More Than One Twin:

An Ecology of Digital Model Applications

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An Outline of the Talk

- Many Models of the Same Phenomenon
- Digital Twins: What Are They? Where Do They Come From?
- How Close to the Real Thing is a Digital Twin?
- A Digression? A Cornucopia of Twins: Maps as Analogies
- Now for Examples: Four Very Different Types of Twin – but of the same place

  VR and AR, 3D City Models
  Smart Buildings: BIMS: Automated Building Control
  Real Time Simulation: Passenger Demand, Trains Supply & Flows
  Long Term Urban Change: The QUANT Model
- Is the Concept Useful ?

Many Models of the Same Phenomenon

- Computing has changed the nature of how we theorise and how we model the physical as well as the social world
- We now have the opportunity and possibility of building many different models of the same phenomenon. This is due to increasing computer power as well as new data sources, some but not all captured in real time.
- This suggests that in the future multiple models of the same thing will become the norm
- This has been anticipated for many years - Counter modelling was proposed BY GCC, George Box, Scott Page, Dirk Helbing & so on …

- The big question is then

  "If we have more than one model and all are plausible, how do we use them, how do we integrate them, and how close are they to the real thing"

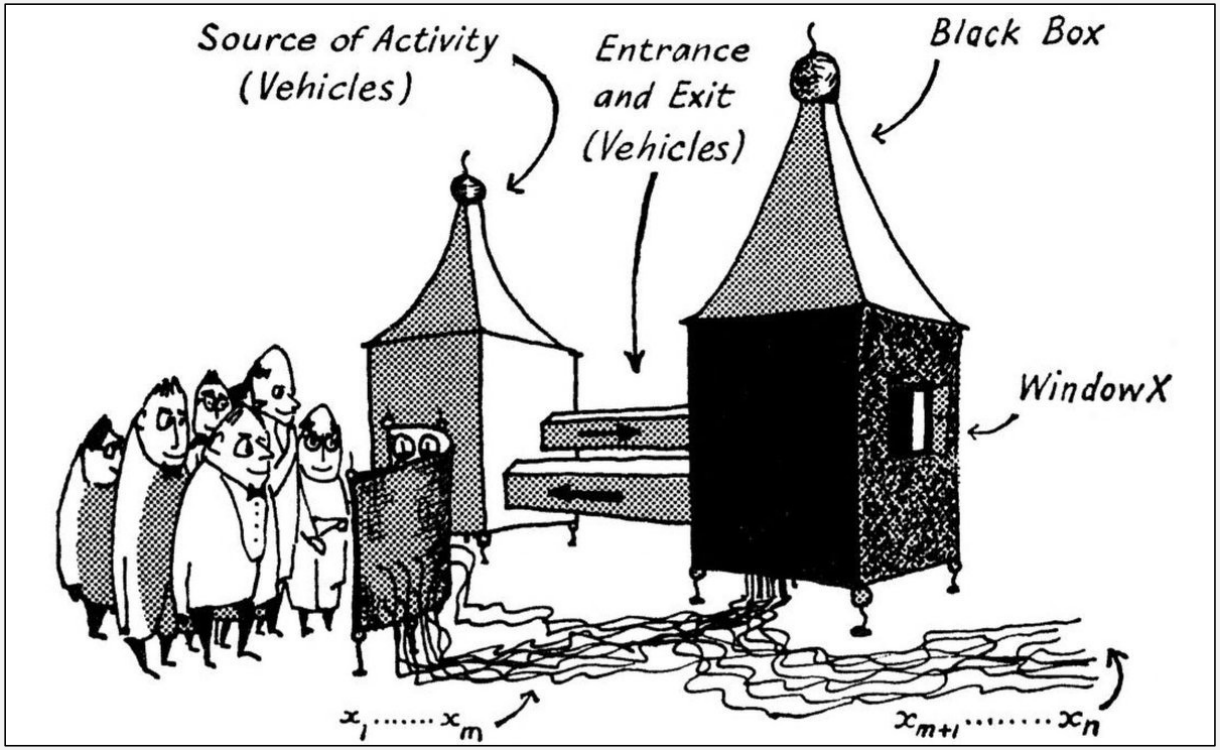
  I am not going to answer the question but simply discuss it
- Clearly different models of the same thing cannot all be as good as one another viz narrow validation used in the past
- How then do we deal with multiple models – this of course is a question of philosophy and theory for it relates to how we resolve differences between us.
- It is against a background that we cannot predict the future, we can invent it but we cannot predict what we invent

Digital Twins: What Are They? Where Do They Come From?

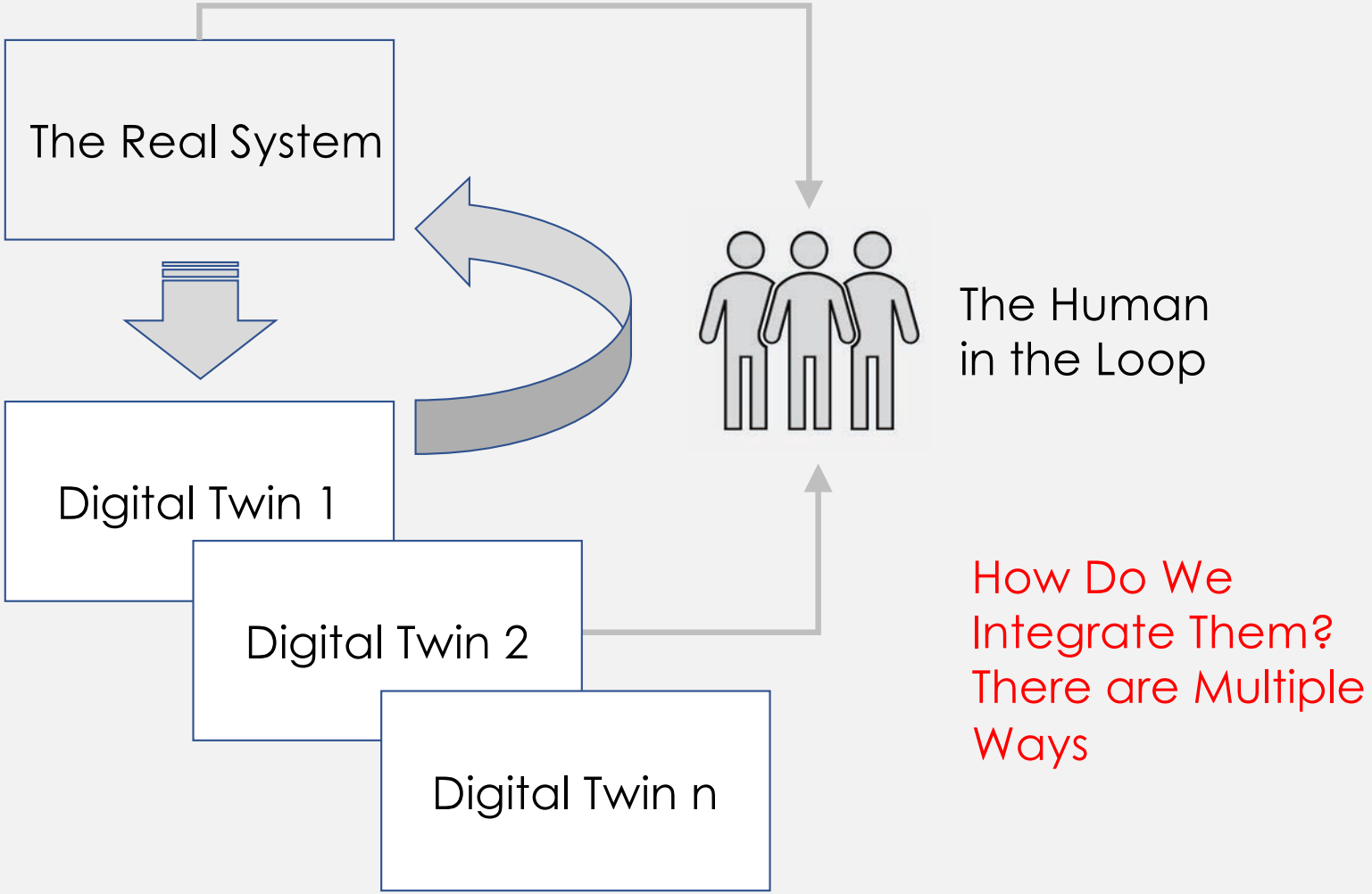
Let me now turn to another idea – the digital twin. Of course we in this audience would immediately say this is a 'model' and ***models are abstractions, simplifications*** of the real thing. And if we can have many models, then many twins? This is weird?

In any model, we throw a lot more away than we keep. In fact arguably the best models are the simplest - but much depends on purpose. So how then can we think a model is a twin – this sounds far too close to the thing we are simulating or representing. But as we move from long to short term and from low frequency to high, our models change and perhaps, some of them will get, are getting 'closer' to the real thing

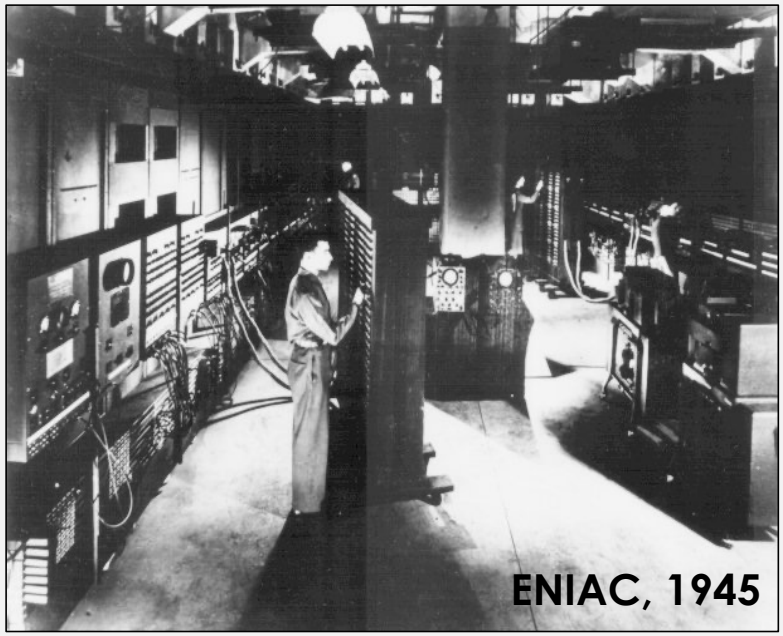
How Close to the Real Thing is a Digital Twin?



Gordon Pask (1961) **An Approach to Cybernetics**, Radius Books, London


The Real System
Digital Twin 1
Digital Twin 2
Digital Twin n
The Human
in the Loop
How Do We
Integrate Them?
There are Multiple
Ways

- In fact you used to be able to get inside the loop at the very beginning. Look at this picture of ENIAC in 1945



ENIAC, 1945

Quoted by Ananyo Bhattacharya in **The Man From the Future** (2021)

'Now we think of a personal computer as one you can carry around with you' said mathematician Harry Reed who joined the project in 1950. 'The ENIAC was actually one that you kind of lived inside'

- Are we moving back to the same thing, full circle?

So the digital twin cannot be ***a mirror image***, it may be a replica, but it cannot be the same as the original (or can it? ……). And to an extent, we assume it is a simulation.

There are some other features. *First* models depend on their ***media*** and if the media is close to the media of the original model, then we might think it is a 'digital twin' – especially if we imagine the system in question is digital. If we want to build 'a digital' model of this, then there is the prospect of building a twin. Then this might be the same as the original

Second can the digital twin be used for ***predicting a future*** that does not exist? Models might be about only the future, not the present – can a digital twin have this role? If there is no present.

There is a *third* feature: is the digital twin ***reactive*** rather than ***predictive*** and if it is predictive, how close is the prediction to the real system?

Thus a digital twin might be a coupling – a relation between the original and digital – ***a transfer of information*** and this is not necessarily so for a model. A model does not formally transfer material from itself to the real, or does it?

Fourth there is a sense in which a digital twin might be used to control a system – and this suggests it might be ***a controller*** or a mechanism to be embedded in the system. Hardly a model. The systems we deal with are not top down, if anything they are bottom up, so does a twin have any role in our world?

Where do Digital Twins Come From?

The term appears to have been first coined in the early 2000s by Michael Grieves (2014) whose expertise in product design initially rooted the concept in production engineering.

In this sense, one can see the twin as being very close to the real thing especially as production systems are being continually automated and this automation is largely digital.

The closest in our world are the components of the built environment that make up the city – buildings, utilities, physical infrastructures – BIMS – it is no surprise that in this perspective of the smart city, this is where the idea is getting a lot of mileage

A Cornucopia of Twins: Maps as Analogies: A Digression

The most evocative metaphors relate to maps – for maps are simplifications and there are many stories that suggest that the level of simplification is problematic. In fact there is a famous paper that some of us know by Benoit Mandelbrot called 'How Long is the Coast of Britain? ***Science*** in 1967. The answer is – the length is infinite but the real answer is 'it depends' --- 'on scale'

But the best digital twin story I have ever heard is the one from Lewis Carroll who in his last work ***Silvie and Bruno Concluded*** (1893) tells of a conversation between himself and a German gentleman about making a map close to the real thing

Let me read it out. The conversation goes like this: between ME and Mein Herr (MH)

ME: 'What a useful thing a pocket-map is!' I remarked.

MH: 'That's another thing we've learned from your Nation', said Mein Herr, 'map-making. But we've carried it much further than you. What do you consider the largest map that would be really useful?'

ME: 'About six inches to the mile'.

MH: 'Only six inches!' exclaimed Mein Herr. 'We very soon got to six yards to the mile. Then we tried a hundred yards to the mile. And then came the grandest idea of all! We actually made a map of the country, on the scale of a mile to the mile!'

ME: 'Have you used it much?' I enquired.

MH: 'It has never been spread out, yet', said Mein Herr: 'the farmers objected: they said it would cover the whole country, and shut out the sunlight! So, we now use the country itself, as its own map, and I assure you it does nearly as well'. (Carroll, 1893 [1982])

This notion of the map being the same as the territory has been explored by others, by Jorges Luis Borges, Gregory Bateson, Joan Robinson, Braudrillard, Gerlenter. Even D. H Lawrence said that "the map appears to us more real than the land" (1925)

Somewhat later, Jorge Luis Borges (1946) in his essay ***'On Exactitude in Science'*** more or less tells the same story of cartographers so obsessed with their art that they decided to produce the most detailed map of their Empire that they could make at a scale of 1 to 1. The next generations less enamoured of cartography than those who made the map had little use for it but Borges concludes by saying *'In the Deserts of the West, still today, there are Tattered Ruins of that Map',*

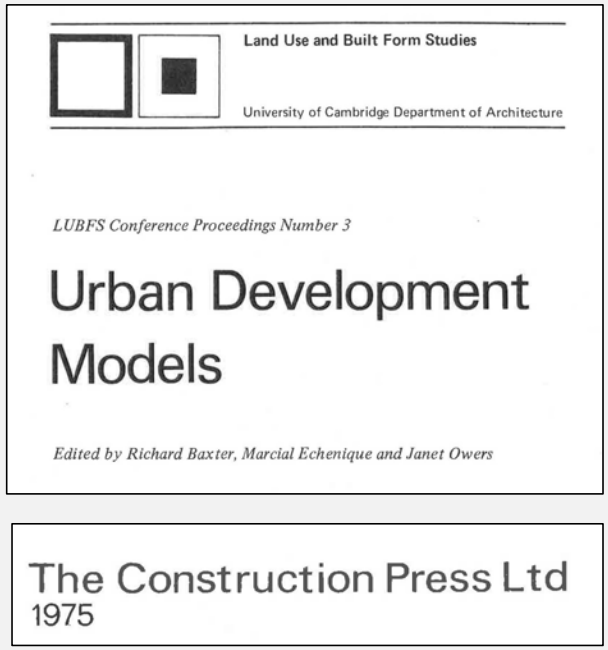
Conjuring up images from the movie ***The English Patient***. I wonder if the same fate awaits the digital twin: possibly in terms of terminology but the power of simulation and the prospect of getting better and better simulations shows no sign of stopping. …… We will see.

The English Patient with his 'map'



Herodotus's ***The Histories***

I would be remiss if I did not say that somewhat independently of these origins, my friend and late colleague Lionel March used this example from Carroll in his paper to the 1974 ***Urban Development Models*** conference at Churchill College Cambridge.

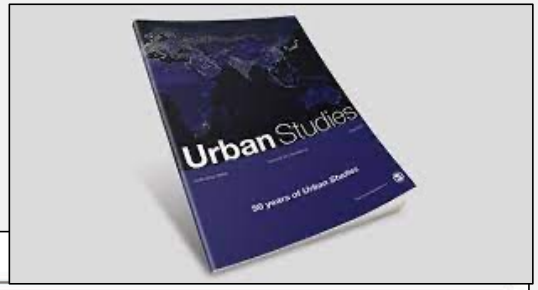


Maps, like models, are made at appropriate levels of detail for different purposes. An exact replica of the world would be of no more use than the Captain's map in another work by Carroll, *The Hunting of the Snark*: the map was "a perfect and absolute blank!" All models – to be useful – must be selective and, if you like, false to reality in some respect or other. Pocket-models may be the most useful in the end.

Now for Examples: Four Very Different Types of Twin

I am going to look at four very different conceptions of the spatial and physical structure of cities,

- ***3D Cities*** – Using a physical representation of the elements that define the buildings in the city – VR, AR
- ***Smart Buildings***, the High Frequency (hf) City – BIM
- ***Flows of Traffic*** which is a problem in demand and supply in term time; this is the hf city with long term implications
- ***A LUTI Model*** (QUANT) – a model of the low frequency (lf) city simulating long term urban growth and change



Special issue article: Big data in the city

A new framework for very large-scale urban modelling

Michael Batty and Richard Milton
University College London, UK

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Andrew Hudson-Smith, Duncan Wilson, Steven Gray & Oliver Dawkins

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Potential Versus Reality
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Talking to the Neighbors
Conclusion



Finding Pearls in London's Oysters

JONATHAN READES, CHEN ZHONG, ED MANLEY,
RICHARD MILTON and MICHAEL BATTY

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Living with a Digital Twin: Operational management and engagement using IoT and Mixed Realities at UCL's Here East Campus on the Queen Elizabeth Olympic Park

January 2018
Conference: GISRUK 2018 · At: Leicester, UK
Project: Near Real Time Urban Data Spaces

Oliver Dawkins[*1], Adam Dennett[†1] and Andrew Hudson-Smith[‡1]

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Sustainable Digital Twins

Sustainable Digital Twins



Sustainable Digital Twins

Data Driven Approach to Modelling the Resource Footprints of Live Data Streams in Digital Twins

From Architectural Design, Volume 75 (6), 42-47, 2005

As the digital revolution deepens and pervades every aspect of daily life, virtual realities begin to penetrate one another in a multiplicity of ways. The amount of sensing data being compiled on the city grows, enabling the construction of virtual realities that can, in turn, be transformed for diverse purposes. Here, Michael Batty and Andrew Hudson-Smith from the



1. Virtual Cities

Jean Baudrillard (1994) defines a simulacrum as a 'simulation of a simulation', a model of a model if you like.[1] In terms of cities in the digital realm, it is easy to translate such a conception into multiple layers of abstraction that we build up from the raw data we sense, perceive and explain in simulating urban form and structure. A generation or more ago, when computers were first used to represent cities, typical simulations were immediate and direct. Either the geometry of the city was used to construct digital 'iconic' models through which one could navigate, and sometimes use for CAD (computer-aided design), or geographic and economic functions were represented using 'symbolic' mathematical models that could be analysed and manipulated for the same ends: better design, better planning. As the digital revolution has matured, these conceptions have blurred, and now there are mathematical models that sit within iconic models, and vice versa, whose symbology exists on many levels. More importantly, perhaps, as computers have come to be used in everything from extracting data remotely, to mining it to find new patterns, visualising it in diverse ways, modelling it for the same diversity, and embedding users virtually into the process of use, models have come to be represented within models, worlds within worlds, as the power of recursive digital construction has gathered pace. This is simulacra: virtual cities within virtual cities where such embedding twists the process in curious but illuminating ways.

We will begin by describing the construction of a digital iconic model of central London that we somewhat euphemistically refer to as 'Virtual London'. Virtual London is in fact a 3-D geographic information system (3-D-GIS), which is in essence a large spatial database that can be analysed and queried. We can view it in 3-D because we can hold and file the data via digital representation of streets and building blocks. However, this is just one way of viewing the data – one perspective on the virtual city – and there are many others that need not stress the spatial dimension nor its built form. We construct this model as a series of data layers that we can overlay in 3-D. We can then embellish the model, adding a variety of digital media that we can deliver and display in everything from web browsers to holographic-like displays.

Such models can also be imported into other digital media. We illustrate the conception of a simulacrum by embedding it within a virtual world – a virtual design studio or exhibition space – which users can enter as avatars and then view and manipulate the model in the presence of other users, who are also avatars. This embedding can be recursive in that we can enter such worlds, view the model and then fly through it, adding new digital media at points where we need to render the environment with different images. Like many of our simulacra, Virtual London is designed so that users can learn about and redesign their environment in a

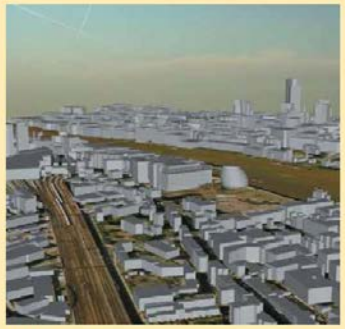


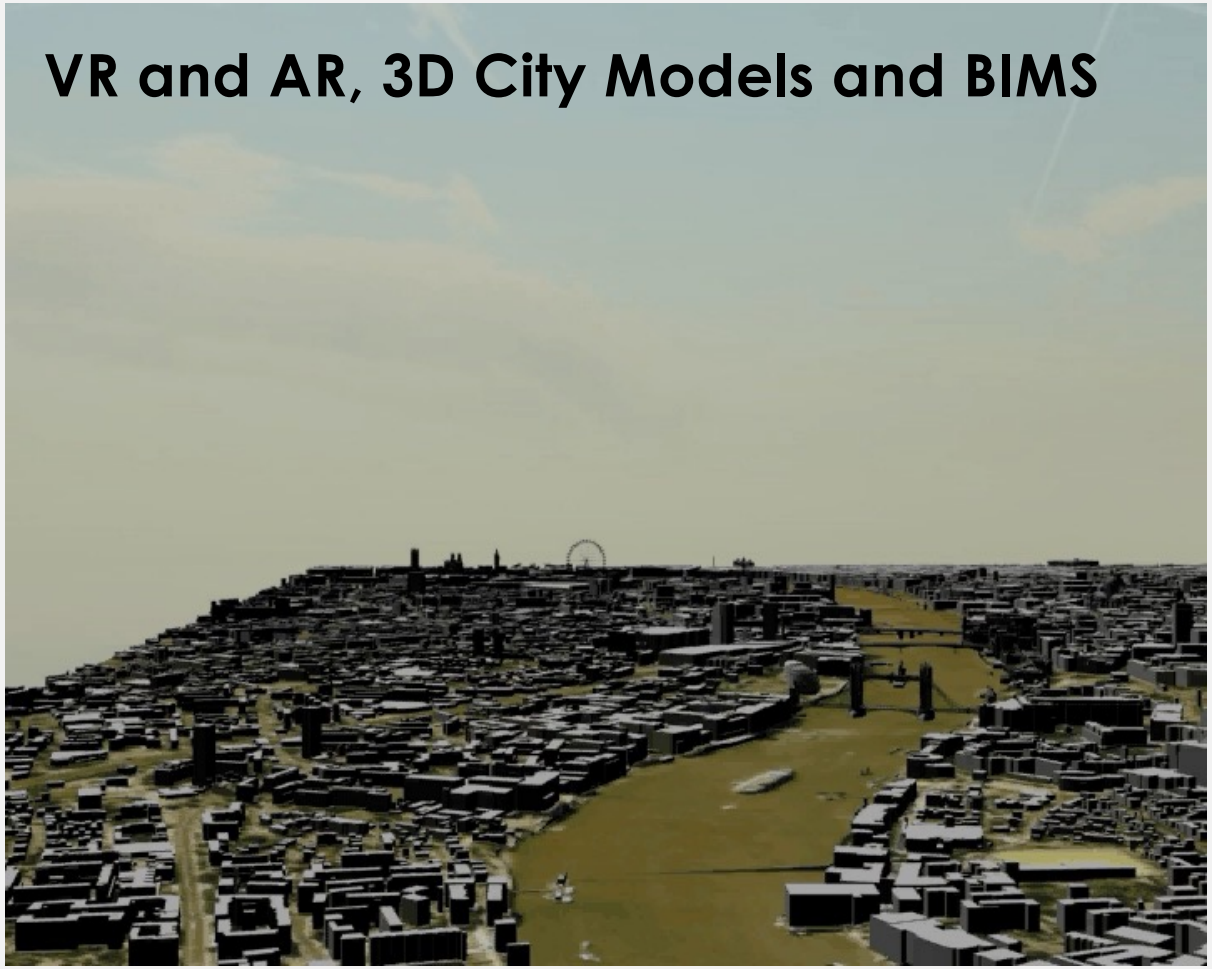
Figure 1: View west from Tower Bridge across Virtual London, showing the raw geometry of the virtual city before it is populated with data.

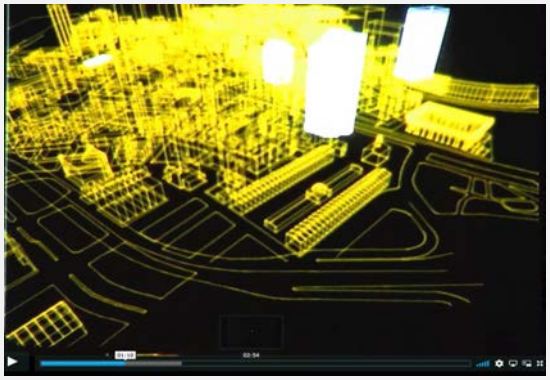




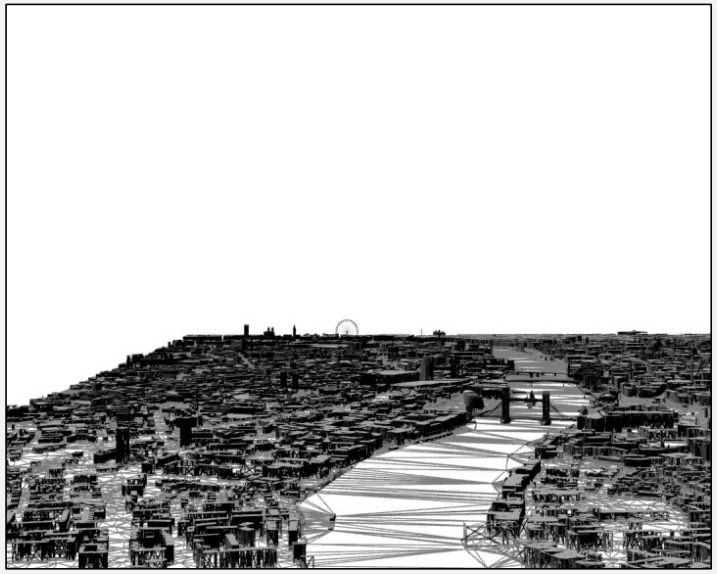
Figure 2: Building the virtual city in layers from the ground up. (a) Extruding parcel data to average height and inserting a LIDAR image of St Paul's Cathedral into the scene. (b) Adding a digital panorama of the area around the Swiss Re headquarters building.

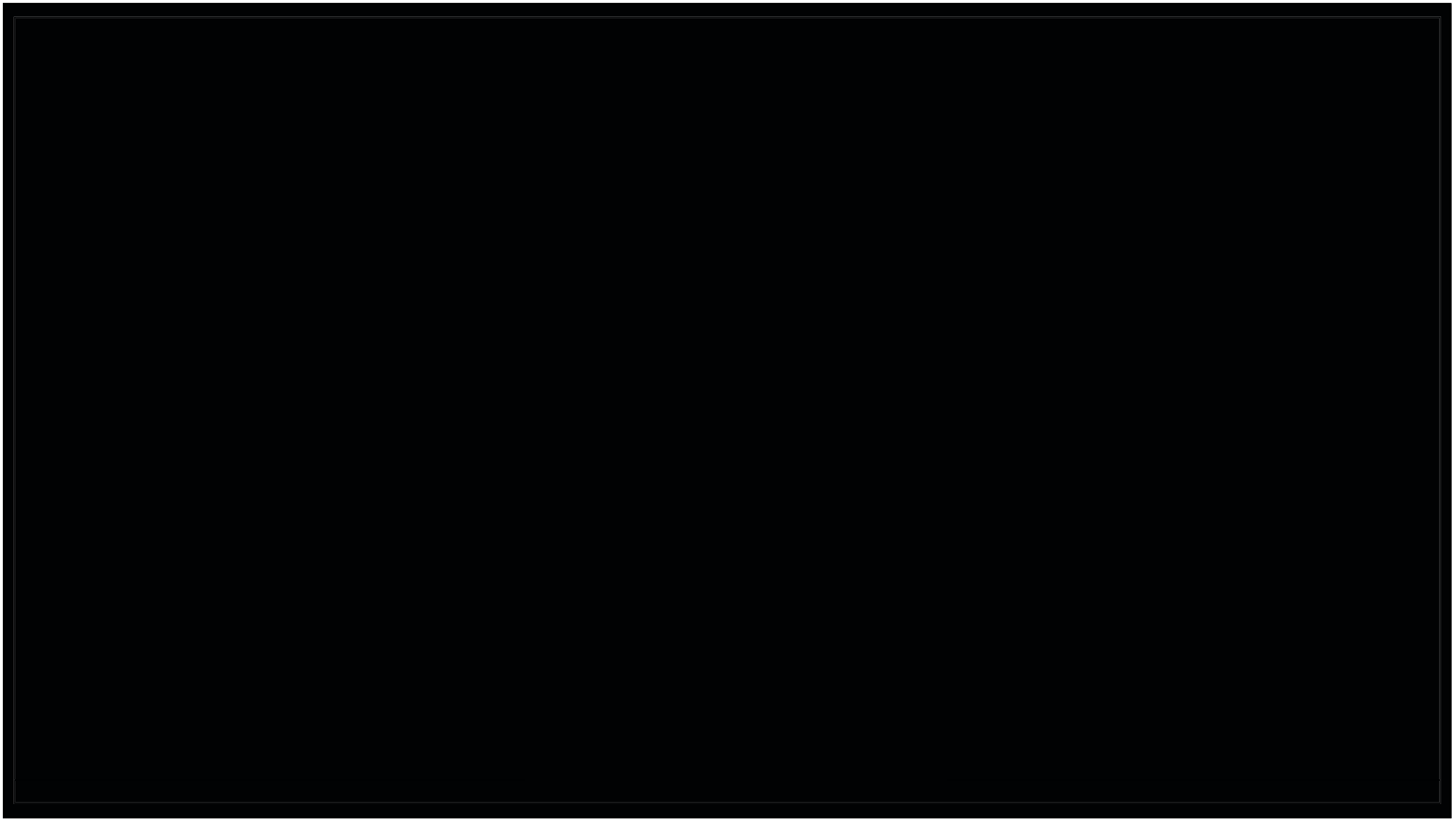
VR and AR, 3D City Models and BIMS

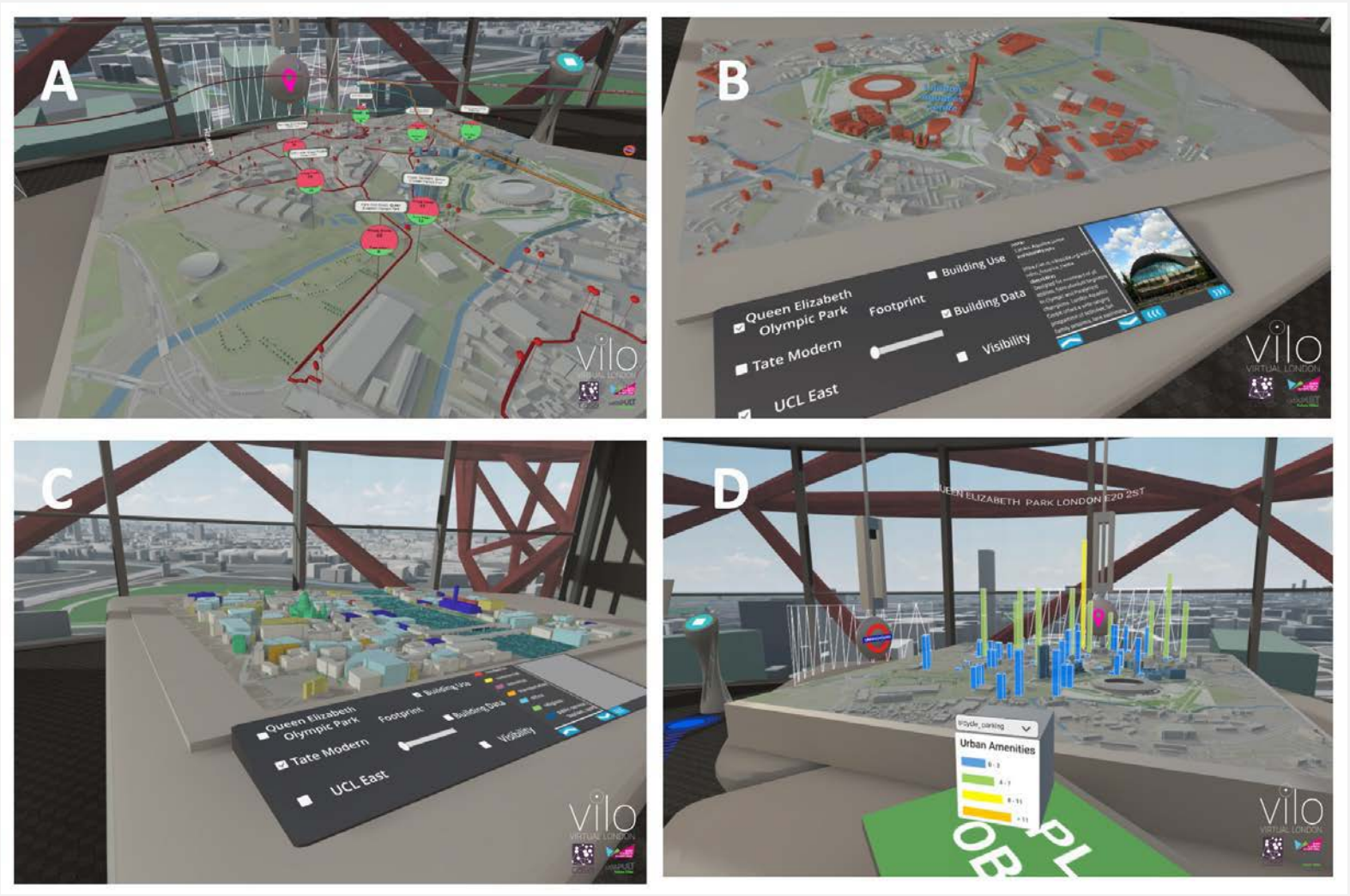


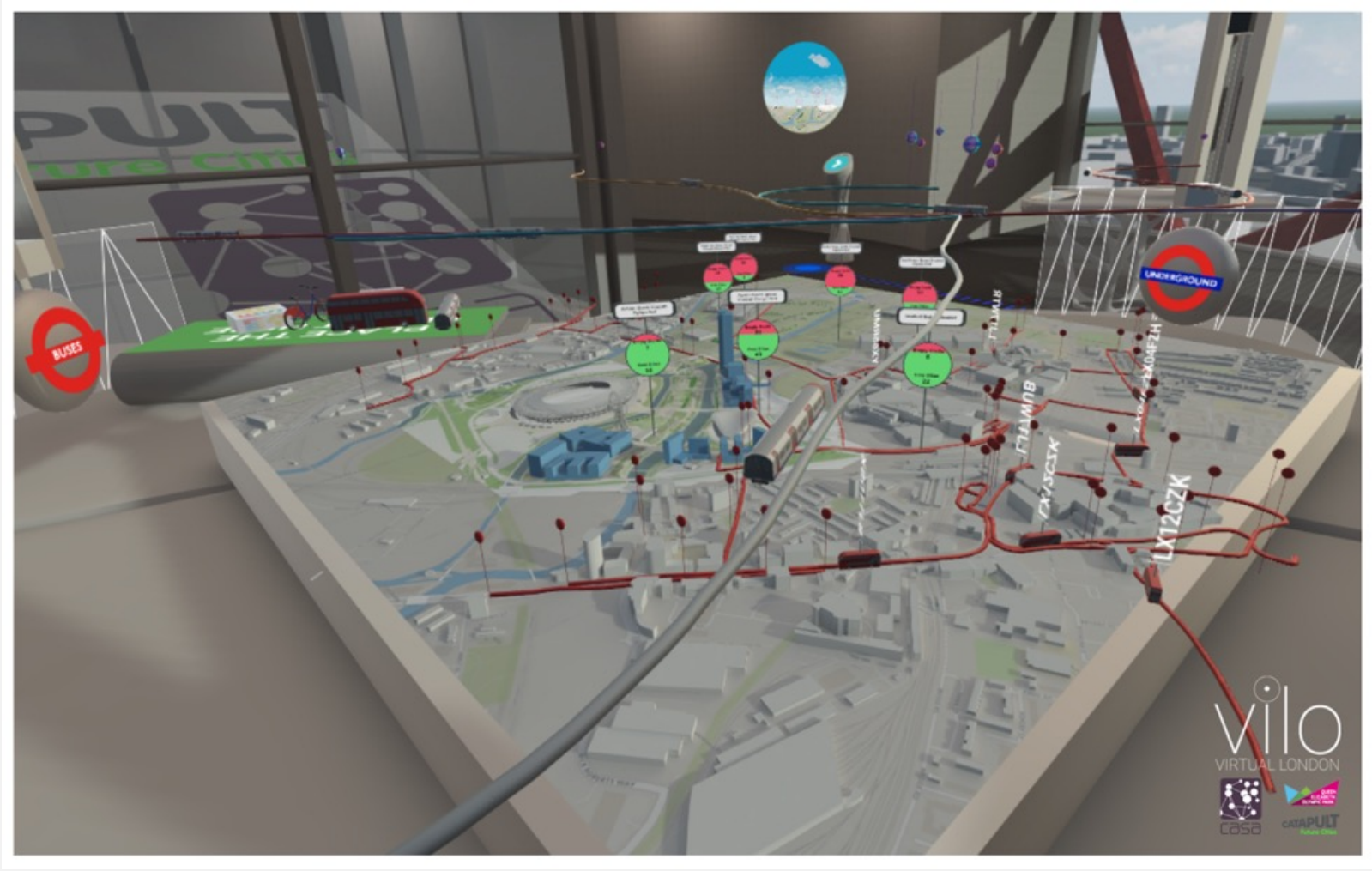








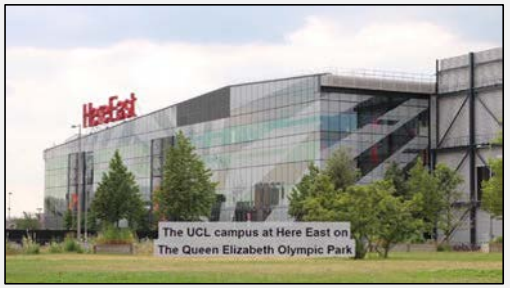

A
B
Queen Elizabeth Olympic Park
Tate Modern
UCL East
Footprint
Building Use
Building Data
Visibility
vilo
VIRTUAL LONDON
C
Queen Elizabeth Olympic Park
Tate Modern
UCL East
Footprint
Visibility
vilo
VIRTUAL LONDON
D
QUEEN ELIZABETH PARK LONDON E20 2ST
Urban Amenities
vilo
VIRTUAL LONDON



Digital Twins and Smart Cities

Smart Buildings – UCL Here East



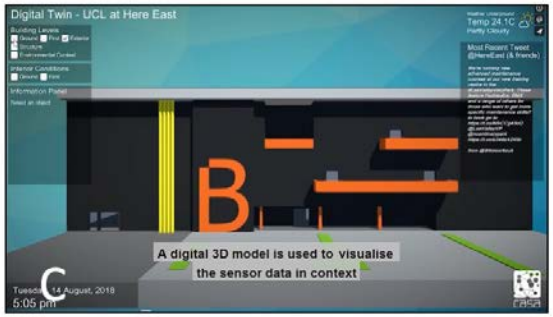




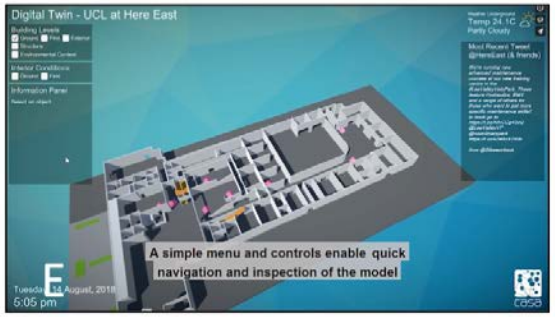



A
The UCL campus at Here East on
The Queen Elizabeth Olympic Park


B
Twenty environment sensors were installed
for a six month trial from April 2018


Digital Twin - UCL at Here East
B
A digital 3D model is used to visualise
the sensor data in context
C


Each sensor measures temperature,
humidity, pressure and ambient light levels
D


Digital Twin - UCL at Here East
A simple menu and controls enable quick
navigation and inspection of the model
E


Digital Twin - UCL at Here East
The wider site context is also visualised in 3D
F


A


IBM Watson IoT Platform
Boards
Devices
Members
Apps
Access Management
Usage
Rules
Settings
Extensions
B
Data is transmitted to a cloud based platform via WiFi

Real Time Simulation: Passenger Demand, Trains Supply & Flows

Demand by Travellers



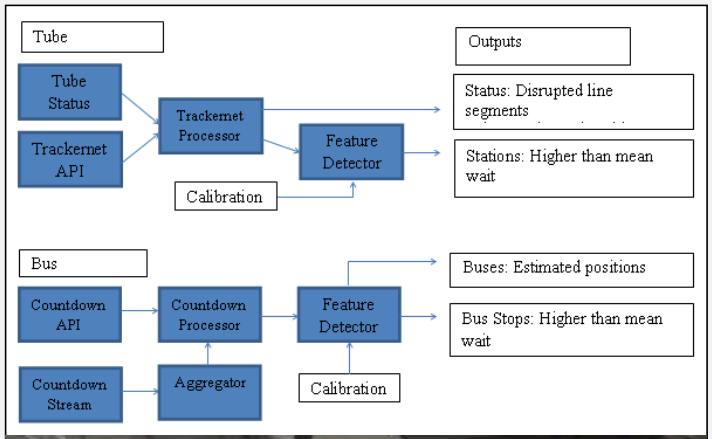






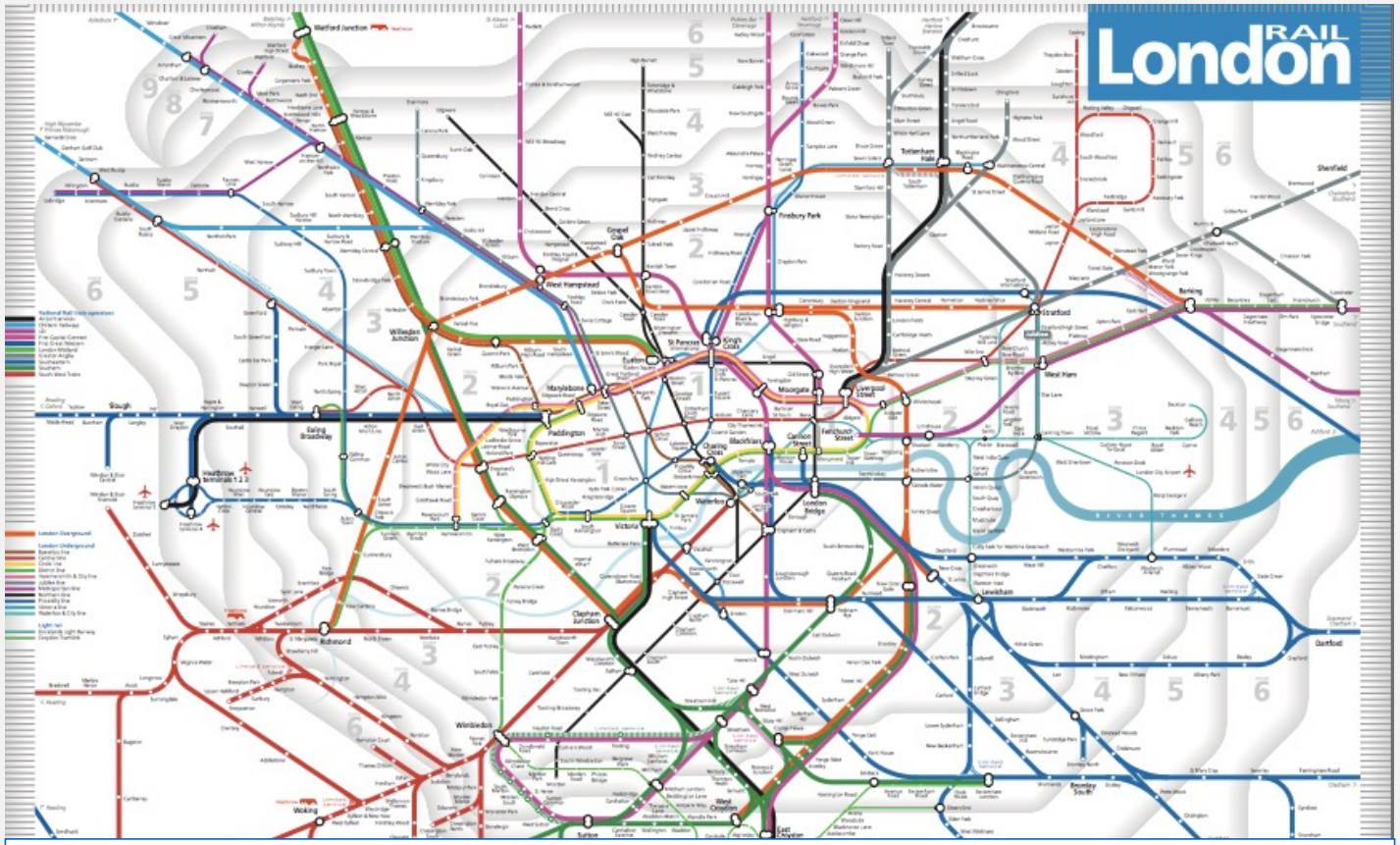


Supply of Trains





How do we match demand & supply without passenger tracking?



Tube, Overground and National Rail Networks in London where Oyster cards can be used



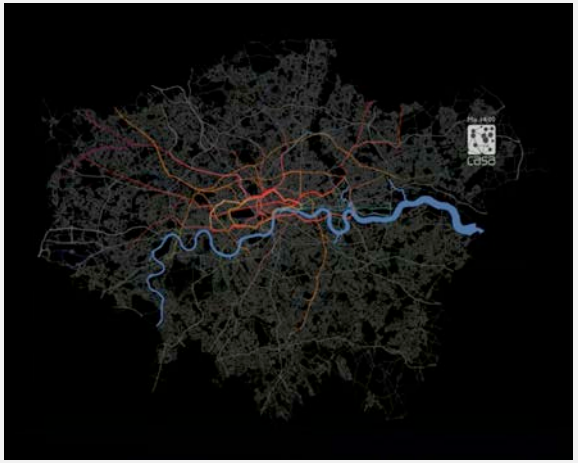
Passenger Demand for Travel: Flows From Tap-In to Tap-Out Data

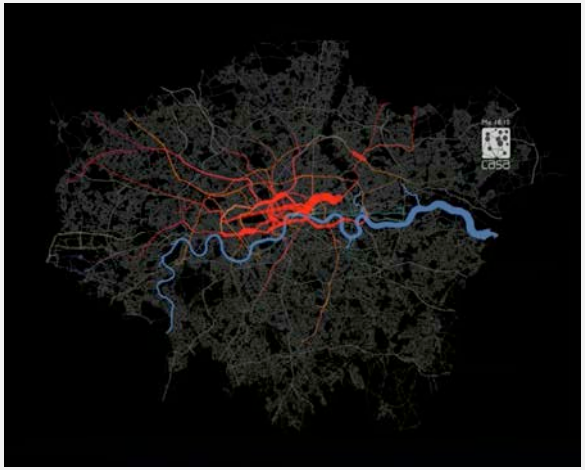

OYSTER GIVES UP PEARLS



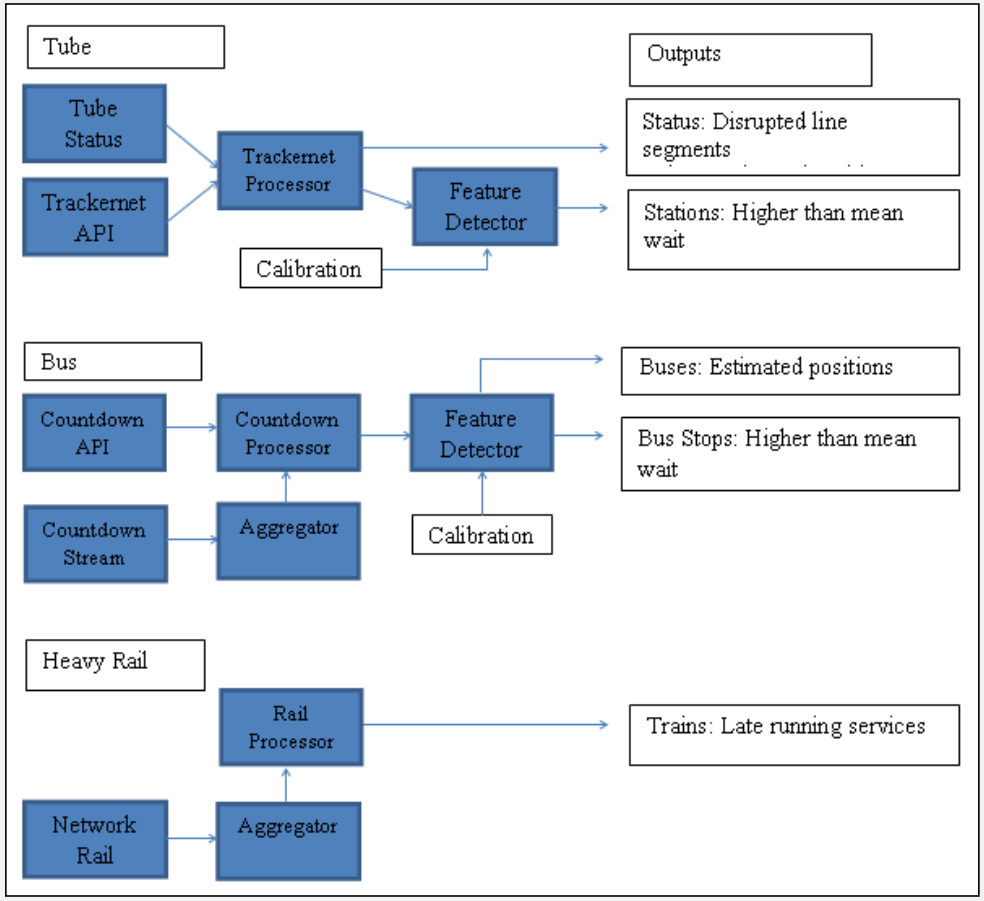






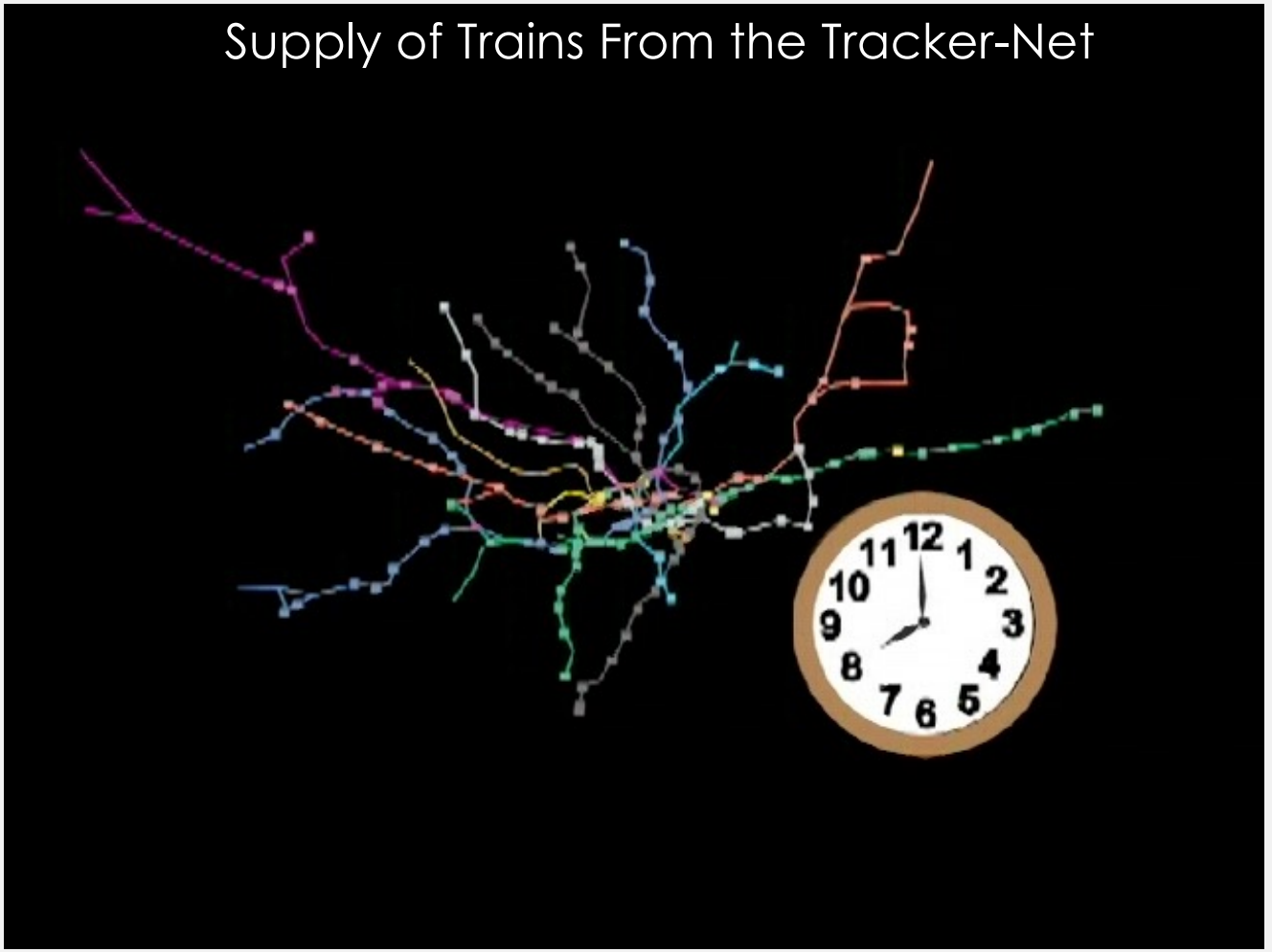


The Public Transport System in Terms of Vehicle Flows and also Passenger Flows from Oyster

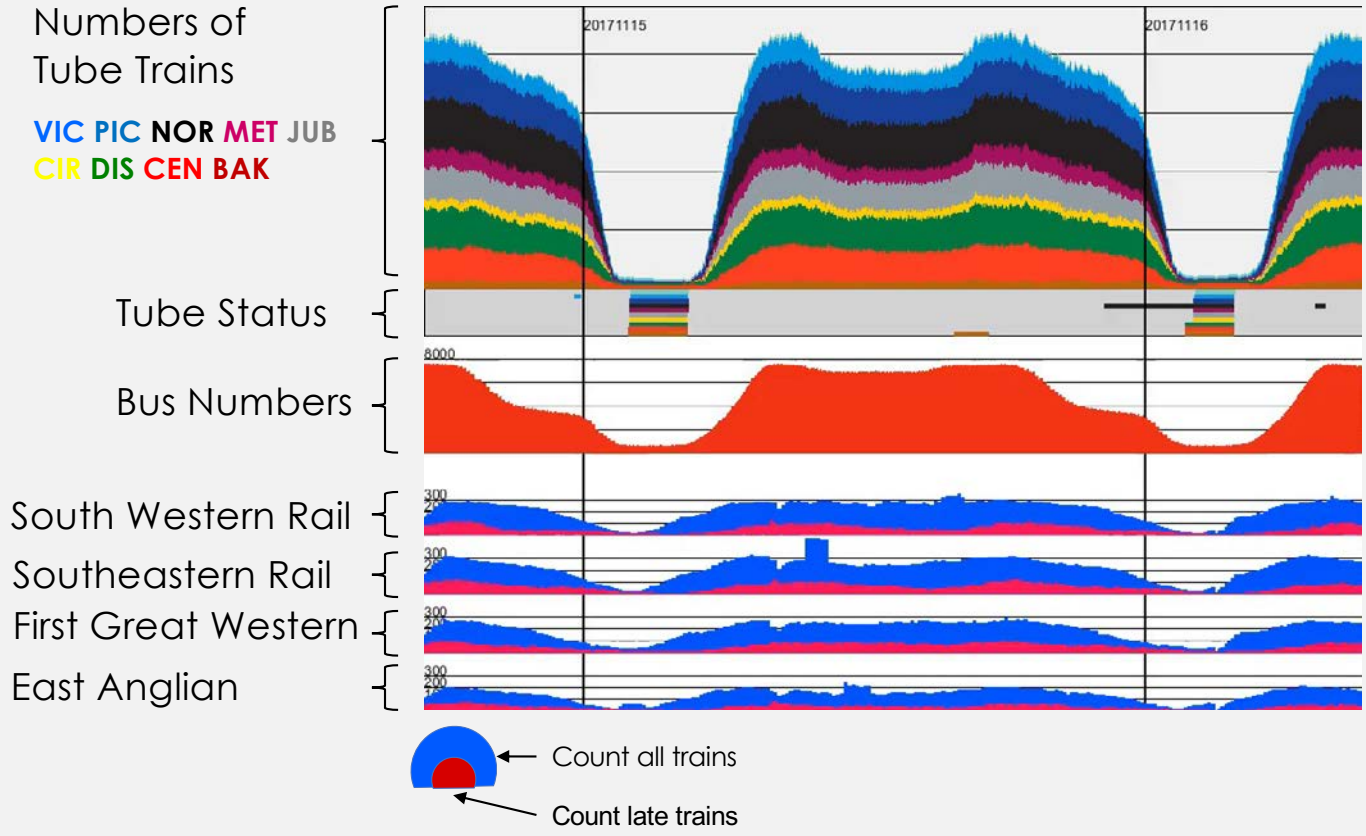







Supply of Trains From the Tracker-Net

Streams of City Data



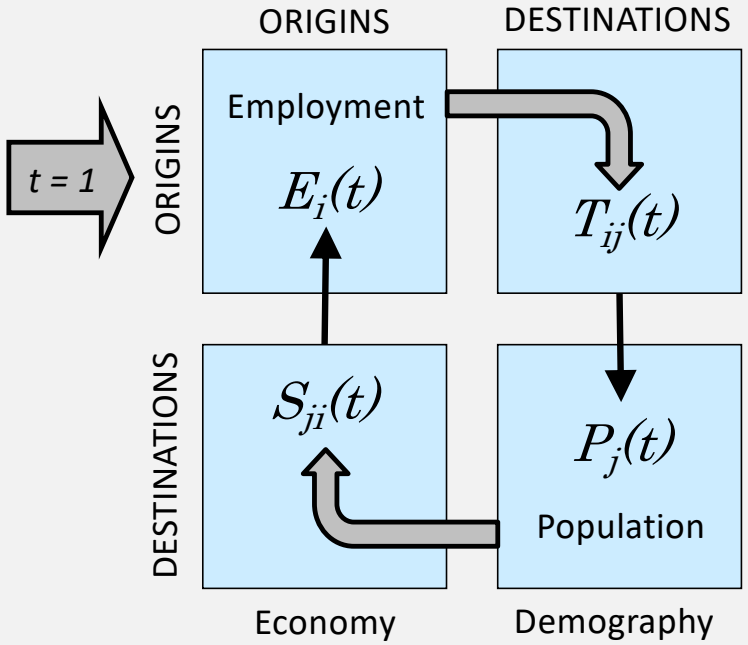


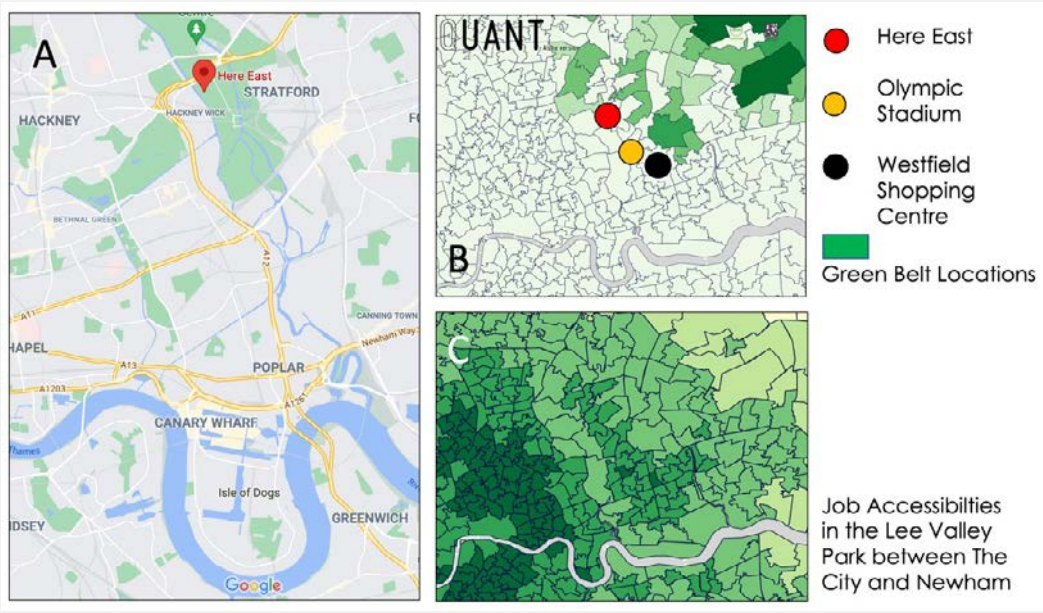
Big Data in 1939

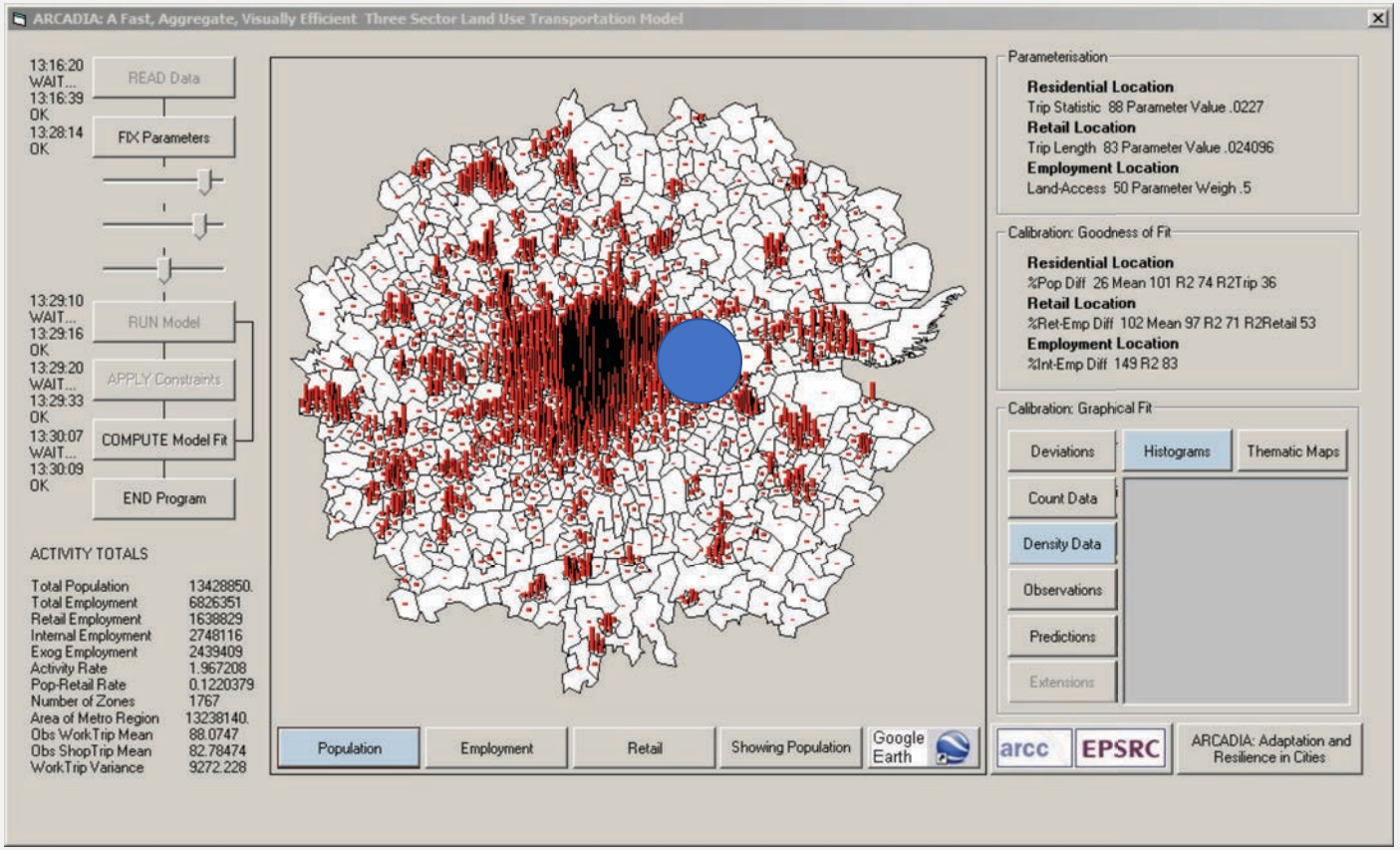
8 March 1939: Some of the four million tickets collected from London Underground passengers are examined in a survey by London Transport to discover the most and least used routes to help future infrastructure development

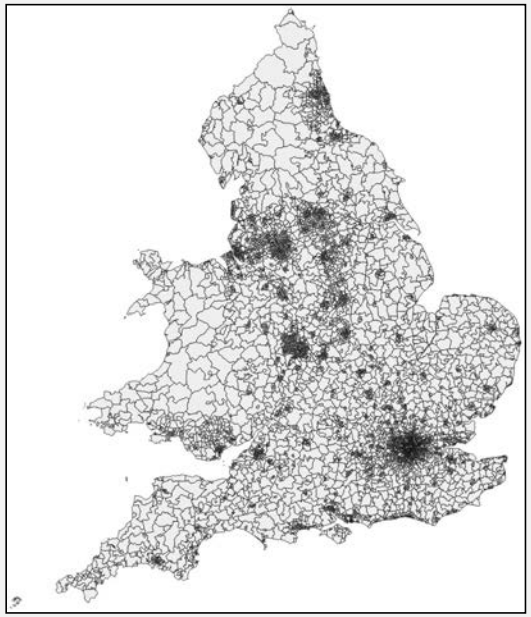
Long Term Urban Change: The QUANT Model

Our model is being built for everywhere. But we can think of it as focused in east London

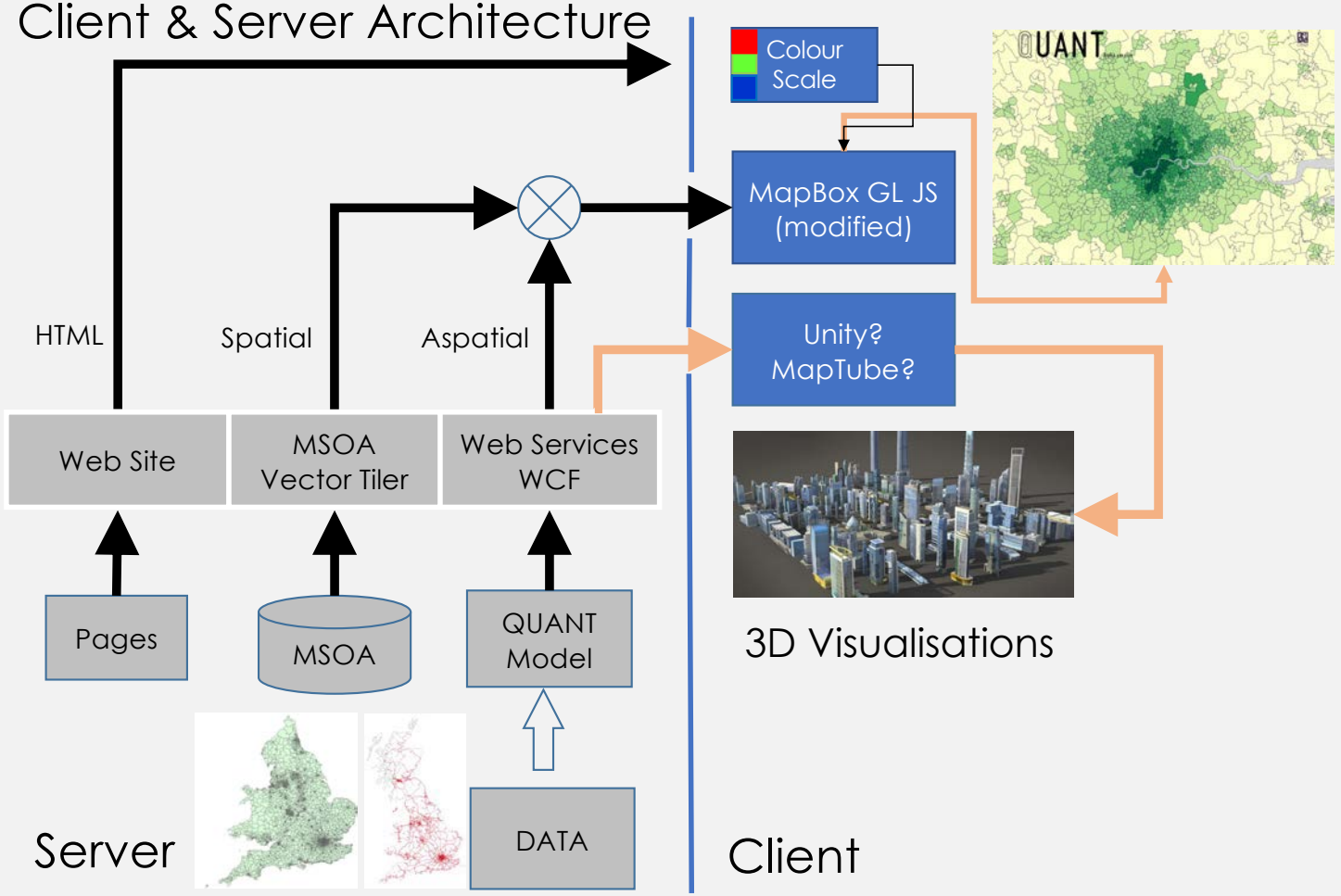


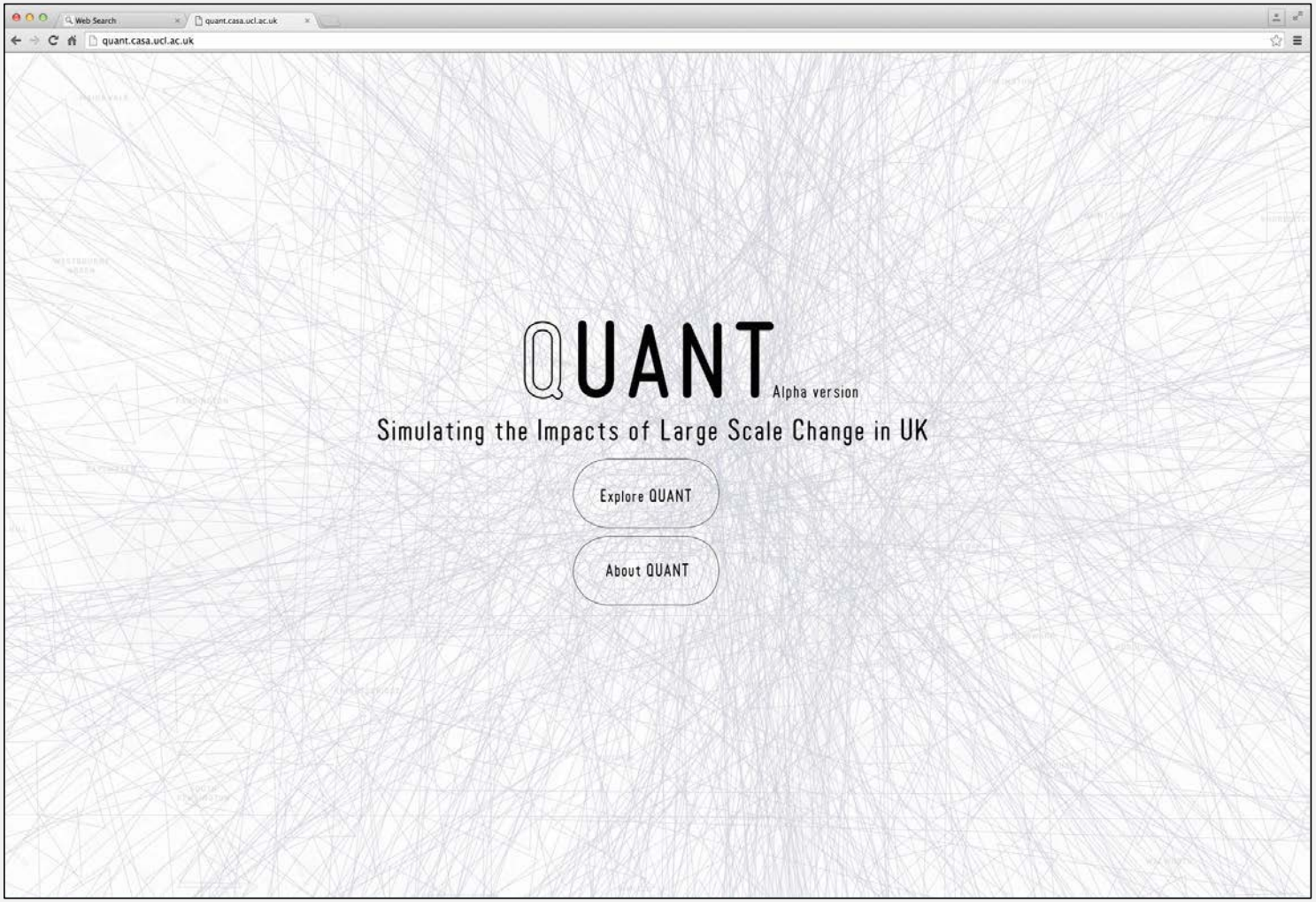



ARCADIA: A Fast, Aggregate, Visually Efficient Three Sector Land Use Transportation Model
13:16:20 WAIT...
13:16:39 OK
READ Data
13:28:14 OK
FIX Parameters
13:29:10 WAIT...
13:29:16 OK
RUN Model
13:29:20 WAIT...
13:29:33 OK
APPLY Constraints
13:30:07 WAIT...
13:30:09 OK
COMPUTE Model Fit
END Program
ACTIVITY TOTALS
Total Population 13428850.
Total Employment 6826351
Retail Employment 1638829
Internal Employment 2748116
Exog Employment 2439409
Activity Rate 1.967208
Pop-Retail Rate 0.1220379
Number of Zones 1767
Area of Metro Region 13238140.
Obs WorkTrip Mean 88.0747
Obs ShopTrip Mean 82.78474
WorkTrip Variance 9272.228
Population
Employment
Retail
Showing Population
Google Earth
Parameterisation
Residential Location
Trip Statistic 88 Parameter Value .0227
Retail Location
Trip Length 83 Parameter Value .024096
Employment Location
Land-Access 50 Parameter Weigh .5
Calibration: Goodness of Fit
Residential Location
%Pop Diff 26 Mean 101 R2 74 R2Trip 36
Retail Location
%Ret-Emp Diff 102 Mean 97 R2 71 R2Retail 53
Employment Location
%Int-Emp Diff 149 R2 83
Calibration: Graphical Fit
Deviations
Histograms
Thematic Maps
Count Data
Density Data
Observations
Predictions
Extensions
arcc
EPSRC
ARCADIA: Adaptation and Resilience in Cities

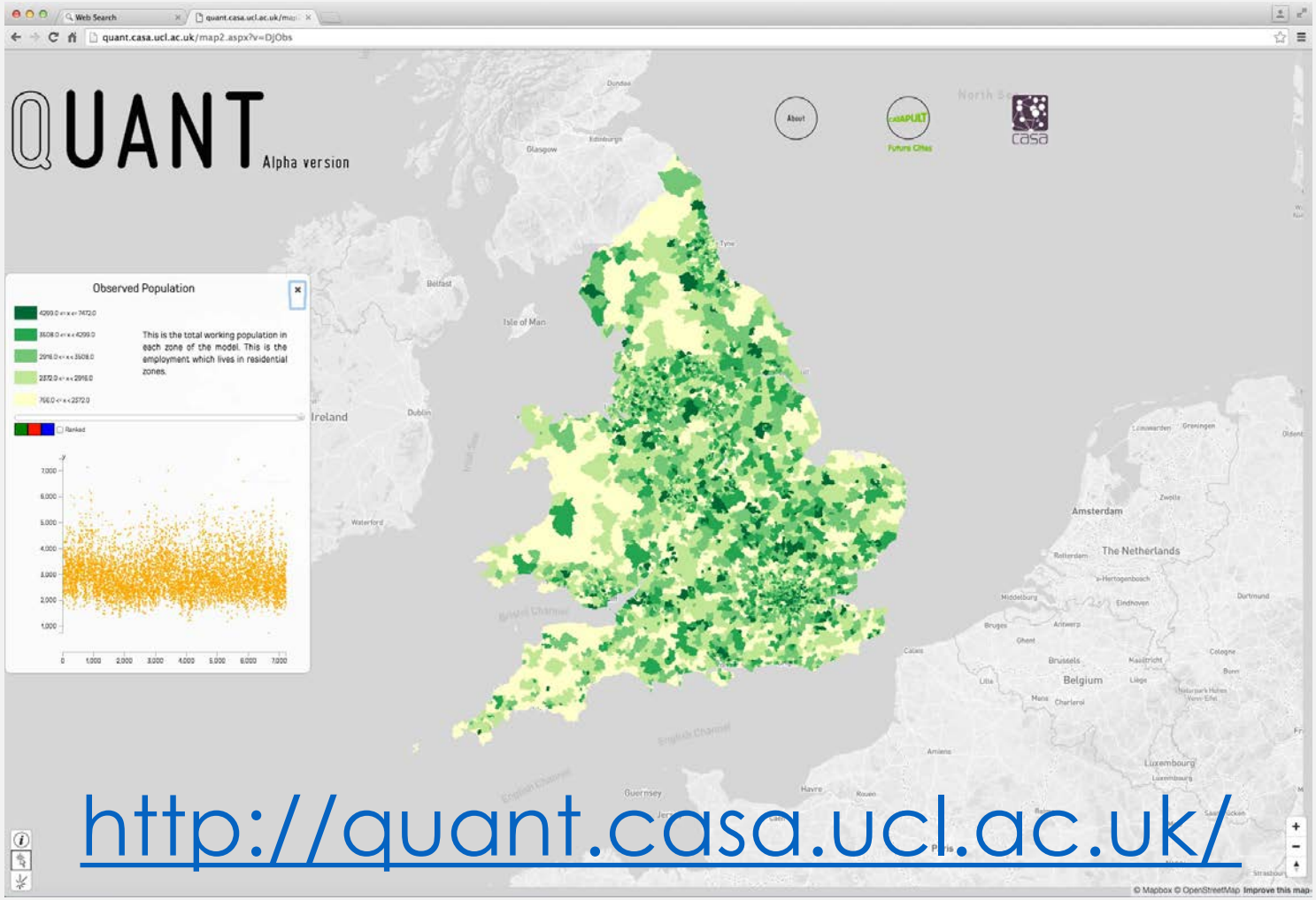


Client & Server Architecture

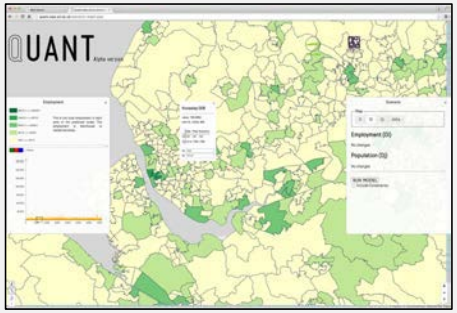



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About QUANT

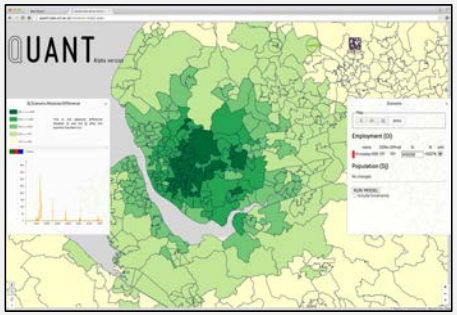

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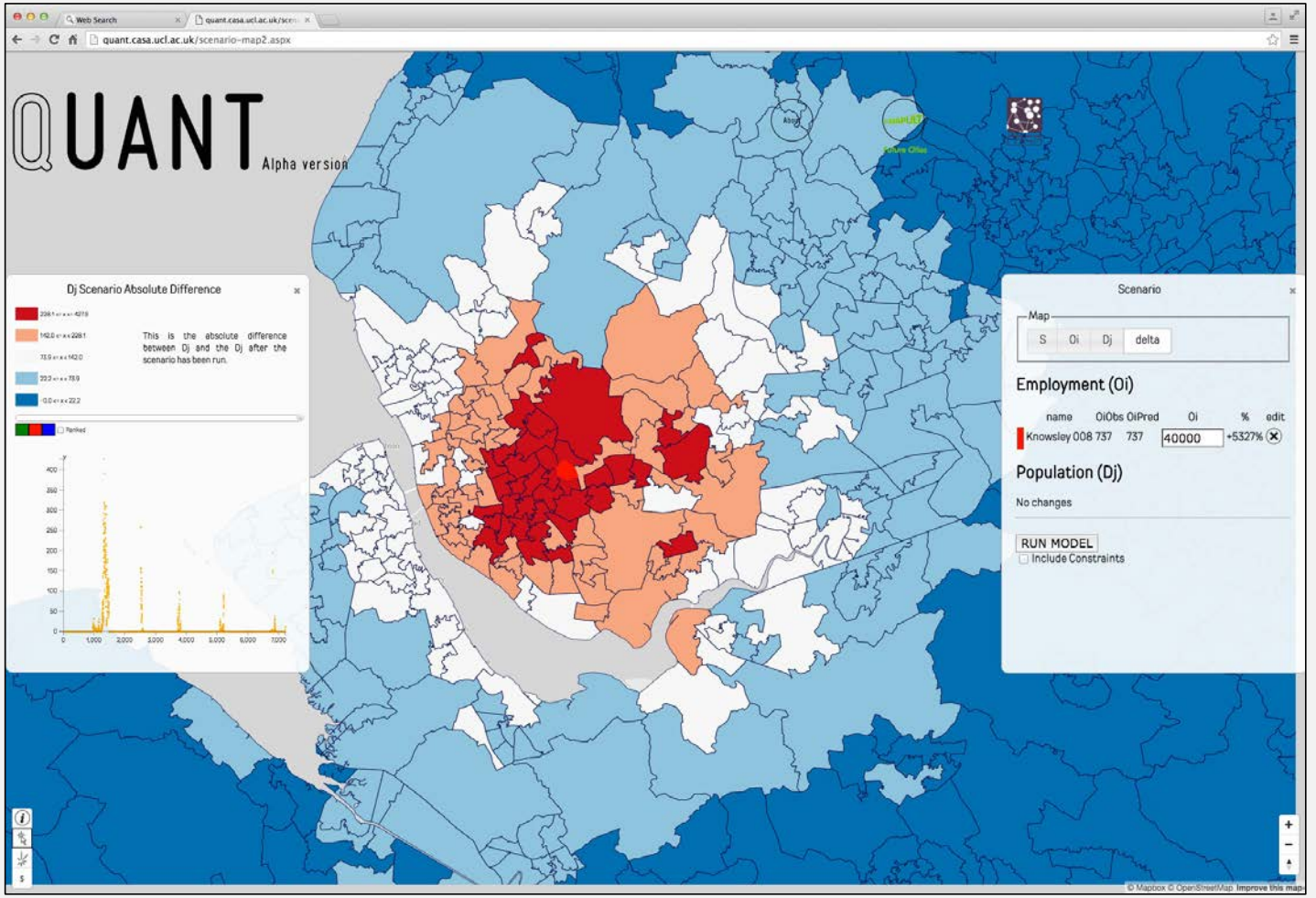


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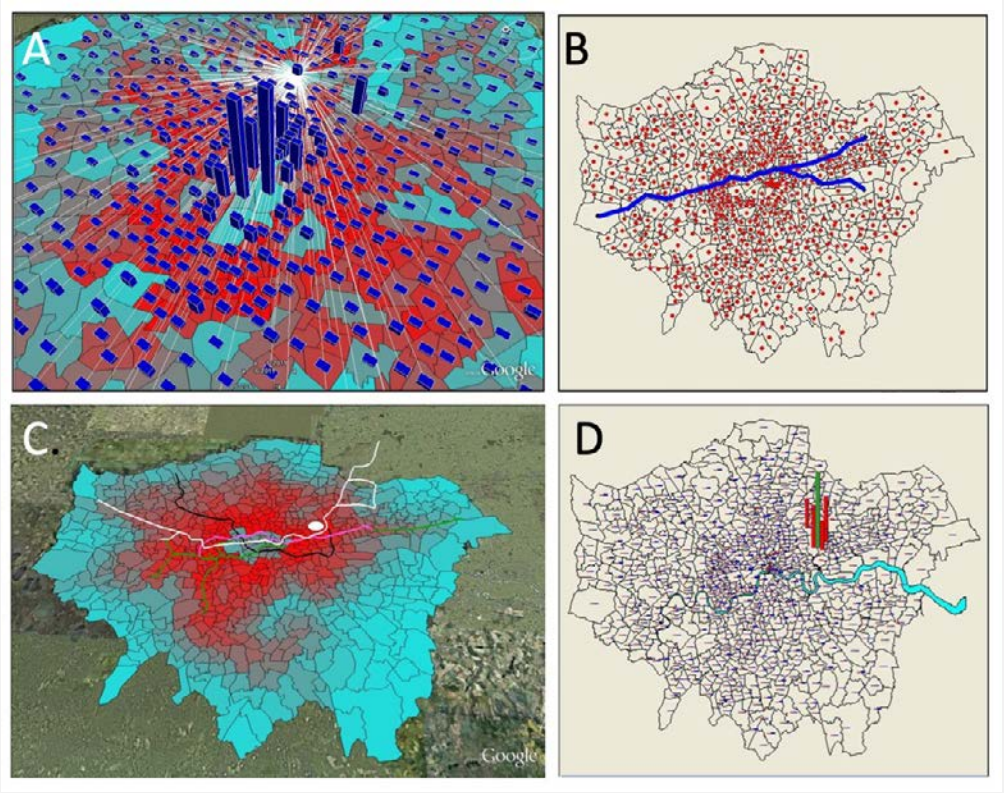








Digital Twins and Smart Cities


A
B
C
D
Google
Google


A
B
C
D
Hackney 013
Hackney 013
value: 11.18408
rank [0..7200]: 4059

Is the Concept of the Digital Twin Useful ?

- I leave you to judge. Like many things, Yes & No. It forces us to think about how cities are changing, how models are proliferating. How do we deal with many models of the same problem? Federated digital twins? Many twins – triplets +++
- It forces us to think about what smart cities really are, which is of course is part of the wider debate about what cities are and how that are being transformed by new technologies.
- It forces us to think about what a model really is and how we can link many models together but how we think of many models and different conceptions system at the same time.

Thanks

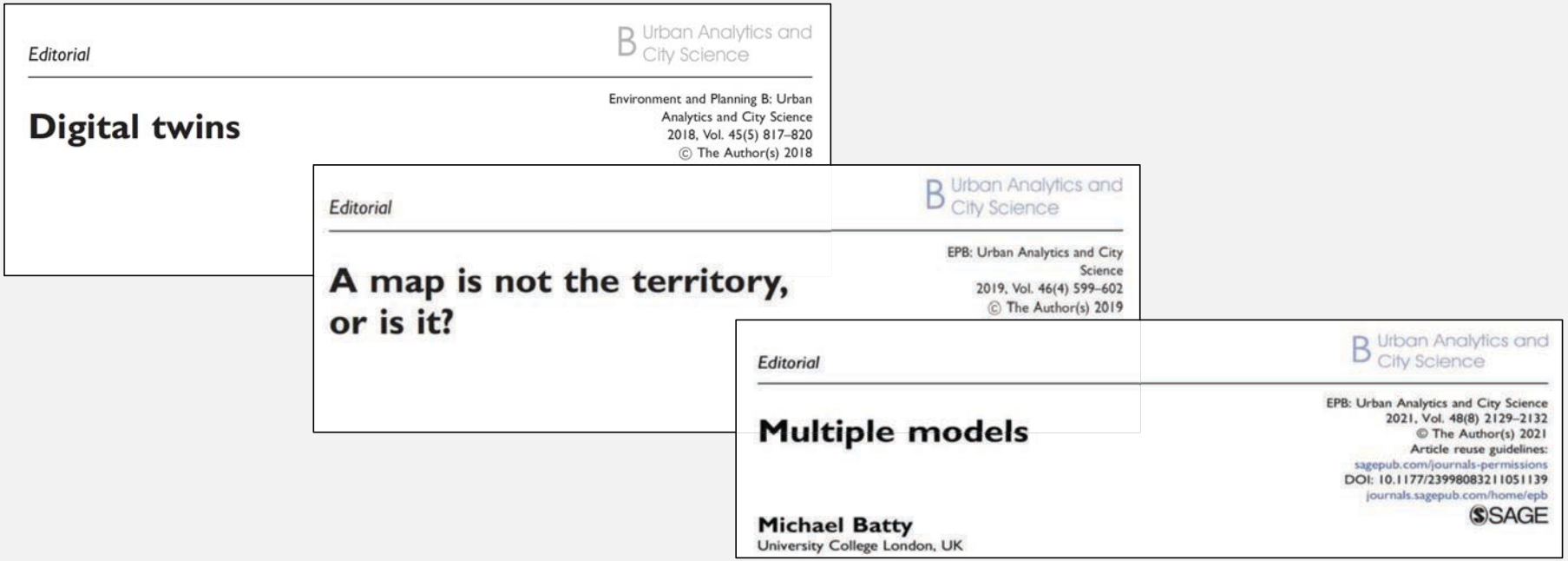
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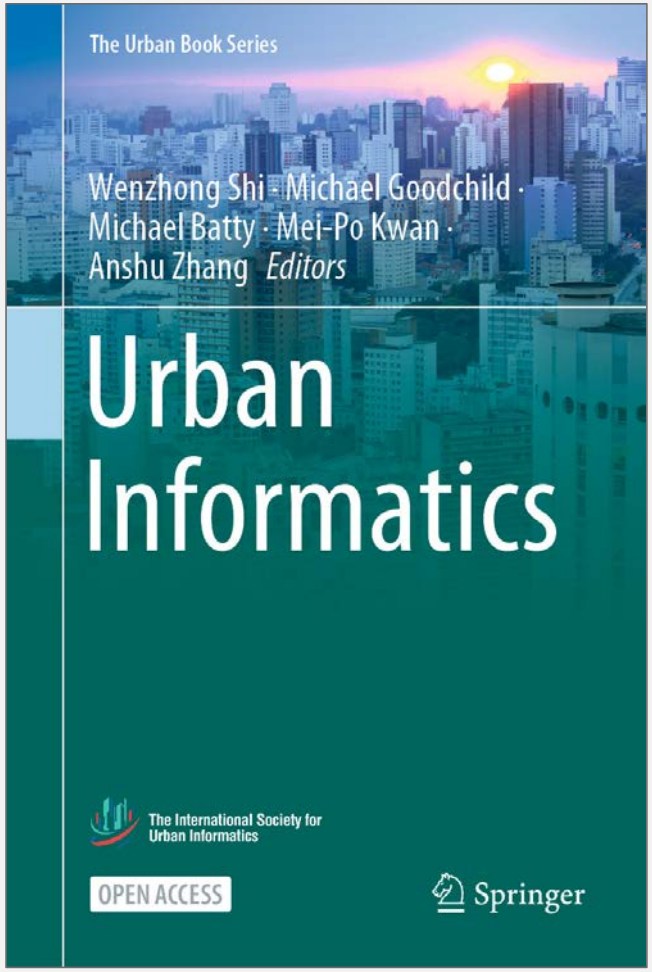
Urban Twins as the most promising approach for the digitalization of cities?

University College London



ice Publishing

Hudson-Smith, A., Signorelli, V., Dawkins, O., and Batty, M. (2021) More Than One Twin: An Ecology of Model Applications in East London, In Wan, L., Nochta, T., Tang, J., and Schooling, J. (Editors) **Digital Twins for Smart Cities – Conceptualization, Challenges and Practices,** Institution of Civil Engineers, London

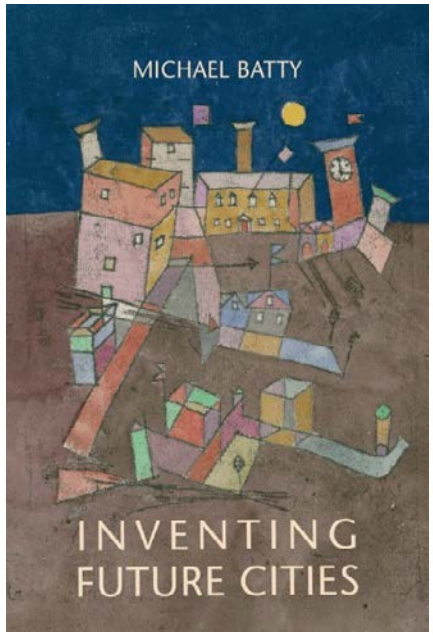


Urban Informatics

Editors: **Shi**, W., **Goodchild**, M., **Batty**, M., **Kwan**, M.-P., **Zhang**, A. (Eds.) 2021

Introduces systematically the principles of urban informatics, including urban system theories, techniques, and tools for urban big data acquisition, infrastructure, and analytics, as well as focusing these new tools on urban problems and possible solutions

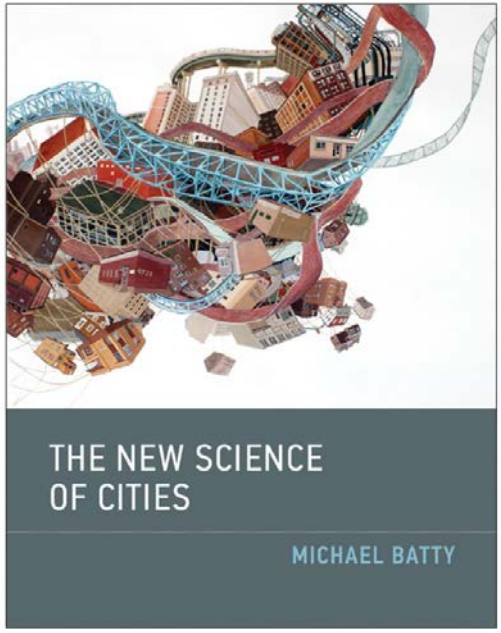
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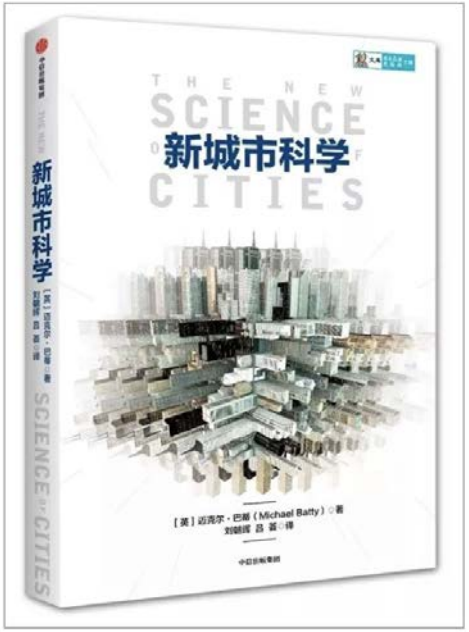
MIT Press, 2018



Translated 2020



MIT Press, 2013



Translated 2020