel began with a short presentation from each panelist. Afterwards, questions from moderators and audience members guided the discussions.

Panelists - Industry Experts
Jason Caldwell (Sanborn)
Michael Koterba (MJ Engineering)
David LaShell (Esri)
Virginie Maillard (Siemens)

Moderator
Farzin Lotfi-Jam (CIVIC-UARC)

Photo 2 - **Industry expert panelists from Sanborn, MJ Engineering, Esri, and Siemens.**

Image credit: Cornell Mui Ho Center for Cities

PANEL SUMMARY

Jason Caldwell (Vice President of Business Development and Sales, Sanborn) gave a brief history of Sanborn, a private company specializing in geospatial analyses, noting that Sanborn was responsible for data capture for the first NYC basemap. In Mr. Caldwell's view, a proper digital twin basemap needs two kinds of data: geometry and texture. He explained that geometry is a digital surface model, and texture, which usually comes from aerial imagery, is the visual representation of the textures of those geometries. He added that airborne LiDAR (Light Detection and Ranging), a remote sensing method used to examine the surface of the earth), can capture an area at 2, 8 and 20 points per square meter or greater, although in many cases, budget limits the level of resolution captured. Mr. Caldwell demonstrated an example of a digital twin which Sanborn recently developed in the city of Denver. Sanborn captured the geometric and texture data and imported it into ArcGIS, in which municipal data assets data were overlaid on the digital twin basemap, which is at a 1"=100' scale accuracy. Mr. Caldwell noted that a digital twin for NYC would be substantially more complicated, but the Denver twin is an example of what is possible.

Michael Koterba (Associate/Manager of 3D Laser Scanning and Geospatial Services, MJ Engineering) noted that MJ Engineering is a 160-person firm of engineers and land surveyors which was an early adopter of laser scanners, and which has a great deal of experience working on reality capture in NYC, especially in using Terrestrial Laser Scanning (TLS). After Hurricane Sandy, his team mapped damage to the subway tunnels by mounting a laser scanner to a subway train, closing the tunnels for four hours, and capturing the tunnels' geometry to look for inundation. Mr. Koterba noted that today, the same process takes only an hour, adding that MJ Engineering's TLS captures have a resolution of many thousands of points per square meter. In response to data siloing, Mr. Koterba's team built an internal tool called "MJ4D," which serves as a hub for different departments and the public to explore digital twins by using their data. The system is accessible at different resolutions and across digital platforms: desktop, mobile, and browser.

David LaShell (Senior Account Executive, Esri) said that he sees a great need for this NSF project. He has substantial experience working with various NYC departments on digital projects, and he mentioned four digital twins that the city currently uses as examples of the potential of using digital twins for climate adaptation. First, the NYC Tax Map and Property Information Portal—which was presented in the previous panel—is, in his view, cutting-edge and essential. Second, he noted that the Citywide Street Center Line (CSCL) is essential to the functioning of city services: Operations such as 911 and NYC311 rely on it for address information for the entire city. Third, the Metropolitan Transit Authority (MTA) has a twin of not just the NYC subway, but of every train line and train location. Mr. LaShell noted that this twin works differently than others, relying on linear reference systems to measure distance between stations and the distance from moving trains to destinations. Finally, the NYC Department of Environmental Protection (DEP) maintains

a digital model of the city's sewer system and water mains that incorporates physics-based hydraulic models for the water system, to predict water levels across the system and logical flow direction for the sewer systems.

Mr. LaShell explained how Esri approaches digital twins. First, he distinguished between reality capture, which is the result of the data collection methods discussed by Mr. Koterba and Mr. Caldwell, and digital twins, which he understands as adding business, government, or other domain-specific attribute data to this reality capture. Second, he added that Esri, like Sanborn, evaluates digital twins from the perspective of outcomes, working backwards from such questions as "What business/ policy decisions are we trying to inform?" and "What goals are we trying to achieve?" He noted that many digital twins are purpose-built and as a result weak in interoperability. Overcoming this tendency and integrating these disparate systems is a major challenge. Mr. LaShell claimed that systems delivered by advanced technologists to governments are frequently unsustainable because municipal agencies are already beyond capacity. With respect to the aforementioned survey-grade basemap, he noted that several private companies also need these data and would pay to have parts of the city modeled in this manner: a potential public-private partnership. Finally, he mentioned White House climate resiliency initiatives as attempts to incorporate community feedback and build equity into climate resiliency efforts.

Virginie Maillard (Head of Technology Field Simulation and Digital Twins, U.S. Region Head, Siemens), began with her perspective on the utility of digital twins and her experiences developing these technologies. In her work, Ms. Maillard takes advantage of this capability by combining geometric models of things such as stadiums with agent-based models of populations to simulate building evacuations in emergencies. In addition to supporting decision-making, her team uses digital twins to train people for jobs. Her team uses physics-informed models to simulate airflow in and around proposed buildings and water flow through a water system. Siemens primarily models the built environment, such as transit systems. However, Siemens recently partnered with the National Science Foundation (NSF) to build a digital twin of a coral reef, to predict response to the externalities of climate change (such as increased water temperature, eutrophication, and acidification) and to help enact policies to protect coral reefs.

To invite panel discussion, Mr. Lotfi-Jam mentioned that in working towards climate adaptation, a digital twin must solve a specific problem. He noted the challenge of integrating data between city agencies, "the gap between the promise of technology and the politics of the situation." He then asked the panel several questions: If a digital twin is a single source of truth that shapes decision-making, how do we regulate that? How do we balance being robust and agile in development efforts with building software that is sustainable?

Photo 3 - **Workshop participants listen to a panel presentation.**

Image credit: Elena Urdaneta

Mr. LaShell cited vendor lock-in as a potential roadblock. He emphasized data interoperability with municipal clients. Using data for climate adaptation cannot hinge on proprietary software that does not have robust interoperability capabilities. He added that in an emergency, city agencies tend to use spreadsheets and share them via email because it is a common baseline. He cited liability of usage as a challenge: "If I make data, and it's open [source], and something happens in your use of that data, who's liable?" Esri has three tiers of data users: policy, operations, and analytics (data science), each of which has different use cases for and needs from their data. Frequently, each set of users does not consider the needs of the others. He noted that policymakers especially need to give more consideration to the needs of operations personnel, and that this can avoid problems with interoperability, among other things.

Mr. Caldwell agreed that data access, especially for the public, is an important consideration. He asserted that GIS is a digital twin, and that the lack of 3D visualization does not preclude it from categorization as a digital twin. Portland, Oregon, used a digital twin (GIS) to engage with the public to make change. The City built a twin of impervious surfaces in Portland to demonstrate what small

landowners can do on their land to help with flooding and runoff, which was overloading storm sewers. Mr. Caldwell cited this as evidence that a digital twin can communicate collaboratively between municipalities, industry, and the public. Finally, he mentioned that "real-time" means something different to everyone, and referred to the addition of temporal data in a digital twin as "4D."

Ms. Maillard replied that she strongly believes it is important to have different disciplinary backgrounds and stakeholders in the room to discuss the issue of data silos. She stated that combining disparate perspectives in this manner is usually fruitful. She added that there is an opportunity to create a collaborative ecosystem.

Mr. Koterba responded that, in his view, everyone is afraid to share their data because they don't want it to be misused. He sees a strong need for standardization of data and release of liability for data use, which would encourage people to share their data. Finally, he commented that in his experience, tools need to be simple: "There is nothing more depressing than spending six months building a GIS inventory of parking signs and coming back later and finding out they're using a spreadsheet." He advocated for strong documentation of tools and instructions for their maintenance upon delivery to clients.

After Mr. Lotfi-Jam opened the floor for questions, private contractor Jim Hall offered an anecdote about building, in collaboration with Mr. LaShell and Esri, a digital twin to help the Mayor's Office deploy COVID vaccines. Mr. Hall noted the time crunch on the project: 10 days to integrate seven different datasets, all of which were read once per minute. He noted that what they built could be considered a true digital twin because it has a temporal, 4D component: up-to-date availability of vaccine appointments. This software eventually became the NYC vaxFinder app, which is still operational. Although it began with a narrow scope (only helping people to find available COVID vaccines), scheduling appointments for other vaccines is now possible through the software. Mr. Hall called attention to the project management structure, noting that the app "evolved over time based on needs and [the] capacity to [implement]." They could not incorporate non-COVID vaccines during the emergency, but the emergency did serve as a launch pad for this particular digital twin. Finally, he credited the project's success to essential support from both Mayor DeBlasio and Governor Cuomo.

Ms. Umberger asked Mr. LaShell how to combat the "spreadsheet problem." Mr. LaShell mentioned the Fire Department of the City of New York and the New York

Photo 4 - **Workshop participants listen to a panel presentation.**

Image credit: Cornell Mui Ho Center for Cities

Police Department as examples of agencies that deal with this problem daily. Each responding department has unique capabilities and dataset access, making data sharing between departments difficult due to liability. Personally identifiable information (PII) and personal health information (PHI) are particularly challenging. He added that these issues are solvable within individual agencies, but harder to address when collaborating across them. He noted, however, that each department's system does manage these problems. In one system, his login gives him access to only the data that he needs and protects sensitive data by limiting user access to it. He asserted that getting all of these individuals on a call together is by far the most productive way to solve problems.

An workshop participant from Siemens asked, "What is the biggest gain in using predictive models for risk management and climate change?"

Mr. Caldwell described a project where Sanborn collaborated with the state of Arkansas. The project included airborne LiDAR capture and setting up sensors in the Arkansas River, which originates in Colorado and travels through Kansas and Oklahoma before it reaches Arkansas. Thanks to the LiDAR-based elevation models, the state knew that a severe storm in Oklahoma would create flooding in Arkansas with approximately 48 hours' advanced notice. This information allowed them to evacuate people, thereby preventing loss of life and avoiding unnecessary damage. Mr. Caldwell mentioned that predictive analytics in urban water systems can help identify areas for preventative maintenance that reduces leaks and general infrastructural damage. Finally, he noted that emergency events such as hurricanes and wildfires are more difficult to model, but predictive models of both event types have helped to train first responders.

Rachel Opitz (Open Geospatial Consortium) asked, "When it comes to building climate adaptation infrastructure in NYC, government planners need to make decisions and citizens need to understand decisions. What is the sense of priority in these use cases?"

Mr. LaShell responded that all the agencies he works with are trying actively to work in and with communities. He offered that it frequently can be difficult to represent communities, and cited NYC311 as an example; while it is an "incredible dataset," the information is not representative of the city as a whole. As such, he concluded that this one tool for community input "is not enough. [All] communities and people [are] not captured in the data."

Developing a digital twin that is representative of the entire population of NYC and their experiences and needs is an ambitious, challenging project, and it is essential to include interfaces that would allow community members to provide feedback. Finally, he cited the NYC Parks Department as an exemplary contributor to city data. The Parks Department constitutes a minuscule fraction of the city budget, but delivers immense value to New Yorkers. Furthermore, the department is sensitive to the needs of underrepresented communities.

Overall, the panelists expressed that while a citywide digital twin could in theory support more equitable planning outcomes, a lot of thought and effort would be required. Table 2 represents the key benefits and challenges/barriers mentioned by the panelists.

Table 2 - **A Summary of the Challenges and Benefits of a Digital Twin for NYC**

Challenges	Benefits
Liability associated with improper data use	Overcoming the limitations of data siloing
Balancing one digital twin with the need for multiple digital twins that focus on specific problems	Enhanced interagency cooperation
Data siloing	An opportunity for public-private partnership
Vendor lock-in and the lack of interoperability	Improved disaster response
Need for interagency cooperation	More engaged, participatory planning
Establishing and maintaining community trust	Cost savings for public agencies
Long-term funding for data management and maintenance	More robust data for quantification of the impacts of public spending
Public agencies and staff that are overworked and underfunded	Creation of a survey grade basemap of the city to enable the diverse work of the public agencies

BREAKOUT GROUPS

EXERCISE FORMAT & DESCRIPTION

The breakout groups leveraged the collective knowledge of the assembled experts in order to understand issues specific to a digital twin of New York City. Workshop participants were divided into six groups, with each group assigned one of three topics for discussion: Data Sources and Platforms, Interface and Experience, and Decision-making. Each group was moderated by a pair of research team members and had a set of guiding questions to shape the discussion. Groups identified users, applications, relevant hardware, software, data sources, and discussed ethical considerations, community and citizen involvement, managerial structures, research gaps and implementation challenges. Although each topic was discussed by two groups, in the interest of brevity, the results have been consolidated. Notable differences between each topic group are indicated where appropriate. A full breakdown of participants in each group can be found in Appendix 2.

DATA SOURCES AND PLATFORMS (GROUPS 1 & 2)

The purpose of the Data Sources and Platforms breakout groups was to understand which sources of information and technical platforms are being utilized to create and manage digital twins. These groups identified the current systems, instruments, and sensors capable of supporting real-time digital representations of cities. The conversation also focused on how to expand the ability of these technologies to integrate citizen-captured data and how to increase the usability of these systems to benefit urban planning and policymaking.

Discussion Questions

The following questions informed the breakout group discussion:

- What data sources are available to create the digital twin?
- What data sources enable us to get close to real-time updates?
- What are the platforms or software options for hosting the digital twin?
- What are current systems, instruments, and sensors used for data collection in cities that could be used to create a digital twin? What needs to be improved? What does not exist yet?
- How can we integrate volunteered/citizen-captured data?
- How can diverse stakeholders contribute to, and benefit from, a digital twin for urban planning and policymaking?
- What are the ethical and data sensitivity issues that should be considered?
- What community dynamics need to be considered?
- What are the knowledge gaps?
- What are key challenges and barriers? (i.e., what data do we need, what resolution, ethics around data capture)
- What else should be discussed in this session that we have not discussed yet?

Photo 5 - **Breakout Group 4 discusses digital twin interface and experience.**

Image credit: Elena Urdaneta

Table 3 - **Potential Sources of Data for Use in Digital Twins**

Data Type	Data Category	Temporal Restrictions	Historic	Availability
Electrical grids	Infrastructure	Real-time	No	Proprietary
Cell towers, fiber optic lines	Infrastructure	Once in a while	No	Proprietary
Basemap	Geometry	Offline	No	Outdated, new capture required
Digital surface model	Geometry	Once in a while	No	New capture required
Orthophotography	Geometry	Once in a while	No	New capture required
Oblique photography	Geometry	Once in a while	No	New capture required
Buildings	Geometry	Once in a while	Yes	Siloed; DOB and DOF
Building properties (use, age)	Infrastructure	Offline	Yes	DOB (needs digitized)
Weather, other than precipitation	Environmental	Once in a while	Yes	Available
Precipitation	Environmental	Real-time	Yes	Available
Sea level	Environmental	Once in a while	Yes	Available
Sewers	Infrastructure	Real-time	Yes	Unsure - DEP/ Wastewater Treatment might have real-time data on flows
Flooding/standing water	Infrastructure/ Environmental	Real-time	Yes	In Progress: FloodNet
Demographics (age, disability)	Social	Offline	No	Available
Vehicle/pedestrian traffic	Mobility	Real-time	Yes	Cameras/VGI
Transit (subways/ buses)	Mobility	Real-time	Yes	MTA/VGI
Institutions (hospitals, jails)	Infrastructure	Offline	Yes	Available
Healthcare capacity	Social	Real-time	Yes	Available
Air quality	Environmental	Real-time	Yes	Some; spatially disparate

Note: “Historic” is defined as the necessity of having longitudinal data for an accurate digital twin. DOB: NYC Department of Buildings. DOF: NYC Department of Finance. MTA: NYC Metropolitan Transit Authority. DEP: NYC Department of Environmental Protection. VGI: Volunteered Geographic Information.

Both groups discussed appropriate temporal resolution for various data. Group 1 identified three temporal resolutions by which to organize data sources: offline, once-in-a-while, and real-time. Group 2 engaged in an in-depth discussion of the term "real-time," and decided that achieving "real-time" data meant a different temporal resolution depending on both the phenomenon being measured and the intended use of the data. For example, predicting the impacts of a flooding event requires a much finer temporal resolution for precipitation and transit data than planning an evacuation in a similar event. Both groups emphasized the benefit that historical data could deliver to a digital twin that seeks to model such processes in the city. Both groups identified critical infrastructure such as power grids and communications equipment as key points of failure in an extreme climate event and emphasized that it was essential they be included in a digital twin for climate resilience. This echoed discussions from the first CIVIC-UARC workshop, "Adapting to Multiple and Cascading Climate Change Hazards and Risks," which identified electrical infrastructure as being particularly susceptible to cascading climate hazards.

Many software and hardware solutions were proposed regarding data management and platforms. The same theme precipitated from both groups: The real challenge of hosting and managing a digital twin in NYC is not in selecting or accessing the appropriate technology. Instead, the most difficult problem would be identifying who or which agency or institution(s) would be responsible for the digital twin's data collection and maintenance efforts. It was agreed in Group 1 that while there would need to be certain projectwide standards for data quality, in general, owners of disparate datasets would need to be held accountable for the information, delivery, schedule, quality, and maintenance of their data.

Data collection was thoroughly explored in both groups. It was agreed that for an efficacious digital twin, certain "foundational" geometric data would require a new collection effort to develop a high-resolution 3D model of the city. In Group 2, the Open Geospatial Consortium Level of Detail 3 was agreed upon as a suitable standard of representation for the city. Proposed sources for new data capture included LiDAR and orthophotography as well as historical and existing building information model data from the NYC Department of Buildings.

The discussion around data collection led participants to explore what kinds of data the city already collects. Furthermore, discussion in the morning panels around existing digital simulation platforms that the city already uses (such as the City Street Center Line model and the NYC Property Information Portal) inspired participants to think about integrating siloed sources of data and models that the city already has into one comprehensive digital

Photo 6 - **Breakout group participants discuss data sources and platforms.**

Image credit: Cornell Mui Ho Center for Cities

twin. All groups identified this as both a key benefit and challenge of a digital twin, and breakout groups in other topics also saw this as a cornerstone capability of the platform. In Group 2, participants explored where it would be possible to "piggyback" on existing municipal operations to minimize cost and maximize the resolution of data collection. One such possibility that participants explored involved attaching sensors or cameras to Department of Sanitation vehicles or to taxis to increase the resolution of traffic data and road condition data.

Participants also explored ethical and privacy considerations of digital twin data sources. Data security and access were identified as key considerations, especially if demographic data, camera or CCTV footage, and/or PII were to be included in the twin. Some applications of the intended twin, especially around extreme heat, would benefit from health data at the population or individual level, and participants agreed on the importance of safeguarding this information in order to preserve community and individual privacy. A trade-off between the spatiotemporal resolution of data and the anonymity of individuals represented in said data was identified, and this further supported the participants' conclusion that each data input would need to have its collection scale and frequency determined on a case-by-case basis. Group members agreed that prioritizing and effectively and equitably addressing ethical concerns would be paramount to the success of the project.

Participants also discussed how to center equity and capture community dynamics in a digital twin. Climate change is a global phenomenon that is experienced by individuals and communities locally. One of the key identified benefits of a digital twin is its ability to enable hyperlocal (neighborhood- or community-level) adaptations and responses to climate change. Participants identified the inclusion of community and minority group perspectives, data collection transparency, and equal data coverage in underserved neighborhoods as critical environmental justice concerns for a digital twin's data sources.

One of the key identified benefits of a digital twin is its ability to enable hyperlocal (neighborhood- or community-level) adaptations and responses to climate change.

Artificial Intelligence (AI) was conceptualized as a key component of modeling in a digital twin. Various machine learning techniques constitute state-of-the-art approaches for modeling various subsystems on which a digital twin of NYC would rely. Large-language models in particular show promise for the synthesis and presentation of information, assuming a rigorously defined structure. It was agreed that combating bias in underlying data sources would be especially important when using data in an AI model. Neural networks, adversarial networks, and reinforcement learning were all pinpointed as relevant model architectures for enabling modeling and simulation capabilities in a digital twin. These structures also have potential to enable dynamism – new component data inputs changing the state of the entire model – in a digital twin.

Implementation Challenges and Barriers

Given that the success of this project depends on the cooperation of various stakeholders from academia, industry, and disparate municipal departments, workshop participants anticipated coordination and communication as challenges to implementing a digital twin of NYC. The primary barrier identified was that of data silos. An immense volume of relevant data is already collected, managed, and used productively by various agencies in New York City. Obtaining the cooperation of each of these departments is a challenge in and of itself, and in order to do so, any solutions proposed for integrating this data must be as low-effort and streamlined as possible for those departments.

Furthermore, the results of this work must be additive and not impede department workflows. Participants identified the need for multiple champions of the project in various departments and cited executive-level support as a milestone for ensuring the success of the project. To begin, participants suggested that the project team identify and engage with the public-sector data providers that will cooperate most readily with the city, and avoid, where at all possible, those providers that are committed to preventing access to their data.

Funding was noted as another major constraint. The project needs to require minimal resource investment from the public sector, and in instances where that is unavoidable, care must be taken to minimize financial expense in order to maintain municipal buy-in. Participants agreed that the fundamental step in obtaining and growing this buy-in would require persuading municipal stakeholders of the benefits of a digital twin.

Another challenge identified, assuming the successful development of such a twin, organizational practices must be developed to update its data inputs and model structures as a matter of course. Embedding a completed digital twin in city operations was noted as key to ensuring that the project does not drown in the ebbs and flows of political will. Participants also identified barriers to ensuring equitable distribution of the benefits of a digital twin: historically marginalized communities are wary of government and may be averse to data collection in their communities, and any public-facing access point to a digital twin might require a level of technological familiarity that is absent in primarily analog communities and elderly populations.

Research Gaps

Participants identified several research gaps relevant to the creation of a digital twin in NYC. Data standards for digital twins are inconsistently defined, and because a digital twin would need to include a variety of data types, the development and adoption of appropriate standards for each type of data and for the project as a whole is crucial. Metadata standards, generation, and management are critical aspects of data management. In a digital twin, metadata quality impacts the interpretability of the twin's outputs and is a key part of getting institutional stakeholders to trust the model. How citizens perceive and trust a digital twin and its use by their government is poorly understood, but getting buy-in from community members is paramount for the success of the project.

Streaming real-time data from physical sensors, ingesting and preparing it for analysis, and storing the data for access by the digital twin is a current research problem with a variety of proposed solutions, but few of these have been implemented successfully in a digital twin of this scale. The appropriate cadence of updates for a digital twin receiving real-time information and the appropriate way for new data inputs to propagate changes across the twin is a serious research gap. A twin used for real-time catastrophe response would need to have these questions answered. The broad range of data sources for a digital twin means that some of these sources are more accurate, more easily accessed and integrated, and more readily deployed for wide spatial coverage. Approaching uniformity in these qualities for data inputs is a key consideration, especially when developing data standards; some standards may be set by technical limitations of sensor technologies.

KEY INSIGHTS

Both groups immediately identified that the selection of appropriate data sources would depend on both (1) what climate-related issues a digital twin was intending to address and (2) whether the digital twin was to be used for future *planning* climate responses or *orchestrating* the municipal response to a climate event (ex. a hurricane) in real time. As previous CIVIC-UARC workshops had focused on climate issues related to urban air quality, extreme heat, and flooding, these three use cases were agreed upon to structure the discussion of data sources. After establishing this, the groups proceeded to identify potential sources of data, detailed in Table 3.

INTERFACE AND EXPERIENCE (GROUPS 3 & 4)

The purpose of the Interface and Experience breakout groups was to understand, from the perspective of both the general public and experienced technical users, how people use technological platforms needed for digital twins. These groups explored the kinds of hardware and software that people currently use, the shortcomings and strengths of existing platforms, and which of these platforms are well suited for navigating a digital twin. The conversations also explored ethical issues, especially around privacy and surveillance, and how digital twins could be made accessible and further environmental justice goals. Technological gaps and barriers to implementation were also discussed.

Discussion Questions

The following questions informed the breakout group discussion:

- How does the public and municipal leadership currently interface with platforms?
- What platforms/software/methods are most commonly used to support the user interface experience?
- How can digital twin interfaces be improved to support more effective and meaningful user interactions and experiences with these technologies?
- What emerging technologies hold the most promise for improving user interface with digital twins?
- What are the knowledge gaps?
- What are key challenges? (i.e., devices, accessibility, audience, capacity to interact with information)
- What else should be discussed in this session that we have not discussed yet?

Participants began by clarifying terms and discussing the differences of a digital twin vs. a model vs. a digital shadow. The groups had different consensus on who the primary users of a digital twin would be: Group 3 decided that municipal leaders and decision-makers were the primary audience of a digital twin, while Group 4 saw a separate but equally important user base in civilian communities.

Group 3 felt that, depending on what data collection and methods were used, civilians would "experience" a digital twin even if they did not actively use it, and were concerned that data collection tools might constitute surveillance or give the impression of surveillance to the public. They emphasized the need for proactive and continuous education and iconography around the digital twin to ensure that the purpose and scope of the technology would be well understood. It was further agreed that transparency about data inputs and their use be well communicated to the public. For Group 3, a key part of experiencing a digital twin is the way in which the information it delivers changes how people conceive of the city: It helps us update our "mental models." Participants identified a strength of digital twins as the ability to convey narratives about the city and its communities in a dynamic, tangible way, one that has the potential for rapid and wide-scale deployment.

These groups discussed the ways that the public and municipal leaders already interface with similar technology and platforms, and Group 4 enumerated several of these platforms. Citizens use public spaces such as libraries and museums, LinkNYC kiosks, NYC311, and interactions with municipal, public-facing employees (for example, librarians). City leadership additionally uses computers, GIS, spreadsheets, dashboards, and paper maps. Both community members and municipal officials use sources such as large-language models, phones, dashboards, apps, and digital maps, although the public's use of these is less comprehensive than that of public employees.

Group 4 noted emergency alerts and mass notification systems as places where individuals currently interface with public technology. Online information hubs and dashboards were understood as digital spaces for technical and non-technical users alike to interface with relevant data, but Group 4 categorized these as separate from digital twins. It was, however, recognized that a digital twin acting as a single repository for multiple sources of data could support and enable the development of these interfaces. The Environmental Protection Agency's (EPA) Environmental Justice Screening and Mapping Tool (EJScreen) was cited as a dashboard interface that is useful to municipal and academic actors, while simultaneously providing value for citizens.

Both groups identified the need for digital twin interfaces to allow users of all technical backgrounds to provide feedback about the data quality informing the interface. The notion of feedback also was seen as an opportunity to incorporate the lived experiences and disparate views of community members, especially those from underserved populations. It was further hypothesized that "contribution follows belonging: people need to feel represented in the data." In this sense, frequent and representative community contribution was seen as a high-value form of engagement

with a digital twin, one that could facilitate a mutually beneficial transfer of knowledge.

The participants had specific suggestions about the most ethical way to engage in this process with community members, including:

» Developing example use cases for prototyping grounded in tangible, high-priority community issues
» Compensating users for their input and feedback
» Providing physical space for community members to participate in the design process

Implementation Barriers

Participants also identified potential pitfalls and roadblocks to the successful implementation of the digital twin. Trust from community members was identified as critical. If the project team and other affiliated experts do not invest the time and resources necessary to build and maintain trust with community members as researchers and public officials, CIVIC-UARC will not be successful. Data silos and political will were again posited as serious impediments. Finally, both groups expressed particular concern with the project's ability to ensure the long-term availability of mission-critical data in a digital twin, especially if that data comes both from communities and government offices.

Research Gaps

Participants identified several research gaps relevant to CIVIC-UARC for further exploration. For example, the discussions highlighted the fact that there is a lack of understanding about how the general public would be able to interface with a digital twin to support their own decision-making. Issues such as language and literacy barriers were mentioned as impediments to universal access to information provided through such a platform. Similarly, questions about the design requirements for downstream digital twin products (such as dashboards) were highlighted as areas of uncertainty. Understanding the limitations of such a platform would be critical if planning and policy decisions were to be made based on a digital twin of the city.

KEY INSIGHTS

Both groups agreed that a one-size-fits-all interface for a digital twin would be a mistake; developing customized interfaces for specific user groups and use cases was seen as paramount. To do this effectively, both groups identified human-centered design practices as good guidelines to adopt for the development of any digital twin. To participants, this would mean diligently trying to understand the users, the context of their usage, incentives for and against their use of the platform, and engaging in a procedural design process that incorporates feedback from those users.

DECISION-MAKING (GROUPS 5 & 6)

The Decision-making breakout groups sought to understand how administrators use data and digital technologies to make decisions in their work, and how individuals and communities use these technologies to inform their choices as they live in and move through the city. Further, these groups sought to establish baselines for evaluating the results of municipal decisions and to understand how a digital twin could deliver additional value to decision-making processes.

Questions

The following questions structured the discussion:

- What data is mission-critical for your work? For making decisions?
- What existing tools do you find useful? What are the required criteria? What are the use cases?
- What are the criteria and methods to assess the efficacy and impact of data-driven decision-making systems?
- How can we ensure that these technologies increase community agency and democratization of the public sphere (and not the opposite)?
- What are the knowledge gaps?
- What are key challenges? (i.e., how can a digital twin channel action given the complexities of how urban environments change?)
- What else should be discussed in this session that we have not discussed yet?

KEY INSIGHTS

Participants in both groups began by examining and collectively defining key terms to inform their discussion. The groups agreed that all such terms are flexible and mean different things to the different breakout groups, but sought to clarify concepts embodied by these terms in the context of this project. A summary of these discussions, with shared definitions synthesized, is in Table 4.

Table 4 - **A Shared Understanding of Key Terms and Definitions**

Term	Definition	Group
Climate adaptation	Modifying and augmenting physical and social institutions with additional resources and tools to build robustness to particular, compounding, and cascading climate hazards	5
Real-time	A minimum temporal resolution of data required to inform decisions in an emergency, or to capture spatial fluctuations in phenomena to deliver utility to decision-makers	5
Equitable	Providing an equal and fair distribution of costs and benefits to all, taking into account historic disinvestment, and acknowledging and overcoming the differential distribution of barriers to access across different populations	6
Decision-making tools	Forms of quantitative analysis, informed processes, values (of decider), and pragmatic considerations such as power dynamics and funding constraints that facilitate a decider taking a prediction and converting it to action	6
Community	Group of people with shared concerns/interests (relational community) or shared administrative boundaries (spatial community)	6
Community agency	Ability of community members to exercise self-determination, to influence the process and outcomes of change in their community	6
Effectiveness (evaluation)	An effective action is one which causally influences an outcome for which there is a reasonable measure or proxy. Evaluation is based on context-specific criteria	6
Democratization	Decisions are impacted by all citizens despite social and economic barriers to including the voices of some; information and systems used by representatives to make decisions are transparent and publicly available; participation in decision-making process is available to all	6
Mission-critical	Context-specific resources vital to the fulfillment of an organization's stated goals, without which the ability to responsibly satisfy these goals is jeopardized	6

Critical Data and Tools

When asked to identify mission-critical tools and data, the groups took different approaches. Group 5 discussed various possible use cases and decided that it was not possible to define inputs and tools as mission-critical without a use case. Group 5 listed certain tools that they find useful in their work, including dashboards, email reports, internal databases, spreadsheets, and the NYC Environment and Health Data Portal. Group 6 focused on flooding, one of the key hazards the project seeks to address, and responded to discussion questions through this lens. They singled out paper CAD drawings, waterfront line maps, weather models, flood inundation sensors, and topographical information as vital for informing flooding risk mitigation decisions. They noted a need for more information about the interior of buildings, which currently is not easily accessible.

Efficacy

Participants across the two groups agreed on the need to understand how decisions impact and are experienced in the daily lives of the general public. Both groups agreed that the most relevant scale for climate action and the evaluation of mitigation efforts in NYC was at the community or neighborhood scale. In measuring the efficacy of climate adaptation choices, loss of life in emergencies was pinpointed as a universally important benchmark. Group 6 subdivided efficacy evaluation into two categories. Community effectiveness is the accessibility of selected adaptations to members of a community, and the compatibility of those adaptations to community values, priorities and goals. Biophysical effectiveness is the reduction in physical impact and risk from disasters, for example, how well a seawall functions in a flood or storm event.

Community Agency and Access

The Decision-making groups agreed that decisions are made at three levels: individual, community, and institutional (municipal government), all of which have disparate decision processes and frequently conflicting priorities. These groups strongly felt that a digital twin must increase the agency of communities and their inclusion in institutional decision-making processes. The example of flood mitigation efforts in the Rockaways was highlighted as a case study for poor participatory planning. In this instance, the Army Corps of Engineers built a floodwall without consulting residents, which, among other things, blocked their view of the beach. The community board, ostensibly the channel through which residents could express their views on the project, is merely advisory; residents felt that the decision had been made before they were in the room.

A future aspect of CIVIC-UARC was conceptualized by participants as an “honest broker,” a resource for community members and municipal agencies to engage together in a safe and impartial setting. A digital twin was postulated as a way to increase community agency by facilitating the analysis of data by laypersons, thereby increasing public participation and knowledge in planning processes and activities. Further, the ability to use a digital twin to simulate the physical structure and outcomes of potential climate adaptation measures makes the downstream consequences of their implementation tangible. These “what-if” scenarios would help communities to make informed decisions about supporting one adaptation plan versus another.

Taking this concept further, CIVIC-UARC could be viewed as a resource and platform for exploring and consolidating individual and community experiences of climate change across New York City. The capacity of the digital twin to make different strands of climate resilience work visible will be critical to realizing CIVIC-UARC’s goals of increasing community agency and equity in climate resilience efforts. Such efforts include ensuring that information in a digital twin is intelligible, transparent, and available in many languages and formats.

An app or other mobile interface for the digital twin would further increase the reach and access of the technology and enable decision-making to occur at the individual, the community, and the institutional level. The digital twin as a “single source of truth” for manifold streams of information about climate change could help address the problem of information overload. The digital twin and CIVIC-UARC, in tandem, ideally could present information such as showing an individual that their home will be underwater in 10 years in a way that is not disempowering and fatalistic but instead is empowering. The information a digital twin provides could help individual residents to better understand their options and advocate for community-level solutions.

Implementation Barriers

Specific impediments to the success of this project were considered at length by these groups. Perhaps the most important challenge cited by both groups was the idea that a digital twin cannot be a solution without a problem: It must be developed to solve a specific issue and deliver value to decision-makers in dedicated domains. Biases and gaps in data sources will be a consistent challenge to the shared goal of increased equity in decision-making, and it will be important to navigate potential sources of bias in the data inputs to the digital twin.

As mentioned in other groups, data silos again were determined to be a critical barrier, but members of Groups 5 and 6 further identified the need for interagency cooperation beyond data-sharing. More holistically coordinated efforts between various city departments were cited as necessary measures for the success of this project and for climate mitigation in general. While CIVIC-UARC could be a platform for institutional collaboration and cross-pollination, it would be a massive challenge to overcome the friction generated by a climate disaster whose externalities affect multiple agencies. Furthermore, some climate risks may fall through the cracks of the purview of all city departments. The lack of municipal ownership of risks such as extreme rainfall and inland flooding presents additional difficulties, as does the lack of technical capacity within city agencies, which frequently find themselves stretched thin in an attempt to leverage adequately existing digital technology such as GIS to support decision-making efforts.

AREAS FOR FURTHER RESEARCH

Research Gaps

Various relevant knowledge gaps were identified. Existing data and models for coastal features and their resiliency are unavailable or poorly determined. Better data sources and methods for modeling coastal phenomena are important for planning and implementing adequate flood resilience and response. Furthermore, better and more formally defined frameworks for evaluating the efficacy of climate mitigation investment decisions will be essential for effective climate adaptation in the future across all hazard types (for example, flooding, extreme heat, air pollution). More granular, downscaled weather and climate models are necessary for urban climate resilience. Extant models from the National Oceanic and Atmospheric Administration (NOAA) and the National Weather Service are unable to separately classify the risks of an extreme weather event in separate areas of the city such as Red Hook, Brighton Beach, and the Rockaways. Appropriate qualitative information was highlighted as necessary for properly conveying the narrative of climate change and its human impacts. However, how to embed this type of information in a digital twin is a topic for further exploration.

NEXT STEPS

This workshop is one step in the foundation of the new Civic-Led Urban Adaptation Research Center.
Below are next steps in the preparation process:

- Share the workshop report with the workshop participants and other stakeholders.
- Use what was learned in the workshop to guide the next phase of the proposal preparation.
- Develop a concept for a pilot-scale digital twin and secure funding to test its potential.
- Continue to build the relationship with our project partners and expand our network of collaborators to other geographies in New York City.
- Develop a theory of change that will inform the new CIVIC-UARC.

We also will consult the key insights from the two other research workshops and continue to advance and refine our ideas in consultation with the two other research areas.

APPENDIX 1 - BREAKOUT GROUPS

Group 1: Data Sources & Platforms *(Farzin Lotfi-Jam & Ioannis Stamos)*	**Group 2: Data Sources & Platforms** *(Sean Ahearn & Timur Dogan)*	**Group 3: Interface & Experience** *(Wendy Ju & Shipeng Sun)*	**Group 4: Interface & Experience** *(Wenfei Xu & Peter Robinson)*	**Group 5: Decision-making** *(Anthony Townsend & Sophie Oldfield)*	**Group 6: Decision-making** *(Anita Raja & Victoria Beard)*
Dylan Culp, NYC Parks	Jason Caldwell, Sanborn	Novem Auyeung, NYC Parks	Alec Appelbaum, All Before Us	Juvie Anne Alfeche, RISE	Mary Bandziukas, NYC DOT
Patrick Gahagan, Esri	Deborah Estrin, Cornell Tech	Lindsey Cassone, VHB	Jacqueline Duke, RISE	Ben Furnas, Cornell	Lindsay Campbell, USFS / CIVIC-UARC
Amy Jeu, CUNY-Hunter	Jim Hall, Independent consultant	George Del Barrio, Universe City / CIVIC-UARC	Joseph Ferdinando, Cornell / CIVIC-UARC	Hayley Elszasz, NYC MOCEJ	Josh Cerra, Cornell
Jesse LeCavalier, Cornell / CIVIC-UARC	Michael Koterba, MJ Engineering	Debargha "Dave" Dey, Cornel Tech / CIVIC-UARC	Matthew Franchi, Cornell Tech / CIVIC-UARC	Michelle Johnson, USFS / CIVIC-UARC	Damara Lee, RISE
Frederic Lescure, Siemens	Fred Ng, NYC OTI	Alex Kobald, Cornell / CIVIC-UARC	Sarah Lipuma, FEMA DHS	Melcher Mack, Mott MacDonald	Masha Pitiranggon, NYC DOH
Ashley Louie, BetaNYC	Rachel Opitz, NYC OGC	Ha-Kyung Kwon, Toyota Research Institute	Lucia Mirabella, Siemens	Virginie Maillard, Siemens	Ishita Rahman, The New School / CIVIC-UARC
Carmela Quintos, NYC DOF	Michael Salvato, Mott MacDonald	Robin Lovell, Esri	Shiori Sasaki, Esri	Lauren Smalls-Mantey, NYC DOH	Emily Sun, NYC Planning Dept.
Roger Weld, NYC DOT	Jerry Clayton, CUNY-Hunter / CIVIC-UARC	Mark Mutter, Arcadis	Lucia Woo, Fugro	Erin Morey, MTACD	Tyler Taba, The Waterfront Alliance

APPENDIX 2 - WORKSHOP PARTICIPANT LIST

Sean C. Ahearn is a professor at Hunter College in the Department of Geography and Environmental Science and director of the Center for Advanced Research of Spatial Information (CARSI). He is a spatial data scientist with expertise in GIS, remote sensing, photogrammetry, and machine learning, with a focus on generative models for movement simulation, spatial temporal models, and urban systems.

Juvie Anne Alfeche is the public program coordinator for the Rockaway Initiative for Sustainability and Equity (RISE), a community-based organization in Far Rockaway, Queens. She manages the Farm Share program, the Rockaway Street Market, and other public events that advance the general well-being of the community.

Alec Appelbaum writes and teaches professionals to write about how communities and systems can thrive amid climate change. For many years he worked as a journalist, covering the greening of cities, and since 2011 has taught writing at Pratt Institute and New York University and coached Yale University students in journalism. He also writes for foundations and trade groups.

Novem Auyeung is a senior scientist at NYC Parks' Division of Environment and Planning, where she leads a team of scientists tasked with monitoring and assessing NYC Parks' natural resources; advising on their protection and conservation; and using research and data to inform policy, planning, design and construction, and adaptive management. She also is part of the NYC Urban Field Station, a partnership between NYC Parks, USDA Forest Service, and the Natural Areas Conservancy, focused on knowledge coproduction across disciplines and bridging the gap between science and implementation.

Mary Bandziukas is a GIS specialist who supports the NYC DOT Design and Construction division in charge of pavement markings. She is part of several new initiatives developing digital tools and automation, including a digital twin of markings and their physical and environmental contexts. Prior to joining DOT, she was a planner at the local and federal levels and contributed to environmental programs in the public and nonprofit spheres.

Victoria A. Beard is the director of the Cornell Mui Ho Center for Cities and a professor of City and Regional Planning at Cornell University. Her research focuses on how planners address urban inequality and poverty, including how underserved communities plan for themselves. She also focuses on access to core urban services, equity, sustainability, and how broader processes create and sustain citywide transformation.

Andrew Buck, AICP, ENV-SP, is a senior urban planner/technologist at VHB, where he combines urban planning with design and technology to help cities, campuses, and communities in the New York metro area, along the East Coast, and in East Asia tackle complex issues such as climate change. Part of his work has involved the development of digital twins deploying a combination of big data, model-based design, and geospatial information systems technologies for a variety of use cases ranging from urban design and development and scenario planning, carbon mitigation and climate adaptation planning, and transportation systems planning and design.

Jason Caldwell is vice president of business development and sales at the Sanborn Map Company. He has 27 years of experience in GIS, remote sensing, and mapping environments, and has consulted for a wide range of clients, including many in government and the energy sector. Prior to consulting, he worked in map production.

Lindsay K. Campbell is a research social scientist with the USDA Forest Service Northern Research Station, based at the NYC Urban Field Station. Her research explores the dynamics of environmental governance, civic engagement, and natural resource stewardship, with an emphasis on environmental and social justice. She is co-lead of STEW-MAP, which maps the social networks and spatial territories of environmental stewardship groups. She also co-leads the Urban Field Station Collaborative Arts Program.

Lindsey Cassone is an environmental and climate planner at VHB, where she works with cross-sector clients on environmental assessments, stakeholder engagement, and various climate adaptation and mitigation efforts. As a researcher and city planner, she is dedicated to understanding how urban communities can leverage data and technology to prepare for and respond to the climate crisis. She holds a master's degree in city and regional planning from the Pratt Institute, a bachelor of science degree in environmental planning and policy from Virginia Tech, and is a Waterfront Alliance WEDG associate.

Josh Cerra is associate professor and chair of the Cornell University Department of Landscape Architecture and principal investigator of the Climate-adaptive Design

(CaD) studio program in partnership with New York State Department of Environmental Conservation. His teaching and research investigate relationships between urban ecosystems, communities, and site development processes, and their implications for climate-adaptive design and urban ecological design.

George Del Barrio is founding creative director and executive producer of The Vanderbilt Republic and MIDHEAVEN Network and Studio. He is also creative director and executive producer at Universe City NYC, Space for Arts, J. Bouey Dance Projects, and Madhura Studios. As a first-generation American, he concentrates his practice on expanding archetypes. Every installation is driven by a resolute humanism; every invention, design, and transformation is in search of "duende" – meaning is not a discovery, but a creation.

Timur Dogan is an associate professor of architecture at Cornell University and director of the M.Arch. program and the Environmental Systems Lab. His research aims to accelerate building decarbonization through educational programming and strategic research at the intersection of design, computer science, building performance simulation, and urban geospatial analysis. The Environmental Systems Lab has created widely used tools such as urbano.io, eddy3d.com, patented algorithms, and building component prototypes.

Jacqueline Duke is a community health worker at the Rockaway Initiative for Sustainability and Equity (RISE), a community-based organization in Far Rockaway, Queens. She is also a customer service supervisor for Queens Library.

Hayley Elszasz is the climate science advisor at the Mayor's Office of Climate and Environmental Justice (MOCEJ). She oversees partnerships with academic institutions to advance actionable climate science, including the New York City Panel on Climate Change (NPCC), Rainproof NYC, the Climate Knowledge Exchange, and FloodNet. She is also the open data coordinator for MOCEJ and works to foster knowledge-sharing partnerships between city agencies, climate scientists, and NYC communities.

Deborah Estrin is a professor of computer science at Cornell Tech in New York City, where she also serves as associate dean for impact, and is affiliate faculty at Weill Cornell Medicine. Her research focuses on digital health, including caregiving technologies, digital biomarkers, small data, and public interest technology. She was previously the founding director of the NSF Center for Embedded Networked Sensing (CENS) at the University of California, Los Angeles, pioneering the development of mobile and wireless systems for ecosystem monitoring and research.

Joseph Ferdinando is a senior product manager at the Allen Institute for Artificial Intelligence's Skylight Program and a fellow at the Cornell Mui Ho Center for Cities. He is a veteran of the US Coast Guard with extensive experience in remote sensing and geospatial analysis. He holds master's degrees in GIS, earth systems science, and computer science.

Claire Fisher is the program assistant for the Cornell Mui Ho Center for Cities, where she provides support for center initiatives, faculty research labs, outward-facing programming, and relationships with strategic partners. She also manages communications for the center, produces and co-hosts the podcast "The Good City," and contributes to the CfC blog.

Elena Freije Urdaneta is a Venezuelan artist and communicator based in New York City. She has a background in pre-modern theater and devised work, which brings community members together to create narrative performances. She holds a master's degree in arts administration from Baruch College, CUNY.

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Patrick Gahagan has been a senior solution engineer at Esri for 20 years, working with the City of New York and other large cities along the East Coast. He is a specialist in 3D, CAD, BIM, and more recently, laser scanning, drone mapping, and Indoors GIS. Patrick builds demonstrations and proof of concept applications that creatively integrate content from multiple platforms, and develops best practices for new technologies that integrate with ArcGIS. Patrick has built digital twins of the Atlanta airport, George Washington's Mount Vernon, and a house he was going to build in New Jersey.

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Jim Hall has been doing technology and data for more than 30 years. He brings a wealth of expertise in navigating the intersection of business strategy and cutting-edge technology, and has a proven track record of delivering innovative solutions that drive organizational growth and efficiency. He is committed to empowering his clients to thrive in the digital era. His customers have included more than 25 agencies in NYC government, the MTA, the Port Authority of New York and New Jersey, and other government agencies.

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Wendy Ju is an associate professor of information science at Cornell University, an inaugural member of Cornell's campuswide multidisciplinary Design Tech department, and an associate professor at the Jacobs Technion-Cornell Institute at Cornell Tech and the Technion. Her research focuses on designing interaction between people and automated systems. She has created numerous methods for prototyping and studying systems for autonomous vehicles and robots. Her current research focus is on urban-scale interaction.

Alexander Kobald is the associate director of the Design Across Scales lab at Cornell University. A designer, researcher, and fabricator, he recently led the design of Tree Folio NYC, a digital twin of the city's urban canopy that uses data from LiDAR scans to map and analyze the shade provided by each tree in the city. The goal is to inform species and site selection to respond to local needs and maximize climate benefits.

Michael Koterba is MJ's Chief Technology Officer and geospatial services manager. For the past decade, he has adapted technology to increase the speed and accuracy of MJ's GIS and mapping capabilities. He spearheaded MJ's in-house initiative to develop MJ4D, a web-based software that allows users to remotely explore a digital twin directly via a web browser. He has implemented the use of laser scanning, mobile mapping, UAV technology, ArcGIS and MJ4D to create digital twins for a variety of projects.

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Wenfei Xu is an assistant professor in Cornell's Department of City and Regional Planning. Her research questions how housing policies, practices, institutions, and technologies have shaped urban inequality, with an orientation toward methods in urban analytics. She works on topics in social-spatial stratification, segregation, race and ethnicity, data science, mapping, and neighborhood change in the United States.

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Image credit: Victoria Beard