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Preface

The [International Conference on Evolving Cities](#) (ICEC) took place as a hybrid event (with both online and in-person delegates) at the [Centenary Building](#) (B100) situated in the Highfield Campus at the University of Southampton, UK from 13-15 July 2022. It brought together leading academics, policymakers, and industry specialists to debate the role of cities in addressing climate change mitigation impacts and accelerating our transition to net-zero carbon. Over the course of three days, there were [11 keynote](#), [48 oral presentations](#) and [10 posters](#) by delegates from over 60 organisations. The themes of the conference are shown in Fig. 1 with participants able to discuss and debate ways to develop multi-stakeholder partnerships and implement innovative solutions to propel cities towards low carbon pathways.



Fig. 1: ICEC themes

This document provides a record of the submitted abstracts for the International Conference on Evolving Cities including all oral presentations and posters presented at ICEC 2022.

About ECCD

The [Energy and Climate Change Division](#) (ECCD) is part of the Faculty of Engineering and Physical Sciences at the University of Southampton. It comprises the Sustainable Energy Research Group (SERG) and the Coastal and Climate Research Group, established since 1990. ECCD/SERG research profiles addresses the University's mission focusing on fundamental understanding applicable to renewable energy studies, energy efficiency and energy for development. ECCD/SERG research [supports the United Nations Sustainable Development Goals](#) (SDGs) with fundamental and applied research across our six research themes. These encompass (i) [Renewable Energy](#), (ii) [Energy Access](#), (iii) [Cities & Infrastructure](#), (iv) [Buildings & Communities](#), (v) [Behaviour & Modelling](#) and (vi) [Climate & Emissions](#). Please check our website www.energy.soton.ac.uk for further information.

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SESSION 1: Solent future transport (1/2)

The Solent future transport zone: Research challenges for evolving city regions

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Solent Transport provides leadership, strategy, and direction to support sustainable economic growth in the Solent area. Originally established in 2007, Solent Transport is a partnership between the councils of the Isle of Wight, Hampshire County, Portsmouth and Southampton. In collaboration with the local community, business, government and transport operators, Solent Transport undertakes research; develops transport policy and strategy; submits and supports funding bids; and lobbies for transport improvements that will benefit everyone.

In conjunction with the Universities of Portsmouth and Southampton, Solent Transport won £29 million from the Department for Transport (DfT) to implement innovative future transport solutions around personal mobility and freight movements. The funding means the Solent area will benefit from several innovative transport solutions including: a Mobility-as-a-Services (MaaS) app for planning and paying for sustainable journeys on-demand, e-scooter and e-bike share schemes, and new approaches to freight distribution, including drone freight trials for NHS deliveries across the Solent to the Isle of Wight, micro-consolidation for last mile delivery and macro-consolidation.

The Solent Future Transport Zone (FTZ) research programme runs from 2021 to 2024 and will assess the extent that local challenges can be addressed such as high levels of car usage and the adverse environmental impacts of freight movement within Solent's urban areas. It will do this by delivering a series of complementary projects within two key themes: Personal Mobility and Sustainable Urban Logistics.

This scene-setting paper will detail features of the Solent FTZ and compare them with the other three FTZs in England (Derby-Nottingham, West of England and West Midlands). It will also detail the planned research and development activities and how these have been adapted in the light of Covid 19 and in response to other initiatives. It will be accompanied by up to seven short presentations on research with respect to MaaS (including interface design, the presentation of environmental information and the optimisation of the underpinning algorithms), monitoring and evaluation (including top-down and bottom-up approaches), and sustainable urban logistics (including the use of drones and consolidation concepts).

Freight consolidation in the Solent region: Concepts, benefits, and challenges

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Freight movement and logistics activities have dramatically increased in recent years due to the increase of e-commerce and other economic activities. In addition to financial and commercial competition effects of logistical performance for businesses, freight logistics activities have significant impacts on the sustainable environment and liveability of cities such as traffic congestion, carbon emissions, noise, road safety, etc. The Solent region is of strategic economic and security importance to the UK, focussed around the two City Regions of Portsmouth and Southampton, the settlements and strategic growth areas within

Hampshire between/adjacent to the cities, the Isle of Wight and the Solent waterway. The area acts as a critical gateway for international trade which underpins a thriving freight & logistics sector located around the two key cities creating particular local challenges around the movement of goods in urban environments.

The Solent Future Transport Zone Freight consolidation project, funded by the UK Department for Transport, aims to explore and demonstrate new consolidation concepts for making urban logistics more sustainable, reducing the impact goods movement has on congestion and air quality in the Solent region. The main goal of this research is to quantify the business-as-usual transport footprint of freight in the Solent region, develop, simulate and trial new freight consolidation concepts to achieve environmental, social and commercial benefits. The consolidation options will trial micro-consolidation for last mile parcel delivery (cargo bikes, walking porters, etc.), and macro-consolidation for first mile delivery by increasing the use of the existing Sustainable Distribution Centre in Southampton and potentially creating a new one in Portsmouth. Extensive analysis will be conducted to evaluate the business-as-usual freight footprint and the sustainability impacts of the consolidation concepts in the Solent region.

Reinforcement learning for intelligent traffic signal controls in smart cities

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As our requirement for urban spaces expands as a society, with an estimated 46 million people living in urban areas [1] in the United Kingdom (UK), so does the need for efficient and effective road infrastructure for use by the over 32 million registered cars in the [2]. It is estimated that 83% of the UK population live in areas where road traffic congestion is a major factor leading to poor air quality for individuals, associated with increased morbidity from respiratory diseases. In highly populated areas, or those which are essential to the economy of the UK, major changes to or renovations of the existing road networks may not be cost effective.

Against this background, leveraging greatly improved sensing capabilities through Artificial Intelligence (AI) can achieve greater traffic throughput in road traffic networks. A subfield of AI, reinforcement learning (RL), can adapt to the unique characteristics and demand profiles present at each intersection in a large city. Through this, RL agents can learn to coordinate signal phases to optimise the flow of traffic and minimise delay and increase traffic throughput. RL-based signal controllers can also be used to minimise the environmental impact and maximise the air quality in a given area when compared to existing commercial approaches.

By using an industry calibrated microscopic traffic simulator and real-world data for road network and network demand, we evaluate the performance impacts of state-of-the-art algorithms as well as the environmental impacts of each RL algorithm when tested on real-world cities. Our results show that state-of-the-art RL algorithms can outperform commercial solutions in efficiency and environmental impact.

Mapping electric vehicle charging points for Hampshire County using multi-criteria decision analysis optimisation

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Achieving net-zero carbon in the UK by 2050 will necessitate the decarbonisation of the transportation systems. However, there are challenges to this, especially for vehicles in cities where the charging infrastructure is at its minimum. Overcoming these challenges will undoubtedly encourage electrical vehicle (EV) use, with commensurate reductions in emission coupled with better environmental conditions in cities, e.g., air quality. Drivers, overall, are reluctant to invest in an EV if they cannot access a convenient charging point within their living area.

This research provides a methodology to support the planning for the optimum siting of charging infrastructure, so it is accessible to as many citizens as possible within a city. The work focuses on Hampshire County in the UK. The multi-criteria decision approach is based on the Analytical Hierarchy Process (AHP) linked to site spatial assessment using Geographical Information System (GIS). The assessment considered key criteria such as road type, road access, on-road parking availability, road slope, proximity to fuel stations, proximity to low voltage grid, current/planned charging points, car parks and population distributions. The process contains two suitability filters, namely, restricted road and suitability mask. In the first, all restricted roads were excluded from further analysis, which resulted in reducing the road segments from over 90 thousands to around 18 thousands. When applying the second filter an overall result of less than 500 suitable EV charging point locations was achieved. These locations were validated using the Google Earth® imaging platform to check actual locations against those predicted by the analysis.

Investigating the impacts of connected and automated vehicles on road carbon emissions: A semi-systematic literature review

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Rapid breakthroughs in Connected and Automated Vehicle (CAV) technologies together with the net-zero targets set for the next three decades raise a serious question about the potential impact of CAVs deployment on carbon emissions from road transport. The uncertainties surrounding this dilemma are profound mainly due to the complex interdependencies between technological capabilities, public travel behaviours and policy interventions. Previous modelling and simulation studies suggest a considerable variation in how CAVs may contribute to carbon saving or give rise to CO₂ emissions. This paper aims to constrain uncertainties and identify the mechanisms through which CAVs may influence road carbon emissions. A semi-systematic literature review was designed and conducted which resulted in identification of 40 relevant publications and documents. Subsequently, 38 mechanisms were ascertained and classified across five major categories: i) emissions per mile; ii) emissions per vehicle; iii) emissions from infrastructure; iv) vehicle miles travelled (VMT); and v) emissions per manufactured vehicle. Several of the identified mechanisms closely relate to vehicle energy consumption (rather than only carbon emissions), accordingly they are also applicable for examining potential implications of automated and electric vehicles (AEVs) in future mobility landscape.

SESSION 2: Low carbon comfort

Low carbon comfort research opportunities

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For the UK to meet its net zero targets, buildings need to completely decarbonise their emissions by 2050. The Centre of Excellence for Low Carbon Comfort (LCCC) is about accelerating the net-zero transition of buildings through a holistic approach to indoor comfort (air quality, thermal, lighting and acoustics) and advances in tools and analytic methods to deeply instrument buildings at scale. The LCCC aims to understand how low-carbon comfort can be delivered cost-effectively at scale, taking a multi-disciplinary approach to optimize socio-technical solutions. This will ensure that future living and working spaces deliver comfort and internal environmental quality as well as low carbon living.

Building management systems (BMS) for low carbon comfort

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In 2018, office and education buildings in the UK accounted for more than 10% of the energy consumption of non-domestic buildings, with some of the highest energy intensities (kWh/m²). Reducing this energy consumption while maintaining user comfort is a key step towards achieving net zero and mitigating climate change. Smart cities show promise in this area because they can process real-time data to optimise their operation, taking into account multiple objectives from various different stakeholders. Specifically, smart buildings will be able to use information about occupants and environmental conditions to use energy and other resources more efficiently. Given this, our goal is to work toward better ways of managing building resources without ignoring the human needs of comfort and productivity. This has the potential to create multiple layered societal benefits.

The work that we present in this talk addresses the challenge of constructing a Building Management System (BMS) which optimises both energy consumption and user comfort. While there has been a lot of recent research and innovation in using artificial intelligence (AI) for BMSs, existing work mainly focuses on energy cost and consumption, treating comfort as a secondary objective. To address this, we propose a new, extended comfort metric, which will build upon current comfort models (e.g., ASHRAE 55 and EN 16798-1). In addition to thermal comfort, it will include indoor air quality and lighting as well as occupant preferences and occupancy patterns. We will present our approach to first integrate the new comfort metric into an existing Reinforcement Learning (RL) based BMS, before incorporating the new metric into a multi-objective RL (MORL) based system at a later stage. We will discuss how our approach to BMS improvement contributes to low-carbon comfort in smart buildings. Our aim is to give stakeholders the flexibility to pivot between fully automated decision-making and suggestions that can be carried out manually based on incentives such as comfort, monetary savings, and reduced resource consumption.

Utilising children as agents of change to reduce heating use in domestic dwellings

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Within the home, space heating is responsible for over 60% of this total, thus gas heating represents the greatest potential for change. Many factors may influence occupant behaviour towards heating usage; some outside the occupier's control such as weather, building fabric and energy cost, but occupier thermal comfort is a primary driver. However, an occupant's energy literacy and personality type may also influence energy use. These traits, along with perceived thermal comfort, can significantly vary with differing cultures and demographics. Demographics within the home, such as age (both younger and older than the main occupant) have seen little research into their respective influences on the main occupant's energy behaviour. These influences could include pressure from the ever-increasing environmental awareness of children or the desire for increased thermal comfort. This study raises the question; do other generations in the home affect the main occupants' heating behaviour, in particular, do children affect the frequency and type of interaction with the heating system in the home?

To address this question, four single hour-long lessons were developed for a primary school in Lee on the Solent, Hampshire. These lessons were taught to classes from year groups 2-6 (6–11 year-olds) ($n \approx 150$) and addressed the basics of climate change and its associated causes and effects, emphasising energy use within the home. A take home activity was provided to the students to complete in their own time, this involved playing a simple game in which they looked around their home and recorded some simple data such as the temperature of the heating or how many windows were open. Results from this game, along with verbal feedback from the students and an online survey by the parents were then gathered and analysed.

The data showed that 100% of children spoke to their parents about helping the planet, with 89% asking their parents to change an aspect of their behaviour in the home. 33% of these were requests to lower the temperature of the heating. Most importantly, of these changes requested, 89% of parents stated that they would maintain this behaviour change for the foreseeable future.

Simulation of outdoor air pollution in Southampton

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The city of Southampton is committed to monitoring and reducing outdoor air pollution, in particular, Nitrogen Dioxide (NO₂) and Particulate Matters (PM_{2.5}/PM₁₀), which have been linked with adverse health effects under short- or long-term exposure. This project investigates the air pollution contributed mainly by road sources, which consist of major and minor roads in Southampton, by using Atmospheric Dispersion Modelling Software (ADMSRoads), and provides further understanding on the air pollution contributions based on qualitative and quantitative analysis. The model was validated by comparing the modelled concentration with the observed data from the Southampton AURN pollution monitoring station. This study has found out that although the simulation exhibits a tendency to underpredict pollution concentrations, the dynamics of the model were relatively promising as it managed to capture the trends over time of the concentration of air pollutants relatively consistently. Therefore, future improvements to the model may be made by applying correction factors to overcome the bias offset to obtain more realistic predictions of air quality. The simulation has also correctly predicted poorer air quality within the Air Quality Management Areas (AQMA) declared by Southampton City Council (SCC), which implies

that road sources have a notable contribution towards the air pollution. The advantages of this model are that it can be quickly altered to predict response to future policy actions and that it has sufficient resolution to be used for epidemiological studies linking air pollution with the prevalence of health conditions in the city. The findings so far indicate that further pollution control measures are still warranted as most of the pollutant concentrations from road sources exceed the latest (2021) WHO air quality guidelines developed to protect public health from effects of exposure to air pollutants.

SESSION 3: Sustainability in business

The impact of sustainability on commercial real estate

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Why now?

Commercial real estate continues to perform multiple functions for occupiers; it houses staff, facilitates collaboration, aids with recruitment and importantly is a physical projection of the occupier's brand and ethos. As sustainability becomes a key part of the wider corporate agenda, many businesses, both large and small, are making key operational decisions based on ambitious sustainability targets and this is influencing the commercial real estate markets. Business space forms a significant part of the built environment, a sector of the economy that produces an estimated 40% of global Green House Gas emissions. Central government have set the industry ambitious science-based targets, and the change in occupier demand means that commercial real estate is evolving. Non-compliance and complacency should be considered a systematic risk to landlords and tenants alike.

What is being done?

As the commercial real estate industry reacts to what is a significant change in dynamics, we are seeing a broad range of initiatives being introduced. These include measurement and data collection, new environmental and welfare certification, adoption of new technologies and changing practices. These are all reflective of evolving tenant demand criteria as well as the individual ambitions of the landlord or developer. There is a realisation that the risks around obsolescence and subsequent decrease in asset value could impact those that fall short of the benchmarks.

What is the future?

The push towards corporate sustainability will continue to be driven by internal and external stakeholders demanding accountability and positive change. As we look forward, the need for the built environment to make a positive contribution to this agenda will become a necessity and is seen by many investors as an opportunity. The market continues to move and adapt - it is likely we will see an increased divergence between commercial real estate assets with a perceived 'Brown Discount' and 'Green Premium'. Although this is generally positive it presents many landlords and developers with challenges. The increased capital cost of obsolescence will need to be reflected in cashflow, and green focused lending may impact liquidity and asset values going forward.

Using the GHG protocol and science-based targets to estimate scope 1, 2 and 3 emissions and set reduction targets for a city-based University: Experiences and early results

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Many institutions and organisations are starting to commit to reducing their operational emissions in line with national targets. These include 'net zero' by 2050 or earlier or the even more ambitious 'net negative'. But in order to turn these commitments into concrete plans for action organisations need to baseline their current operational emissions and use this as a basis to a) set SMART targets and b) develop work programmes that can hit those targets. This presentation will describe how the University of Southampton has used the globally

recognised GHG Protocol to establish its emissions baseline and to start to set ambitious targets via a set of six Sustainability Strategic Plan Goals.

Innovative extrapolation statistical methods for the calculation of carbon emissions for real estate assets

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With governmental entities failing to follow the IPCC's recommendations, some private actors are taking action to reduce carbon emissions. In 2021, Tikehau Capital, a major French asset management company, committed to the Sciences Based Targets, an initiative supporting emission reduction objectives that limit global warming to 1.5° Celsius. Since at this stage no standardized methodology exists to calculate the carbon emissions of real estate, a statistic based innovative methodology is proposed by the authors.

The methodology carried out in order to evaluate the carbon footprint of the real estate assets of Tikehau Capital is presented and developed through this article.

The study treats a portfolio of over 2330 real estate assets in various European countries. The assets are of diverse property types and have a mean surface of over 2550m². The methodology follows the GHG protocol including scopes 1 and 2 of the carbon footprint. The initial calculation of the carbon footprint is made using the final consumption data from each of the assets. The emissions of buildings originate from diverse energy sources, for instance electricity production or natural gas for heating.

However, missing data is one of the main challenges of the study, as the final energy consumption figures are only known for approximately 30% of the overall assets. A twofold process is therefore used, where data is being collected from different asset managers, while at the same time extrapolation is used for most of the assets. To calculate the missing consumption data, the authors have developed an approach using statistical methods and drawing from the literature and additional data collected: surface, user behaviour, occupation. Moreover, the authors use their experience of carbon emission calculations from other real estate assets in order to categorize buildings and transfer knowledge.

The study has to respond to further challenges: taking into account different national contexts - emissions of the energy mix, regulations on constructions over the last decades - diversity of building uses - commercial, housing- and stages in their life cycle - renovation, exploitation, etc.

District cooling – assessment of price models supporting the efficiency

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The global cooling demand in buildings is expected to threefold by the year 2050. Compared to individual building cooling equipment, district cooling is a more energy efficient technology to supply this increased cooling demand. However, many district cooling systems suffer from low return temperatures, which usually originate from the buildings' systems and substations and cause increased operating costs for the district cooling company. Previous studies have

identified the need to provide economic incentives to district cooling customers for them to improve the return temperatures from their substations and buildings.

The aim of this study is therefore to assess district cooling price models which reward customers who achieve high return temperatures. The study is based on operational data from an actual district cooling system located in Gothenburg, Sweden and 26 of its connected buildings. The current price model of the district cooling system, comprising the three price components energy, power, and flow, was evaluated for the 26 buildings for the years 2018-2020. The results showed the shares of the current price model's components ranged from 19-63% energy, 28-78% power and 3-21% flow for the different buildings, based on average values for the three analysed years. This demonstrates the individual variations for the shares of each price component are very large, primarily dependent on the total energy use of the building. It was also seen buildings with a low-cost share of the flow component not necessarily had high return temperatures. Based on the current price model assessment, some incentives to maintain well-functioning substations achieving high return temperatures are provided, although the incentives are rather low. Altered price models, for example adjusting the relative cost of the flow component or changing to a return temperature component, are compared with the current price model to find which one is more favourable for customers with high return temperatures. The outcome of this assessment provides district cooling companies with guidance on how to design their price models.

How the new European taxonomy for sustainable activities will enable the transition to more sustainable cities?

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This paper will analyse how the European taxonomy, and in particular the first two environmental objectives launched in 2021, will impact the real estate sector and enable the transition to more sustainable cities.

The European Taxonomy establishes precise specifications for an economic activity to be considered sustainable. It aims to direct financial flows towards these activities. Of the 6 defined objectives, climate change adaptation and mitigation are applicable since January 2022. The other 4 (biodiversity, water, circular economy, pollution) should become applicable in January 2023.

In 2020 the real estate sector was responsible for 37% of global energy-related emissions and 36% of final energy consumption (GlobalABC). It is therefore one of the most carbon intensive economic sectors, while at the same time reaching all-time high investments of 359 billion € in 2021 at the European market (CBRE).

The authors will use their strong expertise of the taxonomy and of the financial and real estate sectors. The methodology will draw from different consultancies conducted by Green Soluce with real estate investors and developers in light of new financial and environmental regulations. Observations, risks and strategies from a relevant sample of real estate actors will be used. The study will also use a survey on ESG trends in Real Estate investments in Europe conducted in 2021 by Green Soluce. A new round of interviews will be conducted with the same actors in order to follow up on the impact of the taxonomy after its entry to the market in 2021.

Our study will conclude on the impact of the taxonomy on climate adaptation and mitigation strategies in the real estate sectors in Europe but also outline the limits and uncertainties. It will also offer recommendations on how to reinforce the effective use and application of taxonomy-related rules by real estate actors (investors and asset managers but also developers and users).

SESSION 4: Energy technologies (1/2)

Options for cost-effective home heating: A case study of a ground source heat pump installation

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Understanding the relationship between the heat loss of a home and its ability to be heated with a heat pump is increasingly relevant to today's challenge to decarbonise Britain's housing stock, with its high proportion of leaky buildings. This paper looks at a home currently running a ground source heat pump and asks the question: could it have been done more cost effectively but still deliver equivalent levels of comfort to the occupants?

Using hypothetical scenarios, it looks at what could have been done differently, ranging from reducing heat loss to increasing flow temperature. Reducing heat loss incurs higher up-front costs before the installation but lowers the cost of the heat pump and its subsequent running costs. Increasing the flow temperature means the cost of the insulation and up-rated heat emitters could have been avoided but this has a knock-on impact on the cost of the heat pump, the amount of heat required and overall efficiency of the system.

The study uses real performance information from the system's data reporting, as well as physics-based calculations to determine the set-ups required to deliver equivalent levels of heating in the home.

Examining these scenarios, the paper assesses whether the house and heat pump system could have been set-up in a way that would have lower costs over a ten-year horizon, compared to how it is currently configured. It also looks at whether these alternative configurations deliver equivalent levels of heating (and cooling) service compared to the existing set-up.

Finally, it looks at the consequences for installing heat pumps to the rest of the housing stock, using some of the lessons learnt from this study.

Thermal performance analysis of a large-scale water pit heat storage

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Solar thermal application is an effective approach to achieve carbon neutrality. The large-scale water pit heat storage (PTES) is a key component to ensure the stability of large-scale solar thermal plants. Based on the model of type 1535-1301, this paper performs a 2D simulation investigation of the long-term thermal performance of PTES using Trnsys. The accuracy of this model was verified by comparison with measured data from the solar plant in Dronninglund, Denmark. The results show that the average error between the model and the actual measurements is only 3%. In addition, it can be found that the PTES average temperature decreases from 24°C to 12°C before the 80th day due to heat losses. During the charging period from the 80th to 250th days, the PTES average temperature increases to 68°C. In which the PTES formed a temperature stratification with 80°C at the top and 40°C at the bottom. The sloping soil temperature boundary expands and shows a non-uniform stratification of 70-10°C with 10m thickness. The average temperature of the PTES gradually decreases to 16°C during the discharge period after the 250th day. The actual charging and discharging energy are 11,868 MWh and 11,250 MWh per year,

respectively, and the total heat loss is 1,157 MWh. The storage efficiency is as high as 90.1% because PTES is used for both long-term and short-term energy storage. This paper reveals the dynamic thermal process of PTES throughout the year to provide a reference for designers.

Improvement of building envelope performance through phase change materials (PCMs): Results of experimental activities

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The energy demand for indoor thermal comfort represents more than one-third of the total energy demand, thus forcing to introduce new strategies to improve the buildings' performance. Further, the demand for space cooling applications is continuously increasing and is leading to serious environmental issues that force the development of passive cooling techniques to reduce the demand and therefore the consumptions. This, combined with the current scenario in which existing buildings are the greatest share and the rate of new constructions is only 1%, is forcing to find solutions that can be adopted especially in case of refurbishments. Among the possible passive cooling strategies that can be adopted on the building envelope there are heat modulation techniques, which can be achieved using phase change materials (PCMs). Focus of the research was the experimental investigation of the effect of the incorporation of a granular paraffin PCM in a lime-based plaster for the application on the outermost layer of a wall. The plaster chosen was a lime-based one, instead of the more common cement-based, as it is the most appropriate in case of application on historical buildings, while the PCM was in granular form so that the incorporation inside the plaster would avoid any leakage problem during the melting phase. A sample of a reference lime-based plaster was realized and used as benchmark that was compared to the other two samples realized, in both of which 10% by mass of PCM was added and whose melting temperatures were 27°C and 28°C, respectively. These were tested both in laboratory, under controlled conditions, as well as on a mock up building, under real conditions, and their behaviour was monitored in terms of temperatures and heat fluxes. The addition of the PCM allows an increase of the thermal inertia of the building envelope and aim of the research was to verify whether this brought to a reduction of the incoming heat flux, with a consequent reduction of the energy demand for cooling, and a reduction of the temperature fluctuations on the innermost layer of the wall, with the aim of improving the indoor comfort for occupants.

Coupling-up urban buildings together for augmented solar PV output in Bangladesh

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The government of Bangladesh adopted and enacted policies to ensure the mandatory installation of solar photovoltaic (PV) systems in high-rise buildings in major cities including the capital city, Dhaka. The purpose is to shave off some of the demand from such buildings, as well as to meet the escalating power costs in a sustainable way. However, there are limited studies to support the success or otherwise of such interventions and what technical and infrastructural challenges are encountered. One of the issues identified was the reduced power availability from a single tall building area footprint. Hence, this study examines the

prospects of a modified approach for deploying PV systems on the rooftop tall buildings and interconnecting their systems (arrays) to provided augmented power at scale. The study used the theoretical estimation method to understand the feasibility of such array interconnectivity from a sample of fifty-eight buildings (GPS was used to measure the rooftop area of those buildings) located by a road in Dhaka city. Such connectivity lends itself to the reduced balance of system components such as inverter and control equipment. This resulted in a reduction in the cost and transmission losses. The results show that such modification have several advantages over the previous approach endorsing a sustainable way to retain the policy.

SESSION 5: Cities, wellbeing, and behaviour

Levelling up, the much-needed outcome from decarbonising properties

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TBD

Becoming a national park city

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National Park City is not a status conferred by a government, it is an award a city can receive from the National Park City Foundation in recognition of having demonstrated widespread engagement with key sectors within a city and envisioning and implementing the priorities identified in line with the vision.

The National Park city concept aims to break down ideas about humans and nature being separate, with the majority of us living in cities and 'national parks' being generally elsewhere, places most people associate with occasional day trips. It is about creating a city that is greener, wilder and healthier, where it's easy for people to be close to nature and active outdoors.

This project is both about the means and the end, it is a process of citizen empowerment and co-creation which is supported by local authorities but led by a cross section of community groups, businesses, academics and local 'champions'.

The Southampton National Park city project is working with the London National Park City Foundation, both local Universities, local schools and the New Forest National Park Authority to make Southampton a National Park city. Through a process of citizen consultation, a network of local champions and a collective will to see projects implemented in line with the vision we aim to present a portfolio of work to achieve the status by 2025.

This presentation will explore the concept, the process, the challenges and the opportunities of this approach to enhancing human and non-human wellbeing in the urban environment.

Low-carbon resilience planning to improve urban ecological security: A critical review

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Cities are subject to multiple and uncertain ecological security threats due to climate change. On the one hand, cities need to reduce carbon emissions from key sectors, on the other hand, the adaptive capacity of cities need to be improved to resist stress, that is, resilience. In this study, low-carbon cities and resilient cities will no longer be two separate urban goals. In order to mitigate climate change in urban evolving development, the similarities and differences between the two, including design concepts, organizational mechanisms, technologies and implementation methods, are integrated. This review critically analyzes the recent developments on the contribution of building a low-carbon resilient city to improve

urban ecological security. Specifically, the stability of ecosystem structures, functions and processes to external disturbances can be used to reduce the risk of nitrogen in cities, while self-regulating/organizing capabilities within urban systems can be used to increase the carbon reduction potential of different sectors. Co-evolution of ecosystem and external environment can effectively reduce the transfer of PM2.5 between urban areas. The ability to restore balance after disasters caused by climate change, such as floods and torrential rains, can reduce water security issues. The key mechanisms involved in the improvement of low-carbon resilient capacity include determining uncertainty disturbances based on urban characteristics, tracking the city's evolution in the defence, adaptation, and learning stages, and identifying key sectors that can promote resilience and reduce carbon emissions. Overall, under the requirements of coping with global emission reduction targets and climate change, the existing research would put forward the necessary theoretical support. In addition, this comprehensive review would help various take holders correctly understand the dilemma faced by low-carbon resilient city planning in the face of urban ecological security issues.

Moving towards renewable and grid-supportive district energy systems – experiences gathered from design to operation of a case study in Germany

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The pharmaceutical industry is a profit-making sector of the healthcare system and has grown into a self-regulating complex system over the years. Starting from the pre-clinical to clinical development of drugs to the authorisation and marketing thereof, a typical multinational pharmaceutical company of today operates in complex ways which partly emerge from the multiple interactions within and without the company. The complexity is further given by the unpredictability of the outcomes: merely 1 out of 10 drugs that are in development are likely to be approved. The plethora of regulations by authorities such as the European Medicines Agency pose negative feedback on this complex system which is further aggravated by the reimbursement landscape of each country, taking a toll on the innovative side of this privately funded sector.

By analogy, infrastructure operations with distinct supply systems delivering specific critical products and services, pharmaceutical companies have become the exclusive suppliers of drugs within the healthcare system. Increasingly traditional public sector infrastructure provision has been privatised, as has national health services drug development, resulting in high levels of regulation in each, constraining innovation and profitability, hallmarks of the private sector. Just as infrastructure delivers the lifeblood of cities, pharma delivers medicines for the health of individuals: both aim for public health and societal good. Failures in infrastructure delivery, such as unaffordability by the poor, match with pharma failures to provide equitably to all individuals: the poor cannot afford the best drugs. The urban sprawl in cities and the rise of informal settlements without sufficient infrastructure, can be observed in health care by the rise in use of alternative and unreliable medications by sections of the population who are excluded from pharma penetration. Our work studies such analogies between infrastructure and pharmaceutical companies in the hope of a better understanding of the operations of and connections with each other and inspirations about finding solutions from these two similar, yet distinct complex systems.

Reshaping the tourist movement in historical urban areas for enhancing architecture conservation: A case study of the historical district of Koya City

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Architectural strategy in the conservation field should be on both levels tangible and non-tangible. The conservation of the non-tangible part includes signs and symbols. It transmits in various ways, such as the oral, artistic, and literary forms of expression. The visitor of historical places can participate in non-tangible conservation if the architect makes the visitor attracted to the sites. To make the visitor see the cultural heritage value of the sites, the visitor should move to different parts in different directions instead of showing them a few buildings and monuments. The study aims to increase visitor activity and promotes non-physical conservation. Many places like Koya City have a very high architectural value but are still neglected and uncovered by the visitors. Like other historical cities, Koya City attracts different types of tourists of different ages if they go through it. The study will take two approaches: using an existing map to conduct space syntax analysis based on pedestrian movement. The morphology of the historical area is constructed based on the pedestrian period. Then design a questionnaire to collect the required data, specify the locations that mostly visit, and determine the paths that they have taken. Furthermore, it determines the areas where visitors rarely visited and alleys that they don't go through it for different reasons. That gradually will be a neglected place. Based on the findings, the study will design strategies to enhance the tourist movement and enhance non-tangible conservation.

SESSION 6: Solent future transport (2/2)

Environmental and health information effects on travel behaviour in the Solent region, UK

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The Solent Future Transport Zone, a trial programme funded by the Department for Transport (DfT), runs numerous trials of innovative mobility services across the Solent region to help make journeys easier, smarter, and greener. Mobility as a Service (MaaS) is a recently developed concept that provides multimodal journey planning, booking, and payment services through a single platform, i.e., a so-called MaaS app. The Solent MaaS app aims to help Solent residents change their travel behaviour towards the use of sustainable modes of transport (and away from the private car). In addition to providing users with timetabling, mapping, and journey duration information, the MaaS app has the potential to include information regarding the environmental impact of different travel options offered for a given journey, including multimodal options such as e-scooter and bus, or walking and shared car. Similarly, it is also possible to provide users with an indication of the calories they are likely to burn with each travel option. These types of personal and environmental health information are not typically included in existing MaaS apps, yet have the potential to enable MaaS users to make more informed decisions about their journey and its impacts. Given the lack of work in this area, the extent to which these types of information influence behaviour is currently unknown. The current research, therefore, addresses this gap, exploring how environmental and health information might influence self-reported travel behaviours of Solent residents. To explore this, a joint revealed and stated preference survey has been developed. The questionnaire will be disseminated among staff and students at the Portsmouth and Southampton universities before wider dissemination across the Solent region. Resulting data will help shed light on travel behaviour in the Solent region, with the analysis informing app (and wider intervention) design, with a goal to foster more sustainable travel habits.

Mobility as a service, interface design requirements with a focus on gender differences

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Mobility as a Service (MaaS) is an innovative transport solution that aims to provide seamless travel options offered by mobility service providers. It proposes alternatives to private vehicle use and encourages more sustainable travel choices. It is implemented through a single interface, typically a MaaS mobile application (app). Although gender is one of the major factors predicting adoption of new technology, gender differences in interface use have rarely been addressed in designing a MaaS app. Therefore, this study identifies key criteria for gender differences in interface use and investigates design requirements based on the criteria for developing a MaaS app that better suits gender-specific needs. The criteria were defined through a literature review on gender differences in interface usage behaviours. Three main differences were defined as 1) attitudes towards interface use, 2) information processing behaviours and 3) needs for support. Design recommendations using the criteria are suggested as follows. First, females show lower confidence and

acceptance in new technology than males. Thus, a MaaS app should be designed for ease of use by enabling simple access and process for main tasks to better assist female users. Second, females tend to be comprehensive information processors who absorb all the information before reaching a conclusion, in contrast to males who tend to be selective information processors. Simplicity should be prioritised for designing content, such as route and ticket search results that could cause complexity due to multiple options. This could help female users make an optimal decision more efficiently without being distracted by subtle cues. This could also benefit male users who pursue readily available information and want to gather information quickly. Furthermore, providing shortcuts to menus and saved searches could be useful for males. Third, females expressed a stronger need for support when conducting a task in mobile apps. Thus offering help, Frequently Asked Questions (FAQs) and instructions on how to use a MaaS app especially at an early phase of launch would be beneficial. Identified female and male users' characteristics from this study will support optimisation of a MaaS app that elicits positive user reactions and acceptance by all gender groups.

Mobility as a service and sustainable travel behaviour: monitoring and evaluation

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A mode shift towards more sustainable transport alternatives and the reduction of private car usage in cities are critical to achieve one of the UN Sustainable Development Goals, 'Sustainable Cities and Communities'. Mobility as a Service (MaaS) is a new concept that has the potential to shift individuals' travel behaviour towards more sustainable modes of transport as it provides a personalised journey planning and payment across various forms of transport in a convenient and compelling way.

Most recently, a multi-city MaaS app has been developed for the Solent region as part of the Solent Future Transport Zone MaaS project, funded by the UK Department for Transport, to make journeys easier, smarter, and greener. The app allows users to plan, book and pay for sustainable journeys via a smartphone across the Solent region including Southampton, Portsmouth, South Hampshire and Isle of Wight. In this research study, we propose a travel behaviour change monitoring and evaluation approach which comprises the determination of the sustainability indicators, data collection, quantitative and qualitative analysis. The proposed approach aims to collect travel behaviour data using revealed preference surveys and focus groups and analyse the change in travel behaviour caused by the MaaS and its impact on the sustainability dimensions namely economic, social and environmental. The analysis of the data collected through the Solent MaaS app will be demonstrated to enable practitioners, policy-makers, and local authorities to understand the potential impact of the MaaS on individuals' travel behaviour in a car-dependent region.

Future transport zone – top-down and bottom-up monitoring and evaluation

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The Future Transport Zone (FTZ) Programme is a £28.8m series of research-lead projects and innovation trials ("interventions") across the Solent region, running from 2020 until June 2024. Monitoring and Evaluation (M&E) of the projects/programme is seen as an integral

part of the management process and may be defined as the systematic and objective assessment of an ongoing (or completed) intervention, or series of interventions, including the association between project inputs, outputs, short-term outcomes and longer-term impacts. The purpose of M&E is to determine what works, for whom, where, when and why. It provides the link between the project context, its delivery mechanisms, as well as the expected outcomes and impacts. It also provides the mechanism for those sponsoring or involved in carrying out the projects to know (and be able to show) that the effort and costs invested are justified, and M&E activities can help to improve the delivery of interventions during the implementation phase, for example by providing feedback to refine the trials, or in post-implementation review to assist in developing future methods.

M&E can also help to answer important research questions relating to the projects/programme's objectives, such as (at a programme level) "can particular schemes help to solve some of the environmental and sustainability challenges faced by the region, by providing congestion relief and reducing carbon emissions?" and (at a project level), "what incentives and rewards for a particular scheme might be effective in overcoming the barriers and encouraging a modal shift away from the car?". M&E at a Programme level therefore typically has a focus on policy research or "top-down"-driven activities, which are supplemented by activities also feeding from "bottom-up", i.e. being delivered by the individual projects. The overall framework therefore involves developing an integrated top-down and bottom-up systematic approach for assessing the FTZ interventions' design, implementation and outcomes to see whether they worked or not, whether the associated costs and benefits were as anticipated, and whether they had any other consequences, as well as how well they were implemented, by following (and in some cases anticipating) recognised best practice and previous guidance from Government.

SESSION 7: Resilient future infrastructure

Port city infrastructure challenges and opportunities to achieving zero emissions: A case study utilising Portsmouth International Port

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Maritime operations are crucial to the efficient movement of goods nationally and globally but are often high contributors of CO₂e emissions and other air pollutants. The adoption of green low carbon energy systems offers the potential to support the necessary transition of ports and their operations to net-zero and beyond. Ports are often found centrally in large maritime cities and can contribute significantly to both the economic development of a region, but also to significant carbon emissions and poor air quality.

Portsmouth International Port is the UK's largest and most successful municipal port, owned by Portsmouth City Council, and is one of the sites of the new Solent Freeport. It is committed to becoming the first carbon neutral UK port by 2030, and the first zero-emission port by 2050.

The Shipping, Hydrogen and Port Ecosystems (SHAPE UK) project, funded by the Department of Transport, through the Clean Maritime Demonstration Competition, has helped to identify the barriers, infrastructure and regulatory considerations that will enable port managers to install renewable energy generation and storage systems for the port. It has also begun to address the infrastructure and vessel challenges by supplying a working vessel to the port authority, powered by an engine using green hydrogen.

This paper will present some of the findings of the SHAPE UK project, particularly those that are relevant to the development of evolving cities. It will outline the challenges for a port like Portsmouth in achieving its ambitious targets, presenting both opportunities and barriers for achieving carbon neutrality and zero-emissions. The wider discussion will set this case study within the wider interests of Port Cities both within the UK and overseas.

Principles for resilient civil infrastructure

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This paper presents a set of six principles for resilient civil infrastructure: energy, transport, water, wastewater, waste, and digital communications. The principles are mindful of the unique characteristics of civil infrastructure, the increasing contextual challenges to resilience, and the increasing interdependencies of civil infrastructure. The literature review identified 14 principles, and they have been consolidated down to six through a series of international workshops with inputs from over 100 experts.

The principles are a system of goals with the requisite variety to address the resilience challenges of civil infrastructure, and are appropriate for emerging, developing, and developed countries. The principles are primarily intended for use by national governments and those departments, agencies, operators, regulators, etc., responsible for civil infrastructure. However, it is equally applicable to any level of government, institutions, donors, investors, owners, designers and contractors, service providers, and international organizations that are interested in implementing a set of actions that will improve civil

infrastructure resilience contributing to positive economic, social and environmental outcomes for their nation.

To assure progress toward resilient civil infrastructure, a new commitment to ‘net resilience gain’ is introduced, requiring a commitment from stakeholders that all interventions into civil infrastructure, not just those targeted at enhancing the resilience of a system, must demonstrate that they enhance the systemic resilience of civil infrastructure and not damage the wider context.

Key actions, which underpin each principle, are grounded in literature, honed by expert opinion, and brought to life with global examples. Although the key actions are reasonably distinct, their interdependencies are also identified to link different principles. Key actions are intended to foster innovative thinking to solve resilience challenges unique to each nation and guide stakeholders on the interventions to achieve net resilience gain of civil infrastructure. As civil infrastructures become more varied, interconnected, and innovative, and as our environments (natural, social, built, etc.) become more diverse, new key actions will emerge over time. Furthermore, there is a risk of unintended consequences as with any invention. Assessment of the national efficacy of these principles is recommended.

Design and cooperative operation strategy optimization of multi energy source district heating system with solar energy

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District multi energy system has become one of the emerging ways of energy supply for buildings because of its advantages of environment-friendly and energy saving. For district heating, multi heat source system is more complex than traditional single municipal energy supply. Therefore, reasonable system design and operation regulation of multiple energy sources are of great significance to the efficient operation of the system. As one of renewable energy, solar energy has great potential. Therefore, based on the traditional single municipal heating, this study adds regional solar heating, heat storage and waste heat recovery equipment. Using Modelica language, the model of multi heat source district heating system is established on Dymola platform. Taking economy as the optimization objective, the system is simulated to explore the appropriate equipment capacity design and multi heat source cooperative operation strategy of the system. Taking a district heating system in Norway as an example, the optimization results are evaluated and analysed, the advantages of the multi heat source district heating system are shown, and the operation performance and regional applicability of the system are discussed.

Southampton port-city: A circular economy hub for southern England

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If the UK is to achieve the goal of net-zero carbon emissions by 2050, a complete transformation of society is essential. New technologies vital to this transformation such as renewable energy and battery storage, rely on resources with finite supplies and rates of supply that will struggle to match this ambition. The current linear model of resource use creates considerable amounts of waste, losing resources in the process and creating

environmental damage. The transition from a linear economy to a circular economy is one aspect of this transformation that is therefore not only essential but also able to provide considerable social, environmental, and economic benefits. Port-cities are well suited to embrace the circular economy, and this is especially true of Southampton which is ideally placed to lead this transition as a transportation hub, a hotbed of industry, end-of-life products, and secondary raw materials, as well as potential consumers. Port-cities adopting a circular economy can add economic value, reduce the environmental impacts of port activity, and provide social benefits to the local area. This process would provide considerable benefits for Southampton Port-City and the surrounding areas. Despite the clear potential, considerable barriers to this remain. The lack of cooperation of port-city stakeholders and a lack of leadership presents challenges. A circular economy cannot exist if the stakeholders operate in isolation. This paper will present the results of a questionnaire distributed to key stakeholders in Southampton, to estimate current levels of the circular economy activity within the port city; reviewing progress to date; subsequently identifying key opportunities and the potential for the future; suggesting key businesses/industries to be targeted; and developing a co-owned plan of action for the future. This plan of action will then be presented to key stakeholders such as representatives of the port of Southampton, Southampton City council and Hampshire County Council. This will hopefully help establish Southampton as a leader within the UK in adopting the circular economy.

SESSION 8: Energy technologies (2/2)

Interpretable data-driven energy modelling to support decarbonisation strategies – Southampton Highfield Campus case study

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The current trends toward decarbonised, decentralised and smarter energy systems is creating a further boost to the buildings' energy efficiency upgrades. Due to the level of investments required to meet decarbonisation targets, reliable energy performance data serve as the foundation for decision-making in the planning of energy efficiency interventions and carbon reduction strategies. In this context, data-driven methods that use measured data can provide reliable estimates of energy, cost, and environmental impact reduction when used in conjunction with performance benchmarks. Data-driven methods derived from variable-base degree-days approaches, which are widely used for weather normalisation of energy statistics, can be further developed by including additional input variables beyond outdoor air temperature and creating models with not only monthly and daily data resolution but also hourly data resolution, allowing them to characterise dynamic operational profiles. This extension may be possible while retaining interpretability and an approximated physical interpretation of the underlying model coefficients. In this paper, we use this novel approach to aid in the implementation of Southampton University's decarbonisation strategy at the Highfield campus. The methodology and tools proposed are scalable and can be easily implemented in other case studies involving building stock decarbonisation and energy efficiency measures.

Understanding residential cooling loads in hot arid climates: A case study in the City of Jeddah

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Saudi Arabia being located in one of the hot and arid regions of the world is ranked as the third largest country for electrical cooling demand. Almost half of its currently generated electricity is used by the residential sector, where ~70% of this is used to support cooling loads. The Saudi government has an aspiration to be net-zero by 2060, this cannot be achieved without transitioning its current fossil fuel dominated energy supply to a sustainable pathway based on renewable energy and energy efficiency. The Saudi 'energy sector transition plan 2030' included 40GW capacity of solar photovoltaic (PV), based on large scale solar farms but also has some emphasis on rooftop PV power generation. This research investigates how optimum rooftop PV integration within domestic buildings can support electrical loads requirements for air-conditioning. Understanding cooling loads at different times of the day across various seasons is crucial to appropriately size the PV systems, and it also helps in making better investment decisions by the building owners. These issues are especially important considering the low residential electricity tariffs in Saudi Arabia. A year-round monitored electricity consumption data of a villa in Jeddah was analysed in relation to ambient temperature and its relationship to cooling, to provide the basis for optimally designed PV systems. Changes in ambient temperature are highly correlated to residential cooling loads and such changes also affect PV power output.

Results show that daily cooling loads varied between 76kWh in December and 187kWh in July. Summer months presented two cooling peaks with the main peaks observed between 8AM and 10AM, and another peak occurred between 1PM and 4PM. The winter months have only one peak between 12PM and 3PM. The highest summer peak load for cooling was found to be 14kW in July, whilst in winter this was 5.5kW in January. It is therefore clear that understanding the variations in residential cooling loads can help the building owner to choose an optimised PV system with the shortest payback period. It is anticipated that shifting cooling loads to rooftop PV power generation will result in reducing the demand on electricity utilities.

Thermal insulation of gypsum boards made with olive pomace: Characterization and simulation study

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Building insulation is one of the simplest and most effective ways to save energy. The main objective of installing insulation materials in the building is to reduce energy consumption for heating or cooling by increasing the thermal resistance of the building envelope. Several attempts have been made to improve energy efficiency in the building sector to reduce energy consumption. This work aims at the thermophysical characterization of a bio-material based on plaster with different percentages of olive pomace (0, 10, 20 and 30%). The experimental results showed that the addition of olive pomace plays an important role in increasing the thermal resistance of the composite. Indeed, a 39.14% reduction in thermal conductivity was observed compared to the reference plaster. It can be concluded that the gypsum-olive pomace composite can be used to develop light materials for thermal insulation. The experimental results were used in a dynamic thermal simulation with TRNSYS software to understand the thermodynamic behaviour of roofs with plaster and olive pomace. The results showed a reduction of 1.2% of the total annual energy consumption for heating and cooling.

Experience of installing rooftop solar PV systems in Saudi Arabia

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The Kingdom of Saudi Arabia (KSA) is blessed with high solar irradiance, being located in one of the hot and arid regions of the world. This has implication for thermal comfort in buildings where KSA is the 3rd largest country in the world for electrical cooling demand. KSA has an aspiration to be net zero by 2060 and is aiming transition its current fossil fuel dependent energy supply to that from renewable energy. The country 'energy transition plan 2030' included 40GW capacity of solar photovoltaic (PV), based on large scale solar farm projects but also has some emphasis on rooftop PV power generation. This research is in support of the latter as it addresses ongoing multifaceted research that will have direct impact on air-conditioning cooling in the domestic sector in KSA. Here we present research that looks at the practical challenges of PV deployment in such sector. A case study of installation of PV systems in two villas in Jeddah is presented. The electricity consumption

profiles of villas were previously monitored and quantified and was linked to a modelling of the needed PV system sizes. The results indicate that locally used rooftop PV output could reduce the household electrical demand from the grid.

This paper covers the experience of installing rooftop solar PV systems on the roofs of the two villas. As indicated earlier the results of the previous modelled showed that a 15 kWp system will be the maximum that can be used on the roof areas whilst providing a major impact on grid imports. The paper will highlight some issues that emerged during the installation and operation of the two 15 kWp systems. Nevertheless, the results showed that with guidance on sizing and systems' configurations coupled with appropriate in country supply and support, such deployment is feasible at scale. This presented project is part of an international collaboration between King Abdulaziz University in Jeddah, KSA and the University of Southampton, UK, and is sponsored by the Ministry of Education in KSA. The project is now gearing up to install further 18 systems which will be monitored for both consumption and user behaviour over the next three years. In order to provide robust analyses and inform policy, another 20 houses were selected as a control sample, wherein only monitoring sensors will be installed. These interventions can provide understanding of the impact of locally generated PV power on energy savings and the grid network. The research will provide datasets for other to use as well as guidance to planning and policy.

Mapping the Hampshire energy use landscape: A preliminary evidence base for a future local energy strategy

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This paper summarises analysis of the spatial distribution of energy use across Hampshire with a focus on domestic/non-domestic gas and electricity. It then goes on to analyse the relationship between these patterns, fuel poverty and local area emissions before discussing a range of options for both decreasing demand and also de-carbonising and localising supply. It concludes with recommendations for future research that can build on this preliminary analysis to provide robust input to a future Hampshire Local Energy Strategy and Plan.

SESSION 9: Smart cities and data

The unusual nature of cyber security threats facing cities and strategies to mitigate them

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A Smart City is essentially a highly connected ensemble of critical national infrastructure elements. This represents a huge potential for efficiencies and improved citizen services but at the same time a security threat of significant and growing proportions. Smart Cities present certain distinct challenges that differentiate them from other critical infrastructures, namely the highly distributed and fragmented nature of the physical assets and processes that comprise this emerging Smart City concept. In this paper we will characterize the unique nature of the Smart City Cyber Security challenge and discuss some of the approaches that will be needed to contain the threat and contrariwise unleash the inherent value of better-connected systems.

A competency framework for leading place-based digital innovation

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Cities and their infrastructures are complex and interconnected systems. Digital innovation has the potential to address such complexity by supporting the development of cities policy, governance, and management as well as their infrastructure planning and design. For instance, digital tools use cities data to enable informed decision-making that impacts the quality of life for citizens. The development of digital innovation projects requires the right human resources with the right set of competencies. Such requirement is challenging because professionals in public policy and infrastructure management are traditionally trained and work in disciplinary and professional silos. This results in a lack of knowledge, skills, and tools to produce optimal outcomes for communities across multiple sectors. At the same time, there is a need for built environment professionals with an interdisciplinary background to bridge the technical, societal, and operational aspects of cities and their supporting infrastructure.

This paper proposes a competency framework to help city managers and built environment professionals to plan and develop the competences they need to create public value and enable socio-technical and responsible digital innovation projects. A qualitative methodological approach was adopted for this research where data was collected and analysed from different workshops. As a result, the framework defines a three-pillar structure which is based on tasks, competencies and roles required to lead successful digitalisation in the urban built environment. The proposed framework will be validated by conducting and semi-structured interviews in multiple case studies addressing various types of digital innovation projects. The results will help cities to identify the capabilities, knowledge requirements, and skills that enable socio-technical innovation of urban systems, which are essential to improve outcomes for people and the environment. Furthermore, the framework will be used to create a foundation for designing and training qualifications following an interdisciplinary approach which help to break down the professional silos that currently exist in cities.

Machine-learning-based health monitoring and leakage management of water distribution systems

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The reduction of pipe leakage is one of the top priorities for water companies, with many investing in greater sensor coverage to improve the forecasting of flow and detection of leaks. The majority of research on this topic is focused on leakage detection through the analysis of sensor data from district metered areas (DMAs), with the aim of identifying bursts after occurrence. This study is a step towards development of 'self-healing' water infrastructure systems. In particular, the concepts of machine-learning (ML) and deep-learning (DL) are applied to the forecasting of water flow in DMAs at various temporal scales, thereby aiding in the health monitoring of water distribution systems. This study uses a dataset for ~2500 DMAs in Yorkshire, containing flow time-series recorded at every 15-minute interval over the period of a year. Firstly, the method of isolation forests is used to identify anomalies in the dataset which are verified as corresponding to entries in water mains repair log, indicating the occurrence of bursts. Going beyond leakage detection, this research proposes a hybrid framework of DL models - such as recurrent neural networks (RNNs) and transformer neural networks) - and state-space ML algorithms - such as Kalman filter and autoregressive integrated moving average (ARIMA). The ML algorithms are trained to forecast the stationary component of the expected flow patterns in real-time, which is then combined (through Bayesian updating) with the non-stationary component obtained from DL models. As well as providing expected day-to-day flow demands, this framework aims to issue sufficient early warning for any upcoming anomalous flow or possible leakages. For a given forecast period, the framework can be used to compute the probability of flow exceeding a pre-defined threshold, thus allowing decisions to be made regarding any necessary interventions. This can inform targeted repair strategies which best utilise resources to minimise leakage and disruptions by addressing both detected and predicted burst events.

Analysis and evaluation of CT transformation error for non self-contained smart meters installed in smart cities

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This paper demonstrates the usage of knowledge graph technology and linked data to holistically assess the impact of potential flood scenarios in a broad smart city context. It builds on the idea of a Universal Digital Twin based on the World Avatar dynamic knowledge graph, implemented using technologies from the Semantic Web. It connects usually fragmented city data into an ever-evolving, unified data asset, accessible for humans, autonomous software agents, and artificial intelligence. It supports FAIR data cross-domain interoperability, and ensures that data is connected, discoverable and queryable via a uniform interface. This work combines geospatial city data, such as information about the built environment and land use, with near real-time environmental observation data as well as further transient information, such as river water levels and flood warnings. Three new ontologies have been developed to extend the World Avatar knowledge graph and enable

interoperability between prior isolated data sources. The ontologies have been deployed using a high-performance graph database. Computational agents have been developed to incorporate multiple publicly available data streams into the base world of the Universal Digital Twin via application programming interfaces. Further agents act on the knowledge graph to investigate the influence of potential flooding events across different dimensions. Although numerous digital twin efforts have been developed to improve decision making as well as automate city workflows, most of these solutions do not leverage the connected nature of data coming from various sources and often focus on isolated fields. By contrast, this work demonstrates the capabilities for cross-domain impact estimation and context-aware data exploration, which support the United Nations Sustainable Development Goal to improve the assessment of vulnerability, exposure, and risk of communities imposed by flooding events.

Comparison of two methods for assessing rooftops for PV suitability

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Here we explore the deployment of solar photovoltaic systems in cities at scale using Geographic Information Systems (GIS). The research uses the cities of Southampton in the UK and Jeddah in Saudi Arabia as case studies.

In the first case study, a combination of aerial light detection and ranging (LIDAR) data and cadastral mapping was used to estimate rooftop PV potential in Southampton, UK, with the results suggesting up to 35% of electrical demand within the city could be provided by rooftop PV.

In the second case study, a region-based convolutional neural network image segmentation approach (Mask R-CNN) was applied to identification of flat rooftops from satellite imagery in the city of Jeddah in Saudi Arabia. The model was trained on a small sample of rooftops and then was applied to an independent area 4.5 km away. The results, although at a small scale, demonstrate the effectiveness of this approach for selecting buildings with appropriate rooftops for solar photovoltaic (PV) installation, in the context of closely spaced flat-roofed buildings, without requiring cadastral mapping or LIDAR datasets.

SESSION 10: Socio-techno solutions in cities

A carbon and cost assessment of alternatives to a natural gas CHP plant for a University campus

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The University of Southampton (UoS) has set out within its sustainability strategy to achieve net zero carbon emissions for Scope 1 and 2 by 2030. This would require all electrical and thermal loads to be net zero which poses a challenge for a central campus which currently operates a natural gas CHP plant. The energy centre of the Highfield campus at UoS operates two Jennbacher gas CHP engines (each 1497 kW electrical, 1476 kW thermal) alongside a boiler cascade of six 1500 kW units. Heat is fed into a high temperature heat network (90 deg C) supplying the campus buildings. For the 12 month period August 2017 to July 2018 the energy centre imported 66.1GWh of gas of which 45.4 GWh was supplied to the CHP units (69%) and 20.7 GWh (31%) to the boiler cascade. The 45.4 GWh of gas to the CHP generated 19.3 GWh of electricity and recovered 11.5 GWh of useful heat. The boiler cascade delivered 17.6 GWh of heat to the University district heating system. The energy centre operation is further complicated by the constrained electrical supply to the campus from the utility grid. This requires the on-site CHP to run for specific periods of the year for the campus to remain within electrical import capacity limits. A range of alternatives to the current gas CHP system have been assessed including grey, blue and green hydrogen for boilers or gas engines, heat pumps, pure electric heating and biogas.

The paper analyses current (and projected) campus electrical and thermal demands using HOMER in the context of a constrained utility connection. The lack of technology maturity and infrastructure readiness for options such as hydrogen means that current operators of gas fired CHPs face a difficult replacement challenge. Certainly in the short term, balancing the often favourable economics of CHP in the UK against their ever worsening carbon performance due to grid decarbonisation is not a scenario operators expected to face so quickly.

How smart buildings can benefit from privacy-preserving audio analysis

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Smart buildings have the potential to not only reduce the consumption of resources, such as electricity, but also to vastly improve the quality of life for individuals. Buildings of the future may be designed from the ground up or existing buildings may be retrofitted with certain capabilities that contribute to net-zero carbon goals and increased comfort. An important aspect of creating “smart” buildings includes the ability to sense multiple aspects of human occupancy, including how many people are inside, their personal comfort preferences, how they are distributed throughout a building, and their levels of movement or activity. This information can then be used to optimise energy consumption, e.g., by regulating heating, ventilation or lighting. However, techniques for tracking occupants and their activities are typically developed tangentially to issues of resource consumption. Specifically, previous work has relied on sensors such as passive infrared (PIR) sensors attached to doorways or CO2 sensors. While those sensors are affordable, they do not capture the granularity of information that is required to influence resource management or to create controllable and personalized comfort settings. To address this, and capitalising

on recent advances in artificial intelligence (AI), there is an opportunity to revisit the use of audio sensors (such as microphones) to analyse the “indoor scene” of buildings. Here, the AI techniques effectively create a detailed concept of real-time occupancy and activity in different areas inside of a building. While audio sensing is accurate, cost-effective, and easy to retrofit, audio has not yet been widely adopted as an information source due to privacy concerns.

In this work, we tackle two interrelated challenges: using AI to detect occupancy/activity and developing the AI to simultaneously preserve individual privacy including concealing conversational speech content. We will describe the various technical and societal challenges of adopting audio-based sensing in smart buildings. Our proposed solutions examine recent innovations in AI which do not require storing or recording any audio data. Successful implementation of privacy-preserving audio analysis has the potential to be expanded to non-verbal health signals (e.g., coughing or sneezing detection), emergency response, and increased accessibility.

Acceptability of a heat deferral approach for UK residential heating: Impacts from an online focus group approach

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The UK's carbon targets, as defined by the Climate Change Act of 2008, specify an emissions reduction of 80% by 2050, which in 2019 the government has revised down to ‘net zero’ carbon by 2050. In 2017, 17% (64.1 Mt CO₂), of the UK's carbon emissions were associated with non-electric use in the residential sector. The majority of these emissions are associated with natural gas space heating, cooking and domestic hot water. In order to meet UK ‘net zero’ objectives the UK will aim to decarbonise residential heat (currently through electricity and energy efficiency measures), which in combination with electric vehicles could lead to a 200-300% increase in the UK's annual electricity demand introducing serious capacity issues for the electricity system. In the future residential electrical heating or EV charging loads may need to be remotely adjusted to better suit the capacity of the electricity network and maintain substations and feeders within their technical and regulatory limits.

Here we present the findings from an online survey with a UK energy provider's household customers (N=4,100) and online focus group discussion (N=120) which asks whether household would approve of such a scheme and what levels of heat deferral they would be willing to accept at various times of day. The survey also gathers information on the occupier's energy literacy levels personality traits, trust in energy companies, social demographics, thermal comfort and general dwelling information. The results were analysed with reference to these topics providing evidence describing if and how these factors influence stated acceptance of heat deferral. These results helped to identify potential pathways for future research, guiding follow-up online focus group interactions to further understand the influencing factors whilst identifying ways to enhance household acceptance. Moreover, these results could be used to inform national energy reduction policies to aid sustainable development.

Reducing electricity loads and emissions in an off-grid city in KSA

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King Abdullah Economic City (KAEC), Saudi Arabia is currently supplied power in an off-grid mode using 25 MW diesel generators. The City aspires to transition from such fossil fuel supply to lower carbon options which is the main focus of this work. The approach explored here is the development of an overarching methodology to allow the implementation of both renewable energy power supply systems coupled with energy efficiency measures. To achieve a balanced approach, the work first considers demand reduction focussing on air conditioning (AC) loads and then designs of appropriate solar photovoltaic systems to cope with the demand. Available consumption profile data of different building (commercial, residential and leisure) types were analysed to establish energy reduction strategies for the City. The analyses consider cooling degree days to assess any weakness in the current cooling strategies and then develop interventions to address these. KAEC electrical consumption has been measured as 65 distinct electrical loads categorised in term of their AC intensity such as (i) pure AC loads (centralised chiller plant), (ii) independent AC loads (building supplied by an independent centralised chiller plant) and (iii) loads that has AC and independent AC together (buildings with own decentralised AC systems). The results show that the highest twenty loads represent 75% of the total electricity consumption of the City. Whilst six of the top twenty loads are pure AC (centralised chiller plant) and represent between 30 to 45 percent of the top 20 loads depending on the month of the year. The paper also reports on different strategies that have been investigated to reduce the AC consumption which lower the total energy consumption of the City.

Supply chain for PV farms, developed v developing countries

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There is no consensus when it comes to the definition of the supply chain. This disagreement is even greater when defining a supply chain for a particular product, project or organisation. For example, there are differences in identifying the supply chain for PV farms depending the academic or commercial perspective. In addition to that, the supply chain for PV farm varies substantially between developed and developing countries. This research attempts to consolidate available resources to identify PV farm supply chain and compare and contrast their structure in developed and developing countries. The definitions are broken down into elements and analysed to provide a comprehensive definition that encompasses these components. These elements are the main pillars that make the definition of Supply Chain. Some of these elements are 1. (main concept) such as a process, a network or a system. 2. (components) raw materials, suppliers, customers, warehouse, and transportation means. 3 (processes) manufacturing, logistics, inventory, finance, information flow and recycling. 4 (flow direction) upstream or downstream for materials, money and products. Then, the structure, maturity and growth of PV farm supply chains are analysed with respect to developed and developing countries. In addition, imported PV module percentage and market share are considered. The top 5 developed countries in terms of installed PV capacity have been selected, alongside the top 5 developing countries in terms of PV module manufacturing market share. The majority of developed countries

import PV modules, for example, the United States imports 89%, Japan imports 50% and Germany imports 80%. In contrast, developing countries dominate PV manufacturing with 70% for China, followed by Vietnam, South Korea and Malaysia with around 8%, 5% and 4% respectively of global PV module production.

Large consumers absorbing local renewable power generation through direct connection using private wires: a real-life case-study on the Isle of Wight, UK

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Driven mainly by the electrification of transport and heat, and the increasing penetration of low-carbon power generation sources, current electricity networks are increasingly under threat of outages and faults due to reaching cable thermal limits. As such as we make the transition to net zero it is important to manage demand, power generation and flows through the network. This may require the utilisation of large demand centres such as businesses and utility-scale renewable generation sites to provide the required balancing role in network stability.

This research explores the opportunities to connect large businesses directly to a local utility-scale generation site using private wires so that their demand can be met without import from the national grid. This will reduce the power flow through the electricity grid network and therefore will free up capacity for additional power generators and an increasing flexibility in electricity demand. This work presents a methodology that analysed the actual monitored power flow on a real-life private wire between a large factory and a 1.5 MWp anaerobic digestion plant. The work assessed the reduced power flow from the national grid and the corresponding release in capacity. Economic analysis was also conducted using the Capex and Opex data of the private wire and the financial benefits gained by the consumer through reduced grid imports.

The results indicate that the private wire link-up is financially beneficial to the consumer and can reduce their electricity bills by up to 31.4% annually. The paper also includes an economic viability assessment and the rate of return on investment based on the distance between the sites, the level of consumption of the consumer and the agreed tariff price, so that it can be applied to other sites.

Through displacing large demands by local renewable power generation coupled with private wire, it was possible to release additional grid capacity. This in turn will not only provide local authorities with a way of increasing their renewable generation capacity, but also provides businesses with a way of saving on their electricity bills whilst reducing carbon emissions. The results are generalisable and hence replicable for businesses and local generation operators across the UK and elsewhere.

Household occupancy forecasting through PIR motion sensing for care at home. An evaluation of the optimal training dataset period for machine learning approaches

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Household occupancy forecasting has an important role to play in future telecare and care at home response. Technology has made it relatively inexpensive and easy to monitor background occupants' activity and environmental parameters in buildings. The current implementation of occupancy monitoring is often based on the conservative practice of collecting as much data as possible and then analysing them with "black box" machine learning approaches that will trigger some kind of actuators. In social care context, background occupancy monitoring is still in its infancy as "hard" alarms are typically used to trigger acute alerts. This study analysed data from passive infrared motion sensors (PIR) in N=26 households in Southampton (UK) that received care at home. The monitoring duration varied between households from 1 to 8 months. The aims of this paper are to challenge the notion that 'ingesting more training data improves model forecasts', and to identify an optimum lag period in the context of care at home. Here, lag is defined as period of historical data for training activity prediction models. The analysis assessed the performance of linear regression models trained with different lag period for a prediction horizon of 3 hours. Three distinct groups were identified by determining the lag period with the highest prediction performance. These three groups had training periods of 24 hours (1 day), 48 hours (2days) or 168 hours (7 days) of historical hourly activity observations, with most households reaching peak performance at 48 hours. Importantly, for the first group, the performance of the models deteriorated after increasing lag past 24 hours. This demonstrates that too much training data may actually lead to over-fitting. To follow, an inferential analysis of households' contextual variables was undertaken to assess if specific households' features could be used as an indication for the selection of appropriate lag periods for the training of the forecast models. The results did not show any significant difference between the three groups that would allow the generalisation of the findings. Future research should focus on the generalisation and transferability of the results and the identification of the contextual occupancy factors that may have a significant impact on the training of "household-specific" activity prediction models. The findings are important for social care providers, care app designers and telecare managers to gain insights into predictive care with the use of background, unobtrusive occupancy monitoring, with realistic expectations of the data modelling and forecast accuracy.

POSTERS

A specification for a low-cost housing solution for the slum community in Bargaia, Lagos

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The growing Lagos population and the abundance of people who live in slums inspired this study's aim to create a specification of what to include in a low-cost housing alternative for slum communities in Lagos. By reviewing several factors, the following issues were identified: poor services, overcrowding, a challenging climate, and affordability.

This study will focus on achieving thermal comfort, eliminating overcrowding, and exploring the option of using local materials in the design solution. This will be done by reviewing relevant literature as well as modelling existing housing units in TRNSYS to analyse the effect of the thermal mass, the solar absorptance of the roof, the flow of air and window shading on the indoor air temperature to determine their effect on the indoor thermal comfort. It was found that: the solar absorptance of the roof and the flow of air were the most influential for thermal comfort and certain interventions can be implemented to minimise and maximise them respectively; the design solution should be designed for a capacity of 2 adults and 3 children; there are benefits to choosing local construction materials.

Factors impacting environmental projection opinion pre and post

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The project reviews the results of two large surveys of UK energy customers undertaken Pre- & Post- COVID to identify change in attitude towards the environment and factors affecting energy demand.

The impact of cooling on air quality – NO2 personal exposure

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Over 50% of hobs in the UK operate with natural gas. This releases combustion generated NO2 and other pollutants into household air, which are related to asthma and other health outcomes. The project undertook a rapid evidence review showing limited amount of studies on NO2 personal exposure as a results of home cooking.

To address this knowledge gap, the project undertook a series of experiments in a home environment to assess the impact of three parameters; (1) cooking heat level and duration, (2) distance to the source and (3) ventilation rate. The results of these experiments will be reviewed and discussed in the poster.

Understanding harassment in public spaces through a gendered lens on social media using BERT sentence encoders

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Safety is one of the main barriers to active travel uptake in the UK and is frequently characterised or measured by reported road accidents and the likelihood of injury. However, perceived safety is more nuanced, often associated with the possibility of users experiencing criminal behaviour and harassment. Whilst it affects both genders, it disproportionately affects female members of society and consequently impacts the equity of travel using active travel modes.

This study focuses on online discourse on Twitter surrounding harassment. The suggested approach aims to maximise the available commentary by employing iterative unsupervised and semi supervised topic modelling using Bidirectional Encoder Representations from Transformers (BERT) sentence encoding. The methodology enables the selection of semantically similar Tweets that do not necessary use the same keywords as is the case for Latent Dirichlet Allocation (LDA).

In total the study collects 13124 Tweets posted between December 2018 and December 2021 these are filtered using the proposed methodology to 1015 relevant Tweets. For this initial iteration, collected Tweets are in English and limited to accounts that have been created in the UK. The Tweets are cleaned from noise that will inhibit NLP performance and classified into different topics using the Python library BERTopic with additional manual coding. M3Inference is a deep learning system for demographic inference, and it is used to infer user gender to explore the data through a gendered lens.

The findings of the study suggest that in general more women are part of the discourse surrounding harassment on Twitter and a greater percentage of women post about sexual harassment that occurs in public spaces. Significant topics also identified are campaigns, clothing choice and discussion surrounding the definition of sexual harassment. Other themes found within the data include the need for behaviour modification and the documentation of specific events.

Can stainless steel reinforcement bar facilitate more sustainable railway bridges? A review of life cycle cost and carbon analysis

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Bridges are fundamental fixed assets. Keeping bridges operational is of the utmost importance as costs caused by diversions or delays due to maintenance or replacement activities can be substantial. Reinforced concrete (RC) is a commonly used construction material for bridges as it offers versatile and economical designs. The corrosion of steel reinforcing bar (rebar) is however known as the main cause of premature deterioration of RC bridges. Stainless steel rebar, which is inherently corrosion resistant, offers a promising solution to the rebar corrosion problem in RC bridges. This paper presents a review of the current literature studies on Life Cycle Cost (LCC) and Life Cycle Assessment (LCA) of RC bridges which considered stainless steel rebar as a corrosion prevention method. A summary of the key findings together with a discussion on the analysis of the parameters

which impact the outcomes of the LCC and LCA studies is firstly presented and suggestions for future LCC and LCA studies are provided. The paper concludes with an outline for future work for investigating the suitability of stainless steel rebar in RC bridges.

Carbon reduction in NR geotechnical solutions

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It is now unequivocal that anthropogenic carbon dioxide (CO₂) is a major contributor to global warming. Significant levels of CO₂ are also shown by the literature to be emitted by the construction industry and in the construction of railway earthworks. However, there is a gap in knowledge regarding granular detail of emissions in specific earthworks; particularly embankments, soil cuttings, and rock cuttings.

This research aims to produce detailed carbon footprints of these interventions with differing temporal life cycles: maintenance interventions with 2-year lifetimes, refurbishment interventions with 60-year lifetimes, and renewal interventions with 120-year lifetimes. The research will then, via analysis of the case studies' footprints, identify the carbon hotspots and propose ways to mitigate and even offset these emissions. The preliminary findings of the research show that construction site activities account for many of the CO₂ emissions in the construction of railway earthworks.

Stainless steel composite beams for sustainable bridge construction

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Steel-concrete composite beams are commonly used in bridge construction. The corrosion of the supporting steel beams and the shear connectors are however known as a major cause of premature deterioration of composite bridges. Maintenance of bridges, and the associated delays and transport disruptions, are incredibly costly. Stainless steel beams and shear connectors offer a viable alternative solution to the steel corrosion problem in composite bridges located in harsh environmental conditions. This research aims to investigate the material behaviour and structural performance of stainless steel composite beams and to assess the life-cycle benefits of stainless steel over carbon steel composite construction. This will be done through tensile tests on stainless steel headed shear connectors, push-out tests on stainless steel composite specimens, numerical modelling and life-cycle assessment.

Global guidance for sustainable development in port-cities

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Port-cities are at the epicentre of many of the key issues and processes of modern times, such as globalisation, urbanisation and development. They provide considerable benefits, whilst producing negative impacts such as pollution and traffic congestion. Sustainable development in port-cities is therefore of great importance if these impacts are to be managed and a transition to a greener society is to take place. This global study was undertaken by the University of Southampton and engineering consultancy Ramboll and surveyed port authorities in 26 countries and city authorities in 13 countries. This highlighted 5 key approaches to encourage sustainable development in port-cities. These are: Port-city cooperation, the circular economy, renewable energy, reducing pollution, and adding additional social benefits for the local area. These approaches all enjoy high levels of support from both port and city authorities and can enable future port-city development to be sustainable and symbiotic.

Management of rail stress with climate change for modern and legacy track specifications

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Railways have a significant role to play in sustainable transportation. Rail travel is currently the only mode of rapid, large-scale, long-distance transport for both freight and passengers that offers zero carbon dioxide emissions at the point of use. However, our railway infrastructure needs to be more robust and resilient to the combined effects of climate change, traffic growth and increases in vehicle loads and speed. Rail buckling is of increasing concern as environmental temperatures rise and traffic loads, speed and intensity of use increase. A key indicator and control of the propensity for track buckling is the stress-free temperature of the rails. However, determining the actual stress-free temperature of a given section of track is challenging. Knowledge of the factors affecting stress-free temperature will help in the identification of vulnerable sections of track and the development of an appropriate maintenance regime. This study reviews and discusses the factors affecting stress-free temperature in ballasted railway track with continuous welded rails.

Investigation of a pure hydrogen pipeline for the Solent region

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In the transition to net zero, hydrogen in combination with renewable electricity is expected to play a major role as a zero-emission energy carrier, and hydrogen pipelines can be used for large scale and low-cost distribution. The Solent Region has been identified as a strategic location for the development of a hydrogen infrastructure and this report proposes one of the first United Kingdom 'at scale' 100 per cent hydrogen pipelines, running from a proposed hydrogen production facility in Fawley to the Redbridge Causeway, to deliver green hydrogen to multiple end users within the region and to decarbonise them.

This report encompasses findings of a literature review on pipeline construction, technology and design. Through the review of legislation and planning policies, technical, environmental, and socioeconomic considerations relevant to the study area have been

investigated. An options appraisal approach has been adopted for the routeing process and a preferred route alignment identified through the use of selection matrices, by comparing different route proposals against set criteria to avoid major constraints. The economic feasibility of the pipeline has been discussed and through the use of technical gas calculations, a method has been set out to estimate parameters such as pipeline diameter, operating pressures and pipeline capacity.



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