March 4th | Autonomous Aerotropolis: A Digital Twin Model for Enhancing Smart and Connected Communities

Dimitri Mavris, Regent Professor, School of Aerospace Engineering, Georgia Tech
- Aerotropolis - Smart Cities as Engineering Systems Design

Perry Yang, Associate Professor, School of City & Regional Planning and School of Architecture, Georgia Tech
- Aerotropolis - Smart Cities as Urban Systems Design

Kirk Talbott, CIO, Metropolitan Atlanta Rapid Transit Authority (MARTA)

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Smart Cities as Engineering Systems Design:

Towards an Autonomous Aerotropolis Digital Twin

March 2021

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Director, Aerospace Systems Design Laboratory (ASDL)

Langley Distinguished Professor

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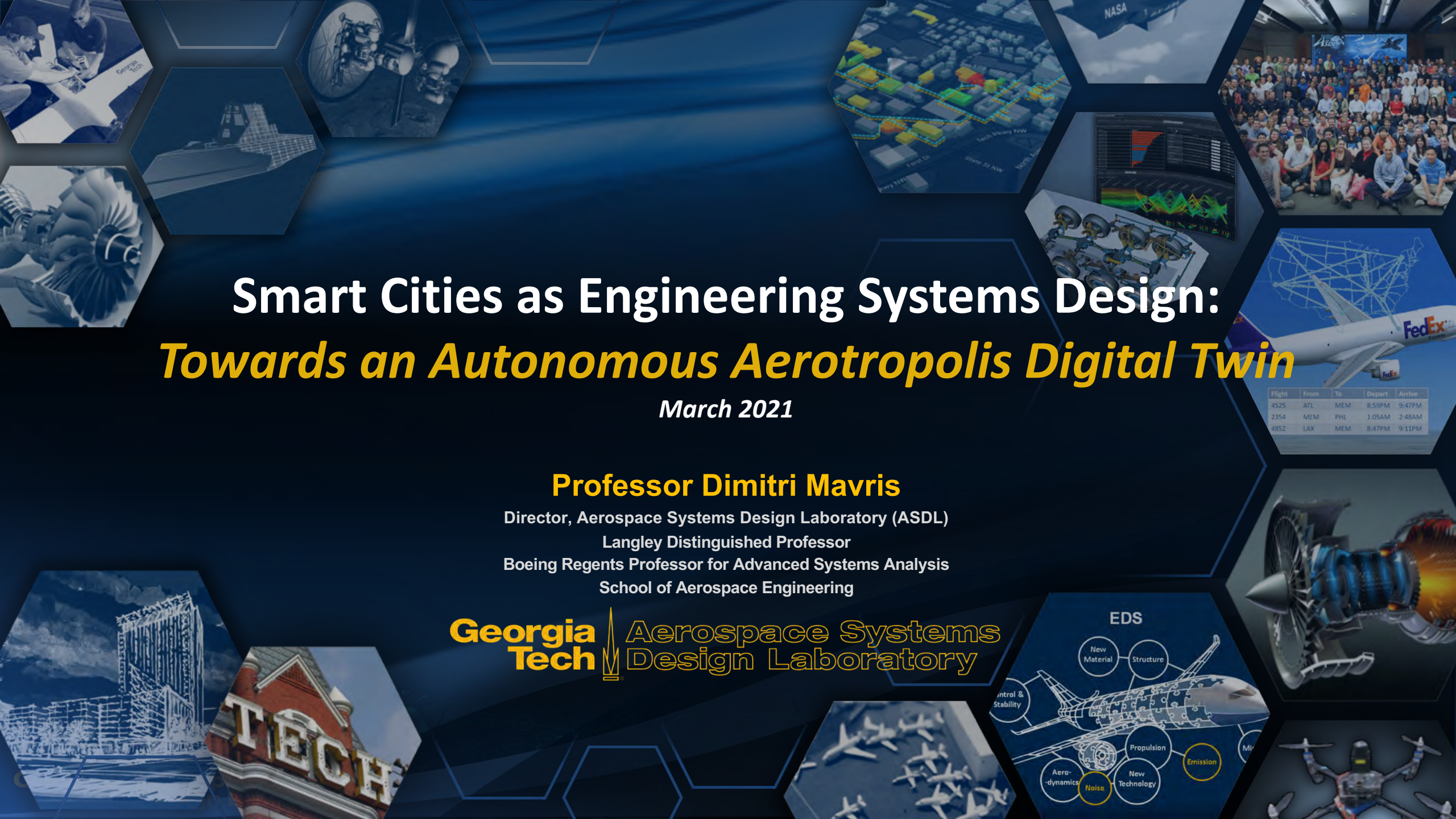
School of Aerospace Engineering

Georgia Tech Aerospace Systems Design Laboratory



A Vision for Smart Cities

Urbanization Growth

Population in metropolitan areas is rapidly rising

…leading to several challenges:

Public Safety

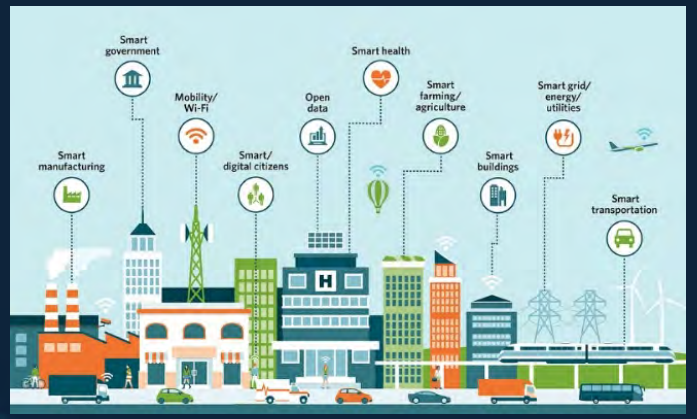
Cost of living

Rising pollution levels

Aging infrastructure

Congestion

Smart Cities to address Urbanization



What are Smart Cities?

- *Urban areas that use different types of data to manage assets and resources efficiently by bringing together technology, government and society [1]*

Why Smart?

- Through “smart” capabilities (enabled by advanced data analytics) , issues associated with urbanization growth can be addressed more efficiently through rapid solution implementation [2]

Smart City Concepts have been emerging to address safety and other major issues as part of continuously rising urbanization growth

Gigatechnologies – 10^{+9} Systems

(i.e. how would you model and design the largest engineered systems that humans create?)

- There is no single perspective or strategy that can change the shape of a city, only shared knowledge and collaboration combined with foresight, shared long-term goals, coordinated short term actions, and continuous measurement and feedback over many eras of change

Social Interaction | Diversity | Resources/Waste | Infrastructure | Education/Creativity | Transportation | Economics

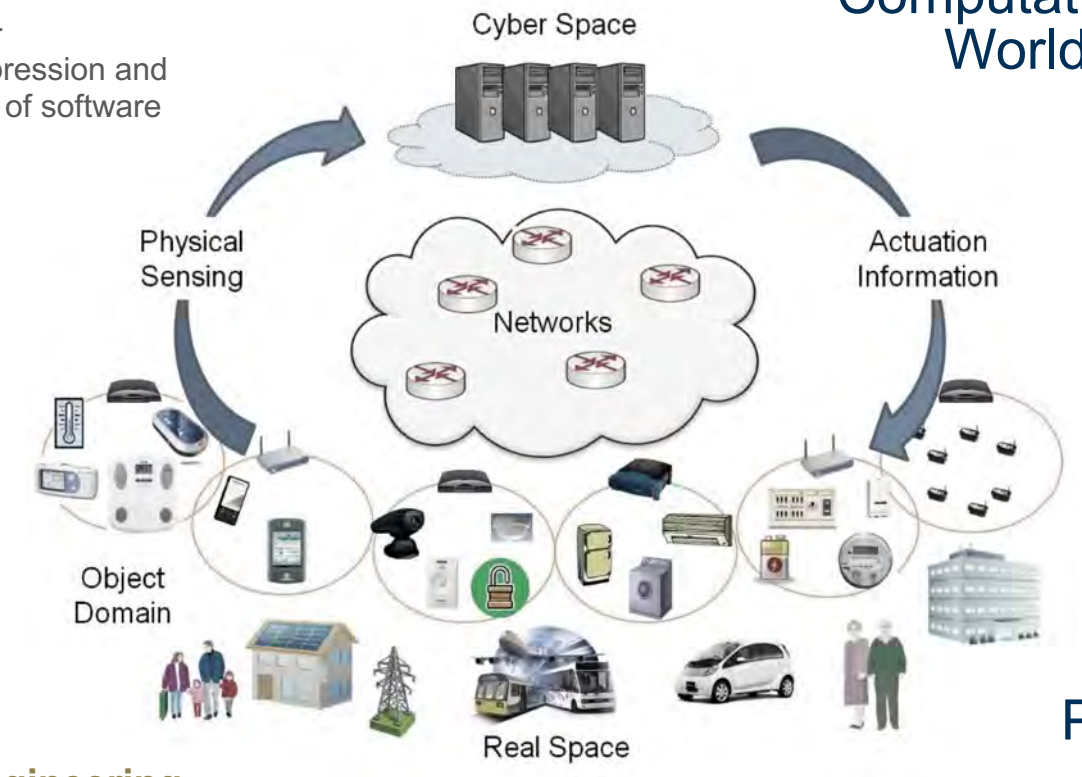
- *"Make no little plans. They have no magic to stir men's blood and probably themselves will not be realized. Make big plans; aim high in hope and work, remembering that a noble, logical diagram once recorded will never die, but long after we are gone will be a living thing, asserting itself with ever-growing insistency."* - Daniel Burnham, City Planner, 1903

Three Classes of Systems

Software Engineering –
Moving from a real world problem to its expression and representation by virtualization and coding of software design

Abstract ↑

Concrete ↓



Computational World

Cyber-Physical World

Physical World

Conventional Engineering –
Moving from abstract design to physical realization

Reference: Wang, Y., Software Engineering Foundations: A Software Science Perspective.
Image: http://www.jaist.ac.jp/is/labs/lim-lab/image/4.CPS.jpg

Aerotropolis Project: Objective ("The Ask")

Motivation:

- ***Address spatial mismatch of housing affordability and job location, through improved inclusiveness in urban mobility and public transit systems***

Objective:

- ***Identify enabling concepts and technologies*** on autonomous mobility to improve traffic and adopt to demand in an Airport City (Airport + surrounding cities and business districts)
- ***Explore data driven-approaches*** for operations optimization and mobility modeling to support efficiency-driven decisions at both tactical and strategic/planning levels

Goal: An SoS-level analysis to support decisions on mobility planning to further boost social inclusivity and reduce mismatch between housing affordability and jobs

Main Challenges:

- *Mismatch* between housing affordability and jobs (as in e.g. work in a city where you still cannot afford to live in, so you travel long hours back and forth every day)
- *Non-inclusive mobility* (e.g. schedules/route that don't effectively serve traffic and demand)
- *Impact of disruptions* (e.g. continuity of service and access during the COVID-19 pandemic)

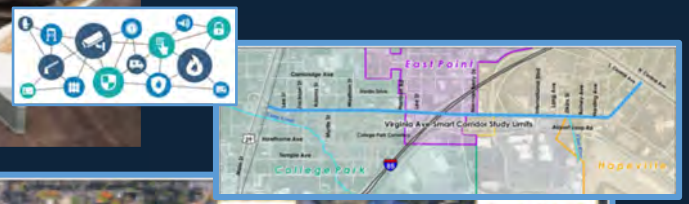
Aerotropolis Project: Background

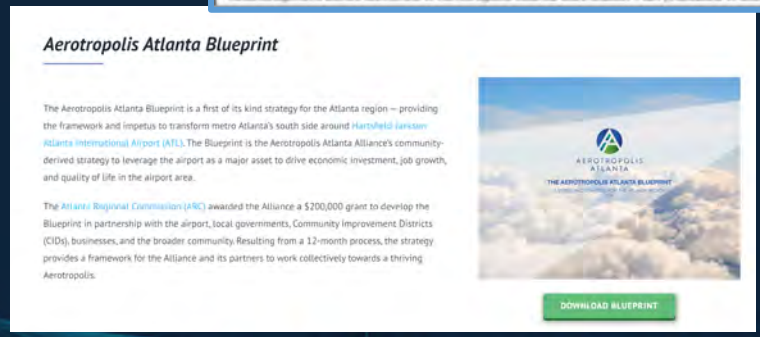
- ***An airport city*** is the ***"inside the fence" airport area of a large airport***, including the ***airport*** (terminals, apron, and runways) and ***on-airport businesses*** such as air cargo, logistics, offices, retail, and hotels. The airport city is at the core of the Aerotropolis, a new urban form evolving around many major airports (Kasarda, 2013)

- ***Aerotropolis Atlanta*** is a planned mixed-use development in Hapeville, Georgia on the site of the former Ford Atlanta Assembly Plant. The site is directly adjacent to Hartsfield-Jackson Atlanta International Airport. The complex is to house offices, retail, and entertainment (https://aeroatl.org/)

- The ***Aerotropolis Atlanta CIDs*** (Community Improvement Districts (CIDs) are locally controlled, quasi-governmental entities established by provision of state law (Article IX, Section VII). CIDs are empowered to serve as the means of funding beautification, public safety and infrastructure projects such as those focused on transportation and water

Urban mobility and public transit system, including Microtransit, PRT and Autonomous Vehicle





Area between Domestic Terminal and College Park to be new Aerotropolis Hub

Problem Scoping: From a City to a Campus/District

Implementation of Smart Cities at the practical level, is hindered by complexities, operational uncertainties and accessibility to data

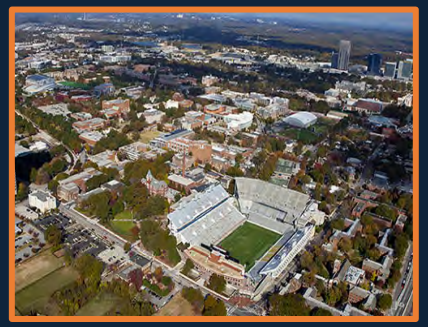
- Modeling and design at the city level is a very challenging task
- Benchmarking and understanding the systems is difficult without dedicated support by the experts
- Technologies and enablers are hard to be proven and showcased at the scale of a city

The proposed solution: ***Use of a campus as a testbed for development and demonstration of Smart City concepts***

Built Environment
Energy & Water (supply & demand)
Mobility
Transportation
Env. Footprint
Security
IT Connectivity
UAS
Supply Chain
Human Activities

Campus/District Level

Built Environment
Energy & Water (supply & demand)
Mobility
Transportation
Env. Footprint
Security
IT Connectivity
Human Activities



Building Level

Use Case: Campus of the Future

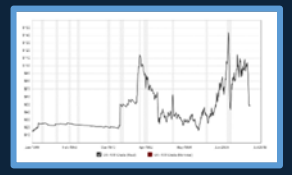
A Multi-layered System of Systems

- Georgia Tech
- *Human Activities*
- *Built Environment*
- *Energy & Water*
- *Enviro. Footprint*
- *Security*
- *Supply Chain*
- *IT Infrastructure*
- *Mobility*
- *Ecological Services*

Desired qualities

Sustainable

Resilient


Rising Energy Costs


Weather Threats


Emergency Events

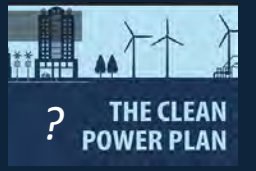

Cyber Threats

Adaptable


Campus Growth


Emerging Tech


Engaged Stakeholders



Changing Policy

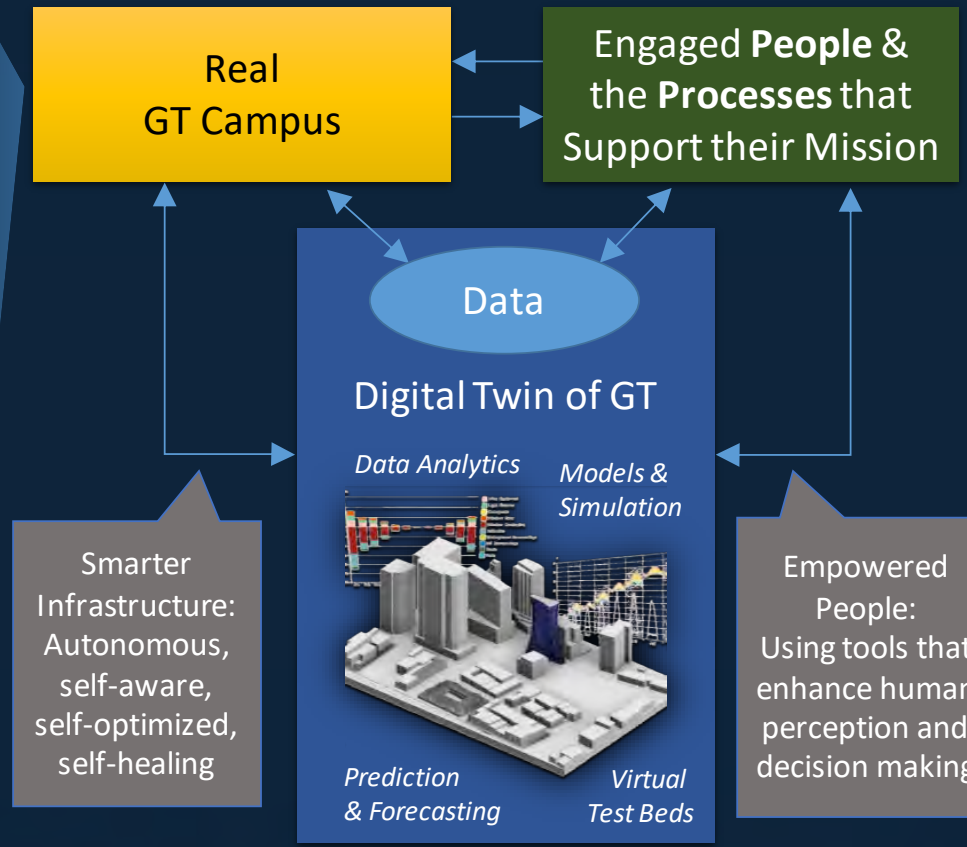
Evolving Cityscape

Vision: Digital Twin of Georgia Tech Campus

- Digital Twin: “Pairing of virtual and physical worlds [that] allows analysis of data and monitoring of systems to head off problems before they occur, prevent downtime, and even plan for the future using simulations.” (Forbes, 2017)

A Multi-layered System of Systems

- *Human Activities*
- *Built Environment*
- *Energy & Water*
- *Enviro. Footprint*
- *Security*
- *Mobility*
- *IT Infrastructure*
- *Supply Chain*
- *Ecological Services*



People:
- Students, Faculty & Staff
- Researchers
- Police & Fire Safety
- Administration & Finance
- Procurement
- GT Facilities Mgmt.
- Parking & Transportations
- OIT
- …

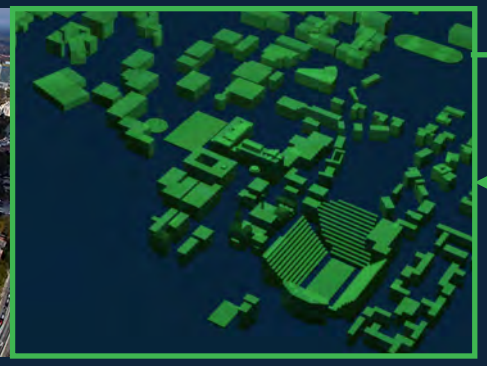
Processes:
- Education & Research
- Event Planning
- Asset Tracking
- Emergency Response
- Fault Finding & Diagnostics
- Maintenance
- Strategic Planning
- Forecasting
- …

Intelligent technologies to fuel innovation, inspire new business models, and transform the workforce

Campus Digital Twin: Elements and Layers

A Real World System of Systems

Digital Twin of the System of Systems



- *Planning / Construction*
- *Renovation / Maintenance*
- *Sustainability / Optimization*
- *Event Analysis / EVAC*

Decision Support

Interactive Visualization

Data Fusion

GIS

- *Areas of Interest*
- *Lands / Roads*
- *Buildings*
- *Infra. Networks*

Data

- *Metadata*
  - *BIM / Occupancy*
  - *Space Usage*
  - *Resources*
  - *Services*
- *Sensor Measurements*
  - *Weather*
  - *Consumptions (Energy / Water)*
  - *Communication / Social Media*
  - *Traffic / Parking*
  - *Crime / Safety*

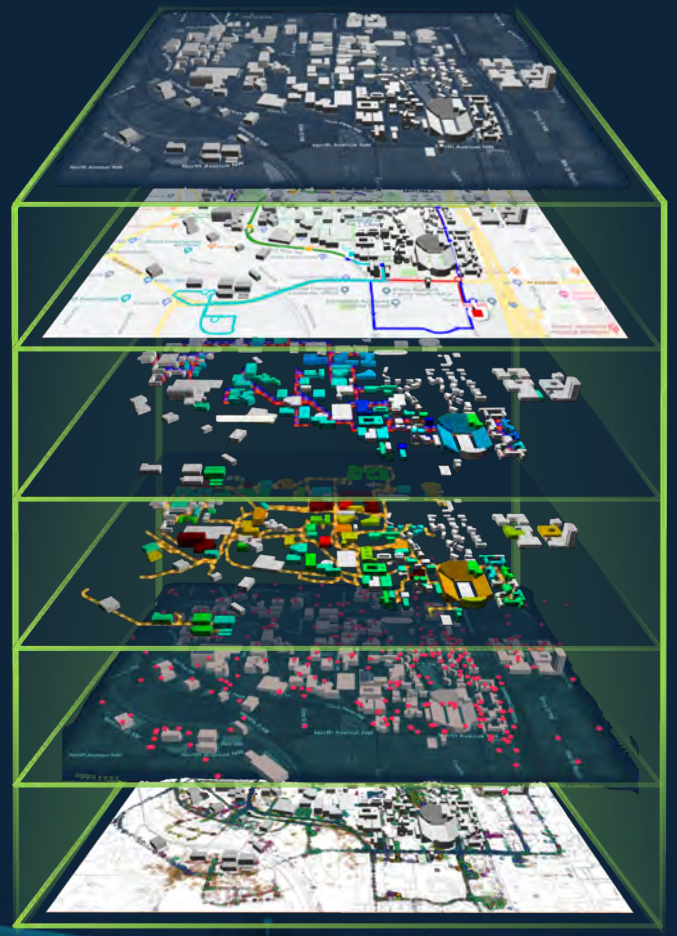
Analytics

- *Statistics*
- *Machine Learning*
- *Predictive Analytics*

Modeling & Simulation

- *Physics-Based Tools*
- *System Dynamics*
- *Discrete Event Simulation*
- *Agent Based Modeling*

Digital Twin for System of Systems consists of mutually interacting multiple layers



Geographic Information Layer

Traffic & Mobility Layer

Energy Layer (Campus HVAC System)

Energy Layer (Electrical Grid System)

Security Layer

Campus Service Layer

Campus Energy: Horizons of Interest

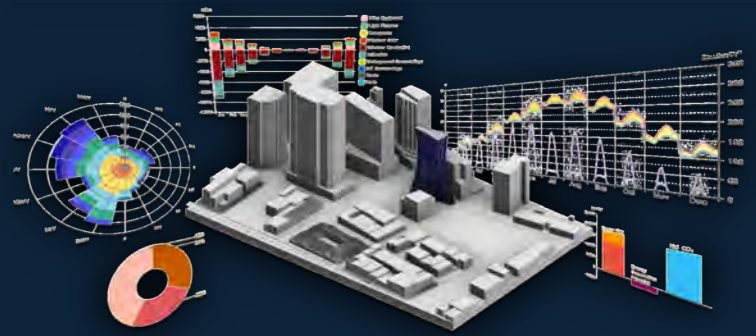
Running Campus Smartly

Focus: Existing campus, improving it as it is

Goals: Cost avoidance, energy savings, reliability, safety

Planning Campus Smartly

Focus: Future campus, Future scenario forecasting



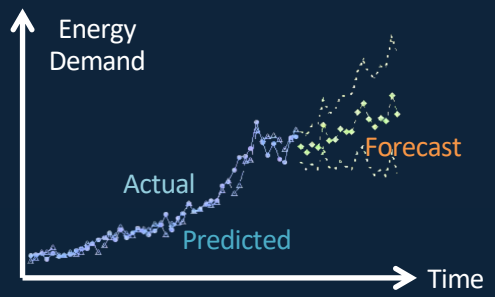
Goals: Data-driven decision making, strategic gaming, etc.

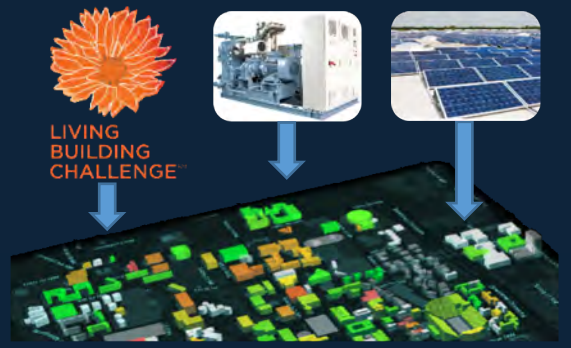
Smart Campus Data Analytics & Simulations support decision making at several horizons

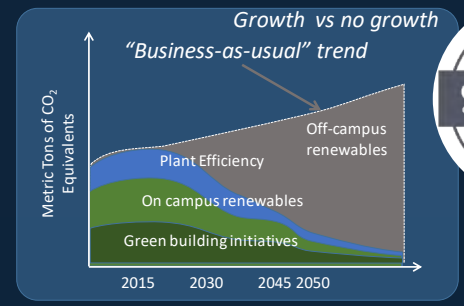
Present → Near Future → Mid-Term Future → Long-Term Future

Campus Energy: Horizons of Interest

	Running Campus Smartly		Planning Campus Smartly	
Planning Horizons	Present & Near Future		Mid-Term Future	Long-Term Future
	Situational Awareness	**Operations Optimization**	**Technology Integration Studies**	**Strategic Planning**
	Explore the Data	Benchmark Performance	Detect Faults & Degradation	Forecast BAU Loads	Explore Alt. Operations	Infuse New Technologies	Design Sys. Architectures	Game Scenarios	Develop Roadmaps







Ultimate Goals	*Intelligently monitored campus*	*Self-optimizing, resilient campus*	*"Virtual Campus" experimental facility*	*Revolutionary planning tools*

Massive Data Available

Sensor data, collected and overlaid onto a digital facsimile of campus, to support infrastructure monitoring and planning

ASDL started with access to:

Meso-scale: 20,000 streams

Data from 150+ buildings & 2 plants
Archived every 15 min for >7 years

- Energy & water metering
- People counters on newer entryways

…cleaned, normalized, and mapped to drive:

Macro-scale Situational Awareness

- Campus-level visualizations
- Baselining for detecting degradation
- Modeling to project future scenarios

…soon to be supplemented with

Micro-scale data streams

- ~10k end points per building
  - Internal temp, air quality
  - HVAC hardware states
- IoT sensors from maker spaces
- Mobile device locations, anonymized

Creating this digital version of campus required that ASDL:

Map & verify data sources Tap into data streams and databases Clean erroneous data	Normalize data by weather and campus schedule Interpret data with help from GT Facilities Management engineers

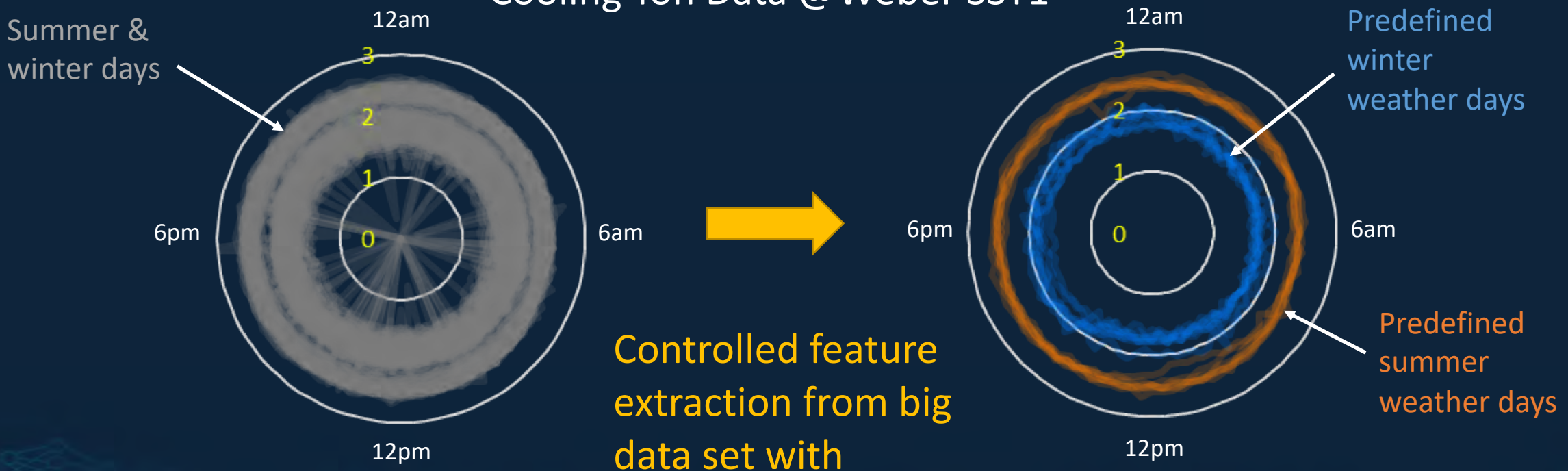
Georgia Tech Aerospace Systems Design Laboratory

FORESIGHT

An Interactive Campus Data Browser for Situation Awareness & Readiness with Predictive Analytics

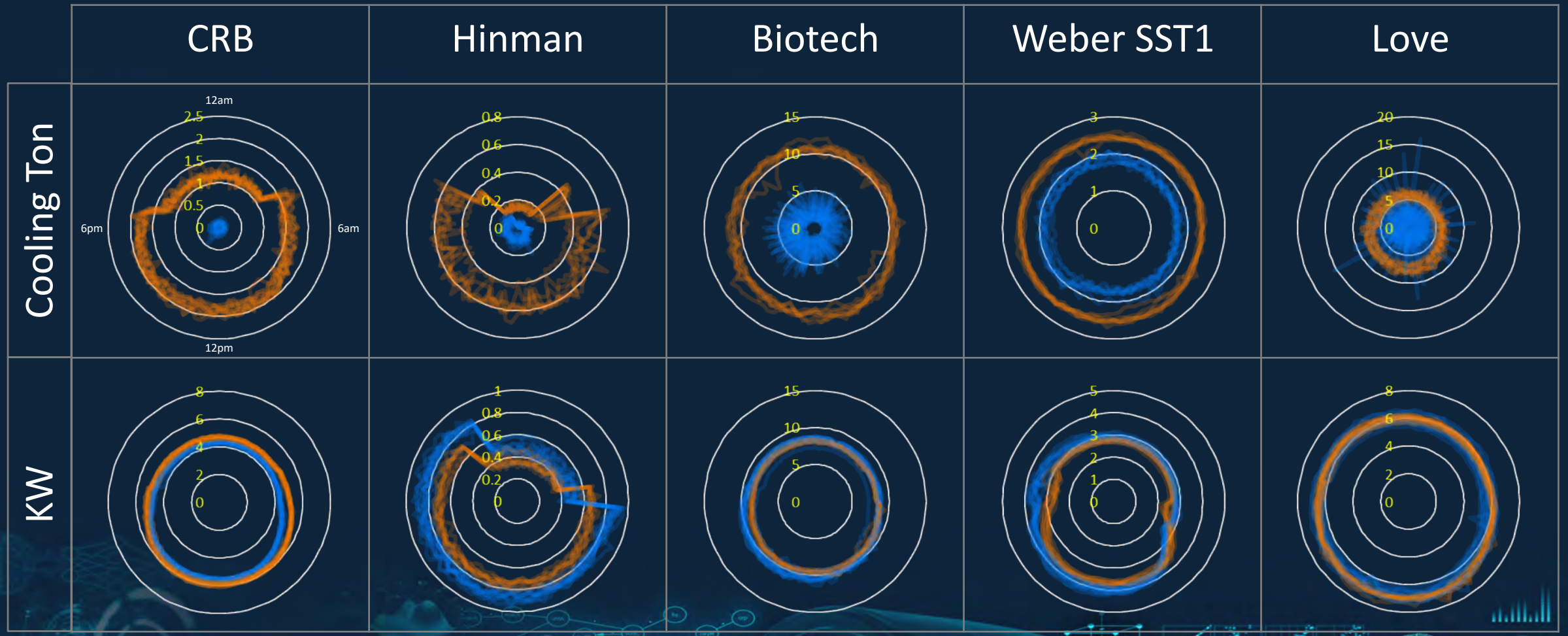
Signatures of Building Performance: From Raw Data to Human Perception

Cooling Ton Data @Weber SST1



Controlled feature extraction from big data set with surgical precision

Daily Building Cooling Energy Profile: Pattern Analysis



Autonomous Aerotropolis

Smart cities as Urban Systems Design

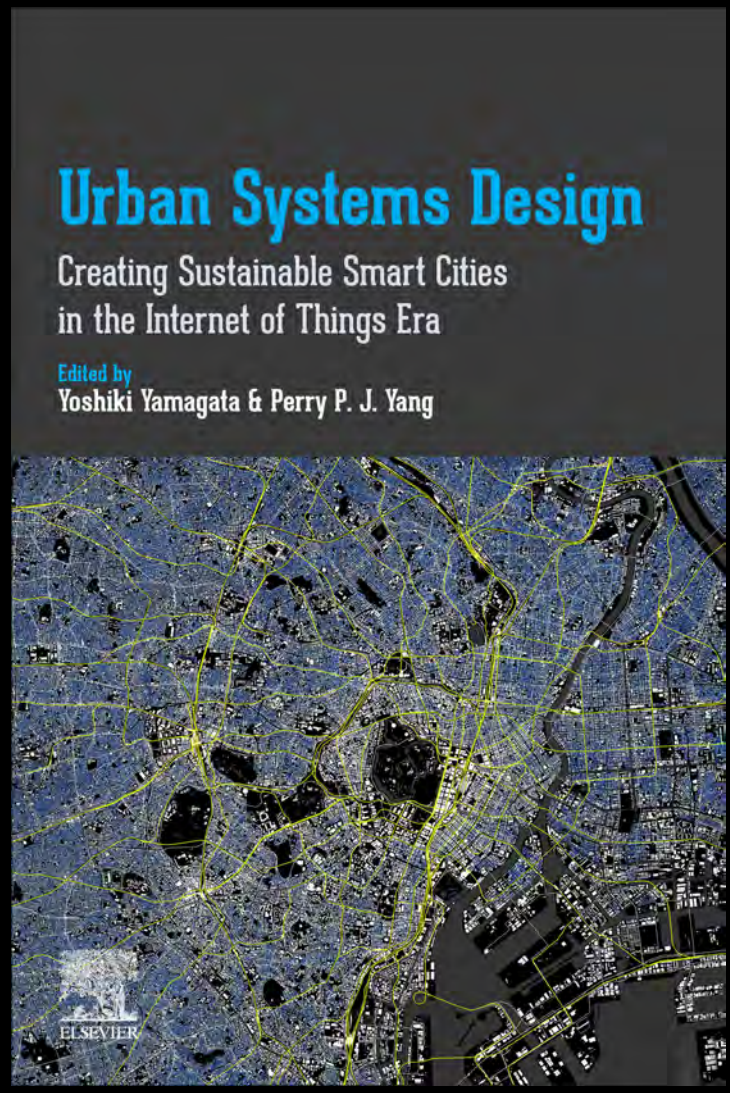
1. Aerotropolis
   - Urban economic engine
   - Social Equity: Spatial mismatch of Job-Housing Affordability
   - Post-pandemic Airport City?
2. Smart Cities as Urban Systems Design
   - Data driven cities
   - Analytics (mobility, energy and human perception)
   - Decisions platform

Perry P. J. Yang, Ph.D.

Director of Eco Urban Lab and Associate Professor

School of City & Regional Planning + School of Architecture

Georgia Institute of Technology



Aerotropolis:
Airport as a global city center

Many global cities are turning their "**city airport**" into an "**airport city**", in which city centers are built around globally significant airports (Kasarda, 2013). The **Aerotropolis** concept seeks to align the metropolitan region to better leverage an airport's assets and provide a framework for the strategic planning and development of economic activity and real estate (Atlanta Regional Commission and Aerotropolis Atlanta Alliance, 2016).

London Heathrow **PRT**
Personal Rapid Transit

HIA Airport City, Doha Qatar, OMA

SkyCity at Hong Kong International Airport

Amsterdam Schiphol Airport City Development

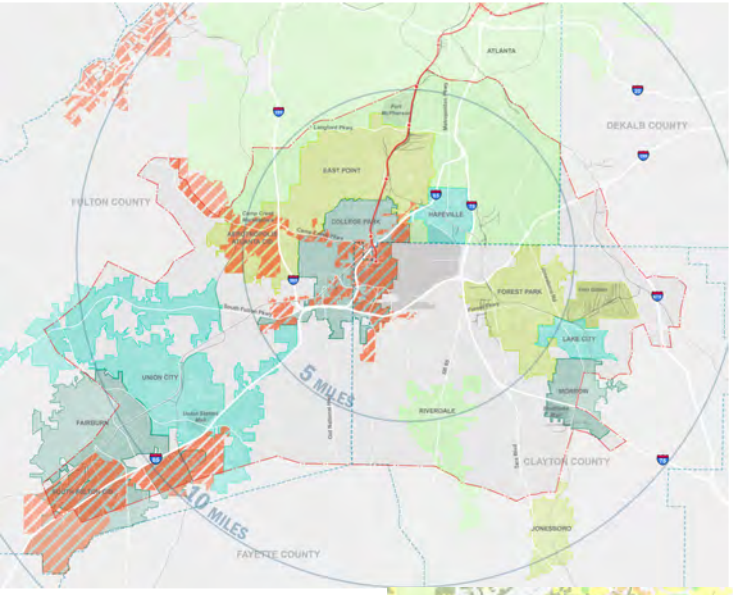
Manchester Airport City

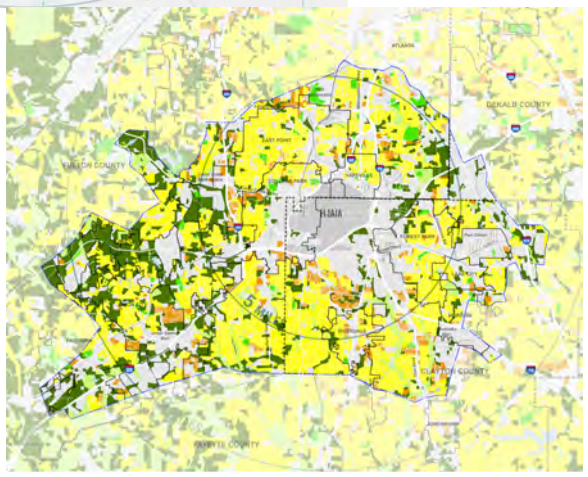
Hartsfield-Jackson Atlanta International Airport (HJAIA)

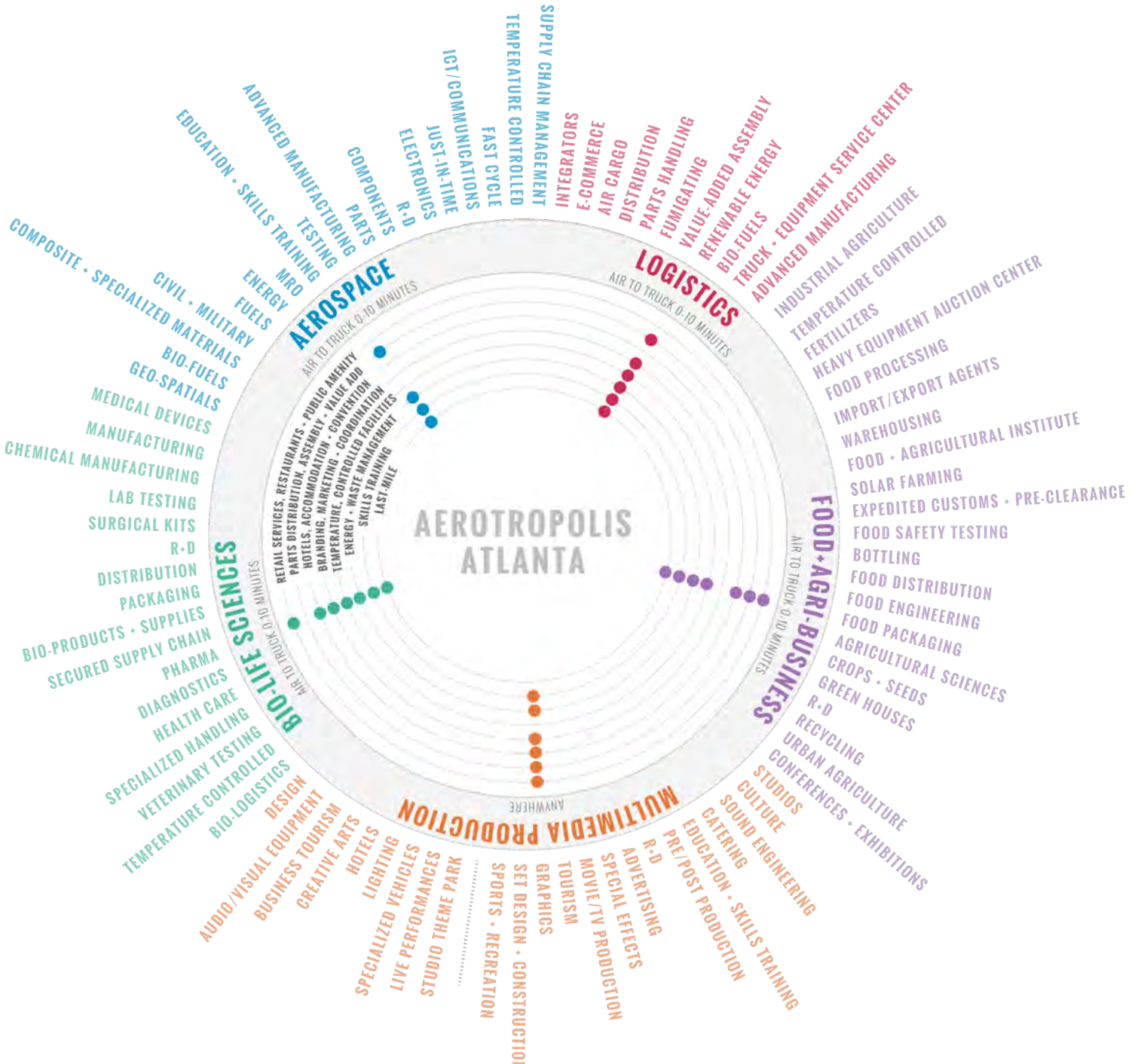
1. The largest hub of the U.S. air transportation system, serves 110.5 million passengers annually (2019), while as an “urban center,” it has a daily average flow of 300,000 people.
2. **ATL Airport Community Improvement Districts (AACIDs)** are comprised of more than 15 sq. Mi. over two districts surrounding HJAIA, and experience unique transportation issues affecting transit users, motorists, freight, and airport passengers.
3. Within the CID boundaries, Atlanta’s **Metro Area Rapid Transit system (MARTA)** operates two heavy rail stations (at College Park and the Airport, its second and third busiest rail stations respectively), along with operating 13 bus routes within the same CID area.

Aerotropolis:

An urban economic engine and
A job center







Aerotropolis:

A social issue: spatial mismatch of Jobs and housing affordability

Lack of connectivity between jobs and affordable housing has a significant impact on regional economic development. Numerous research has shown that spatial mismatch is an economic problem in Atlanta exacerbated by sprawl and poor transit options.

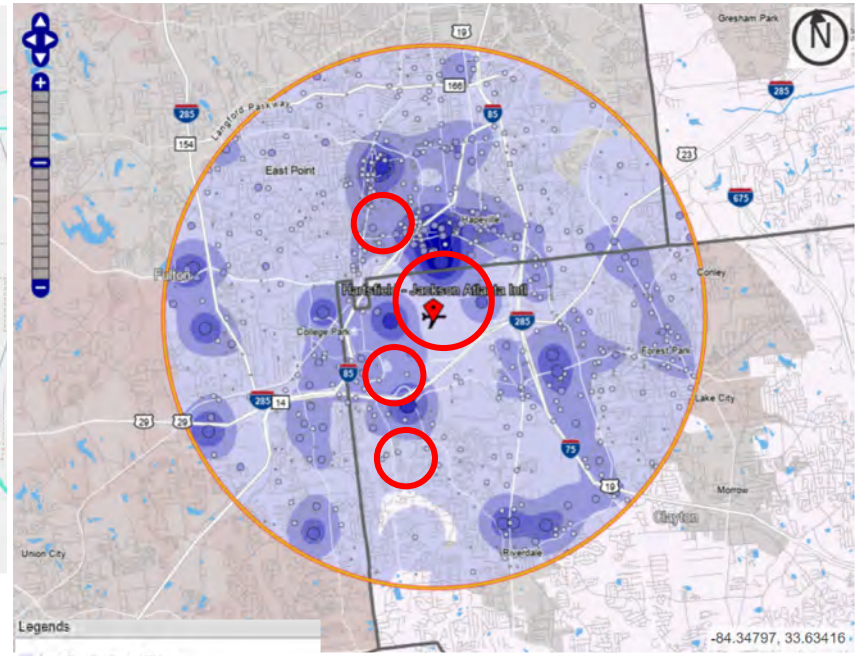
(Atlanta Regional Commission, 2017*)*

- South of Camp Creek Parkway (College Park, East Point)
- Along I-85, south of S. Fulton Parkway (Union City, unincorporated)
- South of Langford Parkway (East Point)
- Williamsburg Park, Windy hill manor (unincorporated regions)
- Northern Forest Park

Source: 2020, Rachel Muller, Zainab Raza, Sanjana Zahin, MCRP, Georgia Tech

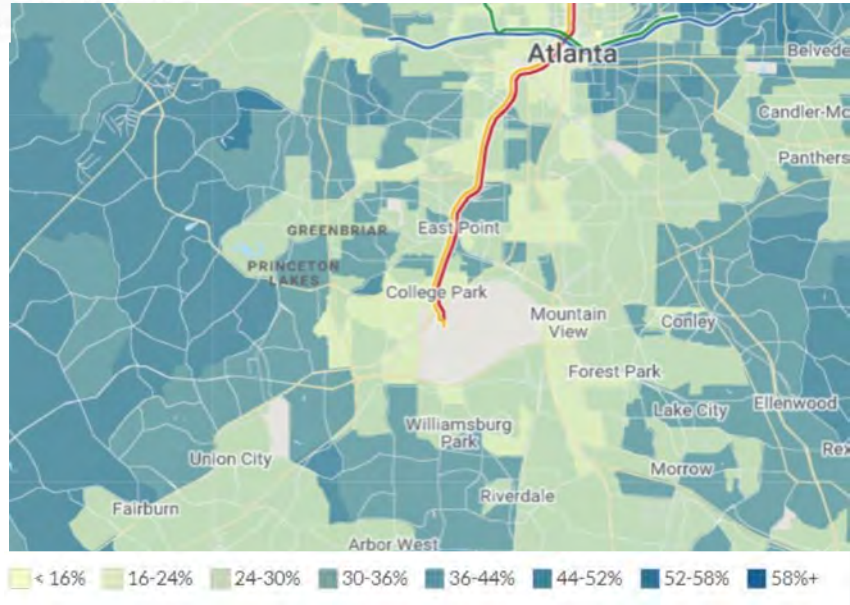
5, 10 miles radius of ATL airport

2017 Low Wage Jobs



Areas outside of ½ mile of MARTA transit route:

Housing+ Transportation Cost



Autonomous Aerotropolis

A post Covid-19 Airport City, a safer, cleaner, nimbler airport city system that is resilient and adaptable to attack and unpredictable d shocks from pandemic or other system disruptions.

College Part MARTA

Virginia Avenue Smart Corridor

Autonomous bus transit between College Park MARTA and International Terminal

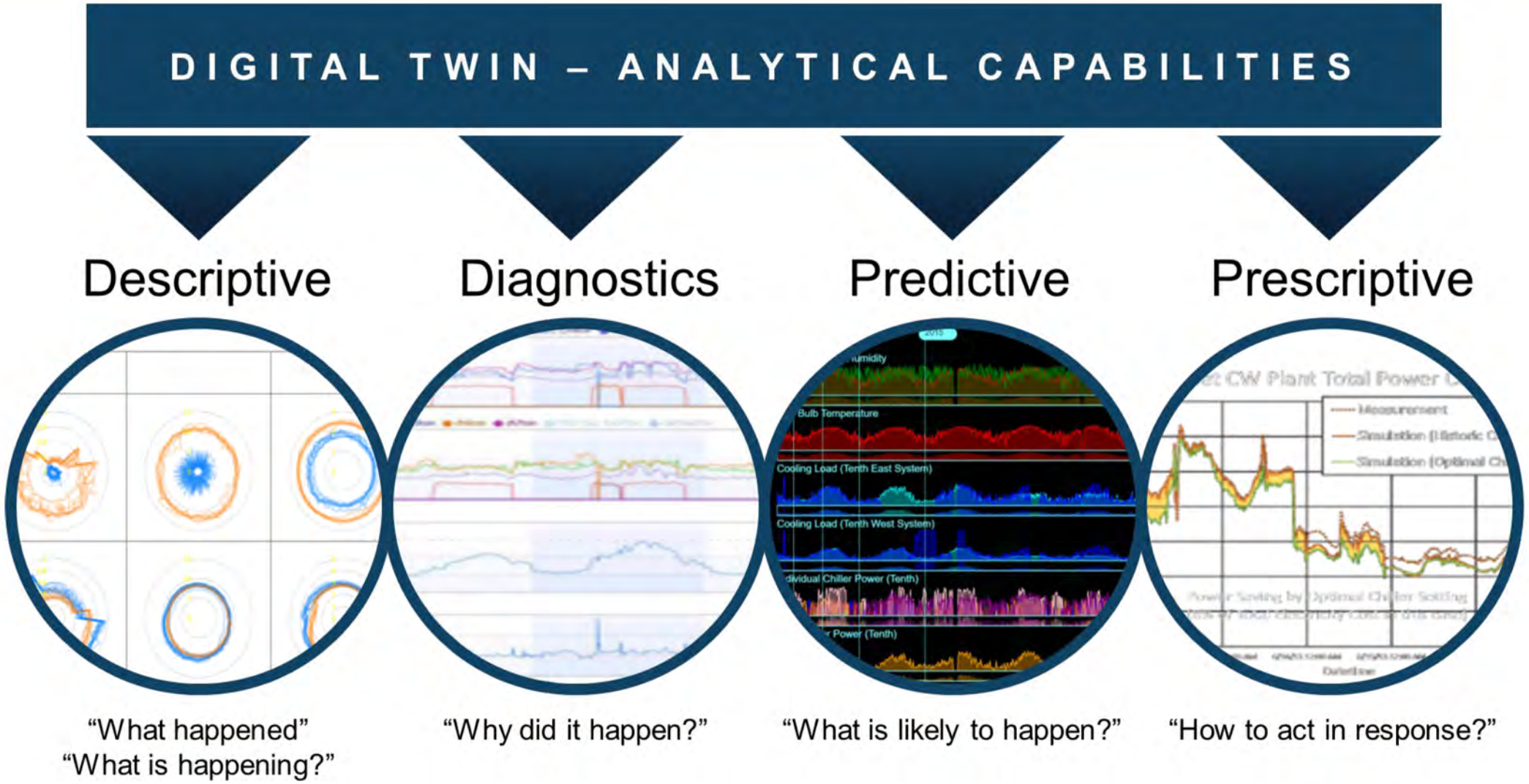
On demand Urban Pod/PRT
On demand AV

AV to Terminals underground tunnel

Airport MARTA

AV to Terminals underground tunnel

Digital Twin – Analytical Capabilities



(Source: Dimitri Mavris, Olivia Fischer and Michael Balchanos, Georgia Tech ASDL)

Smart Cities as Urban Systems Design:
A framework for Aerotropolis

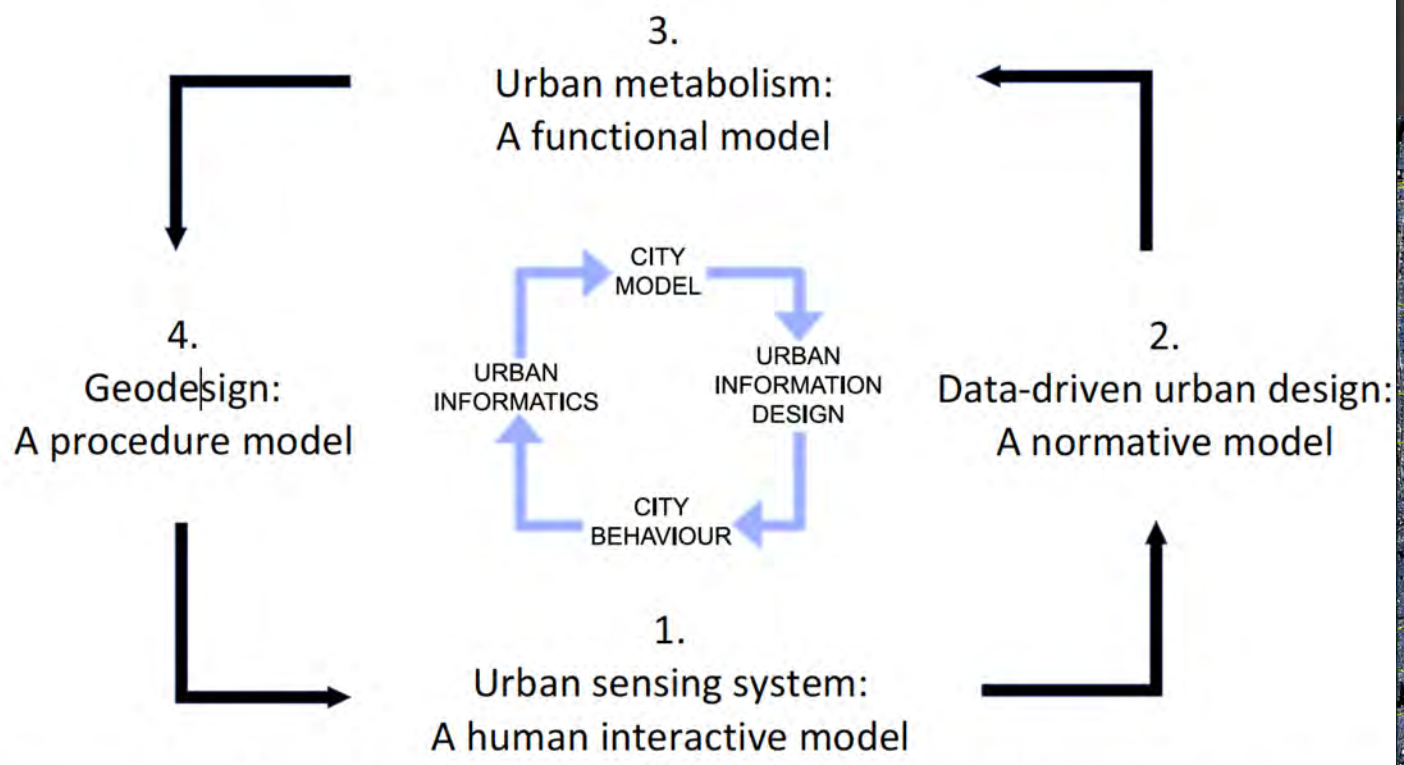
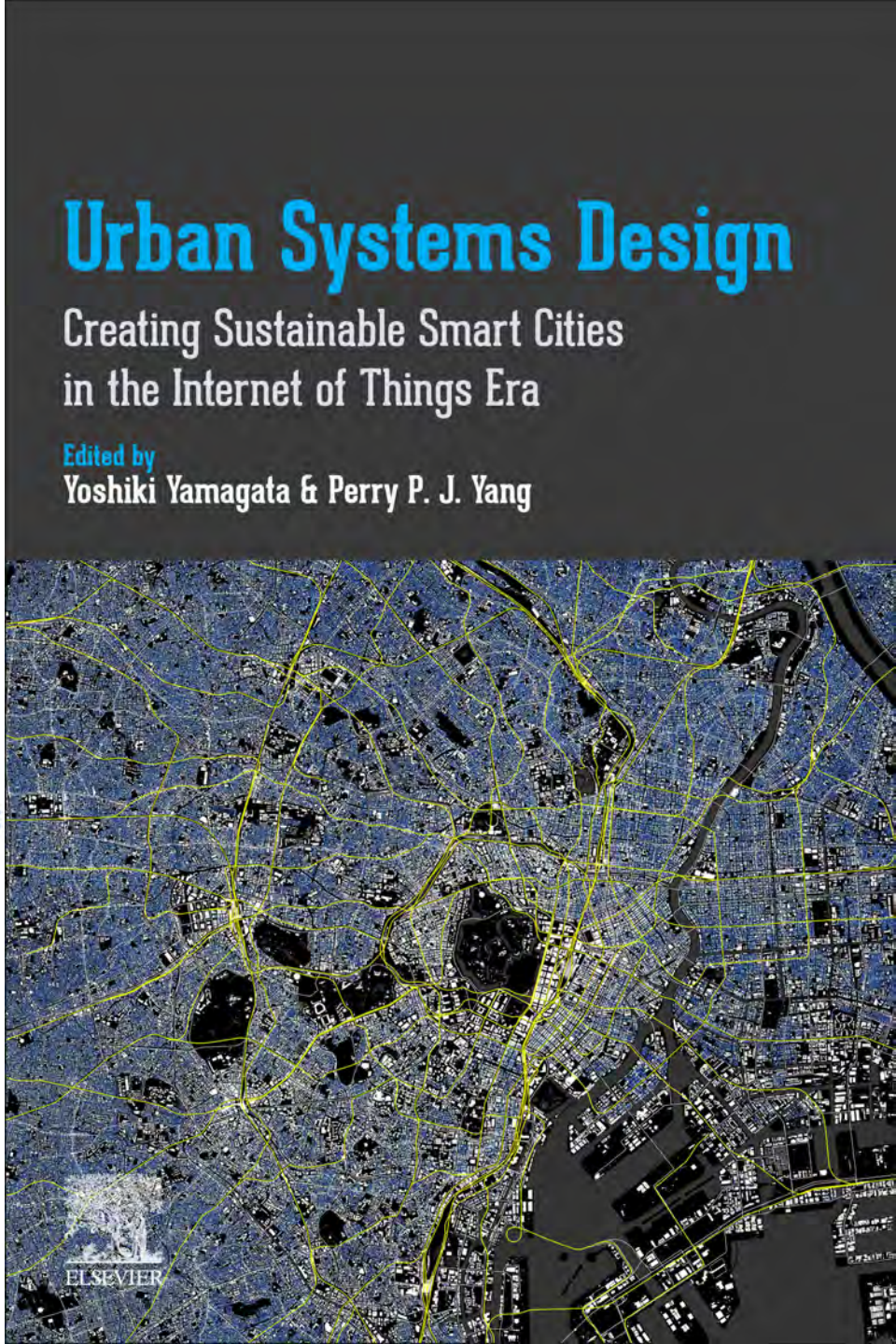


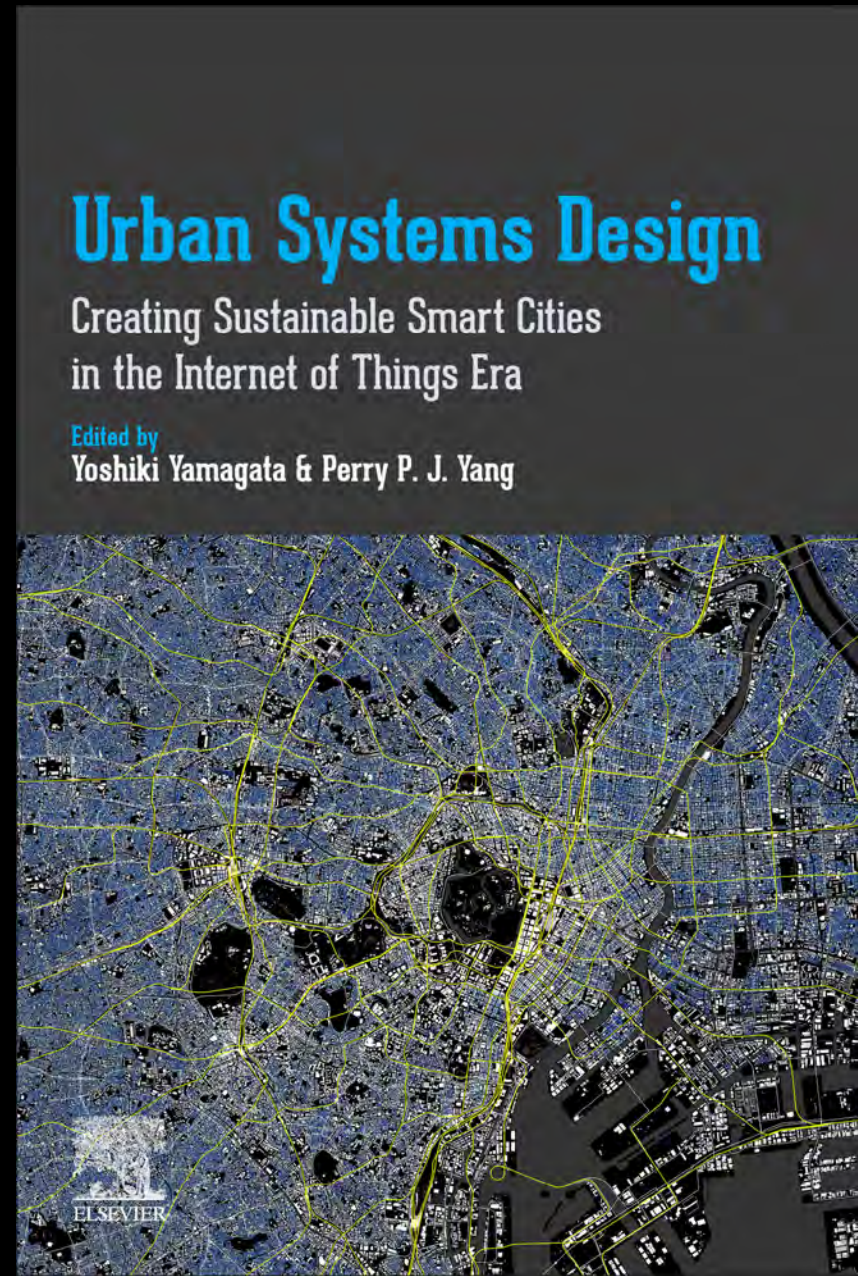
Figure 1.3 Four models of urban systems design.



Urban Systems Design: A **Data-driven** method to smart cities design

From big data, analytics to systems design & decisions

(Image by GCP Global Carbon Project with ETH Singapore, 2019)



Digital Twin for simulating complex urban systems

Urban systems design decision making

Design decisions for smart urban systems

Communication

Stakeholders

Data analytics and modeling

Experience | Performance | People flow

Key Performance Index

Heat waves | Energy balance | Flooding risk | CO_2 | Visual quality | Risk responses | Accessibility

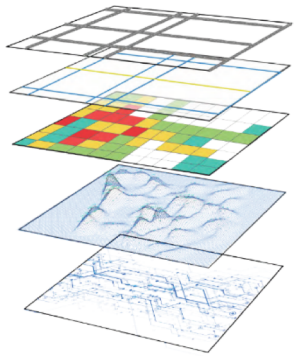
Algorithms determining key performance index from the bigdata

Unstructured data

Social media | Text | Sensor data | Satellite image | Street view image | Video files

Digital city platform

for spatial temporal modeling + design



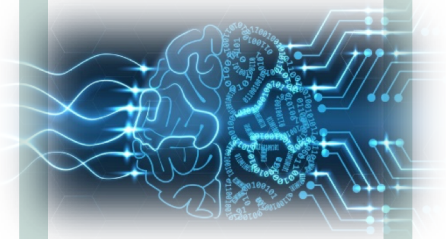
Structured data

Mobile GPS | Traffic data | Building energy demands | Popular time

Social AI:
human safety, comfort, and experiences, social interactions

Environmental AI:
environmental emissions and energy

Communication logics



Source: https://chatbotsjournal.com/how-is-ai-transforming-various-departments-in-an-enterprise-9a3503bbab22

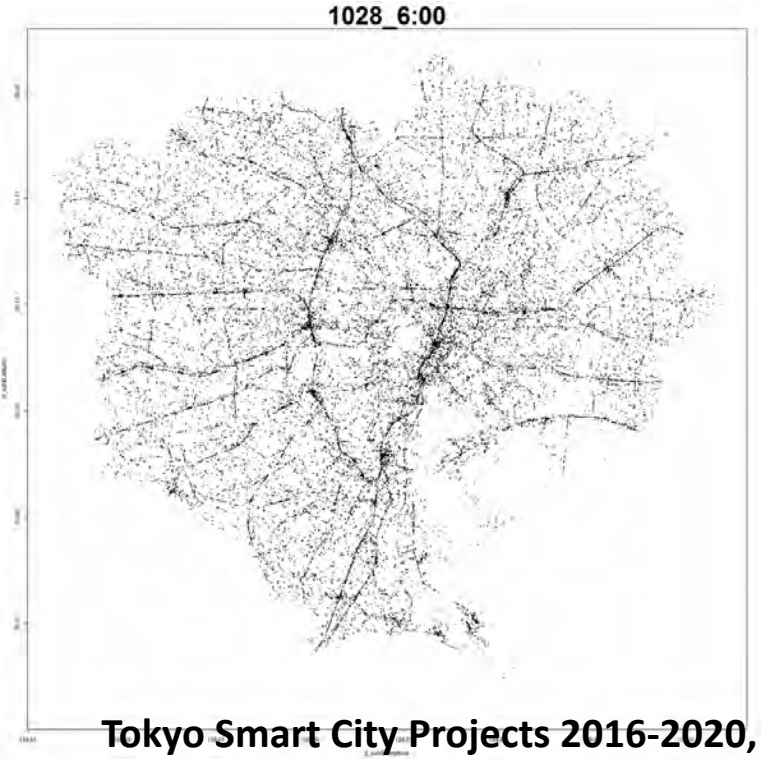
(Yamagata and Yang eds., 2020, Urban Systems Design, Elsevier.)

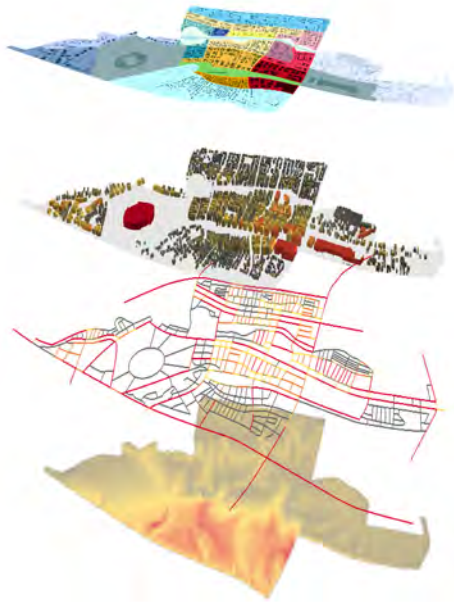
Analytics - Mobility

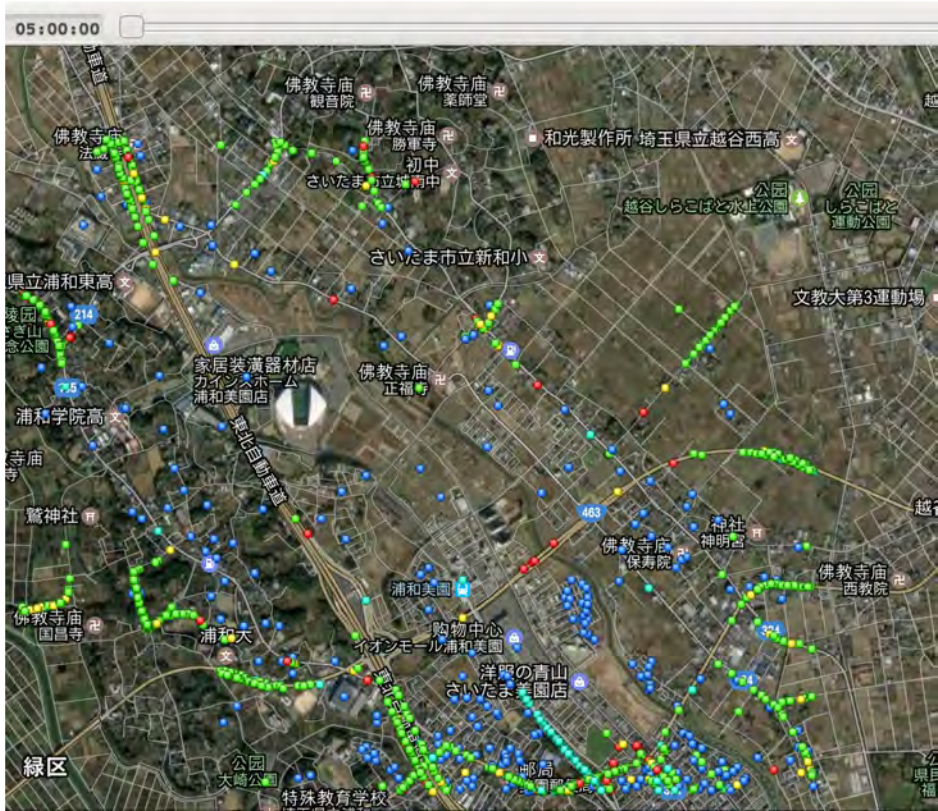
Cities as flows of humans & information

Urban science engages super fine-grain spatial -temporal data in near real time. IoT and big data analytics empowers cities to track flows of energy, materials, water, movement, information in the network, turning them into analytics, deriving properties to address problems for human responses to move decisions.

Urawa-Misono, a main stadium for Tokyo 2020 Olympics







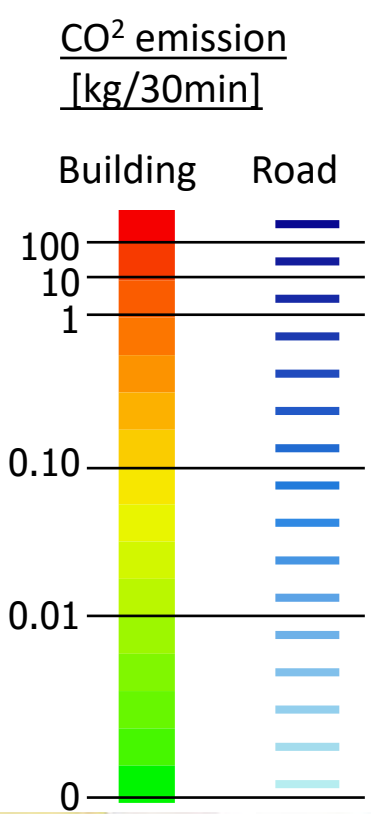
Tokyo Smart City Projects 2016-2020, GCP, NIES, University of Tokyo & **Georgia Institute of Technology**.

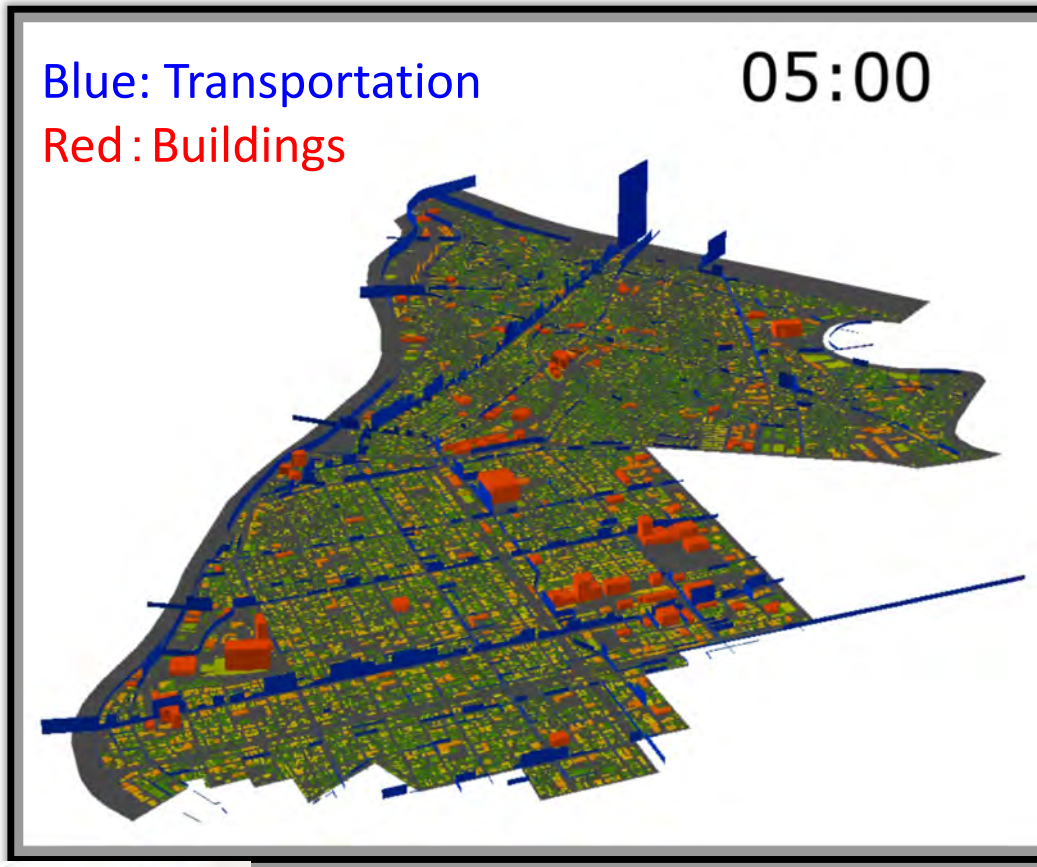
Analytics

Mobility-Building-Carbon

Urban Carbon mapping and modeling

Tokyo Sumida Ward Urban Carbon mapping by Yamagata and Yoshida et al., Global Carbon Project (right)





Urban carbon mitigation design

for Urawa Misono Smart City (Bottom)

Tokyo Smart City Projects 2017,
Yang, Yamagata and Murayama, GCP, NIES, University of Tokyo & **Georgia Tech**,

Smart mobility for community resilience

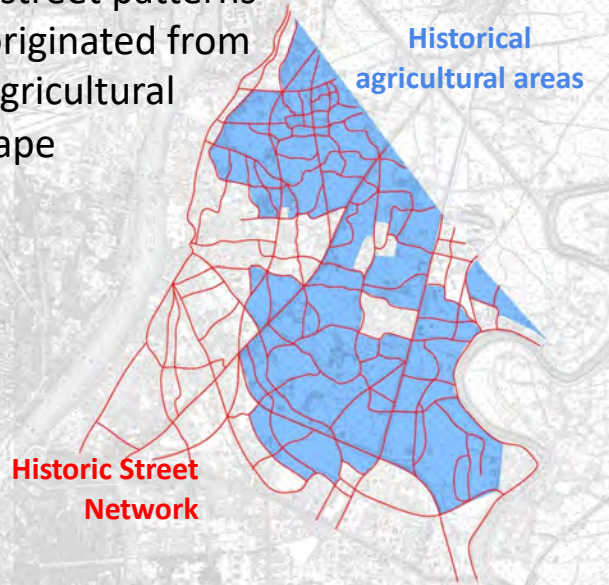
– Tokyo inner city revitalization

Vehicle to Community project: EV not in use becomes energy storage for emergency

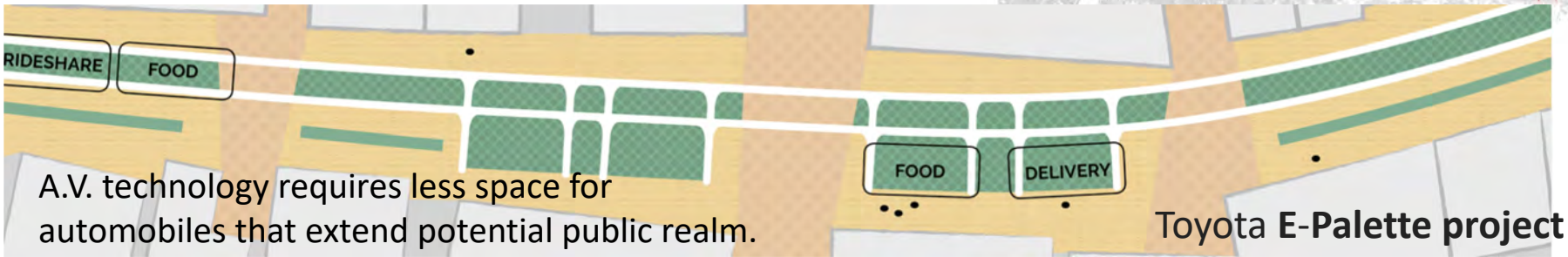
Smart cities as complex social, ecological & technological systems using IoT technologies to enhance mobility & energy resilience

(Tokyo Smart City Project, 2018-2019, Global Carbon Project, NIES, University of Tokyo, Georgia Tech)

Urban street patterns were originated from 1915 agricultural landscape



Simulation of network dynamic route choice (by i-Transport Lab)

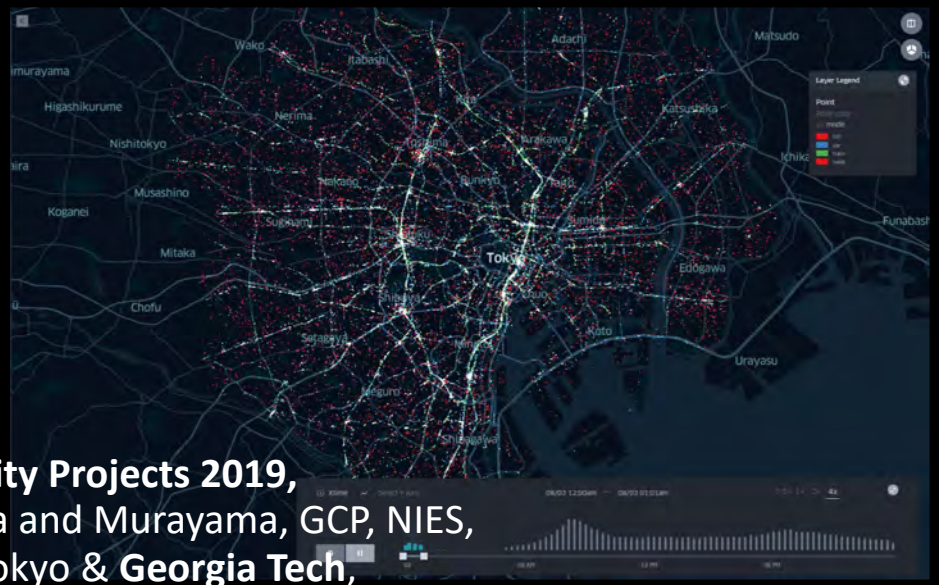


A.V. technology requires less space for automobiles that extend potential public realm.

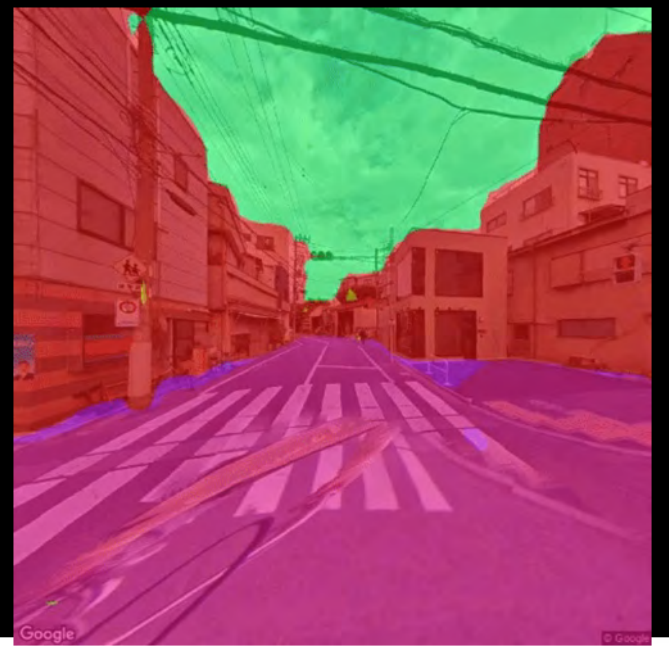
Toyota **E-Palette project**

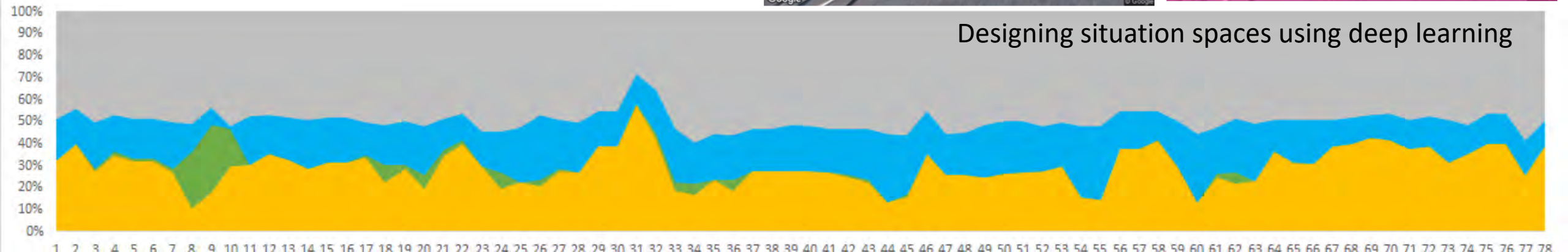
Analytics: Mobility and Walkability

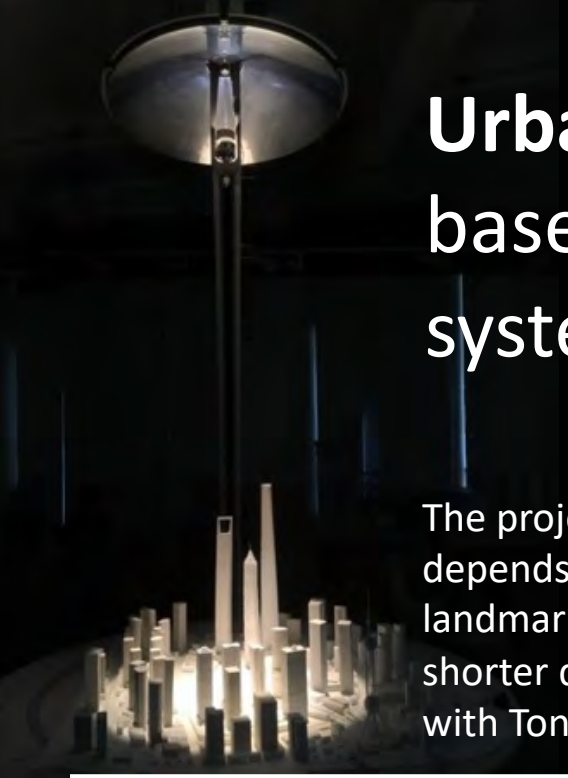
Human environment interactions : Real time data, pervasive computing and IoT are transforming cities into a sensing system. Urban spaces are becoming situational, responsive and should be resilient to adapt unpredictable future changes.



Tokyo Smart City Projects 2019,
Yang, Yamagata and Murayama, GCP, NIES, University of Tokyo & **Georgia Tech**,

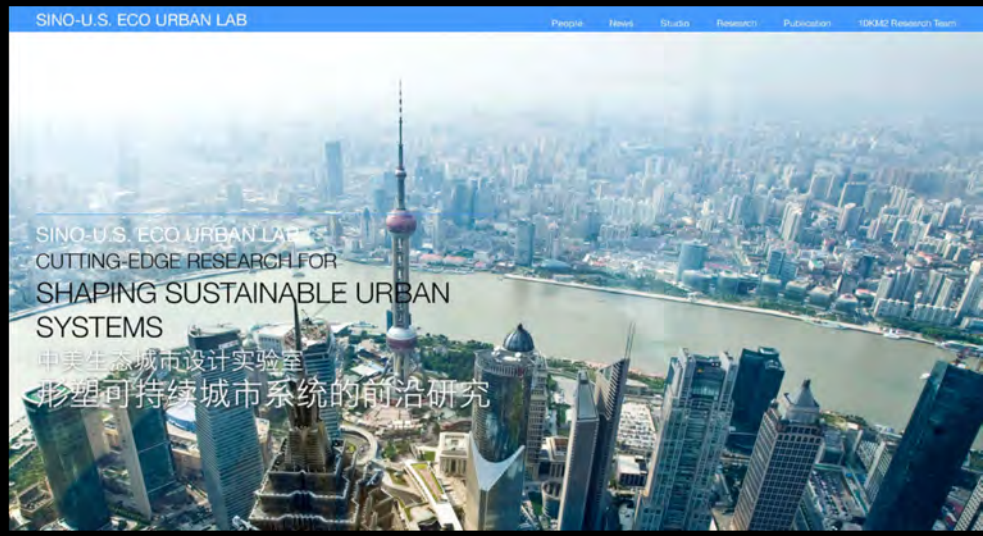


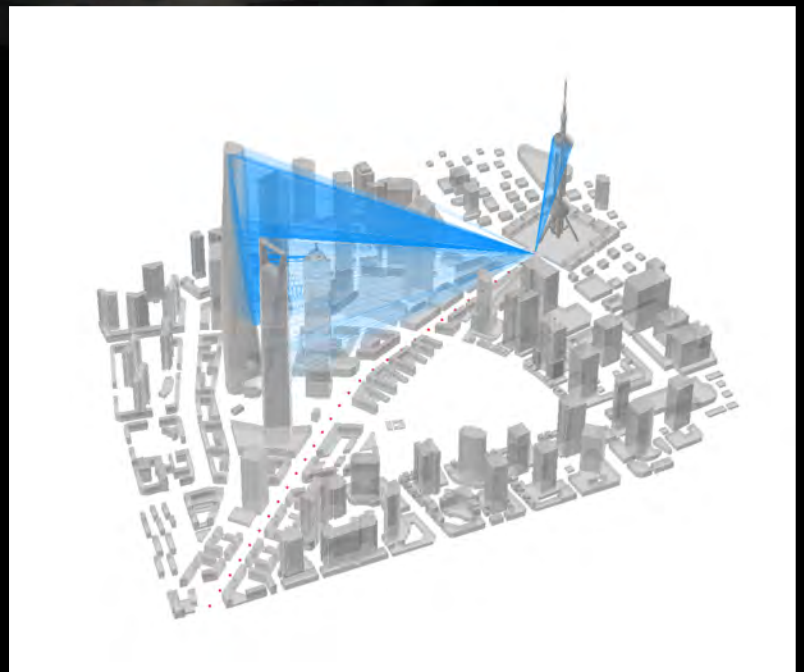


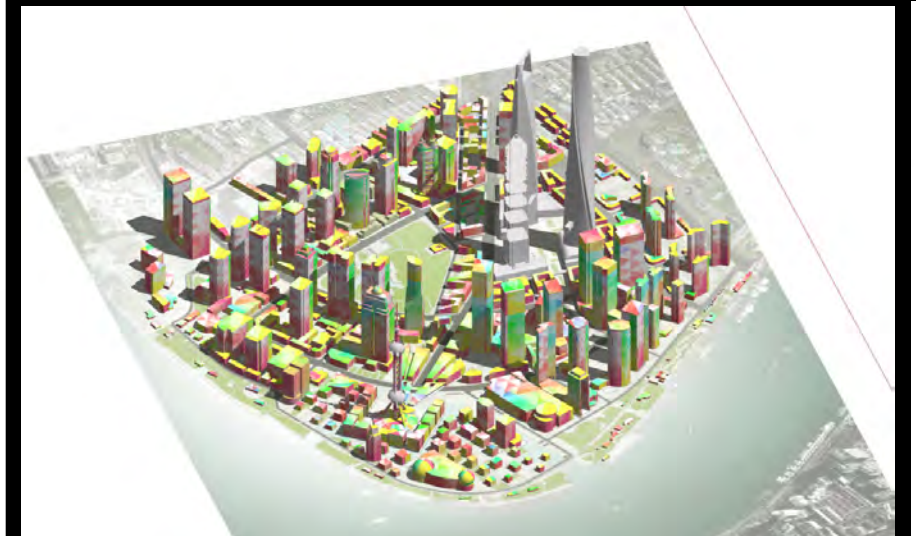


Urban sensing simulation based on Digital Twin city systems

The project aims to design urban Façades LED layout, which depends on both the long distance view from vantage points to landmark, and smaller scale street view to media boards at a shorter distance. (Yang, 2017, Eco Urban Lab in collaboration with Tongji Universiry Urban Lighting Lab)

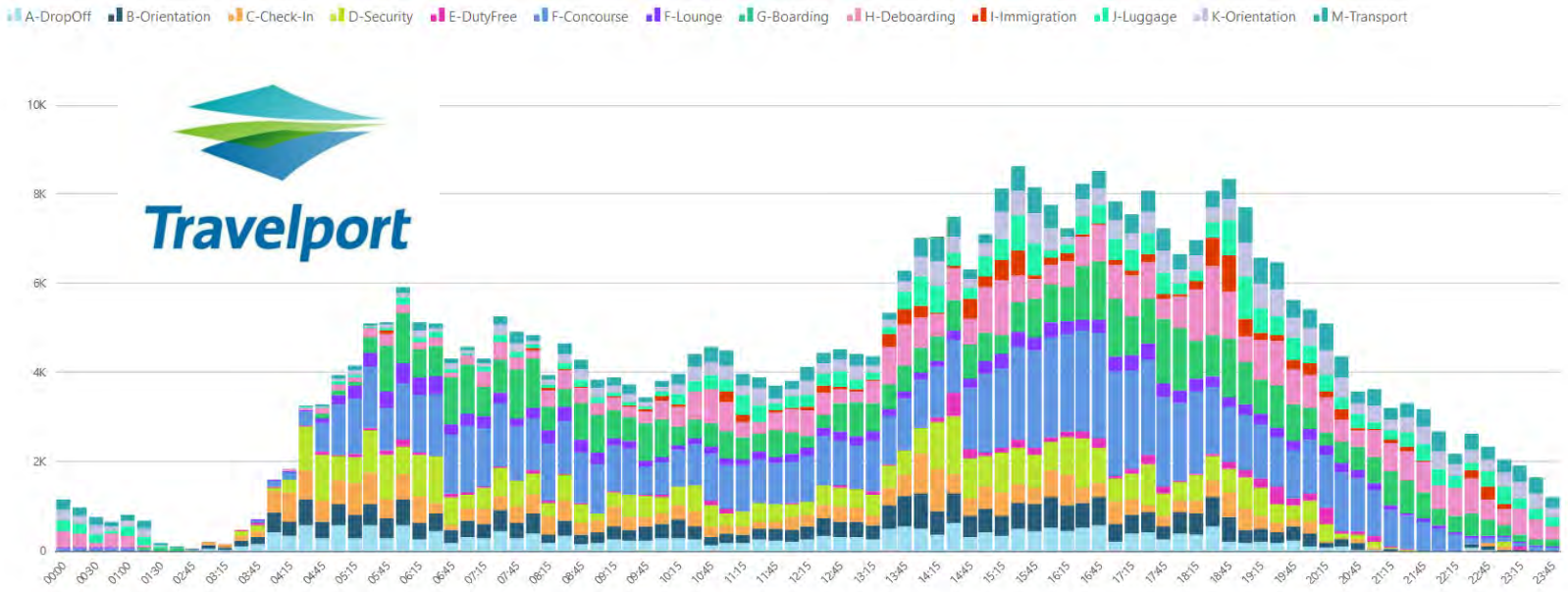






Future work on **Autonomous Airport- Aerotropolis**

Experience, Scheduling, Emerging Airport Traffic Trend Prediction

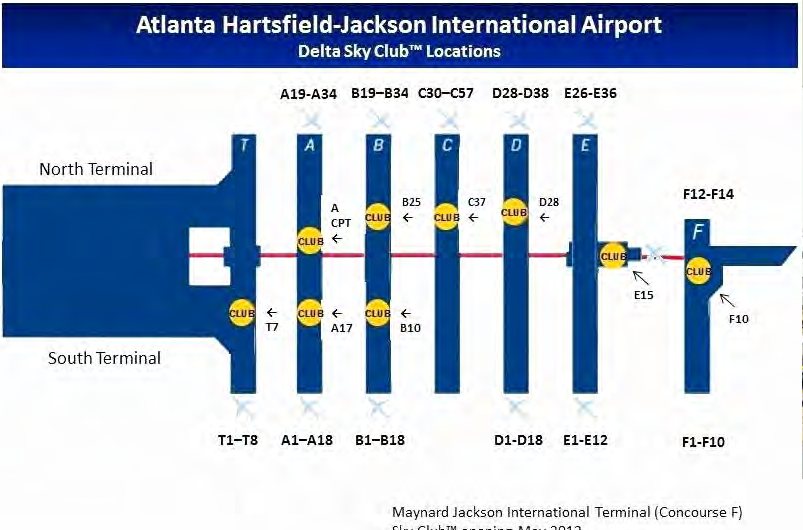


Airport Passenger Big Data using Machine Leaning for classification

(Robin Gardner, TravelPort, 2019)

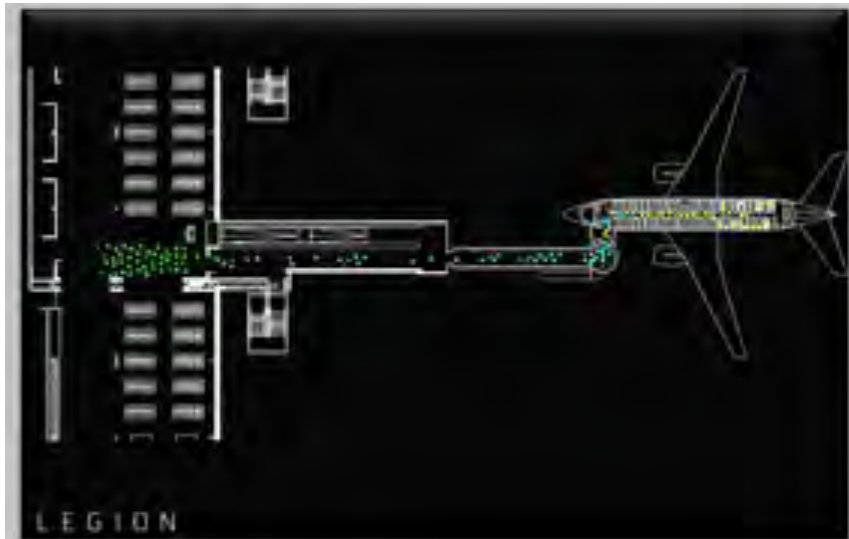
Airport City 3D model navigation guide

- Security wait-times
- Customs & Immigration
- Food / shopping / restrooms / lounges
- ATM / Currency Exchange
- Tram / bus / walking info for terminal changes between flights



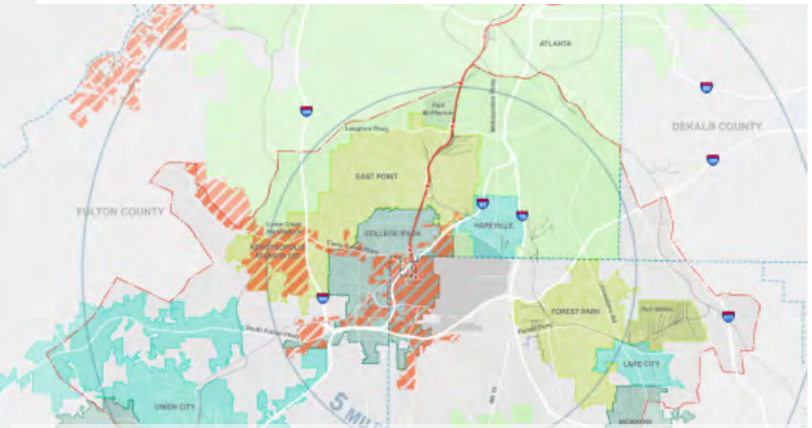
Maynard Jackson International Terminal (Concourse F)

BIM (Building Information Modeling) as a platform



Digital Twin Decisions Platform (for Aerotropolis Atlanta)

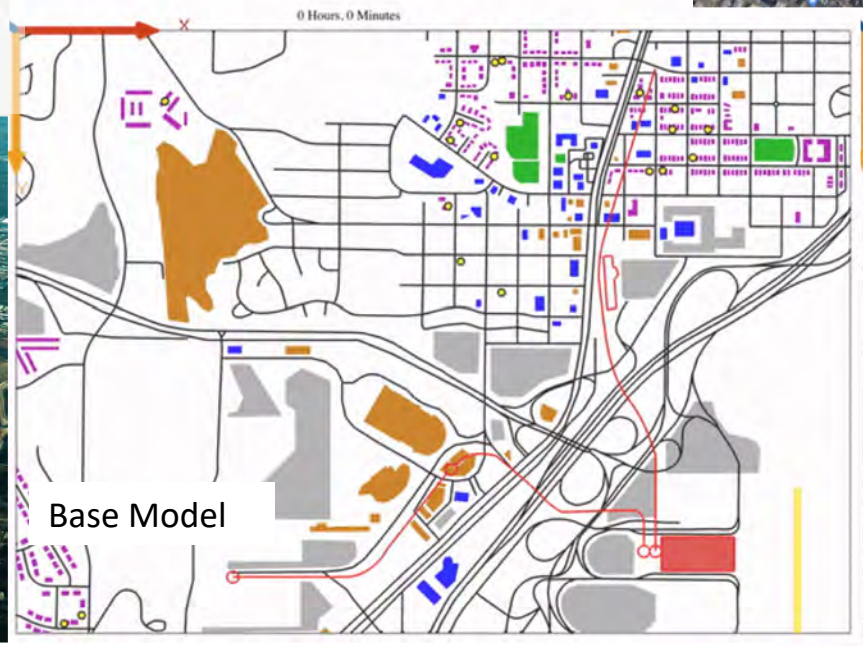
ATL Airport CIDs - Georgia Tech Initiatives

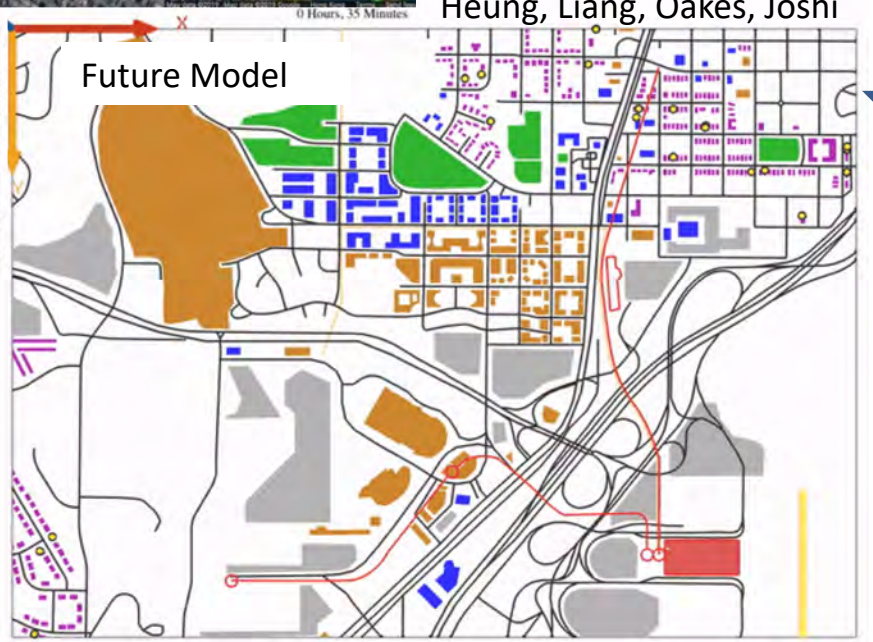


Post Covid-19 Airport City – a safer, cleaner, nimbler airport city system that is resilient and adaptable to attack and unpredictable shocks from pandemic or other system disruptions.

Current parking areas around
2.0km x 2.3km at
Hartsfield Jackson
Atlanta International Airport

Georgia Tech - AACIDs
2020 Smart City Workshop
Heung, Liang, Oakes, Joshi





Digital Twin Decisions Platform (for Aerotropolis Atlanta)

Georgia Tech - Aerotropolis Atlanta CIDs - Initiatives :

Airport Mobility Infrastructure: Decision Support Needs

(Source: Mavris, Balchanos, Yang, 2020)

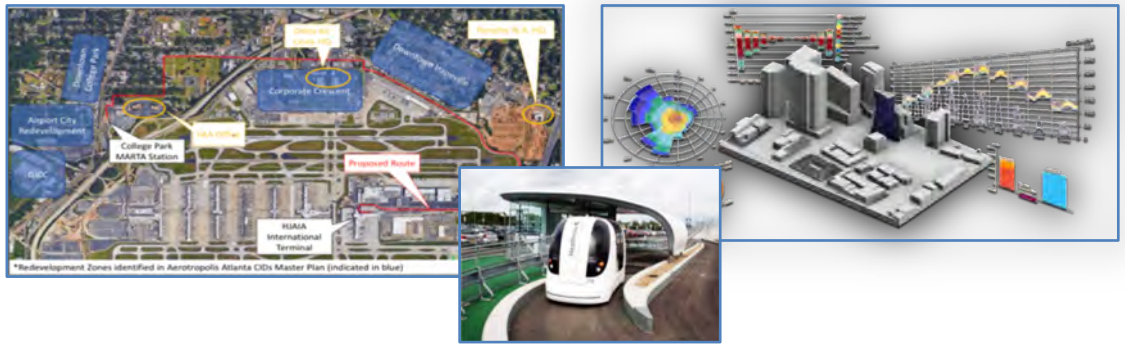
Operating for Improved Mobility

Focus: **Current** infrastructure, improving efficient movement practices

Goals: Efficiency, Safety and readiness, disruption rate reduction, loss prevention, fast recovery

Planning for Improved Mobility (Aerotropolis)

Focus: **Future** mobility mode expansion, Future scenario forecasting



Goals: Data-driven decision making, threat forecasting, risk assessment, strategic gaming, etc.

Data Analytics & Simulations support decision making at several horizons

Present → Near Future → Mid-Term Future → Long-Term Future

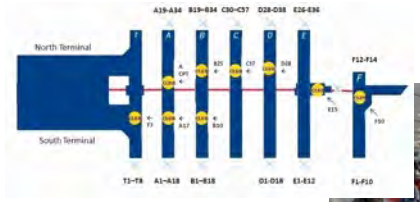
Digital Twin Decision Platform (for Aerotropolis Atlanta)

Georgia Tech - Aerotropolis Atlanta CIDs - Initiatives :

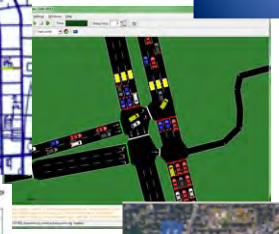
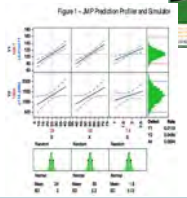
Align with the Decision-Making Horizons

(Source: Mavris, Balchanos, Yang, 2020)

	Operating for Improved Mobility		Planning for Improved Mobility (Aerotropolis)	
Planning Horizons	Present & Near Future		Mid-Term Future	Long-Term Future
	Situational Awareness	**Operations Optimization**	**Technology Integration Studies**	**Strategic Planning**
	Explore the Data	Benchmark Mobility	Traffic Management	Forecast Traffic	Explore Alt. Mobility Practices	Infuse New Technologies	Design Sys. Architectures	Execute Game Scenarios	Develop Roadmaps & Masterplans

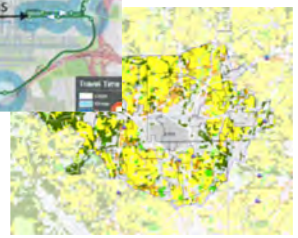








Ultimate Goals	*Intelligently monitored campus*	*Improved traffic, reduced congestion*	*"Virtual Airport" experimental facility*	*Revolutionary planning tools*