COLUMBIA GSAPP | COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK | LiPS Lectures in Planning Series | casa UCL University College London

Digital Twins, Triplets & The Rest

Families of Simulation Models for Urban Analytics

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I have put this on my web site as a PDF and you can get it from

https://tinyurl.com/yyrxwpp7

An Outline of the Talk

- What Is the Smart City? The High Frequency and Low Frequency City. What Does the Digital Twin Relate to?
- Where Do Digital Twins Come From?
- A Cornucopia of Twins: Maps as Analogies
- Hardware Turning into Software and Vice Versa
- Multiple Abstractions: Many Models
- Now for Examples: Three Very Different Types of Twin
  - *VR and AR, 3D City Models and BIMS*
  - *Real Time Simulation: Passenger Demand, Trains Supply & Flows*
  - *Long Term Urban Change: The QUANT Model*
- Is the Concept Useful ?

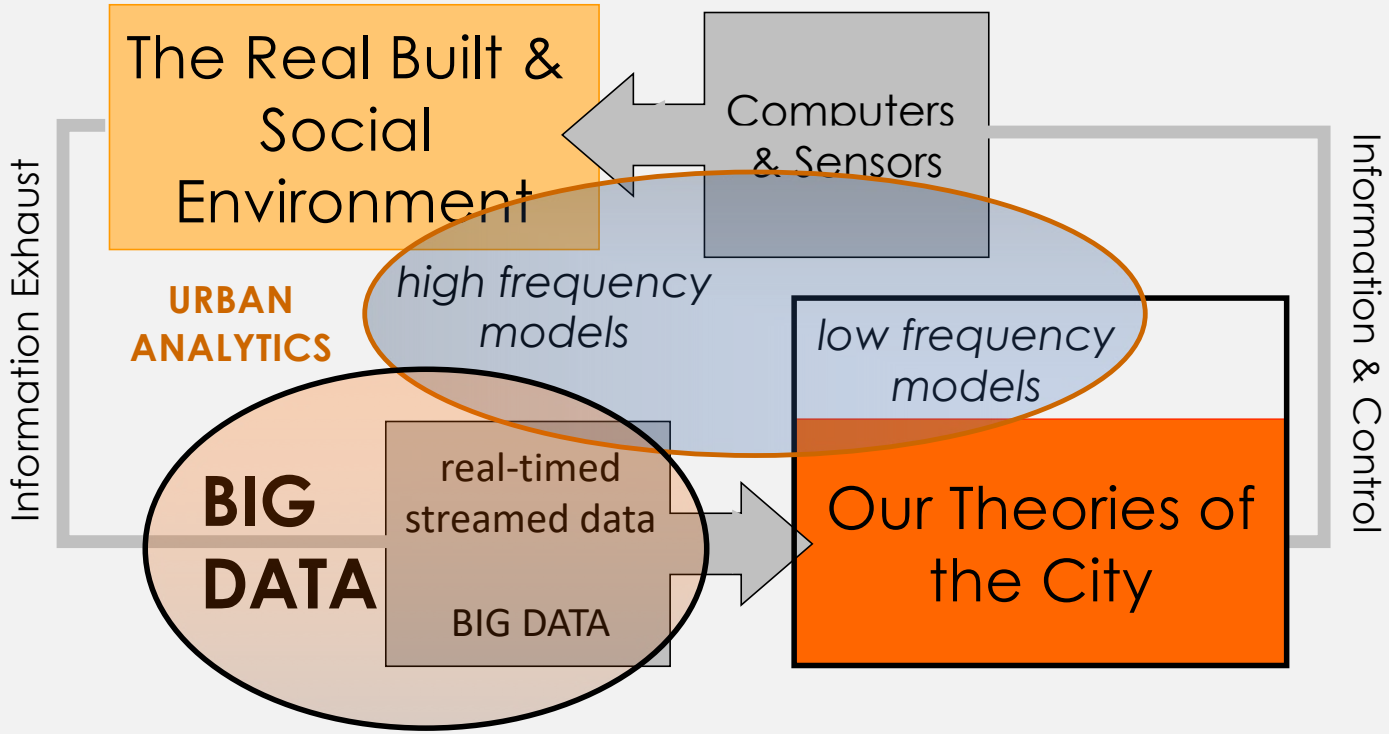
What Is the Smart City? The High Frequency and Low Frequency City. What Does the Digital Twin Relate to?

The smart city has emerged essentially as the ***high frequency city***. That is the 24 hour city or the city over short period. This is not the ***low frequency city***, thus many ideas we have about the long term city barely apply to the short term

Much of this is because of new information technologies and there is an assumption that the the digital world is the world of the smart city where IT is being embedded into the city fabric

I adopt this assumption here, notwithstanding it is controversial

Let me define the smart city from a simple diagram. I have used quite a bit but it helps focus ideas.



Let me turn to the idea of 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

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, just perhaps, some of them will get, are getting 'closer' to the real thing.

This talk is about how close is the model to the original – the real

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 – and 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'

But the best story I have 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'.

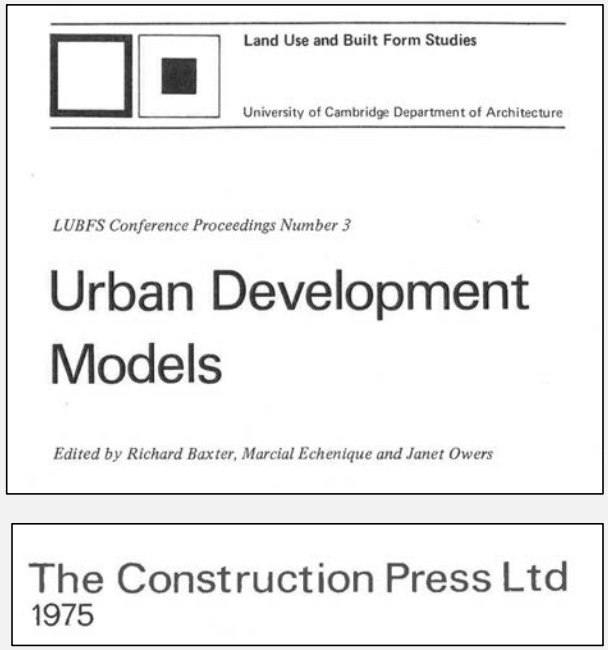
MH: 'Only six inches!' exclaimed Mein Herr. 'We very soon got to six yards to the mile. Then we tried a hundred yards to the mile. And then came the grandest idea of all! We actually made a map of the country, on the scale of a mile to the mile!'

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)

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.



1) Models do not adequately represent the real world of urban development.

There are perhaps two different points here. The first accepts the kind of land use/transportation model that I have discussed but, despite their increasing elaboration, is not satisfied that they adequately represent the complexities and intricacies of the system. In answer to this criticism, I am reminded of an episode from Lewis Carroll's Sylvie and Bruno Concluded in which a German Professor,

> "Mein Herr looked so thoroughly bewildered that I thought it best to change the subject. 'What a useful thing a pocket-map is!' I remarked.
>
> '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?' 'About six inches to the mile.'
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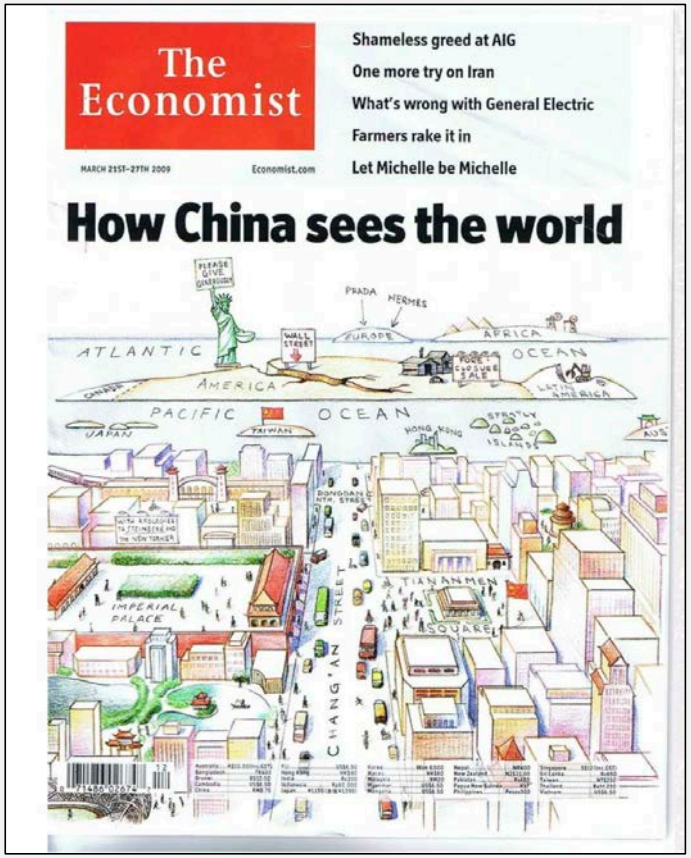
Maps, like models, are made at appropriate levels of detail for different purposes. An exact replica of the world would be of no more use than the Captain's map in another work by Carroll, The Hunting of the Snark: the map was "a perfect and absolute blank!". All models - to be useful - must be selective and, if you like, false to reality in some respect or other. Pocket-models may be the most useful in the end.

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. The prospects are enticing even if the experience continues to daunt it …… We will see.

To Conclude my Interlude: Maps Based on Our Perceptions



Hardware Turning into Software and Vice Versa

Of course, in essence what we are really heading towards here is that software is turning into hardware and vice versa. Building information models are classic in this regard. We can no longer design buildings without such models but for the building to function, the model must remain in place. It's changing architectural design and the management of buildings.

This extends the idea of the smart city in that it is not just about an embedding of soft into hard but of hard becoming soft.

There are some key issues here in that if the twin merges with with the artifact, then the latency between the one and the other is problematic – it can no longer function separately

But for any model to function independently, there must be some latency between the real thing and the thing simulated – the model.

Another feature is that if the twin is so strongly coupled with the original object or artefact or even the social system, the twin disappears if the original system disappears – the dependence is critical to the function of both the twin and the real system.

Much relates to the extent to which the digital will merge with the physical in the future.

In this context, it is clear that the twin cannot predict the future of the system to which is attached for prediction in this context means control, and control is essential for the real system.

Multiple Abstractions: Many Models

Let me quote again from a famous book to impress these points about many models, many twins and so on; and indeed in parallel many variants of cities. I have not speculated at all on digital triplets, quads, identical twins – they are all talking points

While I am throwing out ideas about how close is the map to the territory, let me say recount one of the polemics from Italo Calvino from his 1974 book ***Invisible Cities*** between Kublai Kahn and Marco Polo. One of the stories there goes as follows. I used it in a lecture in Liverpool about 12 years ago, about different models, not unlike the pitch I am giving here. (Model cities, **TPR**, **78** (2))

All Calvino's stories are like this:

KK: *'And yet in my mind I have constructed a model city from which all others can be deduced,' Kublai said. 'It contains everything corresponding to the norm. Since the cities that exist diverge in varying degree from the norm, I need only foresee the exceptions to the norm and calculate the most probable combinations'.*

MP: 'I have also thought of a model city from which I can deduce all others', Marco answered. 'It is a city made only of exceptions, exclusions, incongruities, contradictions. If such a city is the most improbable, by reducing the number of abnormal elements, we increase the probability that the city really exists'. Calvino, 1974, 69

Now for Examples: Three Very Different Types of Twin

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

- First using a physical representation of the elements that define the buildings in the city – building in digital representation, VR, AR and thence BIM – this is the hf city
- Second of flows of traffic which is a problem in demand and supply in term time; this is the high frequency city with long term implications
- Third a model of the low frequency city simulating long term urban growth and change

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.

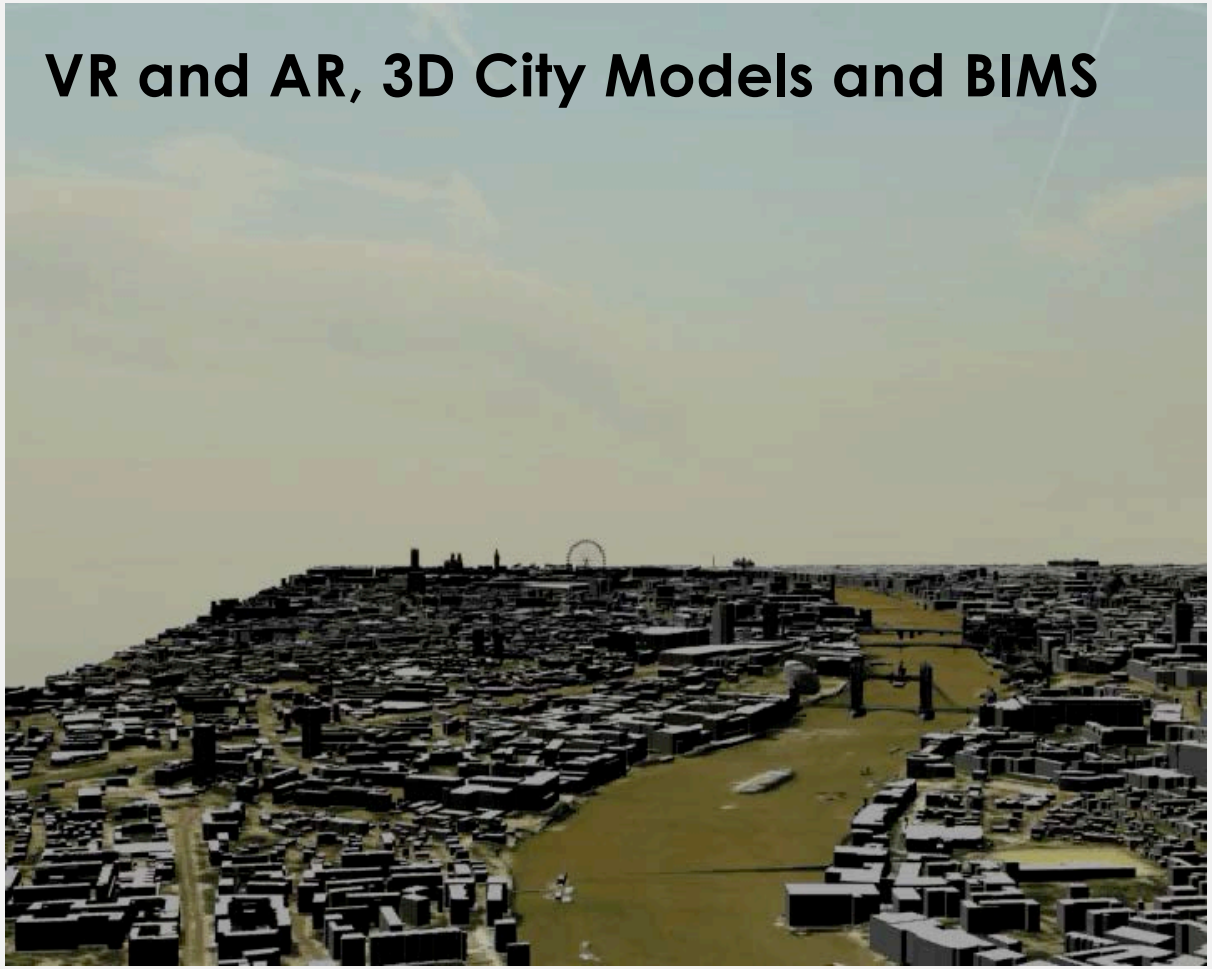
We will begin by describing the construction of a digital iconic model of central London that we somewhat euphemistically refer to as 'Virtual London'. Virtual London is in fact a 3-D geographic information system (3-D-GIS), which is in essence a large spatial database that can be analysed and queried. 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.

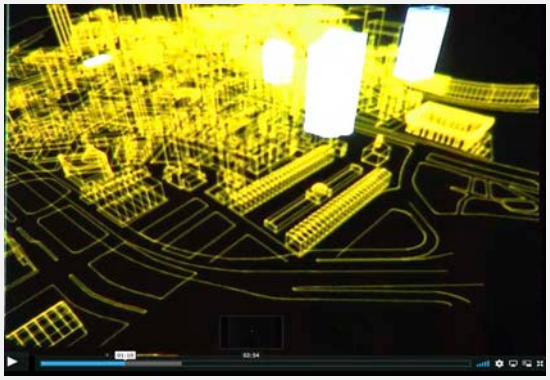
Such models can also be imported into other digital media. We illustrate the conception of a simulacrum by embedding it within a virtual world – a virtual design studio or exhibition space – which users can enter as avatars and then view and manipulate the model in the presence of other users, who are 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

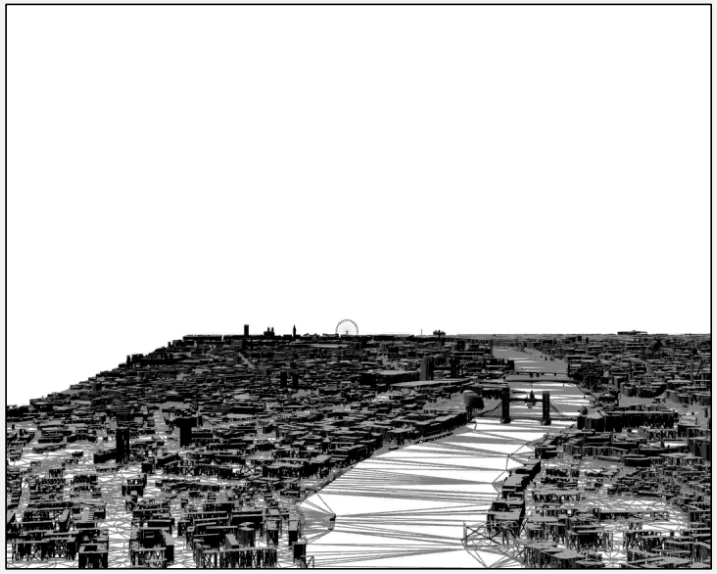
Figure 1: View west from Tower Bridge across Virtual London, showing the raw geometry of the virtual city before it is populated with data.

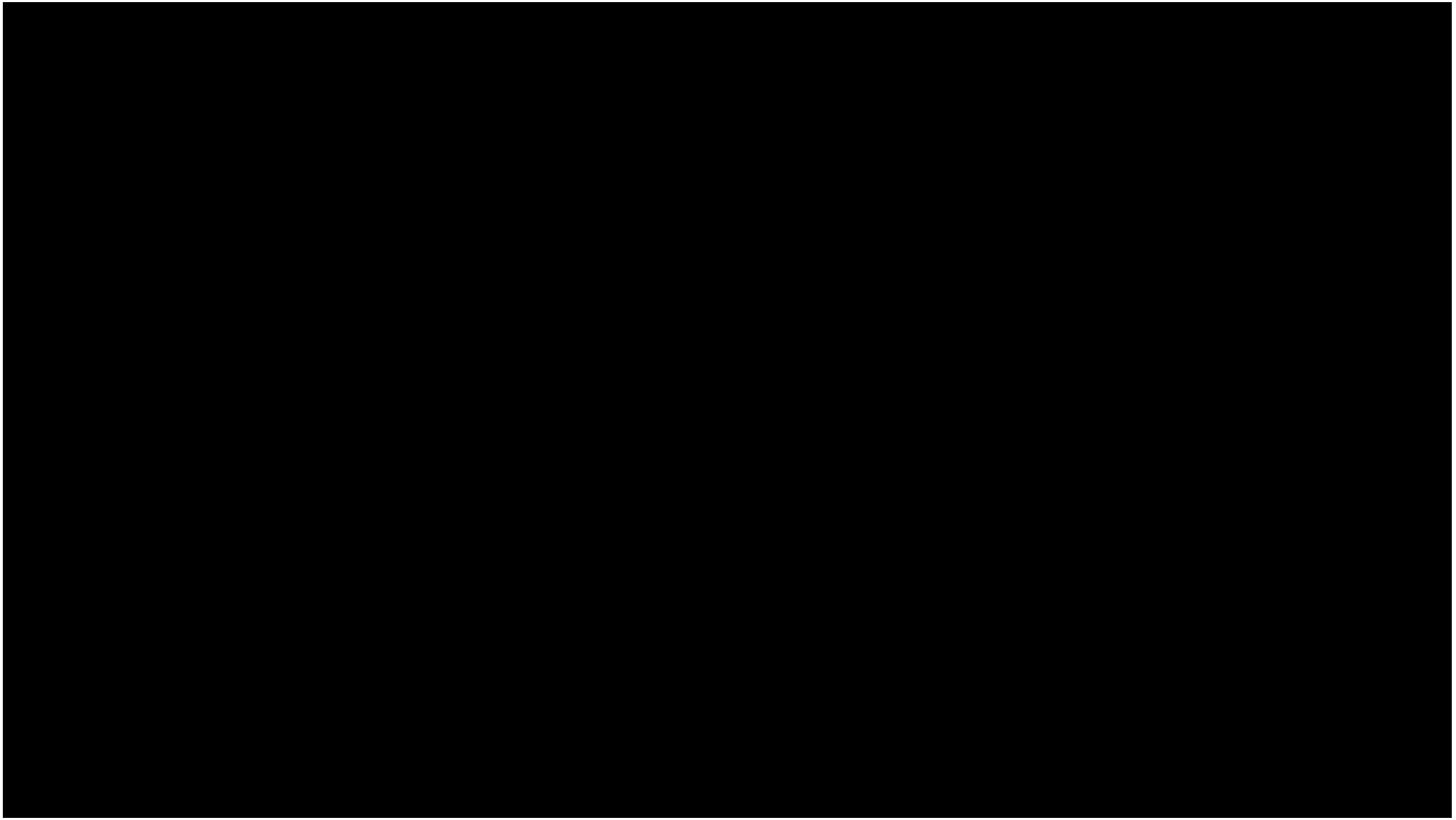
Figure 2: Building the virtual city in layers from the ground up. (a) Extruding parcel data to average height and inserting a LIDAR image of St Paul's Cathedral into the scene. (b) Adding a digital panorama of the area around the Swiss Re headquarters building.

VR and AR, 3D City Models and BIMS



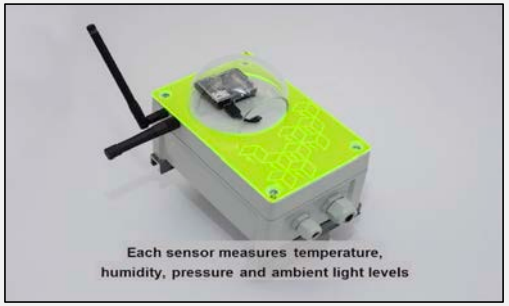







HereEast
The UCL campus at Here East on
The Queen Elizabeth Olympic Park

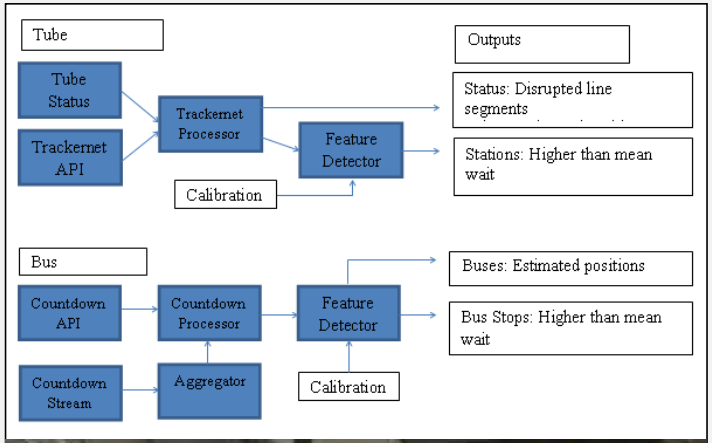

Twenty environment sensors were installed
for a six month trial from April 2018


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

Real Time Simulation: Passenger Demand, Trains Supply & Flows

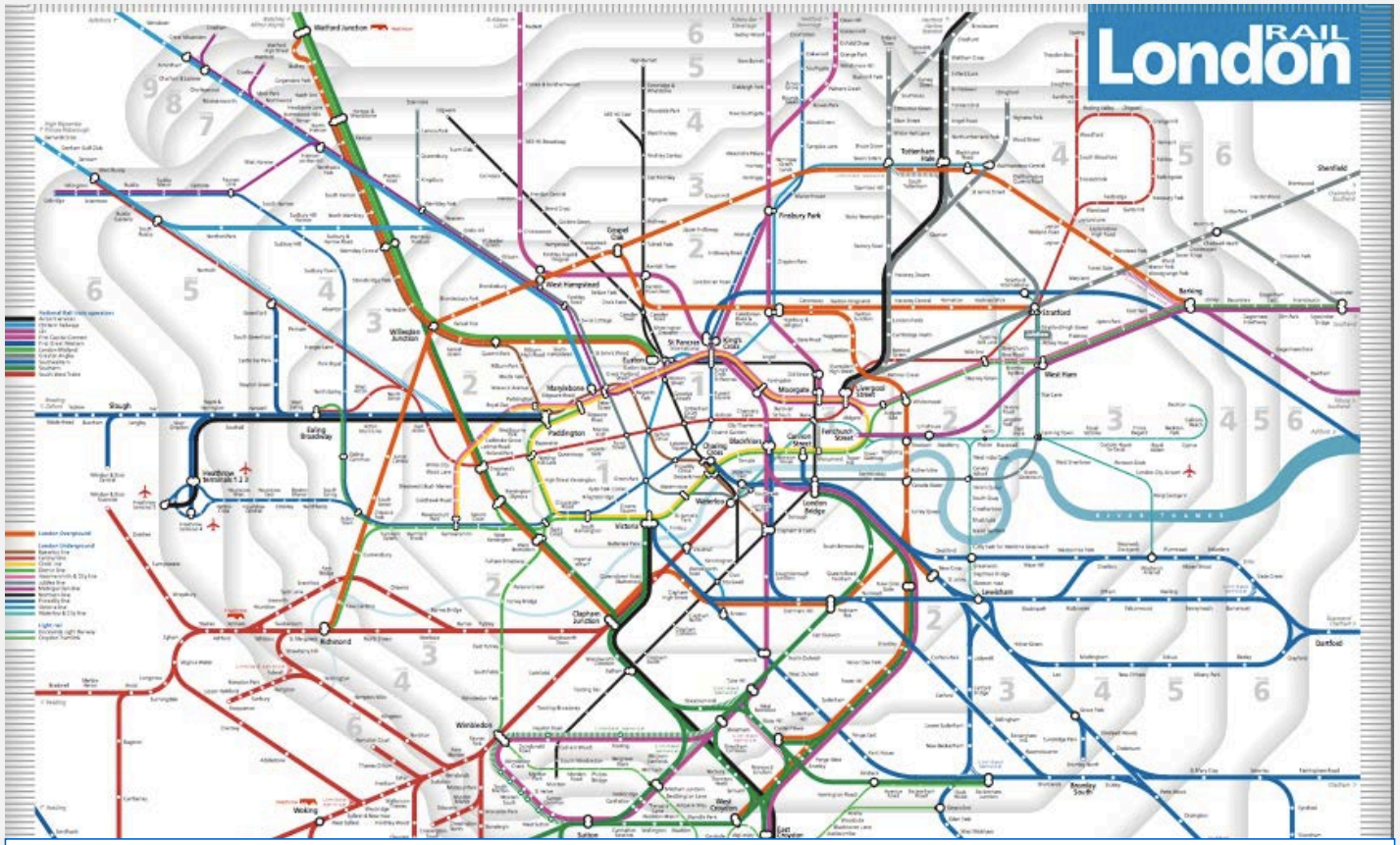
Demand by Travellers

Supply of Trains

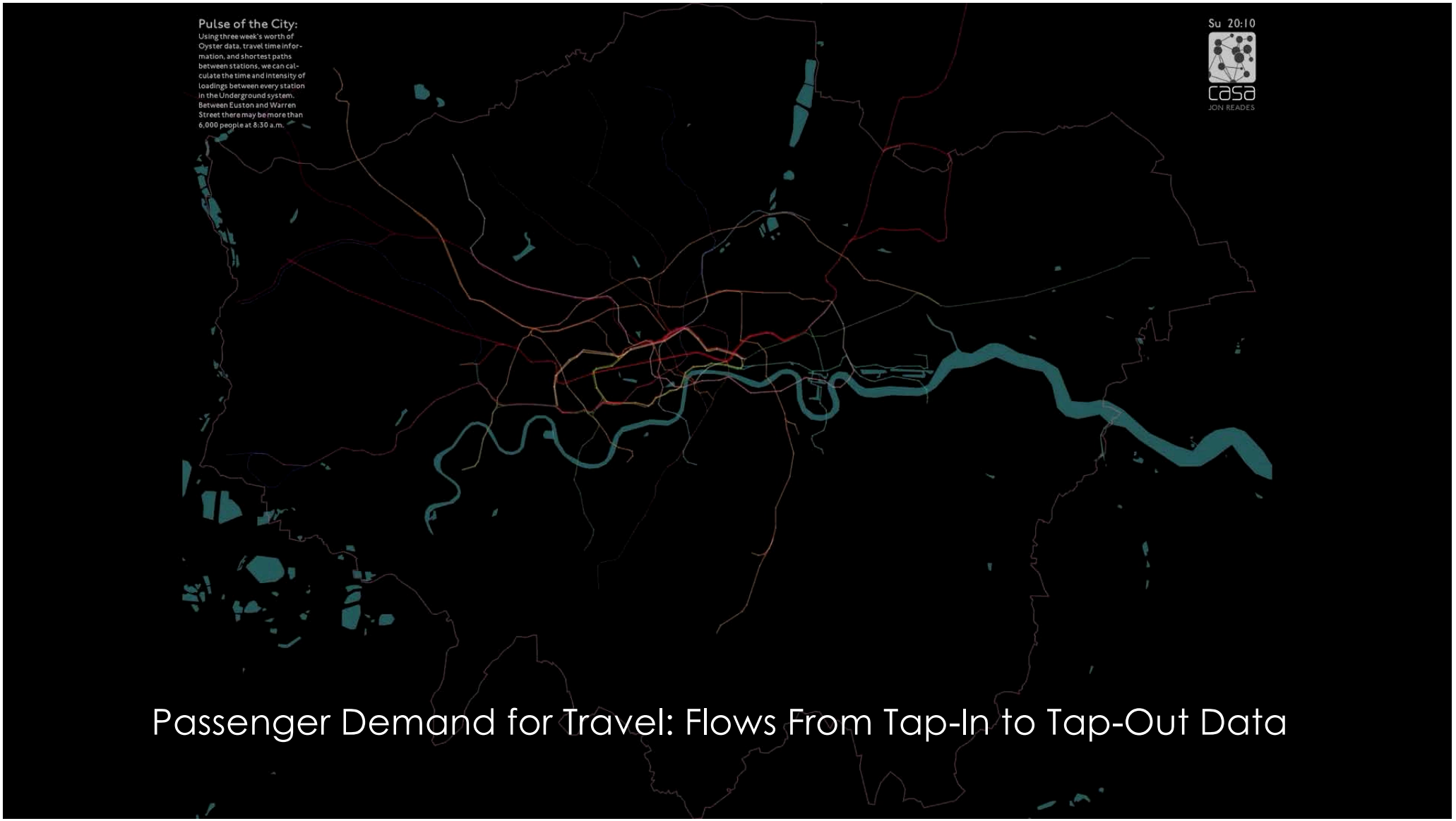


How do we match demand & supply without passenger tracking?

Digital Twins, Triplets & The Rest

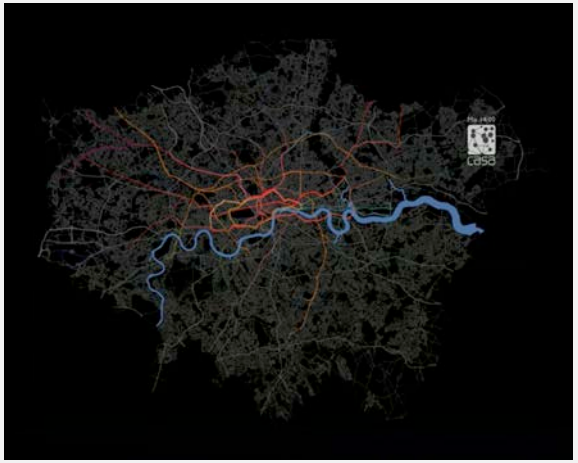


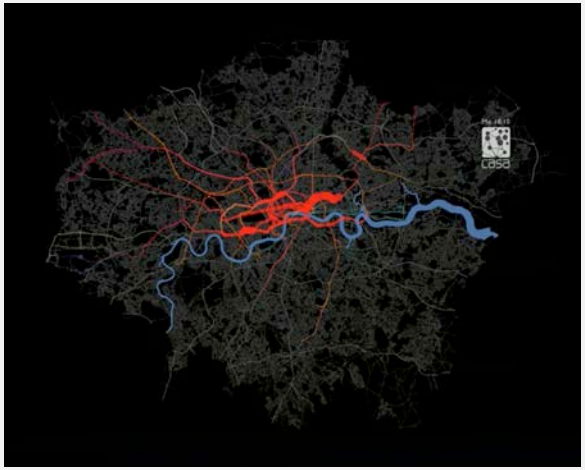
Tube, Overground and National Rail Networks in London
where Oyster cards can be used



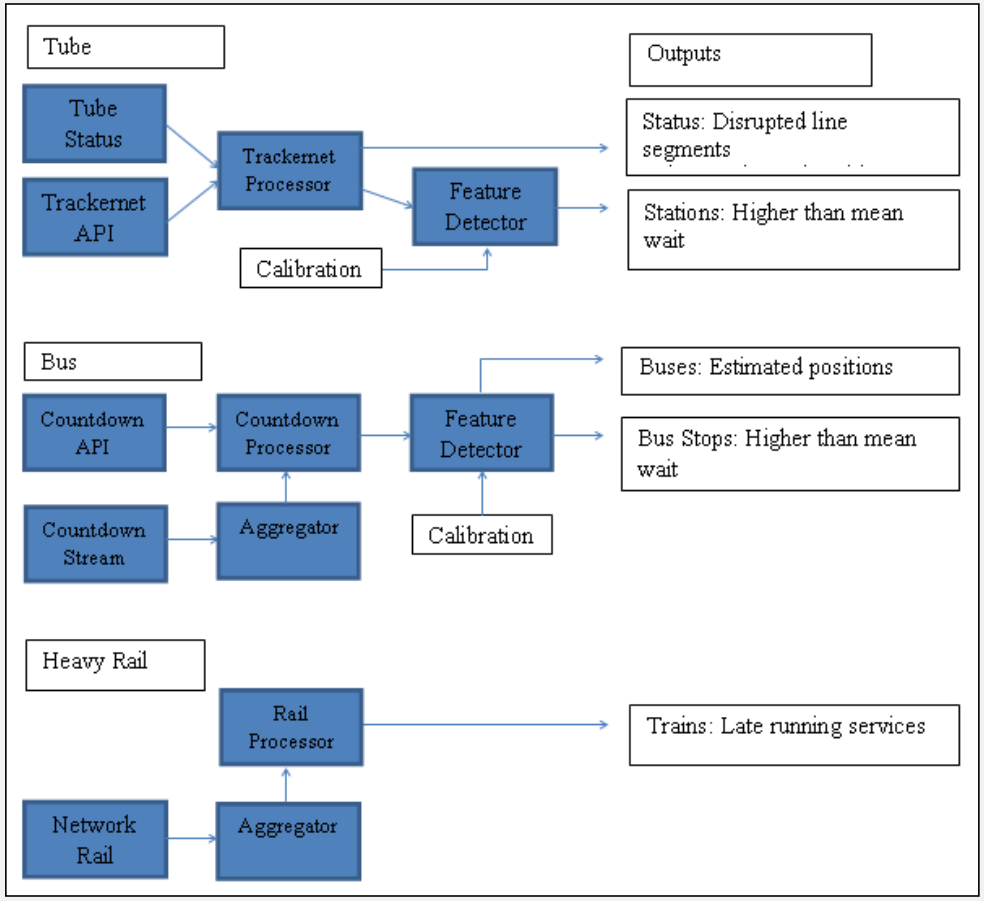
Passenger Demand for Travel: Flows From Tap-In to Tap-Out Data

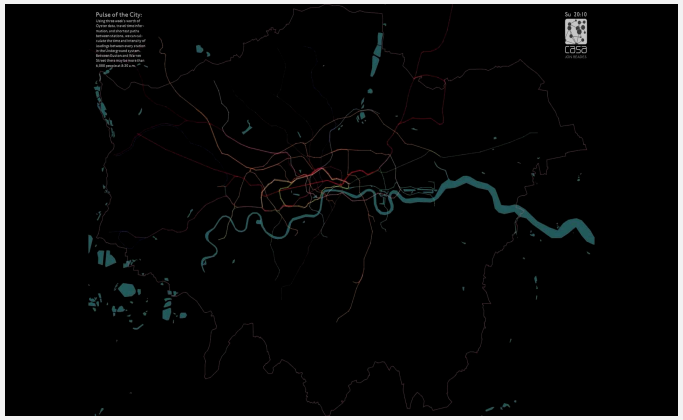

OYSTER GIVES UP PEARLS

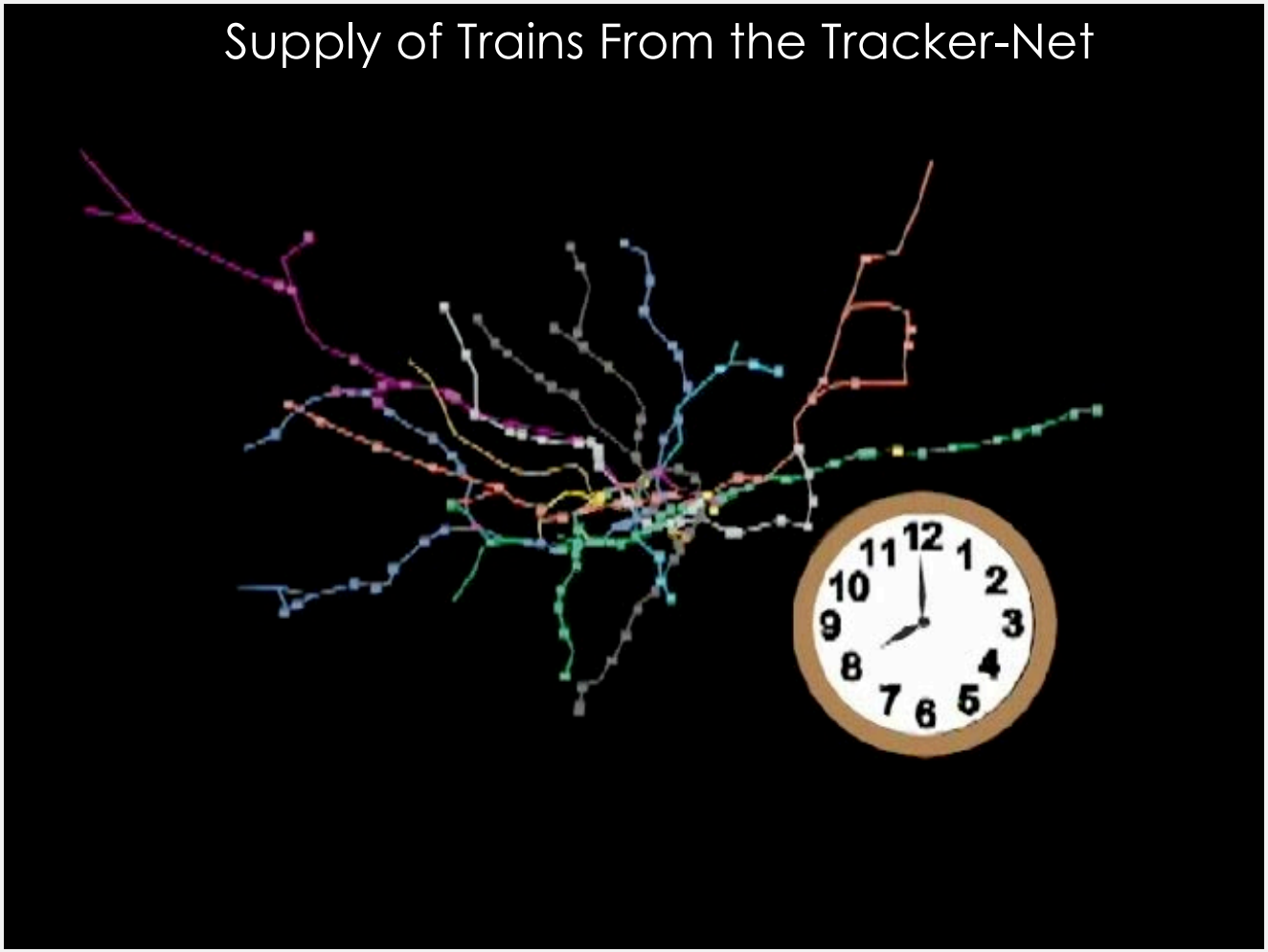




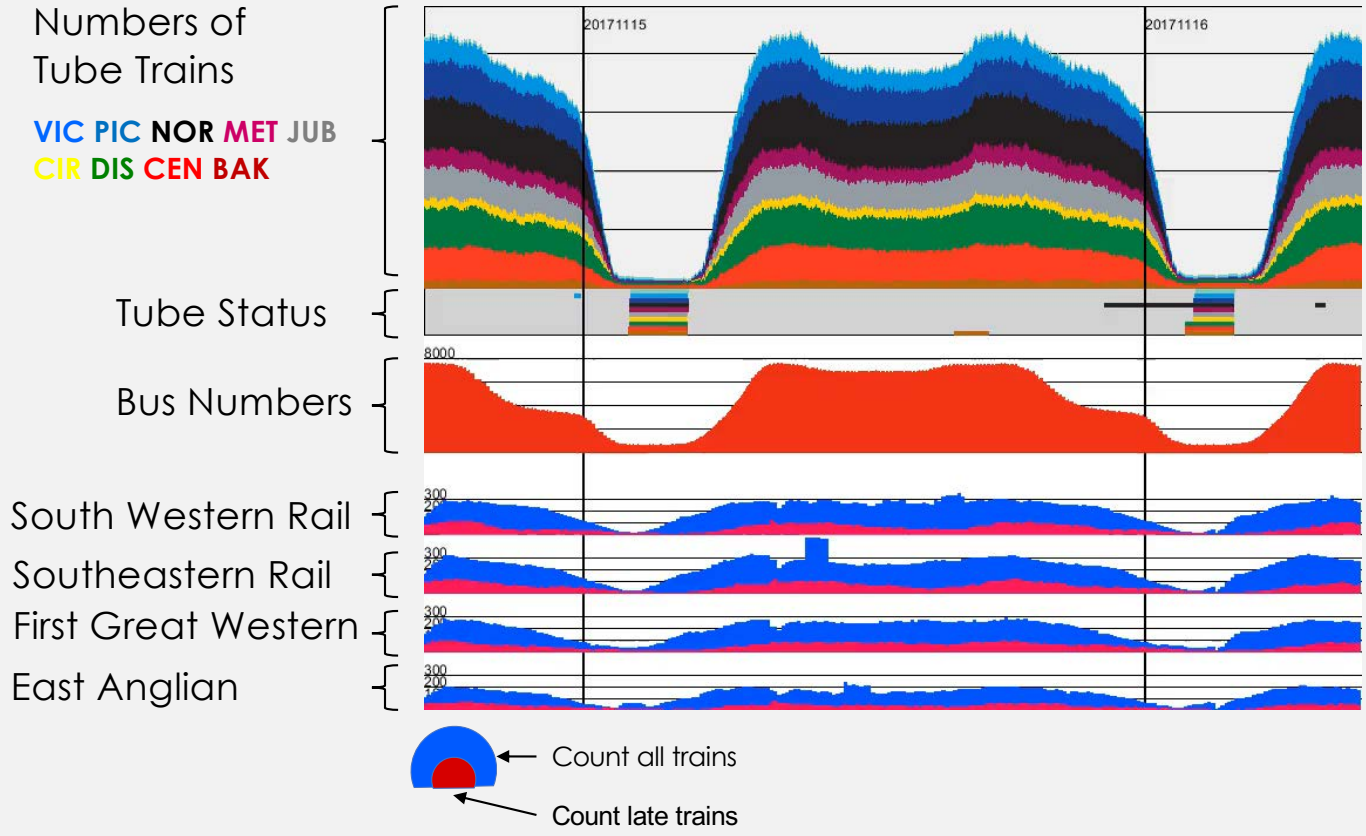
The Public Transport System in Terms of Vehicle Flows and also Passenger Flows from Oyster






Supply of Trains From the Tracker-Net

Streams of City Data

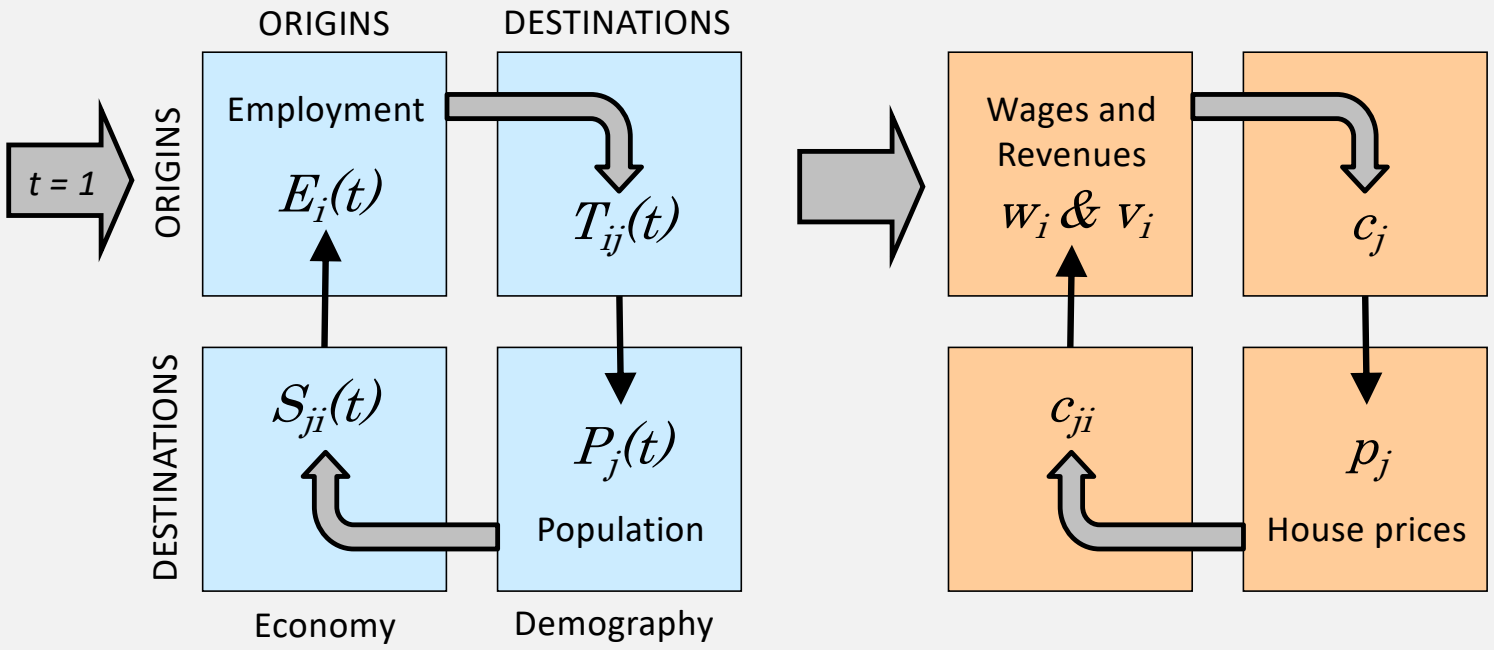


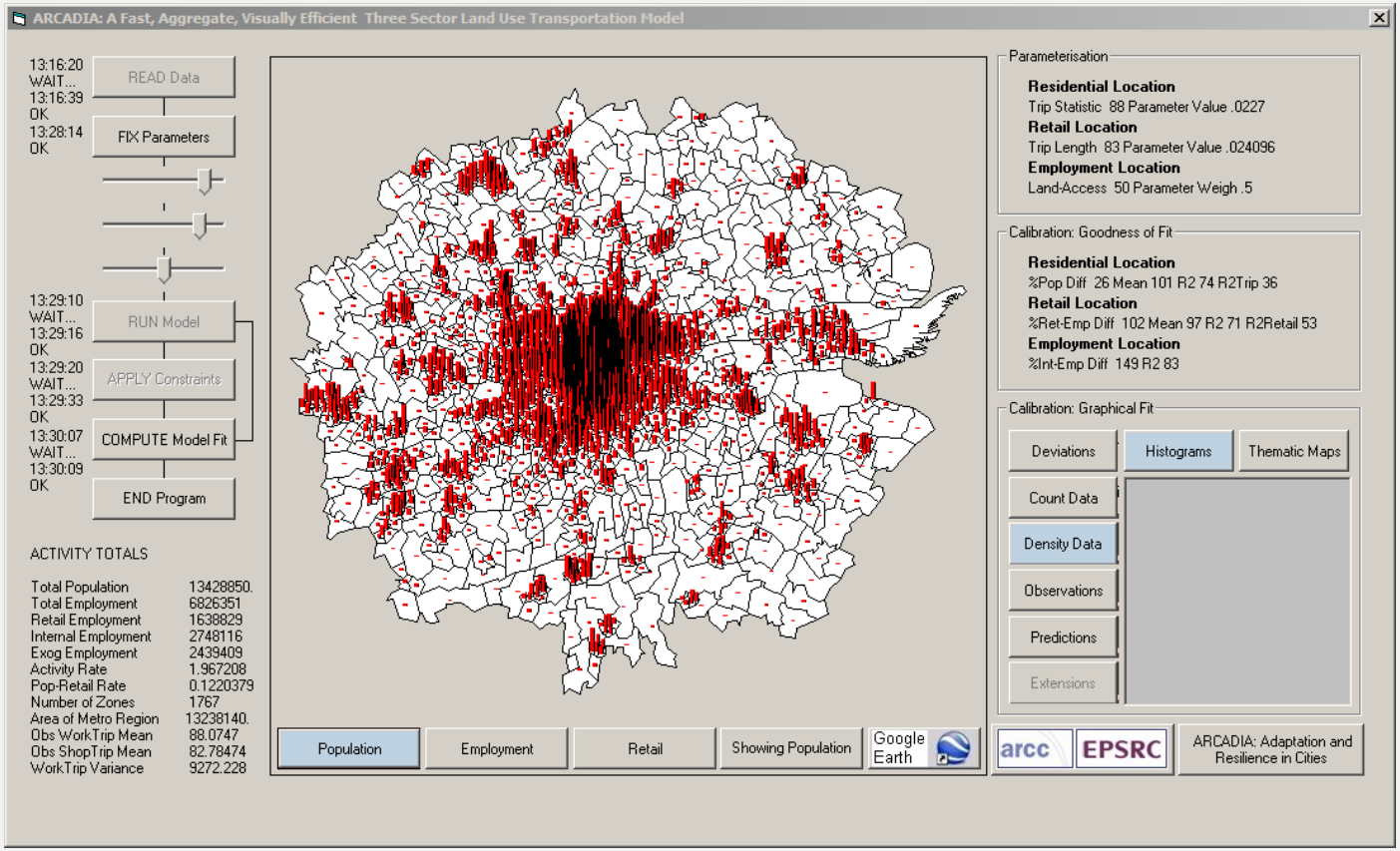
Big Data in 1939

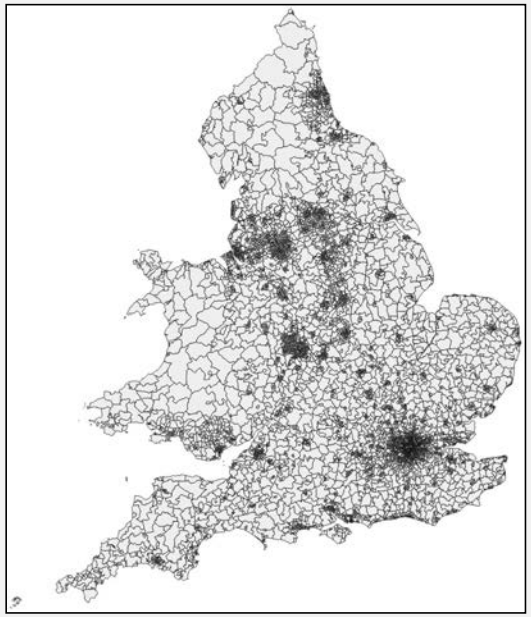
8 March 1939: Some of the four million tickets collected from London Underground passengers are examined in a survey by London Transport to discover the most and least used routes to help future infrastructure development

Long Term Urban Change: The QUANT Model

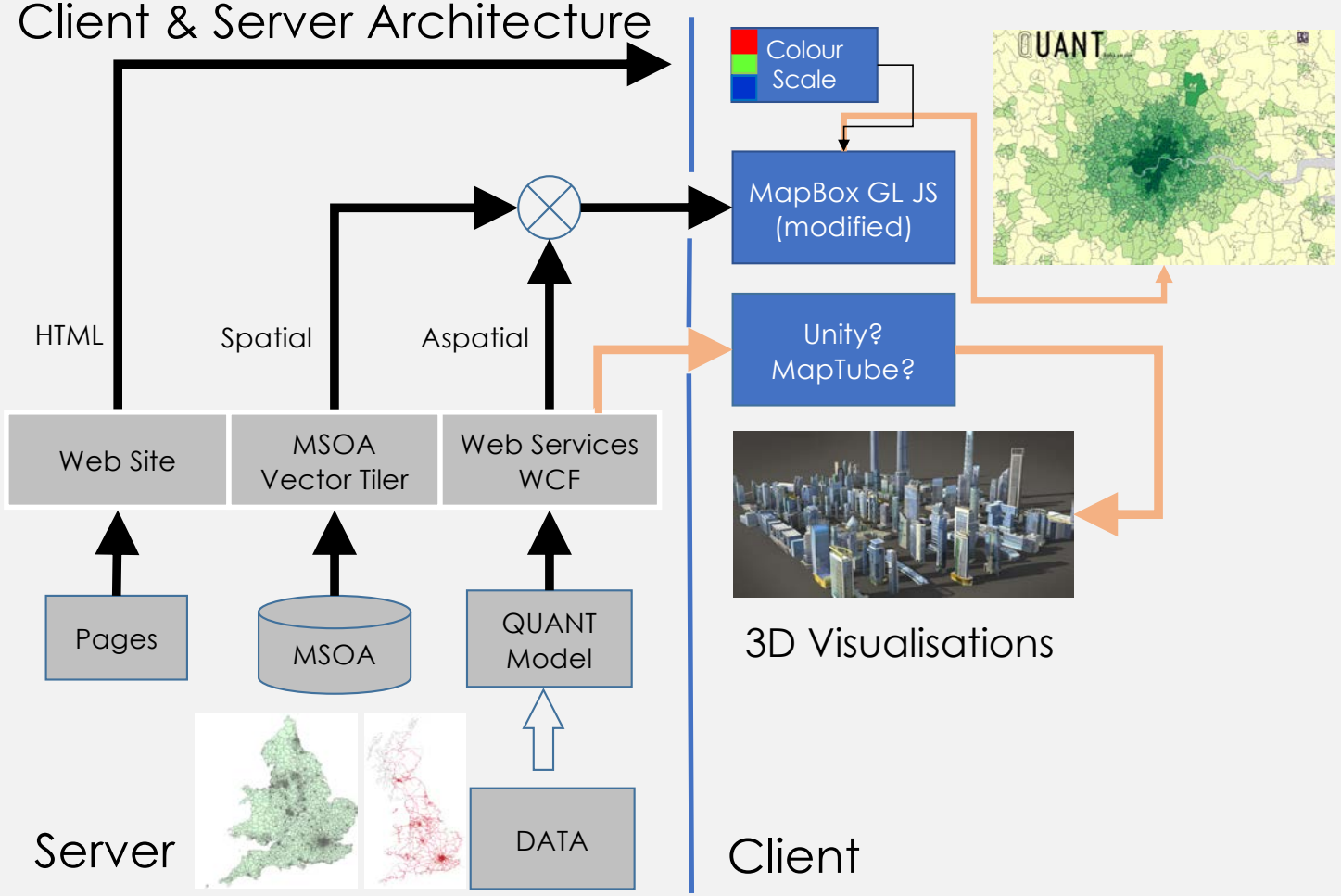
Our model is a LUTI model built sectors that interact using spatial interaction and it is scaled up to Great Britain and it is web-based – all the action is on this kind of implementation, not on the model per se

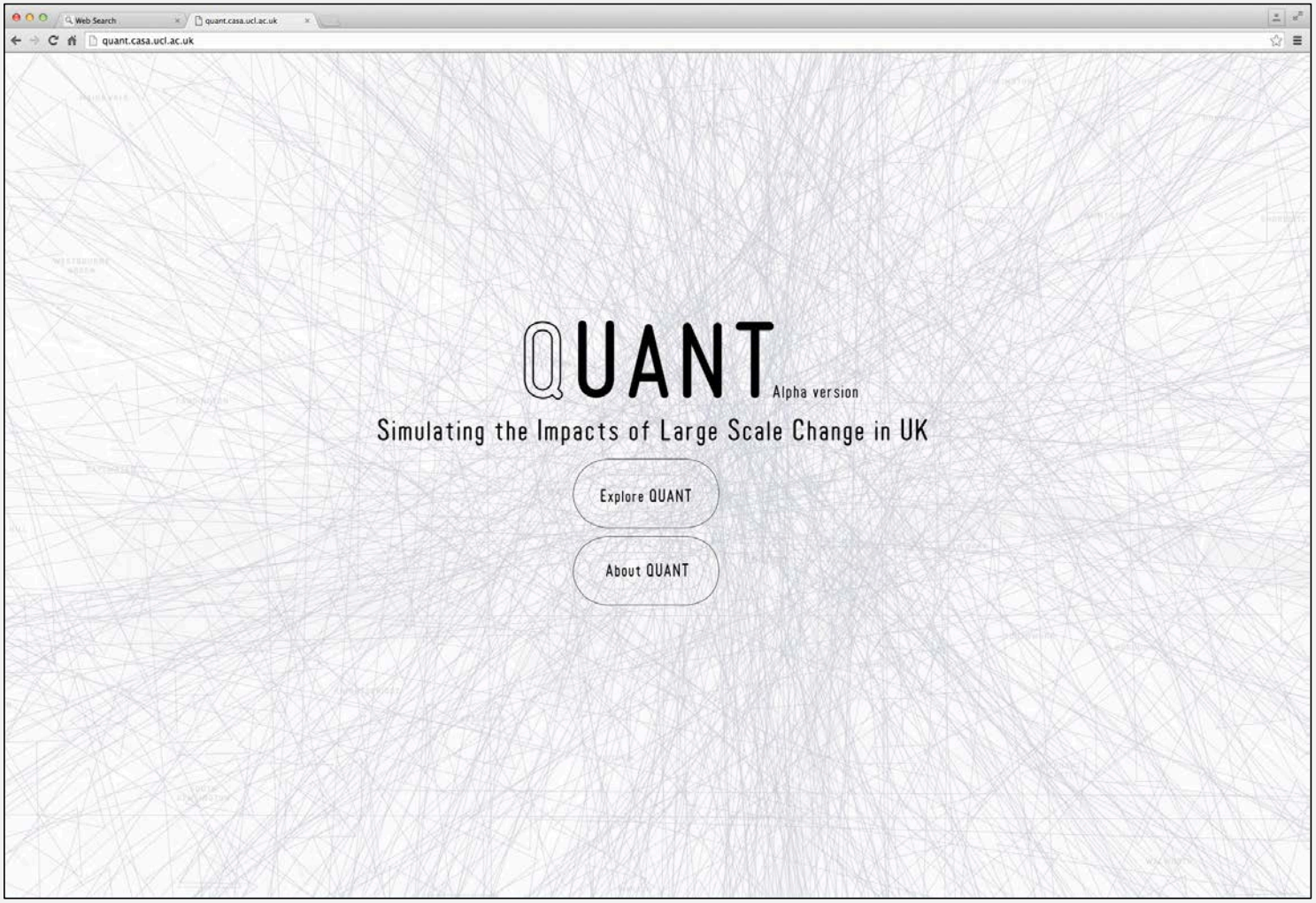



ARCADIA: A Fast, Aggregate, Visually Efficient Three Sector Land Use Transportation Model
13:16:20 WAIT...
13:16:39 OK
READ Data
13:28:14 OK
FIX Parameters
13:29:10 WAIT...
13:29:16 OK
RUN Model
13:29:20 WAIT...
13:29:33 OK
APPLY Constraints
13:30:07 WAIT...
13:30:09 OK
COMPUTE Model Fit
END Program
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

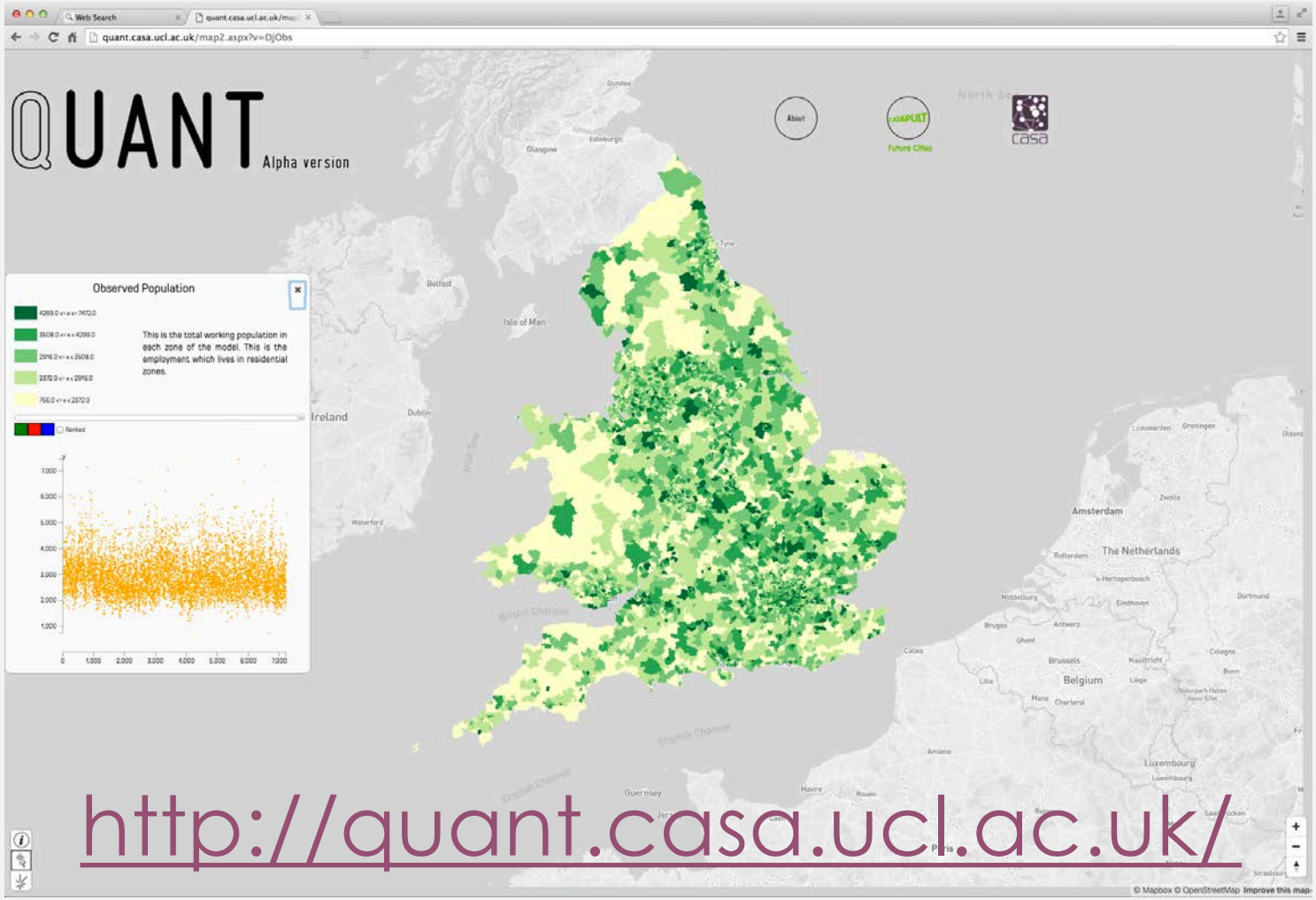


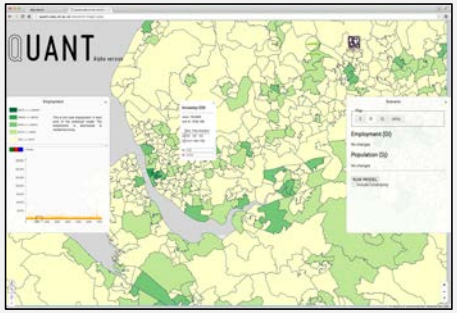
Client & Server Architecture

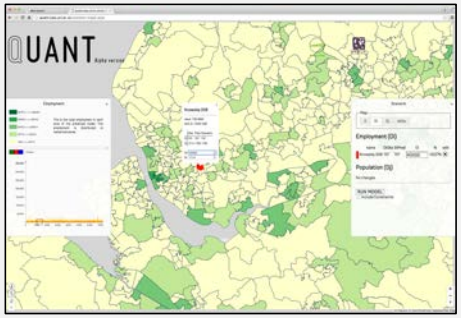


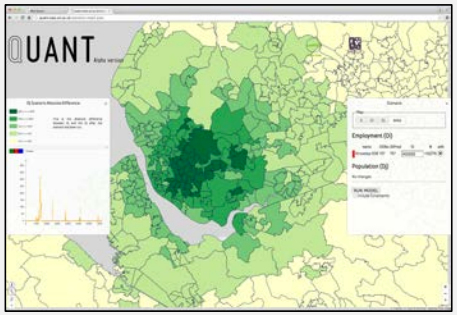

Web Search
quant.casa.ucl.ac.uk
quant.casa.ucl.ac.uk
QUANT
Alpha version
Simulating the Impacts of Large Scale Change in UK
Explore QUANT
About QUANT

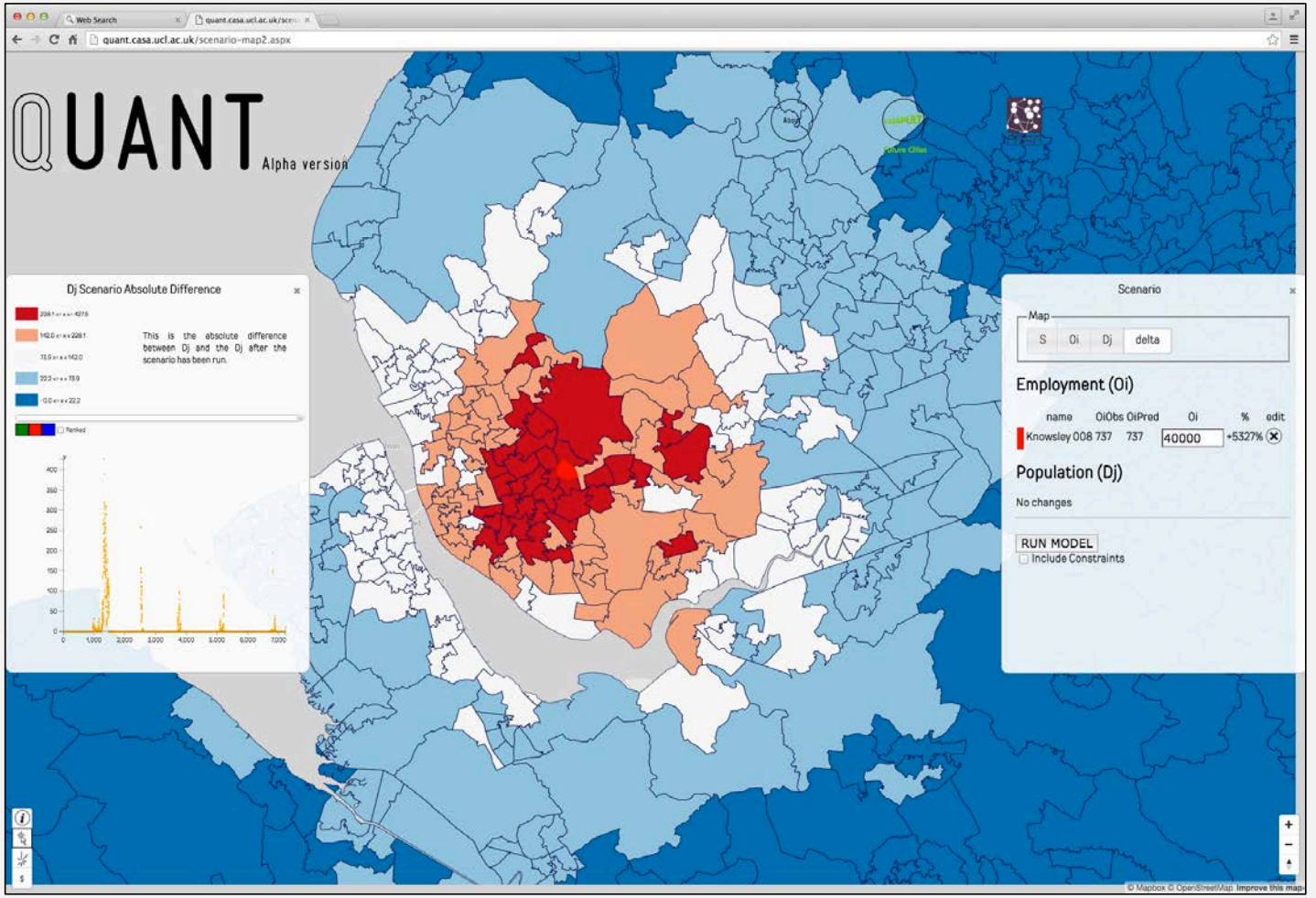

quant.casa.ucl.ac.uk/explore.aspx
QUANT
Alpha version
About
Explore Data
Run Model
Set Scenarios
Home
Employment
Population
Work Flows


QUANT
Alpha version
About
Observed Population
This is the total working population in each zone of the model. This is the employment which lives in residential zones.
Ireland
Amsterdam
The Netherlands
Belgium
Luxembourg
http://quant.casa.ucl.ac.uk/



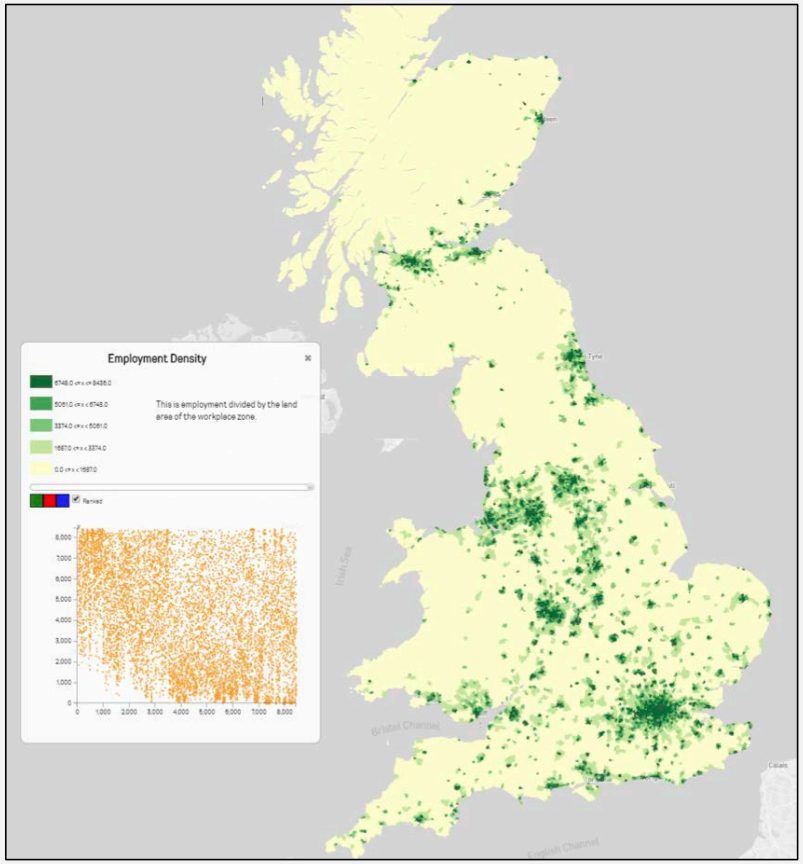




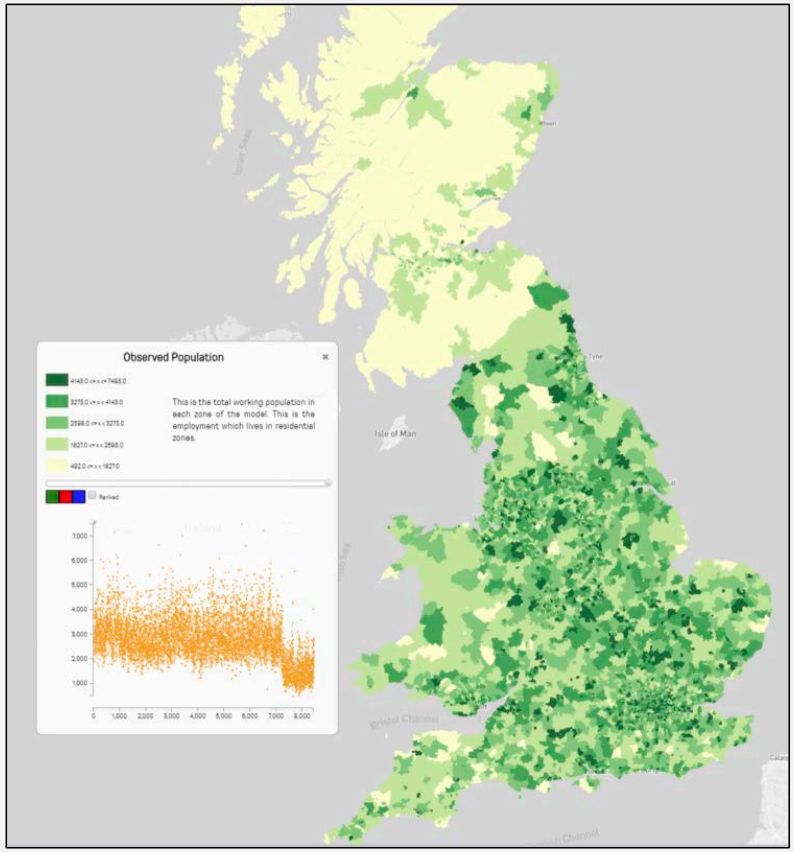


Digital Twins, Triplets & The Rest

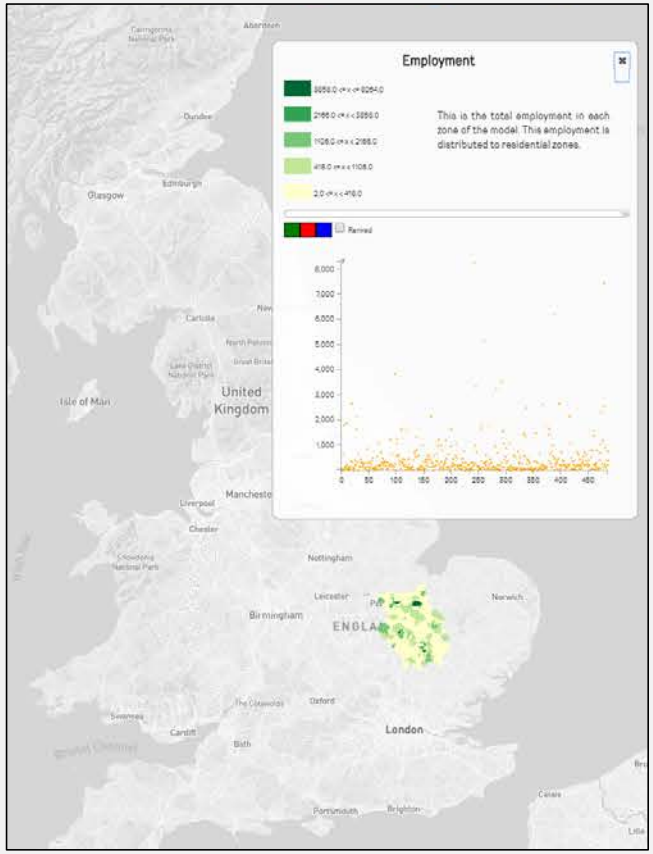
Employment Density

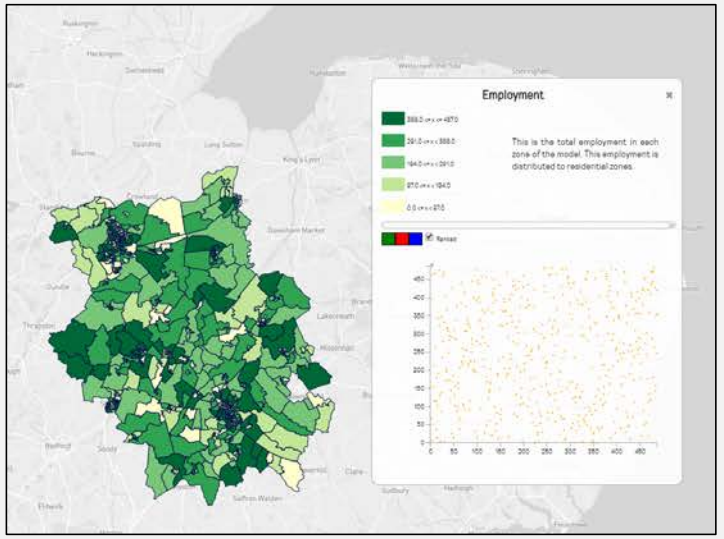


Population Counts



QUANT CAMBRIDGESHIRE
(Cambridge, SouthCam, EastCam, Fenland, Peterborough, Huntingdonshire)





487 LSOAs → 97 MSOAs
We modified the original QUANT model to work at two different geographical scales: MSOA & LSOA and to work with data from two different sources: LUISA & Census

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?
- 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 the extent to which we can link many models together for one system but also how we can think of many models and many different conceptions of the same system at the same time.

COLUMBIA GSAPP | COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK | LiPS Lectures in Planning Series | casa UCL University College London

Thanks

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Editorial

B Urban Analytics and City Science

Digital twins

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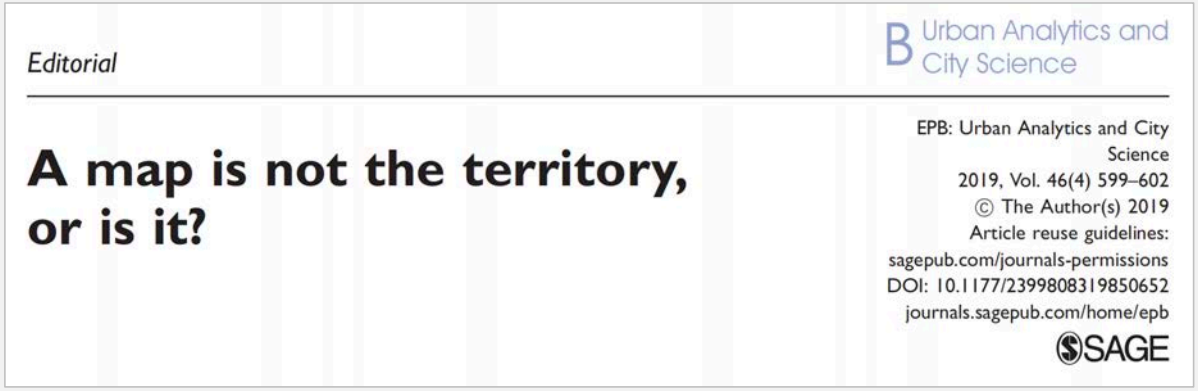

Editorial

B Urban Analytics and City Science

A map is not the territory, or is it?

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