Smart cities as future internet-based developments that adapt to climate change and which green the intellectual capital of urban and regional innovation systems

Mark Deakin[1] and Alasdair Reid[1]

[1] School of Computing, Engineering and the Built Environment, Edinburgh Napier University, Scotland.
lncs@springer.com

Abstract. Many in the academic community find claims made about the virtuous nature of smart cities dumbfounding. In that sense left not only bewildered by the claims which academics make about the virtues of smart cities, but the audacious nature of the expectations advocates of them as developments based on the future internet also harbour. In surveying the foundations of smart cities as developments based on the future internet, this paper shall address the bewilderment over the claims made about the virtues of smart cities by academics and audacious nature of the expectations the IEA, IRENA, UN, WB and WHO now also harbour of them as developments based on the future internet. In rendering both the virtues of smart cities and audacious nature of them as future internet-based developments, the paper shall reveal how cities can be smart in developing the future internet as a basis to meet the social challenge adapting to climate change poses. This shall go some way to close a gap that has opened in the past decade over the foundations of smart cities by reporting on the results of a case-study into the metrics of future internet-based developments. Those metrics that provide smart cities with a system of measurements which link the informatics of digital technologies to data management platforms and connect the infrastructures of future internet-based developments to the management of natural resources. To the management of natural resources as environments that in turn relate the energetic of climate change adaptation strategies to a metabolic which serves to green the intellectual capital of urban and regional innovation systems. Green the intellectual capital of urban and regional innovation systems and qualify whether in meeting the social challenge SDG7 poses this keeps 1.5 alive.

Keywords: Smart cities, Metrics, Future internet-based developments, Social challenges, Climate change adaptation strategies, Intellectual capital, Greening intellectual capital, Urban and regional innovation systems.

1 Introduction

Papers on smart city development have proven contentious and left critics of the movement nothing less than dumbfounded as to the claims they make. This paper addresses the polemic on smart cities and responds to the call for an alternative to the corporate model of the developments high-tech companies champion. It does this by uncovering the genealogy of smart cities and revealing the evolving body of work which this founds as the basis of the development.

As a critical reflection on the foundations of smart cities, this paper serves to double down on the insights Giffinger *et al.* [1], Schaffers *et al.* [2], Calagilu *et al.* [3], Batty *et al.* [4], Leydesdorff and Deakin [5] and Lazaroiu and Roscia [6] offer into smart cities and what they say about them as future internet-based developments. This turns attention to the stage the future internet sets for the management of natural resources as environments that are wise in meeting the social challenge which the joint 2022 statement from the International Energy Agency (IEA), International Renewable Energy Agency (IRENA), United Nations (UN), World Bank (WB), and World Health Organisation (WHO), make on Sustainable Development Goal (SDG) 7. That goal which targets affordable and clean energy and serves to highlight SDGs 8-13. Highlight SDGs 8-13 in terms of the relationship which affordable and clean energy have to economic growth and the urban and regional innovation system which is needed to service the infrastructures that not only sustain cities, but which also allow the communities inhabiting them to become sites of responsible consumption and production. Sites of responsible consumption and production whose climate actions in turn adapt to sustain development.

Drawing on the Tripel Helix Model (THM) of smart cities advanced by Hirst *et al.* [7] and Kourtic *et al.* [8], the paper begins to close the gap in the metrics of future internet-based developments left by the IEA, IRENA, UN, WB and WHO. This is achieved by drawing on the lesson smart cities such as Manchester, Amsterdam, Malmo, Barcelona and London teach us about the metrics of future internet-based developments (also see, Deakin [9, 10]). Those lessons smart cities teach us about the modulation of the future internet into the informatics of the digital technologies underpinning the developments and data management platforms they in turn support (Hirst *et al.* [7]; Kourtic *et al.* [8]; Deakin, [9, 10]). This modulation of the future internet also serves to highlight the top-level issues surfacing as a basis for the development. With computer science, the top-level issues relate to the digital technologies underpinning the data management platforms and as infrastructures supporting the management of natural resources. The management of natural resources that bottom-out as environments for the engineering of intelligent energy systems which the construction sector installs into the fabric of buildings.

The paper goes on to suggest this is how future internet-based developments ground these digital technologies as data management platforms. Ground them as infrastructures relating to the management of natural resources and environments of climate change adaptation strategies. Climate change adaptation strategies that green the intellectual capital of urban and regional innovation systems. Urban and regional innovation systems which in turn serve to verify whether the informatics, energetic and metabolic this accounts for, qualify the status of future internet-based developments as intelligent energy systems that construct buildings clean enough for the net zero growth strategies SDG7 champions to keep1.5 alive.

2 Claims made about smart cities

Smart city development has proven contentious. Hollands [11], Kitchin [12], Söderström [13] and Vanolo [14], are all dumbfounded by the claims the likes of IBM and Cisco make about them. In assembling what they refer to as a polemic on the entrepreneurial legacy of smart cities that high-tech companies promote, this group of academics refer to the development as something which is more symbolic than real. In that sense, the imaginary of a utopian future, univocal in the singularity of the computer science, digital technologies and data management platforms which the storylines of these corporations champion in the name of progress. In seeking to get beyond this polemic and offer something more than a critical insight into the nature of smart city developments, this group of academics go on to call for an alternative to the corporate model of smart cities high-tech companies champion, by uncovering the genealogy of the developments and revealing the evolving body of work which they found as the basis of smart city developments.

As Hollands [15, 16] acknowledges, what such critiques uncover about this genealogy of smart cities is limited to revelations about the social divisions and inequalities of the computer science and digital technology these developments are founded on. In seeking to break with these limitations and found an alternative model of smart cities on that science and technology which is not socially divisive, but instead provides equal access to goods and services (in this instance clean and affordable energy), Hollands [15, 16] calls for a body of work that is not locked into the symbolic imaginaries of entrepreneurial legacies. Not in that sense locked into the symbolic imaginaries of entrepreneurial legacies, or any free-floating utopian future, univocal in the singularity of the science and technologies they offer storylines for, but something more progressive.

3 The foundations of smart cities

What the call for smart city development to be more progressive means is not easy to discern. The tone the statement strikes is clearly neither structurally opposed to nor antagonistic towards smart cities. Not so much calling for a radical departure from the entrepreneurial legacy, as disruption of the corporate storylines high-tech companies found smart city development on. For in going on to assemble a model that reaches beyond the symbolic imaginary and captures the realities of a future in which smart cities do stand as a real alternative, what these critical insights do is set out the foundations for a body of work that double down on the insights which Giffinger *et al.* [1], Schaffers *et al.* [2], Calagilu *et al.* [3], Batty *et al.* [4], Leydesdorff and Deakin [5] and Lazaroiu and Roscia [6] offer as the basis for such a development. That body of work, which is less polemic in nature and serves to offer a series of more constructive insights into the entrepreneurial legacy Hollands [11, 15 and 16], Greenfield [17], Kitchin [12], Söderström *et al.* [13] and Vanolo [14] are all critical of. They are critical of, but also all equally quick to acknowledge, does nevertheless provide the raw material for a new body of work. For a new body of work that is not predominately scientific nor technological, but instead progressively sociological in nature, offering a synthesis of the computer science, digital technologies and data management platforms which uncover the genealogy of smart cities and in turn reveal the foundations of a future internet able to make sense of these developments.

In capturing the evolutionary dynamics of this smart city development programme, Deakin and Leydesdorff [18] and Deakin [9] note it serves to:

- highlight the types of ranking systems that Giffinger *et al.* [1] provides as a tool for cities to be smart in marketing the innovative qualities which they offer;
- throw light on how this marketing tool modifies standard ranking systems by pre-fixing the word smart to cities and by going on to measure the performance of smart cities against rival cities who lack the innovative qualities needed to be smart;
- draw attention to Schaffers *et al.* [2], who claim smart cities do not lie with the marketing of some ill-defined innovative qualities: for example; entrepreneurialism, economic image and trademarks, creativity, cosmopolitism and open mindedness, but instead rest on the cybernetic qualities of that experimental logic which computer science is founded and the digital technologies of the data management platforms that underpin them as a set of metrics which support future internet-based developments;
- show how for Schaffers *et al.* [2], the future internet is based on developments that relate to computer science and the digital technologies of data management platforms which surround a broadband of services. That broadband of services which orientate towards wireless technologies and centre on the use of cloud computing. That orientate towards wireless technologies which centre on the use of cloud computing and whose operation configure the Internet of Things (IoT) as national innovation systems. Those technologies, services and uses, Hernández-Muñoz *et al.* [19] and Álvarez *et al.* [20], also draw attention to the significance of.

4 Advocates of future internet-based developments

When comparing what the research on smart cities conducted by Giffinger *et al.* [1] and Schaffers *et al.* [2] say about the metrics of these future internet-based developments, with the statement Calagilu *et al.* [3] and Lazaroiu and Roscia [6] also make, the problem both encounter in modelling them as the underlying attributes of an experimental logic quickly begin to surface. For when conducting such a comparison, it soon becomes clear the attribute-based account of them offered by Giffinger *et al.* [1] is too free-floating, leaving the relationship between smart cities, computer science and digital technologies of data management platforms open and while Schaffers *et al*. [2] do offer the programme that society needs for the metrics of future internet-based developments to begin closing this gap, it is Calagilu *et al.* [3], Leydesdorff and Deakin [5], along with Lazaroui and Roscia [6], whose approximation of the distance between them which provides the basis to meet this requirement. What the discussion from Calagilu *et al*. [3], Leydesdorff and Deakin [5] and Lazaroiu and Roscia [6] on the metrics of the future internet serves to do is give the development that status which both Giffinger *et al*. [1] and Schaffers *et al.* [12] ask of it. They achieve this by founding smart cities as the basis of future internet-based developments and in terms of the computer science these relate to as the digital technologies of data management platforms. Those which in turn relate wireless services to the cloud computing of an IoT as infrastructures that approximate these in terms of the national innovation systems they go on to study the significance of.

The Triple Helix (TH) model of smart cities that Leydesdorff and Deakin [5] and Hirst *et al*. [7] offer advances this line of reasoning. This is achieved by approximating the role of smart cities in the computer science, digital technologies and data management platforms of those national innovation systems both Calagilu *et al.* [3] and Lazaroui and Roscian [6] draw attention to the significance of and by showing how these evolve as the intellectual capital Leydesdorff and Deakin [5] and Hirst *et al.* [7] suggest is turnkey. They suggest is turnkey and as a consequence, should lie at the heart of any measurement system compiled to account for the metrics of future internet-based developments.

Leydesdorff and Deakin [5], Hirst *et al.* [7] and Deakin [9] achieve this by drawing attention to the informatics of computer science as the basis for the development of a future internet that is founded on the digital technologies underpinning the data management platforms which support the broadband of services they deliver. Future internet-based developments that underpin the digital technologies of these infrastructures and which support the data management platforms this broadband of services stand alongside. The infrastructures which this platform of services stand alongside and they in turn suggest set out a stage for the management of natural resources as environments that are wise.

As Deakin *et al.* [21] indicate, this resource-based account of smart cities in turn suggests that any attempt made by the TH model to uncover the multi-scalar (not just sectoral, or national, but also urban and regional) nature of this intellectual capital means doing something novel. In that sense, searching for the metrics of future internet-based developments, not in national innovation systems. Not in national innovation systems but instead in the infrastructures and platforms these assemble and set out as a stage for managing the exploitation of natural resources as environments which are wise. Which are wise because they meet the social challenge that greening the intellectual capital of the urban and regional innovations systems these are embedded in poses and achieves this by way of and through a material stock and flow analysis. That stock and flow analysis which Deakin and Reid [22] indicate offers the means for any such greening of the intellectual capital found embedded in an urban and regional innovation system to scope out, draw in on and qualify whether the energetic of the renewables installed into the fabric of buildings are not only clean but if the metabolic of the resource consumption is also able to keep 1.5 alive [23].

5 Climate change adaptation

The case for future internet-based developments that set the stage for the management of natural resources as environments which are wise, is that social challenge which the IEA, IRENA, UN, WB and WHO lay down for Sustainable Development Goal (SDG) 7 [24]. That SDG which they review the prospect of meeting in terms of the UNs commitment to affordable and clean energy for all by 2030. That goal which also draws on developments in SDG 8-13 in terms of the relationship between affordability and clean energy, economic growth, industry and the innovation needed to service the infrastructures required for cities to sustain communities as sites of responsible consumption and production. In that sense, sites of responsible consumption and consumption which can sustain communities because they do not either degrade the environment or destroy ecosystems. Do not either degrade the environment or destroy ecosystems but instead are just in restoring them and providing everyone equal access to the infrastructures of that industrial innovation which member states deploy. Which member states deploy to green the intellectual capital of urban and regional innovation as systems overseeing the installation of renewable energies into the fabric of buildings driving the transition to net zero by 2050.

This is a matter the IEA [25], WEF [26] and IRENA [27] report on. They identify the following:

- the installation of renewables offers immediate improvements in the energy efficiency of buildings, mainly from large-scale retrofit programmes;
- currently only about 1% of buildings are retrofitted each year;
- to meet the net zero target, the rate of building retrofit shall have to increase to 2% per annum;
- by 2050, the vast majority of existing residential buildings shall need retrofitting to net zero standards;
- currently about 10% of water and space heating is sourced from renewable energies, by 2050 this shall need to be 43%, with an additional 38% powered by electricity sourced from renewables and district heating plants. The remainder from hydrocarbon fuels;
- about three-quarters of this increase in renewable energies shall be sourced from solar and wind power, the rest from geothermal reserves;
- any energy sourced from fossil fuels shall be subject and carbon capture, utilisation and storage;
- smart grids, artificial intelligence, IoTs and the development of them as the future energy internet, will be key to the integration of renewables into buildings and the operation of this renewable-driven future for energy shall account

for approximately 10% of the energy saving carbon reduction needed to achieve net zero by 2050;

- where access to the national grid is remote, smart micro grids shall drive the development of this future energy internet as an urban and regional innovation;
- within these innovation systems net zero installations shall develop as smart buildings and smart homes. As installations, the operation and use of them shall be automated by way of the IoT and through machine-based learning drawing on big data analytics. This in turn shall offer a demand responsive control of appliance-related energy consumption and the related carbon emission by way of chatbots and through blockchain.

Together the IEA [25], WEF [26] and IRENA [27] suggest the digitisation of this process shall be key to any such ecological modernisation and whether-or-not the transformation of the built environment this is the harbinger of will be sufficiently inclusive in terms of the growth it relates to. However, as IRENA [27] go onto acknowledge:

"To date, the principal focus has been on gathering data on inputs into th[is] innovation process. There has been substantially less activity trying to define meaningful metrics to track the outputs and outcomes from clean energy technology innovation. Such metrics would allow for a more rigorous comparative analysis of the relative performance of innovation support for different technologies."

In short, they suggest the existence of these metrics would provide future internet-based developments with that system of measurements needed to meet the social challenge the greening of any intellectual capital embedded in the urban and regional innovation system poses in terms of scoping out, drawing in on and confirming whether the energetic of the renewables installed into the fabric of buildings are not only clean but have the metabolic required to keep 1.5 alive.

Unfortunately, the metrics IRENA [27, 28] offer to map out the "Innovation landscape for a renewable-powered future", does not provide such a system of measurement. They are instead typically mode 2 in nature, focussing on the "perfect storm" of rising generation capacity, falling costs and increasing job opportunities within the nation states driving these innovations, not as the computer science which they highlight to be the key amplifier of the intellectual capital greening them.

As a result, the digital technologies and infrastructures servicing the data management platforms that support this management of natural resources and as environments which are wise in meeting this social challenge, vis-a-vis greening the intellectual capital of the urban and regional innovation system this future calls for are ignored. The significance of this omission should not be underestimated, because it leaves the smart cities championing the future internet-based developments singled out by the IEA, IRENA, UN, WB and WHO, without the means to meet the social challenge set for SDG7. In that sense without the means to meet the social challenge SDG7 set by confirming whether the greening of the intellectual capital found to be embedded in the urban and regional innovation system administered by nation states, indicates 75% of the estimated 50 billion square meters of floor space built before 1945 and up to 1969 i.e., that share of the stock which is deemed to perform below standard and therefore needing to be retrofitted, shall be renovated at the rate of 2% per annum. That rate which is needed to achieve the circa 90% energy saving and carbon emission reduction required to achieve net zero by 2050.

6 The metrics of future internet-based developments

Drawn from the THM of smart cities advanced by Hirst *et al.* [7] and Kourtic *et al.* [8], what follows begins closing the gap in the metrics of future internet-based developments left by the IEA, IRENA, UN, WB and WHO. Focussing on London as a smart city key to the UK nation state, the rest of this paper shall report on the metrics of that future internet-based development which is greening the intellectual capital of an urban and regional innovation system in the Borough of Sutton and known as the Hackbridge project.

The policy leadership for this project has already been reported on by Day *et al*. [29], Hodson and Marvin [30] and Bulkeley *et al.* [31]. Set within the guidelines laid down by OECD [32] and WB [33], it is the ECs Smart, Sustainable and Inclusive Growth Strategy [34] and this commitment to research and innovation in the computer science, engineering and construction sectors, Bulkeley *et al.* [31] note the UK has sought to participate in the development of by sourcing funding from Horizon 2020 and the European Regional Development Fund (ERDF). They also go on to indicate how the UKs national innovation system has sought to supplement the resources available to fund such future internet-based developments. Funding Bulkeley *et al.* [31] suggest has been secured from the Technology Strategy Board's championing of digital technologies as data management platforms able to support London's commitment to the management of natural resources. That management of natural resources as environments which are wise in greening the intellectual capital of urban and regional innovations as a decentralised energy system, that no longer centres on fossil fuels, but which is sufficiently distributed to concentrate on the renewables of CHP networks, solar and wind power. That development which in the London Borough of Sutton is overseen by Bio-regional and presents itself as the environment of an intelligent energy system capable of installing renewables into the fabric of buildings across Hackbridge.

The case study also serves to reveal the significance of these developments in morphological terms. This is achieved by augmenting the post-building physics modelled by Ratti *et al.* [35] as the computer science found in the informatics of the Digital Elevation Model (DEM) and those digital technologies which Salat [36], Bourdic and Salat [37] and Bourdic *et al.* [38] expand on the status of as data management platforms. Those technologies and platforms Kourtit *et al.* [8], Deakin [9], Deakin *et al.* [21], Brandt *et al.* [39], Mosannenzadeh *et al.* [40-42] and both Deakin [43] and Deakin and

Reid [22] also go on to extend. Initially as the informatics of the digital technologies servicing data management platforms found in the London Borough of Sutton and subsequently by way of, and through the Hackbridge project.

The metrics this case study captures are threefold. The first relates to the computer science found in the informatics of the digital technologies serving the data management platforms of Sutton as a Borough of London. The second, the management of natural resources by society and as environments for the engineering of intelligent energy systems which are energetic and relate to the construction sector’s installation of renewables into the fabric of buildings in Hackbridge. The third to the metabolic of this ecological modernisation as a circular growth economy wherein energy is conserved, not wasted but consumed responsibly from renewable sources restored by nature. These are sustainable developments that in turn allow the community to participate in the adaptations to climate change which green the intellectual capital of the urban and regional innovation system. Green the intellectual capital of the urban and regional innovation system as an ecological modernisation which decarbonises the built environment of Sutton and that sustains the city-district as neighbourhoods in Hackbridge which develop the status of energy efficient-low carbon zones.

Set within the Borough’s vision of Hackbridge as a sustainable suburb, the Master Plan and Energy Options Appraisal conducted for the project, maps out the footprint of the mass retrofit (covering 1.7km2, involving 6,000 people and extending to 2,500 properties) they promote for the city-district and draws upon data sourced as that which provides information on the energy savings and reduction in the carbon emissions resulting from this management of natural resources in the neighbourhoods (Hackbridge [44, 45]; London Borough of Sutton [46, 47]).

The Energy Options Appraisal conducted offers a fourfold classification for the management of natural resources. The first baselines the current situation in terms of energy consumption and carbon emissions. The second is the thermal option, whereby the existing buildings are subject to a retrofit comprised of thermal improvements. The third is referred to as the thermal-plus option. This cuts deeper into the heating and lighting of buildings by extending the retrofit to cover such components and the installation of renewables into the fabric of buildings. The fourth augments these with that CHP, solar and wind option which manages these natural resources as the environments of an intelligent energy system. The fifth escalates the intelligent energy system into the AI of an IoT for the real-time management of this energetic and as the renewables of that metabolic which the ecological modernisation draws on to decarbonise the built environment.

The technologies of these options are in turn clustered as stages 1, 2 & 3. The first cluster focusing of the fabric of the buildings (options 1, 2 and 3), with the second (option 4) centring on the exploitation of natural resources out with the building envelope and as the environment of the renewables this intelligent energy system orientates towards as option 5. These options in turn form the basis of a measurement system able to do what Batty [48, 49] and Kandt and Batty [50] call for. That is, overcome the current impasse which exists in qualifying the informatics of these developments as merely technical and achieve such a computation by not only quantifying what the renewables of the intelligent energy system contribute to the energetic of the mass retrofit, but how the metabolic of this ecological modernisation also serves to decarbonise the built environment.

The analytic and calculus adopted for this material stock and flow analysis offer standard measures of energy consumption and carbon emissions by proprietary unit and in relation to the savings and reductions the retrofit achieve. With an average of 21,116 kWh and 6.7 tons of CO2 emissions per annum attributed to each building, this ecological modernisation decarbonises the built environment to the extent it produces:

- a 3-ton reduction in CO2 emissions, sourced from stage 1. With 2.76 tons of the reduction coming from energy savings related to the buildings and 0.24 tons to the instillation of renewables;
- a further 1.7-ton reduction in CO2 emissions from the servicing of stage 2, generated from the biogas and CHP and supplemented with the solar and wind power installed as natural resources into the environment of an intelligent energy system able to exploit the potential these renewables have as an ecological modernisation;
- a 70% overall reduction in CO2 emissions from stages 1 & 2 as an ecological modernisation which decarbonises the built environment. Which decarbonises the built environment and greens the intellectual capital of this urban and regional innovation system to the extent that it sustains the suburb as a city-district with neighbourhoods which take on the status of an energy efficient-low carbon zone;
- a position whereby the micro-grids, peak load management and dynamic pricing business model of cloud computing developed for the IoT, also has the potential to further consolidate the levels of energy savings and carbon reductions from the renewables. In this instance, by an extra 5%, which is critical in the sense that it places the full potential of the energy savings and carbon reductions into the 75% bracket, which the Intergovernmental Panel on Climate Change [51] suggest puts the retrofit on track to be neutral. To be neutral in the sense which this greening of the intellectual capital is clean enough for the urban and regional innovation system not to add anything more to the current level of global warming. Put in slightly different terms, keeps it within 1.5% of the pre-industrial era. However, as at the time of writing, the retrofit does not yet have the ESCO in place for the city-district to capture the full potential of the savings and reductions available under stage 3, they are left out of the ecological modernisation due to the experimental status of them as the neighbourhoods of energy efficient-low carbon zones;
- situation whereby 28% of this reduction in CO2 emission is attributable to the instillation of renewables, with a relatively small proportion of this coming by way of the buildings (stage 1), the majority through the distributed energy of

the CHP, solar and wind power servicing the heating and cooling systems (stage 2) and a smaller proportion from the business model the cloud computing and IoT these environments relate to (stage 3).

As a landing stage for the 2030 milestone in the transition to net zero, this retrofit can be seen to meet the targets set by IRENA [27, 28] and the World Economic Forum (WEF) for the heating of buildings [26, 52]. For in meeting the 25% renewables threshold and procuring electricity drawn from solar and wind power and procured offsite, these direct and indirect thresholds are met, along with the 58% limit placed on fossil fuel as a source of energy. The savings and reductions tied up with this energetic also allow the savings and reductions sourced from these infrastructures to future proof the retrofit and act as a platform for furthering this transition to net zero in 2050. Here it is anticipated that future innovations in biofuels, geothermal energy, hydrocarbons and carbon capture technologies shall account for up to 85% of the energetic needed from renewables (direct and indirect) over the next 25 years to progress the transition. The enhanced efficiencies derived from this energetic also allow for the anticipated growth in electrical appliances to be factored into the calculus and accounted for in the metabolic of this transition to net zero.

International comparisons can be drawn by referring to the retrofit components of the ECs Strategic Energy Plans (SEP) for 2030 and 2050. The first relates to “From Nearly-Zero Energy to Net-Zero Energy Districts”, the second refers to “Positive Energy Districts”. The results of the former are reported on by Saheb *et al.* [53]. The metrics for the Net-Zero Energy Districts capture the informatics for the management of natural resources as environments covering the instillation of renewables into the fabric of buildings but not as an intelligent energy system. The range of case studies for the Net-Zero Energy Districts show energy savings and carbon emission reductions of approximately 40%. Lindholm *et al.* [54] draw attention to the “Positive Energy District” case studies, especially the intelligent energy systems they highlight as the energetic of the renewables and metabolic of that ecological modernisation which the deep retrofit of this renovation wave relates to. That ecological modernisation, deep retrofit and renovation wave which in Amsterdam, Groningen, Oulu, Bilbao and Trondheim, is forecast to produce a 70% reduction in energy consumption and decarbonisation of the built environment by 2030. Target forecasts that are in line with the climate change adaptation measures which the EC lay down for such renovations to be neutral.

Deakin and Reid [22] and Deakin *et al.* [55] develop these metrics to confirm whether such adaptations to climate change not only sustain any such transformation of the built environment, but in a manner which is sufficiently inclusive. The results of this analysis provide evidence to suggest the cost and benefits of retrofits are socially divided, with the upper and middle income groups benefitting at the cost of the low-income groups being excluded from the renovations due to the status of them as a social group that are environmentally benign, occupying buildings which perform at the upper limit of what is technically possible in terms of energy efficiency and carbon emissions.

This leaves several SDG 7 questions over universal access to and the affordability of the modernisation, along with the inclusiveness of the transformation hanging.

7 Greening the intellectual capital of urban and regional innovation systems

Unlike the IEA, IRENA, UN, WB, WHO and WEF reports on the sustainability of such developments, the results of this case study do tend to indicate how retrofits are not just high priorities of the climate change adaptation agenda, but escalations of what might be referred to as strategies for the greening of the intellectual capital the urban and regional innovation system is embedded in. In that sense, a strategy for the greening of the intellectual capital urban and regional innovation systems gives rise to as the basis of an ecological modernisation which transforms the built environment. This also serves to demonstrate how it is the digital that cuts across this and as the data of an analytic for engineering and construction to deploy in calculating the energetic of this. The initial deployment of the DEM as the key enabling technology and translation of it into a data management platform with the metrics, vis-à-vis, informatics, energetic and metabolic future internet-based developments need for any such greening of the urban and regional innovation system to account for the ecology of such a transformation serves to demonstrate this. As too do the synergies they also offer in the calibration of this against the 2030 and 2050 milestones set for the transition to net zero.

8 Conclusion

The findings of this investigation into smart cities, indicate that critiques of them have been blind-sided by a tendency to qualify future internet-based developments as little more than corporate storylines, while ignoring the cybernetic qualities of that evolving body of research which works to uncover computer science as the foundation of an alternative model. That alternative model which makes smart city development intelligible. In that sense, a development which we should no longer be dumbfounded by, or left bewildered about the audacious nature of the claims they make, but on the contrary get behind and stand alongside. Get behind and stand alongside as the foundation of a programme which uncovers that evolutionary dynamic which is genial in the sense the analytic this offers and calculus that it lays down, rests on the metrics of future Internet-based developments able to make sense of the progress they sign-post.

As such, the knowledge this paper on smart cities produces goes someway to fill the void the polemic Hollands [11, 15, 16] articulates, leaves in its wake and serves to not so much close the gap between this and the body of work that has developed in the interim, but structural hole which is otherwise left behind. Not in this instance as an emergent landscape that either excavates the past, nor recycles imaginary futures as symbols from another era and whose stories provide corporations with powerful straplines, but by founding smart cities instead on a critical synthesis of the scientific and technological prospect which the development of them offer to meet social challenges. In that respect on a critical synthesis of the computer science, engineering and construction technologies underlying the metrics of those future internet-based developments which support the climate change adaptation strategies they contribute towards the analysis of and calculations the case study reported on in this paper serves to demonstrate, not only begin to green the intellectual capital of the urban and regional innovation systems they rest but ecological modernisation this also turns. In that sense, they not only rest on but which the transformation of the built environment also turns as that transition to a net zero growth strategy which generates wealth, secures prosperity and safeguards health and wellbeing by keeping 1.5 alive.

These are links and connections that have hitherto been too tenuous to make, but investigations into the genealogy of smart from the likes of Batty [48, 49] and Kandt and Batty [50] call for as the evolving structures of a city science that study the computation, engineering and construction of futures in which the power of the internet can be deployed as the technology to achieve the SDGs headlined by the IEA, IRENA, UN, WB, IRENA and WEF. This paper offers a demonstration of how to ground this. How to ground this science of smart cities in the technologies of future internet-based developments and what is more, do so by greening the intellectual capital of that urban and regional innovation system which the metrics account for. The metrics account for as an ecological modernisation that transforms the built environment, wealth which this generates, prosperity it secures and health and wellbeing the transition to net zero also delivers on.

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