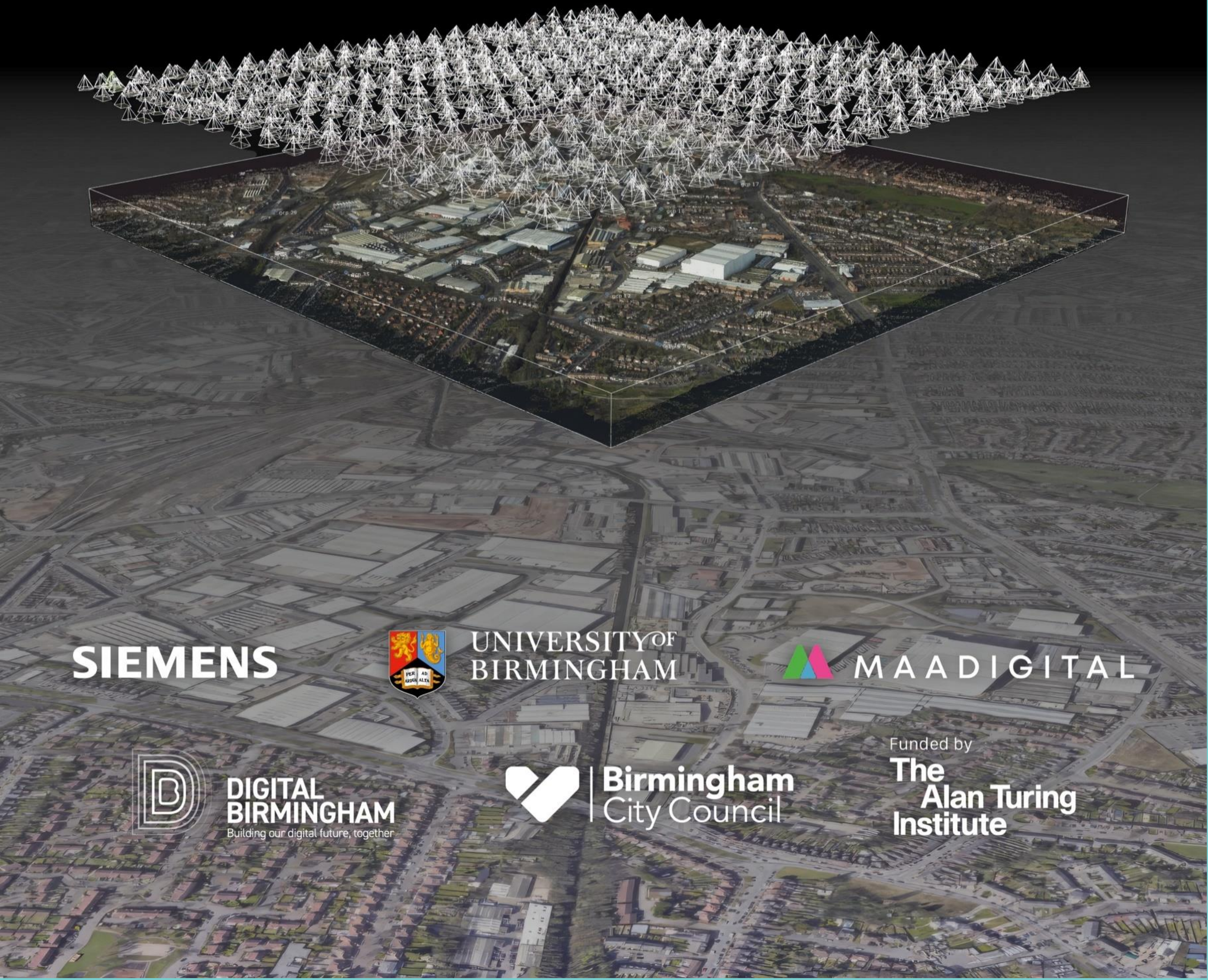
The Tyseley Digital Twin Project

Powering local analysis for better regional decision making

December 2023



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Contents

1. Introduction and Executive Summary

Professor Martin Freer, Director of the University of Birmingham Energy Institute (BEI) and Energy research Accelerator

The Tyseley Environmental Enterprise District, TEED, is an area of 400 acres in East Birmingham. It hosts 250 businesses and up to 4,000 residents and is also the home of Tyseley Energy Park (TEP). The TEED has been designated as an area of high importance in terms of the redevelopment of East Birmingham, as set out in the Birmingham City Council East Birmingham Inclusive Growth Strategy[1]. The Energy Park hosts a 10 MW biomass plant providing green electricity and a 1 tonne/day green hydrogen production plant which fuels 20 hydrogen buses. TEP includes the University of Birmingham Energy Innovation Centre (BEIC) and a business incubator, providing SMEs with tailored packages of support to drive the commercialisation of innovative energy products and services. The vision for this area of Birmingham is as a Green Innovation Quarter[2] to:

- Creating an exemplary and sustainable working and living ecosystem which is recognised for its approach to net zero and sustainability.
- Linking to the city's East Birmingham Inclusive Growth Strategy to promote inclusive growth in TEED that will benefit both local communities and the wider Birmingham area.
- Collaborating with residents and businesses in the community to ensure the area is developed to the benefit of everyone.
- Building on current momentum to attract more businesses to the area to join the green energy revolution.

Working with Birmingham City Council, and funded through the 2022/23 University of Birmingham Alan Turing Institute subscription, the present partnership has created the first stages of the development of a digital twin platform which is being used for the longer-term development of the Green Innovation Quarter. This project builds on an earlier piece of work funded by both Research England's Quality-Related funding and EPSRC Impact Acceleration Account led by the University's Energy (BEI) and Data Science Institutes with Birmingham City Council, supported by Siemens and alongside partners from across the city. This earlier study used a two-day workshop to brainstorm how a digital twin might be exploited by the City Council, the available data, the personas it should serve and the opportunities and barriers that present as it develops. The resulting report[3] also set out a potential route for the development of the digital twin including the IT architecture.

The present project, commencing November 2022 and running until March 2023, has taken these conclusions and created the next development layer by developing several digital assets including a 3D geospatial twin, a high fidelity orthophoto map and a geofenced point cloud of the TEED area then used as a basis for integrating key data and the functionality of the twin (next development layer captured by light aircraft aerial scan, see section 2). Separate workstreams examined the nature of the energy system (see section 4) and transport flows (see section 5) as well as emissions across and around the TEED. The project then initiated the integration of the data with the visualisation of the physical environment aligning with the development of scenarios which illustrated an energy and transportation transition for the area (see section 3).

[1] East Birmingham Inclusive Growth Strategy | Birmingham City Council
[2] Creating Birmingham's Green Energy and Innovation Quarter
[3] East Birmingham Digital Twin Final Report V3.1.pdf

Further exploration into the future scalability of these use cases is considered in this report, building upon the data, digital assets, tools and proposed digital twin framework. These expansion areas are based upon experience of work carried out on other European projects, adapting methods to the specific challenges and opportunities presented in TEED.

This project forms the foundation for the future evolution of the Birmingham Digital Twin programme, with an ambition of building a fully functioning twin for TEED and East Birmingham, later expanded across the city, providing a tool for the City Council teams in key function areas such as planning, energy and transport. The work described in this report is now being continued through the West Midlands Combined Authority / Innovate UK Innovation Accelerator programme, the DIATOMIC project[4]. DIATOMIC is procuring a cloud-based platform on which to assemble the elements of the digital twin, creating a common system for partners to access and develop.

Figure 1: aerial scan of BEIC and surrounding TEP area

[4] Innovation in the West Midlands - Connected Places Catapult

2. Integrating the visual representations of the built environment using software platforms and variable resolution imaging of the TEED area

Colin Kelly Maadigital, James Bellingham Siemens Advanta

2.1. Methodologies and Activities

This project focused on digitalising the TEED area to form a base model of the digital twin for the district. Capturing the geo-spatial data through aerial scanning allowed the creation of an accurate model of the above ground infrastructure, commercial and residential buildings, green spaces and more. A key requirement of the scan was linkage to GIS coordinates, creating points in the digital model linked to real-world points. This linkage is an important feature of a future digital twin and allows for updated scans, additional modelling or importing of data to be linked through these GIS coordinates.

The planned scope of the model included:

- Aerial scanning of the TEED district using photogrammetry scanning.
- Creation of a 3D rendered model of the district to allow for the overlay of data.
- Creation of an energy network demonstrator, based on the model, to showcase the potential of a digital twin.

<u>Aerial Scanning – Drones:</u>

Scanning of the TEED area was originally planned using survey-grade drones, flying at an altitude of 60m with an expected location accuracy of 30-40mm, improved to 20-30 mm with Ground Control Points (GCPs). This method would have allowed the flights to take place under Civilian Aviation Authority (CAA) rules, and therefore would not require specific permissions from individual landowners or residents for the flights, only for the take-off and landing points. Considering the maximum flight time for the drones and other logistical factors, the TEED area was broken up into 7 zones for scanning, each with a take-off and landing point defined. The scanning was planned to take place over a period of 5 days, including contingency for unsuitable weather conditions (e.g. snow). Residents and businesses would have been notified of scanning through communications from the City Council, likely through notices on-street. A Matrice 300RTK with a Zenmuse P1 Lens was identified as the optimal drone and lens.

Figure 2: Drone flight zones including take-off and landing points.

Figure 3: Grid flight plan – illustrative purposes only.

<u>Aerial Scanning – Light Aircraft:</u>

Light aircraft can be used for Aerial scanning, flying at a typical altitude of 1200ft, resulting in minimal ground coordination requirement. Light aircraft scanning is quicker than using drones, with a scan of this area possible in around 2 hours. The trade-off however is a reduction in the oblique angle with the ground, resulting in a resolution of 340mm; in this case it was deemed suitable for the needs of the project and use-cases.

A Cessna 172 aircraft fitted with a Hasselblad A6D and a Zeiss 50mm lens equipped with a high-quality GPS receiver allowed calculation of the exact photo location after the flights have finished. By using this technique (PPK GNSS Post-processing), fewer ground checkpoints were needed in the field.

<u>Ground Control Points (GCPs):</u>

In order to get accurate results from a photogrammetric computation, it was imperative that GCP's were used. These are points that are visible in the aerial images and whose location can be accurately established both horizontally and vertically. A Leica GS08 RTK Rover was used for the capture of the GPS control and GPS data was recorded using OSTN15 British National Grid. The accuracy of the GCP's is 10-20mm, with the locations marked in Figure 2. These are marked in such a way that they are visible from the air but will not adversely affect the fabric of the site. Consisting of survey markers placed in open ground and road markings in urban environments, the GCP's are laid down in the project area of which the centre can be accurately measured with the GPS and can be recognised in the resulting imagery. When using road markings, a photographic reference was also taken ensuring the GCP could be aligned correctly. Verification points were also used to check and safeguard the quality of the Rover.

Figure 4: Distribution of the control points on the Image layer of the ortho projection

Close-up Building Scanning

Additional, higher detail, close-up scanning was planned for the BEIC building, to prove the combination of different scanning techniques within in the same model. This has the benefit of being able to capture more oblique imagery resulting in a high-fidelity building, but requires more ground co-ordination and longer scan times working in latitudinal flights over the façade of the building. Internal scanning of the BEIC building or importing of the BIM model were considered as optional additional scope, depending on the remaining budget following the core scope. For the close-up building scan, a Mavic 3 Enterprise plus RTK module was identified as it could be flown under the A2 category.

Energy Network Demonstrator

The 3D model forms the basis of a demonstrator for the use case ‘Energy Assets and Linkage Planning’ which was one of the 11 priority use cases defined in the workshop engagement with Birmingham City Council and city-wide partners (the prior connected project described here[5]). The demonstrator was planned to use Unity Game Engine to produce a highly graphical and engaging showcase of the energy network overlaid onto the base model of the district, with key assets and datapoints represented as Points Of Interest (POIs). The demonstrator was designed to allow interactivity following a defined narrative, based on the project scope, that the demonstrator should guide the user through.

2.2. Findings

- Due to a change in the CAA rules during the project duration, drones greater than 250g, which includes all survey-grade drones, were not allowed to fly over uninvolved people, including people in vehicles. This required a change to the project plans with an alternative scanning method required; light aircraft was chosen, and the flight completed successfully on 5th February 2023.
- As ownership could be taken of the building, scanning of the BEIC was able to take place, using drones adopting a pillar scanning method.
- Internal BEIC scanning and BIM import was not completed at this stage due to prioritising rest of scope.
- In order to create a clean orthophoto, all images were colour balanced, AI sharpened and moving vehicles on roads were removed.
- The photogrammetry model was then converted to point cloud as an additional output.

[5] East Birmingham Digital Twin Final Report V3.1.pdf. Please note all use cases mentioned were identified through the 2022 workshops that lead to this report and are outlined in detail in this report.

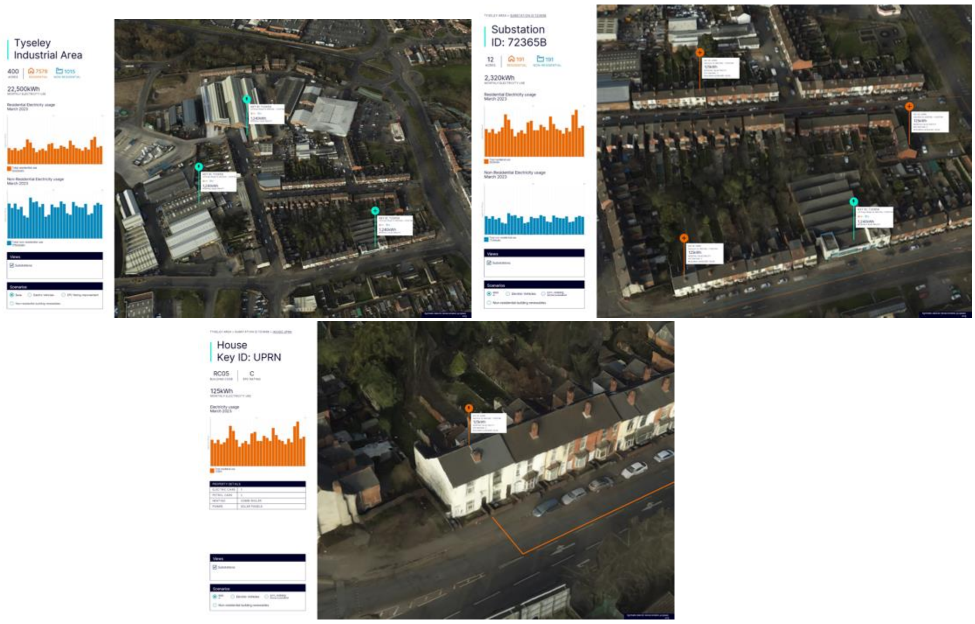


Figure 5: Screen shots from demonstrator, consisting of 3 levels: Area, Substation, Building and 4 scenarios: Base, Electric Vehicle adoption, Increase in Energy Performance Certificate rating, Industry PV adoption.

- Cesium was identified as the online platform to stream the large geospatial datasets for further research use. It is a foundational open platform for creating 3D geospatial applications and can combine numerous datasets, including 3D models, BIM, point clouds and photogrammetry. The platform has the capability to convert the content into 3D tiles which can be streamed online or in game engines such as Unity, Unreal and NVIDIA Omniverse.

2.3. Outputs

This project has produced several digital assets for use by the University of Birmingham and more widely by other stakeholders across the city. Careful consideration has been made to ensure these assets are reusable, and hosting of the assets matched to their intended usage and applications. Assets include:

- **Orthophoto Map**
  An orthophoto map is an image where distance measurements are consistent across the entire image, mostly used for planning and classification analysis and compatible with spatial software like CAD/GIS platforms.
- **Point Cloud**
  Consists of a large set of data points in a 3D coordinate system, where each point represents a specific location in space and contains position, colour, and intensity. Point clouds can be used in architecture, engineering, and computer vision, as they provide a detailed and accurate representation of the shape, structure, and spatial characteristics of the real-world district, compatible with spatial software like CAD/GIS platforms.
- **TEED Digital Model (3D Tiled Dataset)**
  3D tiles are optimised 3D geospatial datasets, served by the Cesium 3D platform, allowing users to overlay data sets, 3D content and other augmentations to continue development of digital twin use cases. The University of Birmingham will hold the license for this platform and maintain this asset.
- **TEED Demonstrator**
  The TEED Demonstrator is an engaging and graphical interactive demonstrator, showcasing electricity consumption at three different levels of granularity across the TEED area (see

section 3.2 of report for more detail). The Demonstrator shows four different predicted scenarios which are based on predictive energy usage algorithm data. The demonstrator uses real static data, its purpose is to engage; the software application is intended to run locally on an iPad or android device.

Figure 6: TEED Demonstrator

3. Evaluation of the next steps for the creation of a city scale digital twin

James Bellingham and Josef Kamleitner at Siemens Advanta, Colin Kelly at Maadigital

3.1. Methodologies and Activities

This digitalisation project sits within the wider digital twin framework that has been conceptualised in a previous project in partnership with Birmingham City Council and University of Birmingham, working with Siemens. This project forms an early step on a longer-term journey in the creation of a digital twin of the TEED area, which could be further scaled across the city, based on the learnings of this initial work. In essence, the TEED area provides a useful scale to try out different approaches for the digitisation of information, with the collection and creation of data that would be of benefit to a digital shadow and eventually a digital twin. This project therefore also contributes to a set of digital assets for Birmingham and continues to develop and scale to provide real value to citizens and businesses in the geographical area. Within the project, Siemens has played a coordination and governance role to ensure the outputs align to the framework and have future scalability in line with the goals of the city. Additionally, Siemens contributed domain expertise in the field of ‘Energy and Digital Utilities solutions’, to identify future opportunities for exploration.

The activities undertaken were follows:

<u>Research into the digital twin use case 'city asset map and linkage planning':</u>

- Conducting research to understand the requirements and potential applications of a digital twin for the use case ‘city asset mapping and linkage planning’.
- Explored existing digital twin implementations in similar contexts to identify insights and best practices.

Stakeholder engagement to determine the challenges and opportunities for a digital twin in the district:

- Siemens explored the needs of key stakeholders, including citizens, businesses, and Birmingham City Council, through meetings, research and workshop content.
- Gathered feedback and insights regarding the challenges faced by the district and identified opportunities where a digital twin could provide value.

Development of a roadmap for deployment of a digital twin:

- Developed an outline roadmap detailing the necessary steps and timeline for the successful deployment of a digital twin in the TEED area.

Development of requirements for a digital twin demonstrator for a part of the district:

- Collaborated with stakeholders to define the specific requirements for a digital twin demonstrator.
- Identified the necessary data sources, discussed modelling techniques, and visualisation tools to ensure an effective and user-friendly demonstrator.

3.2. Findings

Challenges - Several challenges were identified through the activity of this project:

- Connections between the energy network and demand in the district are unclear. For example, it is not completely known which buildings or electrical meters are connected to which parts of the electrical network. This lack of clarity poses difficulties for consumers in understanding who they share energy networks with at a very localised level, and therefore the impacts of their energy consumption at a local level.
- The challenges facing the wider energy sector in identifying opportunities for energy coordination and implementing better cross-vector sustainable practices without having clear visibility of basic energy connections throughout the gas and electrical networks.
- The difficulty in identifying the linkage between key generation and consumption assets if the connections to parts of the network are not as accurate as they could be. For businesses, the lack of clear linkage inhibits their ability to develop strategies to support, invest, and benefit from the creation of local green energy sources and related economies.

Although TEED is a mixed-use area with significant amounts of floor space of non-domestic buildings, it is representative of other city areas in terms of the disparate and inaccessible energy network and linkage data. This information will be needed for local businesses and energy companies to identify collaboration opportunities, energy efficiency improvements, and investment in sustainable technologies. Universities working in isolation face limitations in conducting comprehensive research and analysis on local energy systems, hindering opportunities for knowledge exchange. Furthermore, the Local Authority’s ability to develop evidence-based policies and effectively coordinate energy-related initiatives can be hindered by the lack of publicly available and integrated energy network and linkage data.

Opportunities:

In contrast to the challenges, several opportunities have been identified within the development of a digital twin in the district:

- **Support decision making by various stakeholders:** a digital twin of the district’s energy system could allow energy system monitoring and control to take place with enough detail over appropriate timescales, to allow some benefits to happen. The concept of a ‘digital twin’ is wide-ranging in how it can impact on a geographical area and its energy system. Its development can commence with a visual representation with some additional overlaid detail to help support decision making by various stakeholders. It should be noted that the terminology of a digital twin, digital representation, digital shadow can be interchangeable terms dependent on the sector.
- **Monitoring and control**: adding greater monitoring and potentially control, the digitisation of an area’s energy system can extend through to a near-real time assessment and potentially control. Regardless of the level of monitoring available to a digital twin, the control, revenues and decision-making will have to work within the governance structures and decision-making environment within which the project is located. From previous work, including the West Midlands Regional Energy Systems Operator project[6], there is ample evidence to point to the challenges of who, for example, would own and operate a localised electrical system balancing service.

[6] https://energy-capital-tfwm.hub.arcgis.com/pages/coventry-eiz

- **Data interoperability**: An important area of focus should be the interoperability of different flows of data, to enable multiple digital twins each focused on specific parts of an overall system, rather than a monolithic twin that seeks to do too much incompletely.
- **Linking local energy production and consumption:** Contributing to the development of a local green energy economy. Citizens and businesses could actively participate by supporting, and benefiting from, local renewable energy sources, potentially reducing energy costs and carbon footprint. This approach could encourage additional sustainability-focussed businesses and business models and provide opportunities for the City Council to promote the growth of the green energy sector, attracting the necessary investment, in turn creating job growth and fostering a resilient and sustainable local economy in East Birmingham.
- **Collaboration:** Engaging partners in the area to collaborate on the district's environmental goals, through use of the digital twin, enabling businesses to foster innovation, knowledge sharing, and resource pooling through collaborative engagement. This has the potential to collectively address environmental challenges, allowing businesses to explore new markets, and in turn, gain a competitive edge. Universities can leverage engagement with partners to conduct collaborative research, share data, and pursue interdisciplinary initiatives.
- **Interdependencies and synergies identifying new innovative approaches**: A digital twin can also provide a more holistic, systemic view of interrelated topics across an area. This comprehensive perspective could empower the group of stakeholders with a deeper understanding of the district's sustainability challenges and foster a sense of collective responsibility in addressing them. A twin could identify interdependencies and synergies between different sectors and in the future, analysing complex systems, and identifying innovative approaches for addressing sustainability challenges. For example, engaging citizens on the impacts of potential energy scenarios, such as increased Electric Vehicle (EV) charging or housing Energy Performance Certificates (EPC) improvements.
- **Empowering people to make informed choices:** A digital twin can contribute to achieving the district's sustainability goals through enabling informed decision making. Businesses can also benefit from the creation of market demand and opportunities, such as EV charging infrastructure or energy-efficient housing solutions, in turn driving green economic growth and innovation. This forms an interesting research area, expanded further by putting the data and tools in the hands of researchers. Enhanced decision-making processes can be enabled across the city, with engagement driving public support for sustainable initiatives, and fostering a sense of ownership and shared responsibility for the district's energy transition.

<u>Requirements for the Digital Twin demonstrator</u>

Through engagement within this project team and wider stakeholder groups, including input from 2022 city council workshop sessions, the following requirements for the TEED digital twin demonstrator have been identified:

Functional Requirements:

- 3D photographic map view with move, zoom and rotate functionality.
- Border view to define the extents of the model scope.
- Network and asset location mapping, showing connectivity for feeders, substations and housing loads.
- Mapping of key assets in layers, with the ability to toggle visibility.

- Ability to select examples of substations and houses to see further detailed information, static data visualisation.
- Selection of example future scenarios to display the expected changes in demand.
- Visualisation of energy consumption based on the selected level.

Map and Data Sources:

- Point Cloud Data Tyseley Scan.
- Polygon View Tyseley Area (if building level polygons, under licence from Ordnance Survey).
- Detailed Scan BEIC Building.
- Energy 'Wire Map' per distribution (house / road based).

Energy Data and Sources:

- Location of sub-stations (KML format).
- Energy usage of sub-station data (CSV format).
- Sub-station energy distribution (Polygon / KML format).
- Synthetic electrical network 'Wire Map' for the area (noting actual data from NGED is not public).

3.3. Outputs

<u>Roadmap for the Digital Twin</u>

As part of the phased approach to building a digital twin for East Birmingham, the focus of the TEED was selected, due to the mix of challenges and opportunities present and to enable starting with a manageable focus area. The following steps are envisaged, some of which are completed as part of this project.

TEED Digital Model: The model is generated from the scan of the district and hosted in an online environment, enabling data to be added and overlaid by different stakeholders later, supporting future development.
TEED Demonstrator: The demonstrator will showcase some of the possible digital twin outcomes, building upon the digital model, integrating a static set of real data, simulation of energy usage and future energy scenarios, and engaging visualisation.
Future Development: Not yet completed, but part of the proposed next steps.

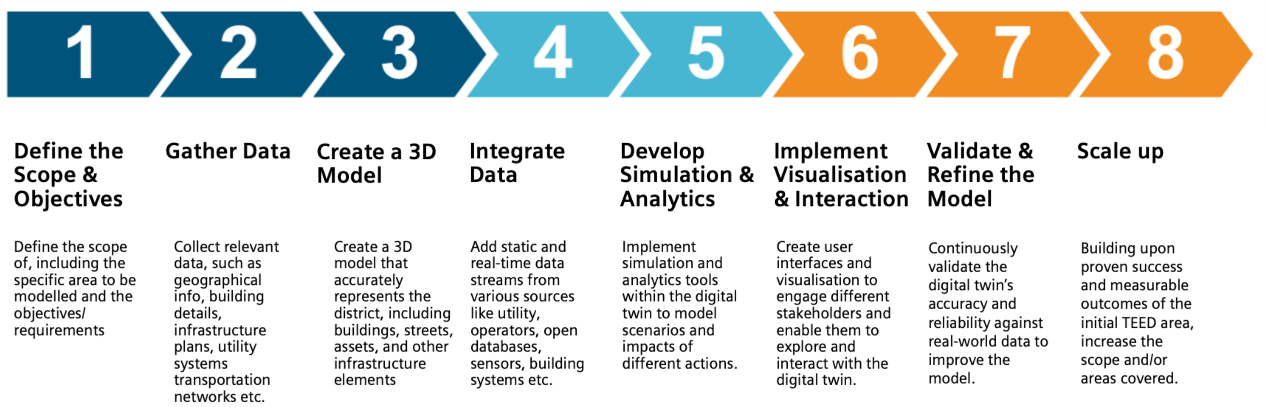


Figure 7: Proposed development roadmap for the digital twin

3.4. Next Steps

This project is the starting point in developing a digital twin for the TEED area with the potential for future expansion to cover the wider East Birmingham, providing a testbed for smart approaches that will eventually benefit the city as a whole. Research outcomes and digital assets from this project already enable development and research in this area and should underpin future funding bids. Below are outlined future potential expansion options including use case scope expansion, and are based on experiences and technologies applied to similar data in other digital utility projects:

- **Identification of existing electrical grid bottlenecks:** Identification of bottlenecks in the existing local electrical grid infrastructure can better inform energy distribution and accommodate greater levels of renewable energy integration. This could be done by utilising grid sensor measurements and power system state estimation, which would require detailed grid topology and measurements. This type of digital twin would allow for near real-time and long-term analysis, highlighting critical areas/events by integrating with the 3D model demonstrator.
- **Photovoltaic (PV) disaggregation & forecasting:** The grid impact of PV installation is critical, and various data sources, including PV potential maps, demographic data, and load curves, can be integrated in the digital twin to assess this impact. These maps when combined with grid topology and substation data, can allow assessment of the existing grid's capacity to accommodate PV installations. The digital twin can enable the disaggregation of existing PV installations and predict their future impact, aiding in understanding and coordinating the grid's handling of PV integration. Individual benefits of PV installations, such as cost, energy consumption profile, sizing, and break-even points, can be assessed. The digital twin could consider simulation of additional options like EVs, heat pumps, and batteries and their impacts on network performance. This could provide targeted information to, and drive collaboration with, energy suppliers to offer tailored solutions, including financing options. The digital twin could also be used to explore the potential of energy communities, encouraging shared PV installation/ownership. This comprehensive evaluation could therefore support individual benefits and community-driven sustainable energy initiatives.
- **EV Charging Infrastructure:** Coupling existing EV capacity map and demographic data provides a preliminary estimation of the grid capacity available for EV charging. Currently, there is only one public charging station available in the TEED area, and it appears that most cars are parked and may therefore be charged at private residential properties, although, there are many properties in the TEED area without off-street parking. However, there is a growing need for charging infrastructure for residents and employees / clients in industrial and commercial areas. To enable specific grid planning for EV charging, more detailed data is necessary. The integration of more detailed data, such as grid topology, substation data, and demographic information, along with collaboration with property owners, will enable more accurate grid planning for EV charging and support the coordinated development of charging infrastructure within the district. Furthermore, there is potential for cooperation with industrial and commercial property owners to gather EV charging data, allowing for optimization of the charging infrastructure. By working together, the digital twin can analyse the data and identify opportunities to enhance the efficiency and effectiveness of EV charging.
- **Heat pump adoption:** A digital twin project provides an opportunity to expand further covering the integration of heat pumps and HVAC (heating, ventilation, and air conditioning) systems. By incorporating these technologies, a digital twin can help to inform energy efficiency approaches for heat. Additionally, a digital twin would allow more accurate modelling and analysis of energy usage for heat within the district. Modelling based on climate change forecasts, considering potential future climate conditions, could enable the digital twin to

better evaluate the resilience and performance of the district's energy systems, allowing for proactive planning and adaptation strategies. In addition, a digital twin could be used to investigate the impacts of home improvement grants and CO_2 pricing, by analysing the effects of these factors, providing insights into the potential incentives and cost savings associated with energy-efficient home improvements, as well as the implications of carbon pricing on energy consumption and emissions. Overall, a digital twin project could leverage these key elements to coordinate the integration of EVs, PV systems, heat pumps, and HVAC, align load profiles with EPC data, incorporate climate change scenarios, and assess the impacts of home improvement grants and CO_2 pricing. This holistic approach can provide the opportunity to promote energy efficiency, resilience, and sustainability within the district.

Figure 8: Aerial scan of part of TEED with residential (orange) and non-residential (blue) substation electrical flows visualised.

4. Evaluation of different methods to allocate buildings to energy networks

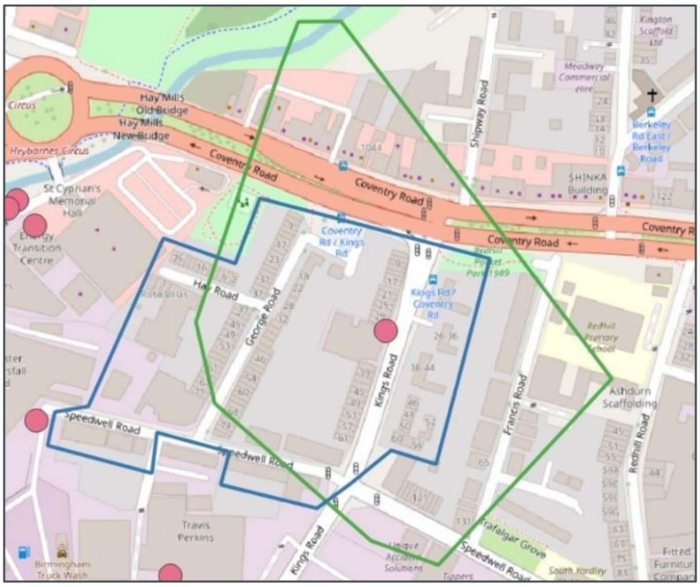
Dr Joe Day and Dr Grant Wilson, Energy Systems and Data Group, Birmingham Energy Institute, University of Birmingham

The TEED is an area of interest for Birmingham City Council and other stakeholders to develop an informed approach to delivering decarbonisation through use of data and digitalisation. Precise geography of the low voltage network for the electrical system is an ongoing gap in Britain's energy system data, which has limited the potential for scenario-based energy system planning within hyperlocal areas. By increasing the accuracy of polygons, used for designating the geographical areas served by low voltage substations (electrical low-voltage service areas), it is likely that analyses of demand can be improved. This has the potential to improve the modelling of local energy systems in such areas given the opportunity to balance local power flows using investment in network upgrades and load-shifting strategies.

4.1. Methodologies and Activities

It was decided to use the time within this project to investigate how the Low Voltage (LV) network service areas, reported by the Distribution Network Operator itself, would relate to a 'gold standard' approach of using the online Electronic Mapping Utilisation (EMU) tool to investigate the network connection of each individual building in the TEED area.

The LV substation boundaries were therefore created within the Tyseley project from 'manual' visual inspection of the EMU online mapping application via approved access to National Grid Electricity Distribution's (NGED) dataportal[7]. This EMU online mapping software was considered to be the most accurate option given availability, although it is recognised that the network visualisation data shown on the platform is itself based on the digitalisation of different historical datasets such as physical drawings, and thus it is subject to errors. Open-source mapping software QGIS[8] was then used to create polygons representing the substation boundaries by defining a layer and exporting it as a geospatial shape file. Publicly available boundaries for the LV substation areas in NGED's licence area use a Voronoi method[9] to allocate polygons to the co-ordinates of each substation[10]. The differences between the two boundary methods are highlighted in Figure 9. It can be clearly seen that the Voronoi polygons are imperfect as they only consider the lines of equidistance between points on a 2-D plane, i.e., it spatially splits a 2-D plane into polygons created by distances 'as the crow flies', rather than an actual network topology which will be based on a number of factors such as road layout and the location of high power consuming sites (often with their own connections directly to the 11 kV network). The LV substation points were sourced from a public NGED dataset[11] and augmented by filling in missing data from the dataportal[7].



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[7] https://dataportal2.westernpower.co.uk/Home/About
[8] https://qgis.org/en/site/
[9] https://www.nationalgrid.co.uk/downloads/118177
[10] https://connecteddata.nationalgrid.co.uk/dataset/spatial-datasets
[11] https://connecteddata.nationalgrid.co.uk/dataset/distribution-substation-location-easting-northings

Figure 9: Example of the inconsistency between the Voronoi method (green outline) of assigning substation boundaries and the actual boundary (in blue) derived around the LV substation shown by the central pink circle.

Two top-down data views were available on the EMU online maps (shown in **Error! Reference source not found.**10), an Ordnance Survey (OS) street view and a network topology view. At first, the street view was used to manually trace back from each property back along its feeder to its parent substation. On the OS map, for most residential buildings and smaller non-domestic buildings, the LV feeders are shown connecting into the building footprints, although in some cases (particularly industrial estates and larger commercial buildings with mixed uses / many sub-units) these direct connections are not shown, so assumptions based on proximity of buildings to the LV network had to be made. However, this method of inspecting the street maps was time consuming and prone to misinterpretation. Eventually, by virtually casting the street names on to the topology diagrams, a faster and more efficient method was used to allocate blocks of properties or entire streets to the network. An effective process of determining boundaries between service areas was to toggle between the two maps to find the specific property either side of a normally open switch (or other break point in the network), to then note the address of that property, and then use it as a boundary for the LV substation polygon. The mesh nature of the network (possible interconnections and loops between feeders and substations by the closing and opening switches) warrants further attention in future studies.

Alongside observing the online network maps, QGIS software was displayed on another monitor by using dual screens. This allowed the corresponding discovered points (representing the vertices of the polygons of LV substation service areas) from the EMU maps to be created in QGIS by using the Open Street Map raster layer and the 'new temporary scratch layer' tool to draw the polygons that would represent each LV substation. For some residential LV substations, the feeders for each property were also determined, and service areas drawn, which split an LV service area into even smaller areas served by an LV feeder. This was felt to be important because these assets will also have a thermal constraint (i.e. a maximum flow current) and, being underground, will be costly to reinforce should demand increase through the electrification of domestic heat and transport.

The point layer of Unique Property Reference Numbers (UPRNs) was obtained from a dataset supplied by the OS based on their Address Base Premium[12] product. This geospatial dataset has co-ordinates to represent every addressable property in the UK as well as information on what the property's use class is under a basic land and property unit (BLPU) alphanumeric code; for example, RD04 corresponds to a residential terraced house. There is occasional uncertainty around the validity of the BLPUs of some buildings (e.g. when compared to OpenStreetMap or Google Street View, a building may obviously have been assigned a wrong BLPU code or in some instances, a building could exist but not have a BLPU code or even a UPRN). Some categories would be useful to have more detail (e.g. a differentiator between mid-terrace and end-terrace properties). Nevertheless, UPRNs are a useful unambiguous identifier for properties and provide linkage to other useful datasets related to energy such as Energy Performance Certificates[13].

[12] https://beta.ordnancesurvey.co.uk/products/addressbase-premium
[13] https://epc.opendatacommunities.org/

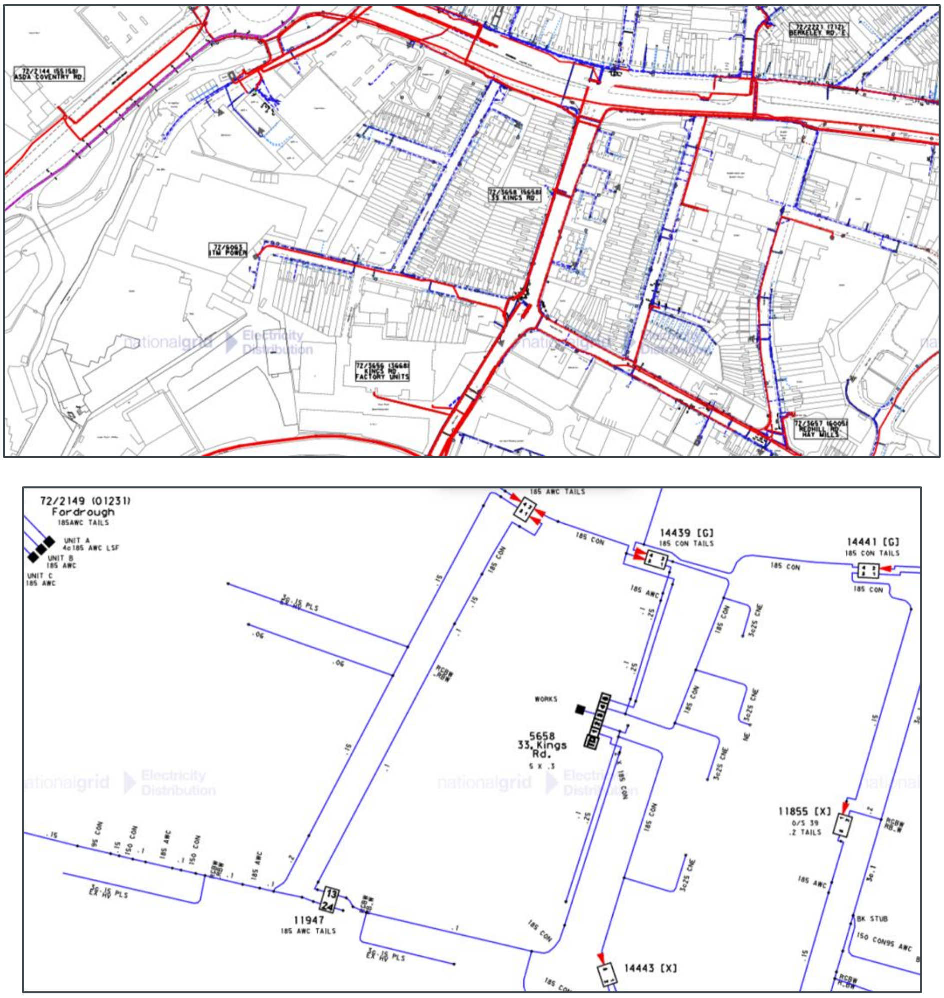


Figure 10: The two views in EMU Online, the above is the OS street map view and the below is the network topology view. Both figures are copyright to National Grid Electrical Distribution

From the Address Base Premium data, UPRNs and their BLPUs within TEED were filtered to remove obvious non-building or electricity consuming records (such as roads, land used for storage, advertisement hoardings or bus shelters) to leave only a layer of points representing residential and non-residential properties which could then be loaded into QGIS and displayed alongside the created LV substation boundaries.

One assumption introduced here was that each property would have only one electricity meter, which is often, but not always, true. Therefore, by counting the filtered UPRNs in each LV substation polygon (performing a spatial join in QGIS) a value for the total number of residential and non-residential buildings was derived for each area. These were eventually validated against a further dataset provided on request by NGED which gave the number of unique meters, (meter point administration numbers, MPANs) per LV substation according to their internal CROWN platform.

4.2. Findings

Figure 11 shows the 78 LV substation boundaries and Table 1 details the comparison of assigning properties to LV substations using two different methods.

Electricity Infrastructure Mapping

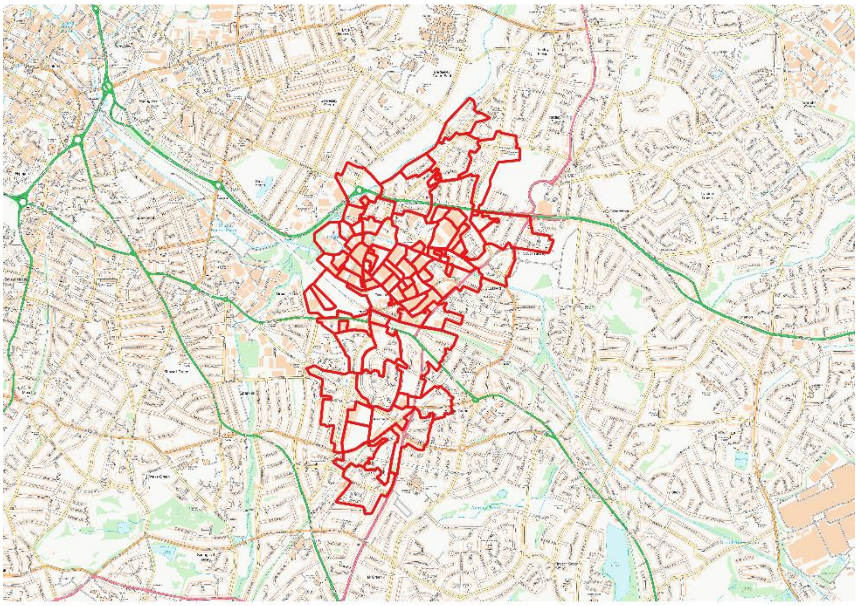


Figure 11: The 78 LV substation boundaries for the TEED area and wider Tyseley and Hay Mills ward. The base map is OpenStreetMap.

Table 1: Subset of data to show the accuracy of the LV substations assigning methods: NGED's Voronois versus this project's manually drawn boundaries. The full table is in Appendix *1*

LV Substation Name	Properties Assigned Correctly by Voronoi as % of Manual	Properties Assigned Correctly by Manual as % of Voronoi
231 Berkeley Road - Yardley	73.5%	95.5%
33 Kings Road - Tyseley	79.9%	52.2%
753 Warwick Road	54.7%	56.1%
83 Berkeley Road - Hay Mills	100.0%	39.6%
883 Coventry Road - Hay Mills	78.4%	100.0%
Amington Road North	0.0%	0.0%
Arbuthnot Engineering – Amington Road	100.0%	18.2%
Atlas Works	100.0%	11.1%
Berkley Road East	54.9%	100.0%
Birmingham Bio Power	0.0%	0.0%
British Rail Warwick Road	40.0%	8.0%

4.3. Outputs

Use Case 1: Hyperlocal Demand Modelling

Following this method (the first of its kind in the University of Birmingham's Energy Systems and Data Group's research to provide definitive asset boundaries and building-substation relationships), a use case was developed to validate predictive hyper-localised, half-hourly electrical demand models.

The Centre for Net Zero have developed 'the Faraday Tool'[14], based on sample data from Octopus Energy customers. It is a predictive model which takes its inputs based on a "population" of user-defined building archetypes. The archetypes and numbers can be defined programmatically through an API or manually via drop down menus. The archetypes have four main variables whose

[14] https://www.centrefornetzero.org/work/faraday-electricity-consumption-profiles/

possible values have to be defined as shown in Figure 12, leading to 60 available combinations. Further archetypes (which have not been used here) can be created and account for the presence of low carbon technologies such as heat pumps, solar PV, batteries and EVs.

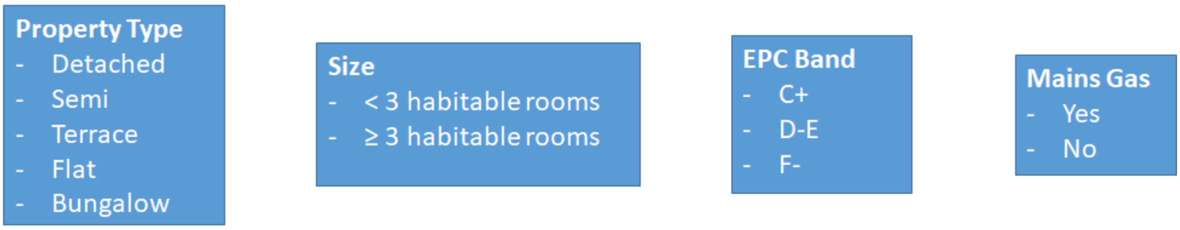


Figure 12: The inputs used to create the archetypes for the Faraday Tool.

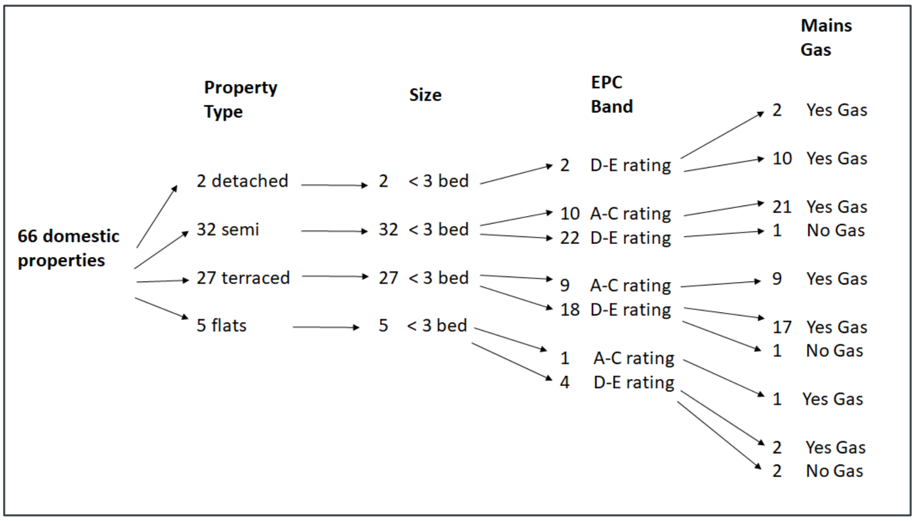
For populations consisting of different numbers of different building archetypes, a half-hourly load profile can be generated for a chosen day and month of the year. The load profile accounts for diversity between users i.e. the peaks of individual consumers are not concurrent, leading to the overall peak demand per consumer being lower than the sum of the individual customer peak demands.

Following this approach, a case study area was found where the theoretical demand calculated using the Faraday Tool could be compared with observed / monitored electrical demand data for the same geographical area. NGED have recently released more network monitoring data with the data for higher voltage substations having increased availability given NGED have historically needed to collect information on these larger assets. Lower voltage substations have less data visibility as they have not been required for regular monitoring. However, in early 2023, samples of low voltage monitoring data have been released to the public[15]. The closest LV substation in this sample to TEED was Denham Road in Yardley, which neighbours the TEED area. By using the aforementioned manual / visual method for creating substation boundaries, the shapefiles for each of the substation's 4 LV feeders were derived (see Figure 13). It should be noted that Denham Road is a substation which serves purely residential properties, so non-domestic electrical demands do not need to be considered. The limitation of the Faraday Tool at the time of the research project showed its limitation to domestic demand data only. Since the NGED data was available in 10-minute granularity, and given for each phase line of the feeder, a data parsing step was required to get the total power for the LV feeder, thus changing it to 30-minute granularity.

[15] https://connecteddata.nationalgrid.co.uk/dataset/lv-load-monitor-data

Figure 13: The manually drawn LV feeder boundaries for Denham Road LV substation.

After this parsing step, the Faraday Tool archetypes needed to be defined for each property. This was done in QGIS by using the Address Base Premium UPRN layer combined with EPC database, containing all data attributes for the Faraday Tool inputs. However, one problem arose in that only half of the properties had an EPCs, creating a need to create synthetic EPCs for each property without one. This was done by creating two copies of the layer of UPRNs (one with all the UPRNs and one with only the UPRNs with EPCs) and then using the ‘Distance Matrix’ tool in QGIS, assigning the attributes of the EPC of the nearest neighbour to every UPRN which did not have an EPC. For example, a house with no EPC but next to a house with a rating of C, 4 habitable rooms and mains gas would also be assumed to have all those attributes. The ‘Property Type’ was not required to be found this way, as it is universally covered through the BLPU column within the UPRN data. After this, the archetype counts were derived for each feeder and input into the Faraday Tool to generate an output half-hourly load curve as shown in Figure 14; the timeframe selected was a week in December 2022 to overlap temporally with the NGED data.



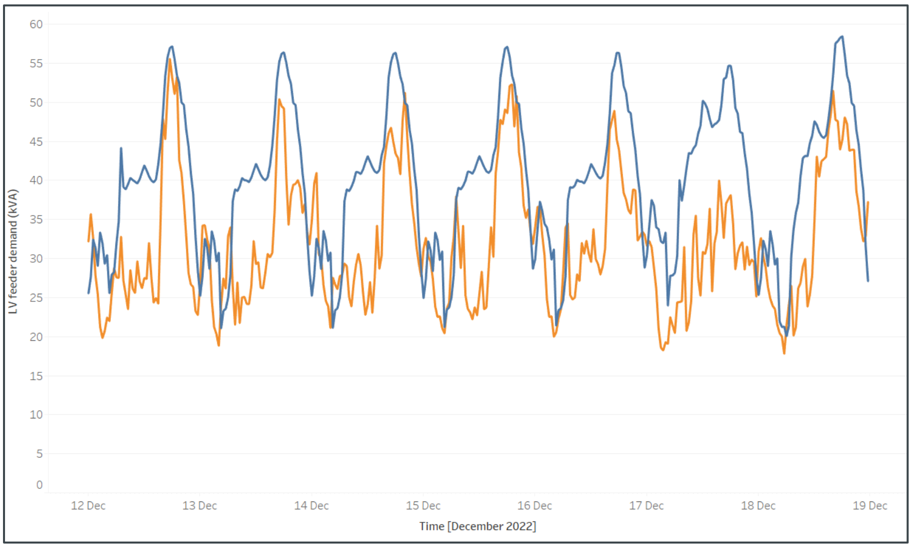


Figure 14: The Faraday Tool archetypes, real monitoring data (in orange) and synthetic data predicted by the Faraday Tool (in blue).

It can be seen from Figure 14, that there is some level of agreement between the synthetic demand created using the Faraday tool and the observed demand measured by National Grid Electrical Distribution, particularly at the evening peak consumption times. This trend was replicated across the other four LV feeders. However, the monitoring data (perhaps expectedly) is noisier and shows significantly less consumption in the middle of the day. This could be due to differences in population characteristics between the residents served by Denham Road LV substation and the sample of Octopus customers from which the Faraday Tool generated profiles are based. These dissimilarities could arise from variations in ages, work patterns and incomes among different groups of consumers.

<u>Use Case 2: Future Scenarios for the Digital Demonstrator</u>

Next, for the purposes of displaying monthly electricity consumption under different scenarios, additional datasets were required. A subsequent Strategic Innovation Funded project, also covering the TEED area, had identified estimated annual consumption for each LV substation area. It was agreed with NGED that sufficiently sized samples of data were acceptable to be shown on this display. This resulted in samples of greater than 5 buildings (the meter counts per LV substation area were later verified by NGED) an estimated annual consumption value could be used in further calculations to ultimately display monthly kWh consumption. Moreover, an advantage of the dataset provided by NGED displayed a split between each estimated annual consumption into a profile class (PC); PC1 and PC2 as domestic consumers whereas PCs 0, 3, 4, 5, 6, 7 and 8 represented non-domestic consumers. Therefore, the estimated annual consumption values could be known for both the aggregates of residential and non-residential meters within a substation area.

The next step was to disaggregate this annual value into monthly figures, creating profiles that showed the variation in electrical demand across days of the month. The month was chosen to be March 2023 as this was a recent month, close to the launch date of the platform, and as it represented more of a 'shoulder season' with mid-range electrical demand (i.e. it is not representative of higher values due to winter or lower values due to summer). This was conducted using two datasets; ESPENI[16] containing national GB electricity demand and generation by source on a half-hourly basis, and the default period (half-hourly) profile class coefficients from Elexon[17]. The total

[16] https://zenodo.org/record/3884859
[17] https://www.elexon.co.uk/data/

daily electrical demand for an area of interest was determined by finding the percentage of the total yearly GB electricity used within a day and allocating consumption to that day equal to the annual total multiplied by that percentage. The daily figures were then added, to obtain monthly values. Next, the total domestic electricity demand was found by a similar method instead using the sum of the Elexon half-hourly values for each day. Finally, the non-domestic daily consumption was assumed to be the difference between the total demand and the domestic demand.

To emphasise this with an example, for 28th March, the ESPENI proportion of total annual consumption was 0.00258 and the sum of Elexon coefficients for a domestic profile class for the same day was 0.00282. The total estimated annual consumption for the TEED Industrial Area was 53,262 MWh while the domestic equivalent was 8,496 MWh.

- The total daily electricity for 28th March would be calculated as 0.00258 * 53,262 = 137.5 MWh = 137,500 kWh.
- The domestic consumption for the same day would be 0.00282 * 8,496 = 23.95 MWh = 23,950 kWh.
- The non-domestic consumption for that same day is then the difference between these values, which is 137,500 – 23,950 = 113,550 kWh.

Completing this process for each day of the month yields both a sub-monthly profile and monthly total. This process was repeated for the smaller Kings Road substation (using the domestic and non-domestic estimated annual consumption values provided by NGED) and a sample of 3 illustrative properties within Kings Road (dividing the domestic estimated annual consumption for Kings Road by the sample size, then adjusting by +10% for an E rated EPC property and -10% for a C rated EPC property).

Finally, three different scenarios were felt to be useful to explore:

1. Energy Performance Certificate improvements to domestic properties;
2. Electric Vehicle penetration at 50% of domestic properties;
3. Renewable generation (solar PV) on non-residential buildings.

The number of properties were taken from the total amount of domestic and non-domestic building-type UPRNs in each substation polygon. For the first scenario, the domestic electrical demand was predicted to fall by 10% (in line with the findings from the National Energy Efficiency Database[18] showing in 2019 the average C rating used 10% less electricity than the average D rating). By far the most common category of domestic Energy Performance Certificates in TEED was D (at just under 50% of the total of those properties with an Energy Performance Certificate), although a significant portion of these could potentially be improved to a C or above rating following retrofit or other energy efficiency measures.

For the EV scenario, an annual figure of 2650 kWh[19] was assumed to be spread evenly across the year (i.e. 2650/365 = 7.26 kWh per car per day) and added to profiles, while for PV, 50% of non-domestic properties were assumed to be able to host a 30 kW PV installation. To translate this installed capacity to an annual value, the West Midlands standard load factor (9.8%)[20] was used to calculate an annual kWh (annual kWh = capacity * 8760 * 0.098) which could be split into a sub-annual profile using the solar coefficients from the ESPENI dataset.

[18] https://www.gov.uk/government/statistics/national-energy-efficiency-data-framework-need-consumption-data-tables-2021
[19] https://www.electricnation.org.uk/wp-content/uploads/2019/07/Electric-Nation-Trial-Summary-A4.pdf
[20] https://www.gov.uk/government/statistics/regional-renewable-statistics

These methods were used to produce new daily profiles which could be toggled on the digital display to be viewed on an iPad or android device. Examples are shown in Figures 15 and 16, giving an indication of potential changes to daily and monthly electrical demand. In future, these could also show the impacts of the electrification of heating and be more temporally granular, to allow for a 'plug-and-play' model of future energy system designs (aided by the 3-D visualisations created by Maadigital).

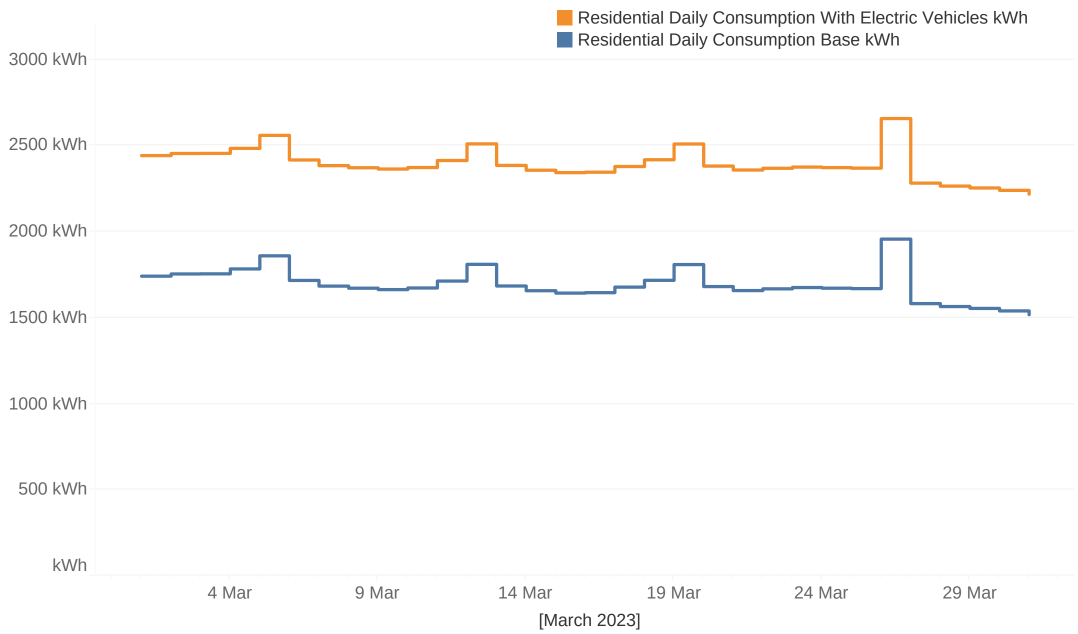


Figure 15: The total daily electricity demand for the residential properties in Kings Road. LV substation area in the baseline scenario (below in blue) and EV scenario (above in orange). The weekly spike in demand is on Sunday.

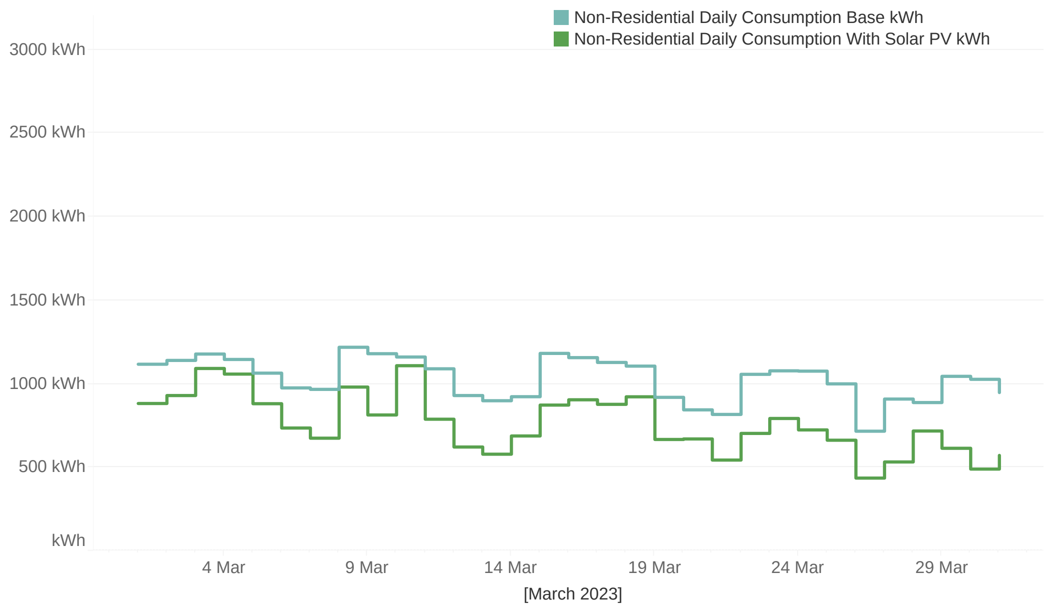


Figure 16: The total daily electricity demand for the non-residential properties in Kings Road. LV substation area in the baseline scenario (above) and in the solar PV scenario (below).

As well as for the whole TEED area and Kings Road case study area, the calculation for monthly totals and sub-monthly profiles is repeated for the following 17 substation areas (shown in Table 2) for which the sample size was sufficient.

Table 2: Monthly demands of LV substations of sufficient sample sizes under potential scenarios

LV Substation Name	March 2023 estimated monthly demand (MWh)	Estimated monthly demand (MWh) with improved EPCs	Estimated monthly demand (MWh) with non-residential PV
33 Kinds Road – Tyseley	84.24	75.82	75.90
Waterloo Road – Hay Mills	295.33	265.80	271.33
South Yardley – Coventry Road	365.76	329.18	337.58
Kings Road Factory – Units rear Carter	36.36	32.72	24.88
James Rd Ind Estate - Tyseley	27.15	24.43	-15.64
Redfern Road - Tyseley	20.53	18.48	-142.27
Kings Road - Hay Mills	95.69	86.12	62.30
Wharfdale Road (West) - Tyseley	123.93	111.53	104.10
Stockfield Road Bridge – Acocks Green	67.12	60.41	61.90
Tiffield Road – South Yardley	134.64	121.17	110.63
Redhill Road - Tyseley	89.26	80.33	55.86
883 Coventry Road – Hay Mills	39.41	35.47	17.50
Kinds Road. industrial Units – Tyseley	75.00	67.50	65.61
Berkley Road East	240.94	216.84	145.97
Wharfdale Road	170.09	153.08	153.39
Hay Hall Road	92.89	83.60	40.71
G.A.F.	78.57	70.71	66.05

4.4. Next Steps

To build on the learnings of this project, the following steps are suggested:

- Use machine learning approaches to scale methods of assigning accurate polygons to LV substation service areas. For example, weighted Voronois or tracing along the road network to find the nearest substation.
- In the absence of accurate scalable methods, continue to engage with the sector to encourage Publication of LV boundaries themselves or, use a digitalisation team to manually create these boundaries over a larger area.
- Consider the mesh nature of the LV network in more detail and how this could be used to mitigate
reinforcement.
- Use machine learning approaches to improve the accuracy of building uses (e.g. mid-terrace vs. end terrace).
- Use machine learning approaches to improve the accuracy of linking buildings to energy meters (requires data from Electralink and Xoserve).
- Scale the creation of non-domestic synthetic demand at half-hourly level.
- Scale the creation of low carbon technology synthetic demand at half-hourly level.

- Analyse the potential mitigation of network reinforcement through storage and other load shifting approaches.

Figure 17: overlay of electrical data within the demonstrator.

5. Evaluation of digital twin approach to air quality measurement from transport data

Prof. Francis D. Pope and Dr Omid Ghaffarpasand, School of Geography, Earth, and Environmental Sciences, University of Birmingham

Road transport is a cornerstone of modern civilisation, with many profound and positive impacts on the economy and human well-being. However, it is also associated with undesirable and unsustainable impacts, including urban air pollution, climate change, noise, and congestion. For example, in 2021, road transport accounted for 34%, 13% and 27% of nitrogen oxides (NOx), particulate matter (PM) and carbon dioxide (CO2) emissions in the UK, respectively[21]. As a result, much attention has been paid to sustainable road transport over the last two decades.

Digital twins of urban transport are a promising asset for assessing and improving the level of sustainability within transport systems. Digital twins provide a testbed for modelling and analysing the impact of current and future policies and strategies in a digital environment, ensuring that taxpayers' money delivers the expected results. They also provide a new digital environment in which to study and develop innovative solutions. However, the lack of spatial and temporal road data is the main obstacle to establishing a reliable, continuous, and validated data flow between the digital and physical twin of road transport. With the rapid advancement of technologies such as remote sensing, machine learning, and telecommunications, data collection from urban environments has been revolutionised. For example, vehicle location and speed data are now being collected instantaneously for telematics equipped vehicles. Remote sensing systems for the measurement of vehicle emissions can provide detailed real-world understanding of on-road emissions. However, the lack of an evaluated and documented approach with which to translate these data sets into meaningful urban mobility outputs is hindering progress. This project aimed to show how the combination of these real-world data sets can provide a detailed spatial and temporal understanding of different dimensions of the transport environment. The approach presented provides a roadmap towards the development of digital twins for road transport.

5.1. Methodologies and Activities

The first raw material for the analysis is annual vehicle telematics data collected from road transport for the TEED area within East Birmingham. The spatial scope of the project is shown in Figure 18(a). The data was provided by a UK-based telematics company, the Floow[22]. Telematics data can be collected from GPS-enabled cars whose drivers, to receive fairer insurance premiums, voluntarily share their locations with telematics companies. The data used in this project is collected from approximately 3-7% of passenger cars travelling on West Midlands roads during the study years: 2016, 2018, 2021 and 2022. This percentage provides a reliable representation of road traffic in the study area, whereas most previous transport research has relied on data from a few GPS-equipped test vehicles, for example see[23]. To provide some context, there were over three million different types of vehicles travelling on West Midlands roads in 2017. The study years 2016 and 2018 provide a detailed understanding of road traffic before the major disruption caused by the COVID-19 pandemic, which was first reported in the UK in early 2020.

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[21] DfT, Transport Statistics Great Britain:2021, https://www.gov.uk/government/statistics/transport-statistics-great-britain-2021/transport-statistics-great-britain-2021

[22] www.thefloow.com

[23] Omid Ghaffarpasand, Mark Burke, Louisa K. Osei, Helen Ursell, Sam Chapman, and Francis D. Pope, "Vehicle Telematics for Safer, Cleaner and More Sustainable Urban Transport: A Review", Sustainability, 14(24), 16386 (2022). Available at https://www.mdpi.com/2071-1050/14/24/16386

We translated the collected vehicle telematics data into the speed-acceleration profile of the roads using the geospatial and temporal mapping of urban mobility (GeoSTMUM) method recently proposed[24,25]. The method examines the results over GeoST segments, geospatial polyline features. GeoST-segments are aligned with the direction of traffic flow. They cover all road features such as roundabouts, junctions, service roads, etc, GeoST-segments vary in length from 15 to 150m. GeoST-segments are divided into 35 different time slots, averaged over one year (2016 or 2018), consisting of daily time slots (00:00 to 06:59, 07:00 to 08:59, 09:00 to 11:59, 12:00 to 13:59, 14:00 to 16:59, 16:00 to 18:59 and 19:00 to 23:59) for five days a week (Monday, Tuesday, Friday, Saturday and Sunday). The studied speed-acceleration profiles of the GeoST-segments are then converted into the vehicle emission factors using the real-world exhaust emissions and fleet composition measurements. The real-world emission and fleet composition measurement datasets were generated by the remote sensing device, EDAR, which provides individual vehicle emission measurements, and Automatic Number Plate Recognition (ANPR) cameras[26].

5.2 Visualisations and Findings

In this section we briefly summarise the results of the project. The spatial distribution of the average speed of passenger cars in the study area is shown in Figure 18(b). A similar shapefile can be generated for the other studied parameters. With this data type, a hotspot analysis can be performed on both spatial and temporal elements of the study area. Meanwhile, the interlayer analysis between the outputs of the approach and the other urban shapefiles such as land use, energy construction, schools, hospitals, retail, etc. can be followed. In addition to the geospatial representation of the outputs, the approach presented here can provide hourly/daily variations in 2D format for the studied parameters. For example, we show the daily variation of the probability distribution function (PDF) of the average speed for different days and three different time slots. The same graphs can be generated for the other studied parameters. For example, Figure 18(c) provides the PDF profiles of the average speeds in the evening rush hours of weekdays. Distinct road traffic dynamics can be easily discerned in the PDFs, such as the influences of both morning and evening rush hours.

The methodology used here can also be used to assess potential scenarios or policies. For example, Figure 18(d) shows the potential impact of a 20% replacement of old Euro 5 passenger cars with EVs on the average NOx emission factors in the study area. Here, the black solid lines are for the Business As Usual (BAU) status, while the red, green and blue dashed lines are for the case of a 20% replacement of the old fleet regardless of fuel type, petrol only and diesel only, respectively.

[24] Omid Ghaffarpasand and Francis D. Pope, "Telematics Data for Geospatial and Temporal Mapping of Urban Mobility: New Insights into Traffic Behaviour and Complexity. Available at SSRN: http://dx.doi.org/10.2139/ssrn.4129692.

[25] Omid Ghaffarpasand and Francis D. Pope, "Telematics Data for Geospatial and Temporal Mapping of Urban Mobility: Fuel Consumption, and Air Pollutant and Climate-Forcing Emissions", Science of Total Environment, 894(10) 164940 (2023), Available at https://doi.org/10.1016/j.scitotenv.2023.164940

[26] Omid Ghaffarpasand, David Beddows, Karl Ropkins, and Francis D. Pope, "Detecting high emitting vehicle subsets using emission remote sensing systems", Science of Total Environment, 858, 159814 (2023). Available at https://www.sciencedirect.com/science/article/pii/S0048969722069145

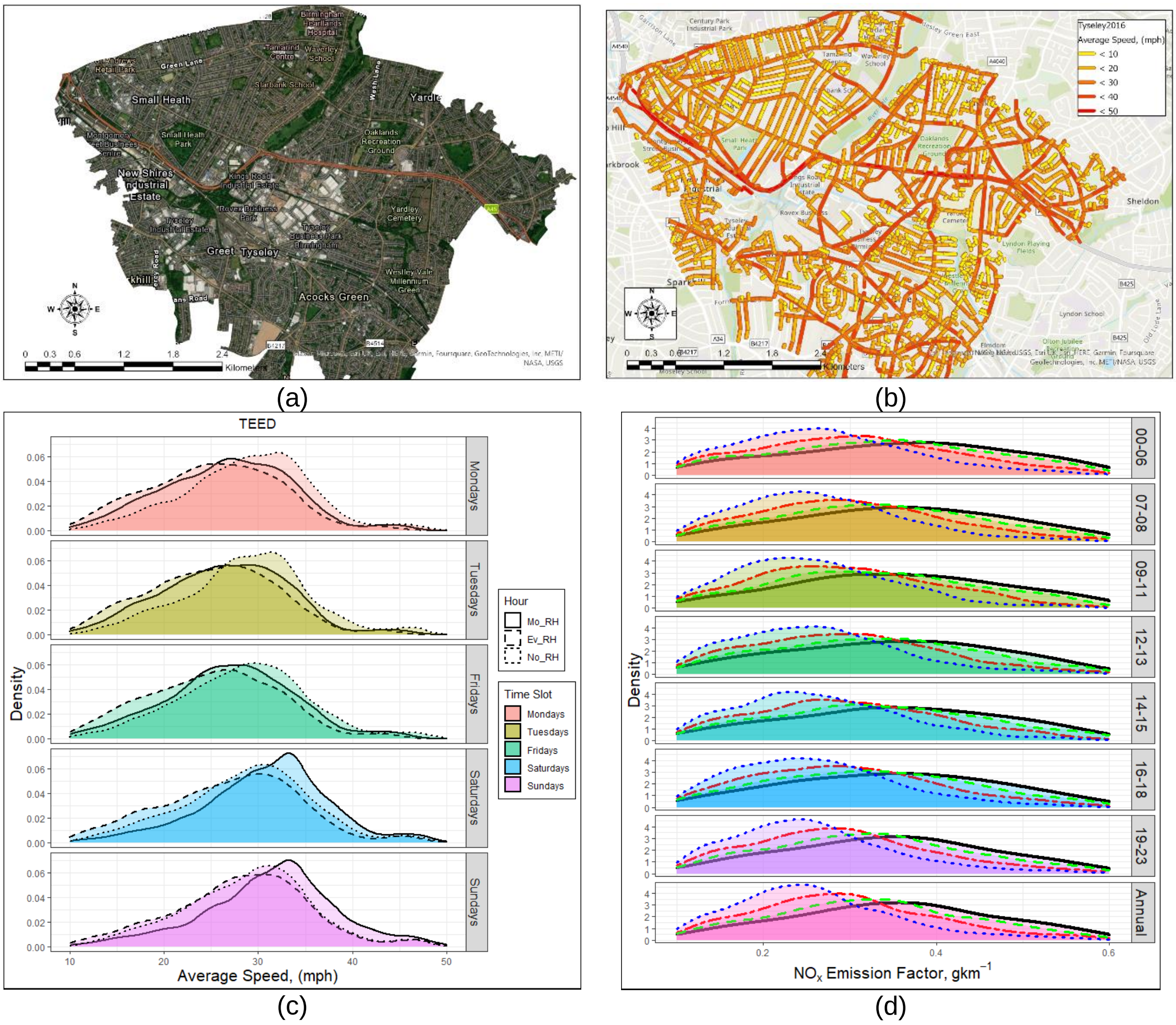

Figure 18: (a) the spatial scope of the project; (b) the annual distribution of the average speed in the study area, for 2018; (c) the daily variation of the average speed for the three different time slots; (d) the hourly variation of three electrification scenarios, while the black solid line is BAU status.

5.3 Next Steps

The results of the methodology used in this project are reported in geospatial platforms that can be easily aligned and integrated with other urban features or studies. The approach is easily extendable both spatially and temporally. The proposed next step is to map the results of this project and the other outputs, especially energy infrastructure, and find the relationships between them within a geospatial context. The output of this project should be compared with similar initiatives for other transport modes such as public transport, active travel and freight transport. A long-term vision of the project is to apply intelligent algorithms to learn existing trends and correlations to predict the future of road transport and possibly analyse the impact of future policies, particularly towards the UK's net-zero carbon ambitions.

6 Public Engagement with the Digital Twin project

Mossen Randeree, Public Engagement lead, Birmingham Energy Institute

Digital Twins and Urban Analytics are rapidly developing technologies that have the potential to revolutionize the way we understand and manage our cities. By creating a virtual replica of a city, Digital Twins can be used to simulate different scenarios and predict the impact of changes to infrastructure, transportation, and other systems. Urban Analytics, on the other hand, uses data science and machine learning to extract insights from large datasets about how cities operate.

The Digital Twin for East Birmingham will include data on energy, transportation, air quality, and other factors that are important for understanding this region of the city of Birmingham and will be used to simulate different scenarios to predict the impact of changes to infrastructure and policy. Thus, it is essential to engage with communities and key stakeholders from the earliest stage of digital twin development. This section describes some of the key engagement activity undertaken by the University's Public Engagement lead and the wider team of the BEI with support from work experience and internship placements.

6.1. Methodologies and Activities

Over the lifetime of the project (November to March 2023) and after project completion (April to August 2023) a wide range of stakeholders were engaged to share learning and gain insights to shape the digital twin project. These stakeholders included those from the local community (including schools) from business and industry (regional and international) and policy makers as well as international visitors.

6.2. Engagement activity

Over the ten-month timescale described, over 500 engagements were achieved collaborating with University of Birmingham's School of Engineering, WM Air Programme, the University's Institutes of Data Science and Energy (BEI). Activities also engaged the Department for Business and Trade and over 100 international representatives from countries including Singapore, Denmark, Sweden, Turkey and India.

The following summaries the engagement activity:

- Business Engagement: 180 businesses were engaged.
- International Business Engagement: over 70 international representatives were engaged, along with 10 UK Business Development representatives for internationalisation.
- Education (workshops): seven workshops were delivered including with Pioneer Group and Birmingham Museum and Art Gallery.
- Education (placements and internships): two work experience pupils, ages 15 and 17, were involved. An undergraduate student and a Masters level student intern nurturing ambassadorial roles in a younger age-group.
- Community: four Public Engagement and community events supported or delivered.

All photos included sought permission ahead of photography.

<u>Engagement with business community and related Government activity</u>

180 businesses were engaged including internationally with discussion and activity around:

- An introduction to the Tyseley Digital twin project and the partnership with the Alan Turing Institute.
- The University of Birmingham campus digital twin project and proposals for research using the digital twin to
    - change transport choices (e.g. active travel)
    - impact air quality and carbon, exploring the potential opportunities of switching to a four-day week.
- The opportunity to apply regional digital twin learning globally.
- Regional net zero strategy and the aspects of data and knowledge required to progress at pace and at scale.
- District energy, heating and cooling systems as well as population and pollution, linking to potential avenues for exploring localised Digital Twin solutions.
- Regional energy systems mapping and potential opportunities for decentralised power network configuration and management.
- A tour of the research facilities and activities at TEP.

Groups engaged to build on, or explore, new collaborations:

- WM Innovation Alliance.
- Innovate UK
- National Grid Electricity Distribution.
- Department for International Trade (now Department for Business and Trade, DBT).
- Organised by UKinIndia, partnering with Energy Systems Catapult and West Midlands Growth, BEI hosted a senior delegation of power systems experts & government officials from India.
- IEEE Power & Energy Society.
- Leaders from global transport businesses including visitors from Turkey, Singapore, Sweden, Denmark and Ireland as well as UK organisations such as Transport for West Midlands and Transport for London.
- Business Development Coordinators from across the country, responsible for developing links for international inward investment particularly for the Green Economy.
- Professor Dame Angela McLean, the Government's Chief Scientific Adviser.
- Ordinance Survey and the Office for National Statistics.
- Greater Birmingham Chamber of Commerce.
- Net Zero Together.
- Sustainability West Midlands Conference.
- Green Business Summit.

Figure 19 - 30th March 2023
Net Zero Together Event, The Exchange, Birmingham

Figure 20 - 18th April 2023
India visitors (Department for International Trade)


Figure 21 - April 2023
India Delegation

Figure 22 - April 2023
Global Transport Businesses


Figure 23 - 18th April 2023
UoB IEEE Power & Energy Society

Figure 24 - 17th May 2023
Greater Birmingham Chamber of Commerce

Figure 25 - 18th May 2023
West Midlands Growth


Figure 26 - 24th May 2023
Net Zero Together Event

Figure 27: 22nd June 2023
Visit by Professor Dame Angela McLean, Chief Scientific Adviser

Figure 28: 14th June 2023
Green Business Summit

<u>Education and community engagement: placements, internships, and workshops</u>

Seven education workshops as well as various meetings and community engagement. Discussions and activities around:

- Environmental challenges, sustainability and technology solutions.
- Introducing the Tyseley Digital twin project and the partnership with the Alan Turing Institute.
- Regional and global issues as well as topics on data for air quality, emissions, energy use, sustainable heat, transport and potential applications for Digital Twin concepts and related communication activity.
- Recycling and the circular economy.
- Augmented reality (AR) systems.
- The research activities of TEP.
- Training, skills and apprenticeship opportunities through the net zero transition.
- Careers related to urban analytics and data science.
- Engagement with local councillor and discussed some of their issues within their region.

Groups engaged:

- South & City College Hall Green, Birmingham
- South & City College, Birmingham
- Ark Victoria School, Birmingham
- Ilsley School, Birmingham
- University of Birmingham Global Environmental & Sustainability undergraduate course
- University of Central Birmingham
- Institute of Physics Education Forum
- The Pioneer Group
- Birmingham Museum and Art Gallery, responsible for educational activity at ThinkTank and other engagement centers around the region.
- University of Birmingham Campus Family Day.

Figure 29: 13th July 2023
Sustainability West Midlands Conference

Figure 30: 26th April 2023
Global Environmental & Sustainability Course

Figure 31: 27th April 2023
South & City College Bordesley Green

Figure 32: 27th April 2023
Eden Girls Academy

Figure 33: 16th May 2023
University of Central Birmingham

Figure 34: 27th April 2023
Alston and St Benedict's Primary Schools

Figure 35: 18th May 2023
Ark Victoria School

Figure 36: 28th June 2023
Institute of Physics Education Forum

Figure 37: 6th June 2023
Pioneer Group

Figure 38: 13th July 2023
Ilsley School

Figure 39: 4th July 2023
Discussions with Birmingham Museum and Art Gallery and Thinktank

Figure 40: 19th July 2023
Teaching assistant and community event

Figure 41: 26th April 2023
Ark Victoria School's Open Event

Figure 42: 26th July 2023
Summer University of Birmingham Campus Family Day

Figure 43: 19th July 2023
Ark Victoria Summer Fete

Multi-group engagement

The Urban Analytics and Digital Twins Turing Regional Engagement event brought together regional partners, including universities, city councils, businesses and other organisations interested in the opportunities presented by urban analytics. This was an opportunity to share the learning through the East Birmingham Digital Twin project and the development of the Diatomic Innovation Accelerator programme led by Connected Places Catapult, looking to accelerate place-based innovation in the West Midlands through data to enable better decision-making.

Figure 44: 31st May 2023
The Urban Analytics and Digital Twins Turing Regional Engagement Event

Figures 45, 46 and 47: visual captures of TEED

7 Glossary of Terms

AI	Artificial Intelligence - refers to computer systems that simulate human intelligence. It includes algorithms and software enabling machines to perform tasks like learning, problem-solving, and recognizing patterns.
AR	Augmented reality - a technology that superimposes a computer-generated image on a user's view of the real world, thus providing a composite view.
BIM	Building Information Modelling is a digital system for designing, constructing, and managing buildings and infrastructure. It employs 3D models with detailed data on materials, costs, and schedules, facilitating collaboration among project stakeholders for better decision-making and project efficiency.
BLPU	Basic Land and Property Unit (BLPU) is defined as an area of land in uniform property rights or, in the absence of such ownership evidence or where required for administration purposes, inferred from physical features, occupation or use.
CROWN	An in-house multi-functional asset management system used by NGED.
Digital Shadow	Closely related to a Digital Twin, a digital representation that mirrors the current state and behaviour of a physical entity or system. Data collected from the assets through sensors, Internet of Things (IoT) devices, or other sources and provides a feed of information into the model.
Digital Twin	A Digital Twin refers to a virtual representation of a physical object, system, or process. It is highly detailed and dynamic, replicating the physical entity, typically in near/real-time. Digital Twins are often used to monitor, simulate, and analyse the behaviour, performance, and status of their physical counterparts.
EMU Tool	Electronic Mapping Utilisation platform – which needs a login from NGED. It is an interactive mapping and visual display of cables and assets of NGED. The data is not downloadable or machine readable, i.e., the aim is for human users (https://www.nationalgrid.co.uk/downloads/3862)
Game Engine	Software used to create and run video games, providing tools and functionalities for graphics, physics, audio, and game logic, streamlining the game development process.
kWh	A kWh, or kilowatt-hour, is a unit of energy and represents the amount of energy equivalent to one kilowatt (1 kW) of power expended over one hour (1 h). It's a standard unit for billing electricity usage and is often used to quantify the amount of energy various appliances and devices consume.
MPAN	Meter Point Administration Number, a unique identifier used in the United Kingdom's electricity supply system to pinpoint and manage individual electricity meters at properties. It helps utilities and authorities track energy usage and billing for each metered location.
MWh	A MWh or Megawatt hour, is equivalent to 1000 Kilowatt hours (kWh) see above.
NGED	National Grid Energy Distribution (formerly Western Power Networks) is the electricity distribution network operator for the Midlands, South West and Wales.
Orthophoto	An aerial image that has been geometrically corrected (ortho rectified) so that the image is uniform from edge to edge. Orthophotos are corrected to remove terrain effects.
Photogrammetry	A three-dimensional coordinate measuring technique that uses triangulation from photographs as the fundamental medium for metrology or measurement.
Point Cloud	A digital 3D representation of a physical object or space, comprised of individual measurement points, each one with an x, y, and z coordinate. Point clouds are typically captured using either laser scanning or Photogrammetry.
Shoulder Season	shoulder season refers to the months building up to, and following on from, the heating season (October-April), so months like September and May, where a portion (but not the majority) of properties are transitioning their heating systems to be on or off.
TEED	Tyseley Environmental Enterprise District - Tyseley Industrial Area has been identified as a principal location in Birmingham for CO2 reduction as part of a low carbon, low waste economy through encouraging recycling, energy production and renewables including manufacturing and supply chain development.
TEP	Located in East Birmingham, Tyseley Energy Park (TEP) is on a mission to transform clean energy innovation in Birmingham and the West Midlands by stimulating and demonstrating new technologies and turning them in to fully commercially viable energy systems
UPRN	Unique Property Reference Number, a unique identifier assigned to every addressable property in the United Kingdom, facilitating precise location and property information in various applications, including land and property management, utilities, and local government services.
Voronois	Voronoi diagrams, are used to define and to delineate proximal regions around individual data points by using polygonal boundaries.

8 Appendix 1: accuracy of LV substations methods

Table A1 - The accuracy of the LV substations assigning methods (NGED's Voronois) versus this project's manually drawn boundaries.

LV Substation Name	Properties Assigned Correctly by Voronoi as % of Manual	Properties Assigned Correctly by Manual as % of Voronoi
231 Berkeley Road - Yardley	73.5%	95.5%
33 Kings Road – Tyseley	79.9%	52.2%
753 Warwick Road.	54.7%	56.1%
83 Berkeley Road – Hay Mills	100.0%	39.6%
883 Coventry Road – Hay Mills	78.4%	100.0%
Amington Road North	0.0%	0.0%
Arbuthnot Engineering – Amington Road	100.0%	18.2%
Atlas Works	100.0%	11.1%
Berkley Road East.	54.9%	100.0%
Birmingham Bio Power	0.0%	0.0%
British Rail Warwick Road	40.0%	8.0%
Cousins Warwick Road	100.0%	6.8%
Croda Paints - Shaftmoor Lane	100.0%	17.3%
Eaves Spring Road – Tyseley	100.0%	8.0%
Euro Packaging Warehouse	100.0%	27.3%
F.H.S. Ltd.	100.0%	100.0%
Farr Filtration - Kings Road	100.0%	14.3%
Fordrough	100.0%	11.1%
G.A.F.	50.0%	42.2%
Grayson Automotive	100.0%	2.0%
Grunderling Ltd.	100.0%	100.0%
Harmo Industries (now Walker)	100.0%	35.4%
Hay Hall Road	70.0%	92.1%
Kings Road - Hay Mills	20.9%	100.0%
Hazelwood Road – Acocks Green	83.5%	95.3%
Heathcliff Road – Tyseley	7.1%	10.2%
Holder Road – Yardley	87.4%	95.9%
Hollyhock Road	82.6%	84.5%
Hoskins Redfern Road.	100.0%	33.3%
Imex - Kings Rd, Tyseley	100.0%	94.0%
James Rd Ind Estate - Tyseley	100.0%	77.4%
Kestrel Avenue - Yardley	98.9%	89.4%
Industrial Units, Kings Road – Tyseley.	22.2%	50.0%
Kings Road Factory, Unis rear Carter	100.0%	33.3%
Knights Road	12.0%	11.7%
Kwikform	33.3%	1.0%
Lidl, Coventry Rd	100.0%	23.0%
M.Y.Holdings – Wharfdale Road	100.0%	100.0%
Marston Scaffolding, Warwick Road	100.0%	24.4%
Mereway Ltd.	100.0%	16.7%
Ninfield Road – Acocks Green	74.5%	90.6%
Railway Museum Warwick Road – Tyseley	100.0%	100.0%

Rainsford & Lynes, Kings Road	100.0%	0.7%
Redfern Park Way – Tyseley	25.0%	100.0%
Redfern Road - Tyseley	11.5%	90.0%
Redhill Road – Tyseley	61.9%	100.0%
Reynolds Tube No. 1 – Redfern Road	100.0%	57.1%
Reynolds Tube No. 2	100.0%	7.1%
RTITB. Training Centre, Amington Road	100.0%	100.0%
Salvage Dept. James Road – Tyseley	100.0%	100.0%
Serck Aviation	100.0%	33.3%
Shaftmoor Lane	73.0%	82.2%
Smith, Wharfdale Road – Hay Mills	100.0%	7.8%
Coventry Road - South Yardley -	44.3%	100.0%
Spring Road - Tyseley	83.0%	70.1%
Spring Road (WEST) – Acocks Green	67.4%	91.4%
Stockfield Road Bridge – Acocks Green	53.0%	56.5%
Tiffield Road – South Yardley	100.0%	80.8%
Transport Dept. Fox Hollies Road	100.0%	1.8%
Tyseley Wharf No. 1	100.0%	5.0%
Walkers Food, Brickfield Road.	100.0%	0.8%
Waterloo Road – Hay Mills	42.6%	89.7%
Westley Road – Acocks Green	88.6%	78.5%
Wharfdale Road	28.7%	100.0%
Wharfdale Road (West) - Tyseley	21.5%	96.7%
Yarnfield Road – Tyseley	70.1%	97.4%
York Road – Hall Green	88.3%	98.6%
Zip Textiles ACB	100.0%	50.0%

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