Sustainable Connected Cities:

Vision and Blueprint towards Managing IT for City Prosperity and Sustainability

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With the continued global trend of rural to urban population migration, traditional city management approaches are being challenged to both develop and sustainably manage the economies, societies and environments of their cities. Many are turning to computing technologies for assistance. While computing technologies are becoming ever more advanced, appropriate management approaches and frameworks for a city to optimize contributions from such computing technologies are often lagging behind. This paper presents a vision for sustainable connected cities (SCC), and a nascent city management framework called the Sustainable Connected Cities Capability Maturity Framework™ (SCC-CMF™) - for how to implement such a vision, and a case study application. The contributions of design science research are briefly discussed in relation to these approaches.

Keywords: connected, cities, city, development, smart, intelligent, technology, innovation, sustainable, sustainability, maturity, management,

1. Introduction

Today cities are estimated to be responsible for 80% of all global greenhouse gas emissions [1], however they only account for approximately 50% of the global population [2]. Rural-to-urban migration is expected to reach over 70% of the world's population living in cities by 2050 [1], escalating the upward pressures on the use of available resources and environmental impacts – a trend recently highlighted by the Fifth Assessment Report (AR5)[3] published by the Intergovernmental Panel on Climate Change (IPCC). Many of these challenges have consequences for cities to rethink their governance regarding planning for long term development, competitiveness and sustainability. As a consequence, numerous city approaches are proposing a portfolio of actions including the innovative employment of computing technologies to stem or even reverse these urban pressures. Identifying relevant management artefacts can help make sense of these urban challenges and frame how cities can evolve sustainably by innovatively employing computing technologies.

2. Application of Design Science Research to Develop Artefacts

We selected Design Science Research (DSR), as it is a problem-driven approach to providing artefacts. DSR "creates and evaluates IT management artefacts intended to solve organizational problems" [4], P77. Table 1 presents an artefact typology of outputs from Design Science Research as defined by March and Smith [5]. Rossi and Sein [6], and Purao [7] propose a fifth artefact – listed as better theories, where DSR contributes to a better understanding of the phenomenon through reflection and abstraction. Table 1 displays the main artefact contributions of this paper.

Table 1: Design Science Research Outputs

Output	Description	Main contributions of paper
Constructs	The conceptual vocabulary of a domain	Description of the Sustainable Connected Cities Capability Maturity Framework (SCC-CMF)
Models	A set of propositions or statements expressing relationships between constructs	Postulate on relationships amongst constructs
Methods	A set of steps used to perform a task – 'how to' knowledge	Cataloguing key activities postulated to assist maturity
Instantiations	The operationalization of constructs, models and methods	Case study application

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Furthermore, Hevner et al. [4] offer guidelines for high-quality design research. Below describes the seven guidelines and how they are achieved within this paper:

1. Design as an Artefact: Design science research (DSR) involves a process to create artefact(s) - being any designed object with an embedded solution to an understood research problem [8]. Table 1 illustrates the resultant artefacts from this paper's research.
2. Problem Relevance: The objective of design-science research is to develop technology-based solutions to important and relevant business problems [4]. Section #1 and #3-4 outline the Relevance Cycle with-regard-to specifying the domain problem, opportunity and potential.
3. Design Evaluation: The utility, quality, and efficacy of a design artefact must be rigorously demonstrated via well-executed evaluation methods [4]. The Sustainable Connected Cities Capability Maturity Framework (SCC-CMF) is evaluated using a combination of descriptive evaluation method (using informed argument and scenarios with information from the knowledge base and the opinions of experts); and then moving to observational evaluation (using a case study approach). Artefacts were evaluated in terms of correctness, completeness and utility of the constructed artefacts.
4. Research Contributions: Effective design-science research must provide clear and verifiable contributions in the areas of the design artefact, design foundations, and/or design methodologies [4]. This paper describes how the three cycles of design science research (DSR) activities [9] can be applied to an emerging research domain of Smart Cities. The paper also contributes to defining the acceptance criteria for evaluation of resultant design artifacts for Smart Cities by applying past knowledge to building novel design science artefacts for the Rigor Cycle.
5. Research Rigor: DSR relies upon the application of rigorous methods in both the construction and evaluation of the design artefact [4]. Sections #5-8 of this paper outline the Rigor Cycle, applying past knowledge to building novel design science artefacts.
6. Design as a Search Process: The research should be organized as a search for the solution of the problem [4]. Sections #8-9 outline the Design Cycle regarding iterating between building and evaluating the artifacts.
7. Communications of Research: DSR must be presented effectively both to science-oriented as well as practice-oriented audiences [4]. The publication of this paper in proceedings of EDSS serves to address both academic and practitioner audiences, given the general cross-sectional appeal of EDSS audiences.

The remainder of this paper broadly aligns to the three cycles of DSR activities defined by Hevner [9] and Takeda et al. [10] five stage iterative approach:

1. Problem awareness: Section #1 and #3-4 - identifies what the problem is and why it is a problem.
2. Suggestion: Section #5 suggests the solution to the identified problem – i.e. the Sustainable Connected Cities Capability Maturity Framework™ (SCC-CMF™)
3. Development: Sections #6-8 develops the solution (i.e. artefacts).
4. Evaluation: Section #9 tests and validates the artifacts by presenting a case study application of these artefacts.
5. Conclusion: Section #10 offers summary and general conclusions.

3. Underpinning Knowledge Base

Traditional approaches associated with organisational management theory begin to break-down, or at their very best – border on being over-stretched, when applied to managing something as complex as a city. However, approaching the management of cities in terms of the resources a city possesses and the organisational capabilities required to manage those resources may hold potential for how to manage IT for city prosperity and sustainability.

Much of the published literature in this space can be related to the resource-based view (RBV) for examining the competitive advantage of a firm, stating such advantages lay primarily in the application of a bundle of valuable tangible or intangible resources at the firm's disposal - resources that are neither perfectly imitable nor substitutable without great effort [11]. However, RBV does not sufficiently illuminate what are the management mechanisms associated with these specific resources and how they may help the firm achieve superior performance. Dynamic capability view (DCV) aims to fill this through the clarification of management mechanisms that are required to integrate and reconfigure resources by focusing attention on the firm's ability to renew its resources in line with changes in its environment.

The authors postulate that the RBV and DCV can offer new perspectives on how to approach management of IT for city sustainability and prosperity. Dynamic capabilities are defined as "the firm's ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments" [12]. Obviously, the concept of a city may be different from that of a firm; however the city can be considered as a collection of resources, requiring appropriate mechanisms to confer superior city performance from its resources – similar to that of a firm.

4. What is a Sustainable Connected City?

Addressing sustainability challenges of modern cities is increasingly becoming an imperative requiring national and international cooperation e.g. Leipzig Charter 2007[1], Kyoto Protocol[2]. These initiatives emphasise development and growth based on low carbon trajectories i.e. sustainable forms of economic growth and development that minimise (or even eliminate) carbon missions. While solutions to these objectives are often multi-faceted, many include the need for investment in innovative computing technologies that will enable greater efficiencies towards achieving a post carbon economy[3]. The rationale for so many sustainability initiatives seeking to leverage computing technology's innovation cadence can be explained by Moore's Law[4]. Indeed computing technology has become so universal and flexible, it has earned the economic categorisation as a "general purpose technology[5]" [14]. To qualify, it must deliver continuous price-performance improvements over time, be pervasively and universally utilized, and enhance the ability to invent and innovate new products, services, operating and business models, etc. Computing technology has all three characteristics of a general purpose technology. As a consequence of possessing these attributes, it offers great potential to help cities alleviate sustainability pressures through "resource decoupling" [15], where the negative relationship is broken between promoting city prosperity (economic/societal) and environmental impact intensity. This potential was recently illustrated by an ACEEE report showing that for every 1kWHour of energy consumed in a US datacentre, an average of 10kWHour is saved across the broader US economy [16].

Moreover, the potential of information technology isn't limited to instrumentation, automation and analytics; it also enables "network externalities", the "spill-overs" from connecting additional users (or nodes) to a common network. Think of the first community of telephone users, or a more contemporary example - Facebook subscribers, as new users are added to each community – the value to being part of that community increases. Simply put, increasing the user size of a network makes all current users better off, often referred to as Metcalf's Law [17]. A common understanding of a city is that it comprises of a network of networks [18], thereby promoting connections within and between those networks can foster better decision-making, and increase opportunities for distributed problem-

[1] EU member states agree to protect, strengthen, and further develop European cities in a sustainable manner
[2] An international environmental treaty which legally binds countries that signed into the treaty to reduce their production of greenhouse gases by defined targets over a specified time period
[3] Post carbon economy: An economy where renewable energy sources will ultimately replace fossil fuels as the primary energy source in economic activities.
[4] Moore's Law states that the number of transistors on a chip will double approximately every two years for less or equal cost
[5] Previous examples of general purpose technologies include the steam engine, railroads, electricity or the internal combustion engine.

solving and participatory governance – impacting city competitiveness, sustainability and well-being of city inhabitants. The more nodes or users connected; the more value that is generated

The concepts of sustainability and connectedness are at the heart of the vision for Sustainable Connected Cities (SCC), where

> *computing technologies intelligently connect a city for the sustainable development of its economy, environment and quality of living*[6].

'Sustainable development' is taken from the Brundtland Commission [19], which states “development that meets the needs of the present without compromising the ability of future generations to meet their own needs". The potential impact of ‘triple P’ city management (people, planet, profit) using computing technologies is reinforced by Maccani et al.’s analysis on published literature confirming the positive effect of computing technologies on cities [13].

5. Introducing Sustainable Connected Cities Capability Maturity FrameworkTM (SCC-CMFTM)

To provide a systematic means to frame, evaluate and manage the sustainable development of cities and to help guide decisions about people, policy, infrastructure, investment, and the use of computing technologies; Intel Labs Europe, the Innovation Value Institute at NUI Maynooth, and the Business Informatics Group at Dublin City University, in collaboration with Dublin City Council, have researched the *Sustainable Connected Cities Capability Maturity Framework*^{TM} *(SCC-CMF*^{TM}*)*.

The SCC-CMF aims to

- Unwrap the complex ecosystem of a city into domains for tackling city sustainability
- Provide a common language between diverse stakeholders to set goals, evaluate improvements and benchmark over time
- Offer scenarios that are vendor independent and technology implementation neutral
- Define improvement roadmaps using milestones and reference landmarks

A capability based view (CBV) framework is designed to provide a stable view of the entity under investigation. While a city’s municipalities, management hierarchies, processes, technologies or people might reorganize, a capability is more enduring and constant. Capabilities possess properties such as the people, processes, and technologies that are used to instantiate the capability. They can be hierarchical; containing nested relationships, as well as horizontal connections.

The SCC-CMF taxonomy comprises of six city domains (A) - refer to Figure 1 - for tackling city sustainability, each domain is managed by the use of an enabling platform (B) to drive sustainability and connectedness within and across the six domains, for impact across a city’s economy, environment and society (C).

[6] The concept ‘Sustainable Connected Cities’ is analogous to the term ‘Smart Cities’, however SCC is extended with the explicit objective to balance viability of a city’s economy, resources and quality of living.

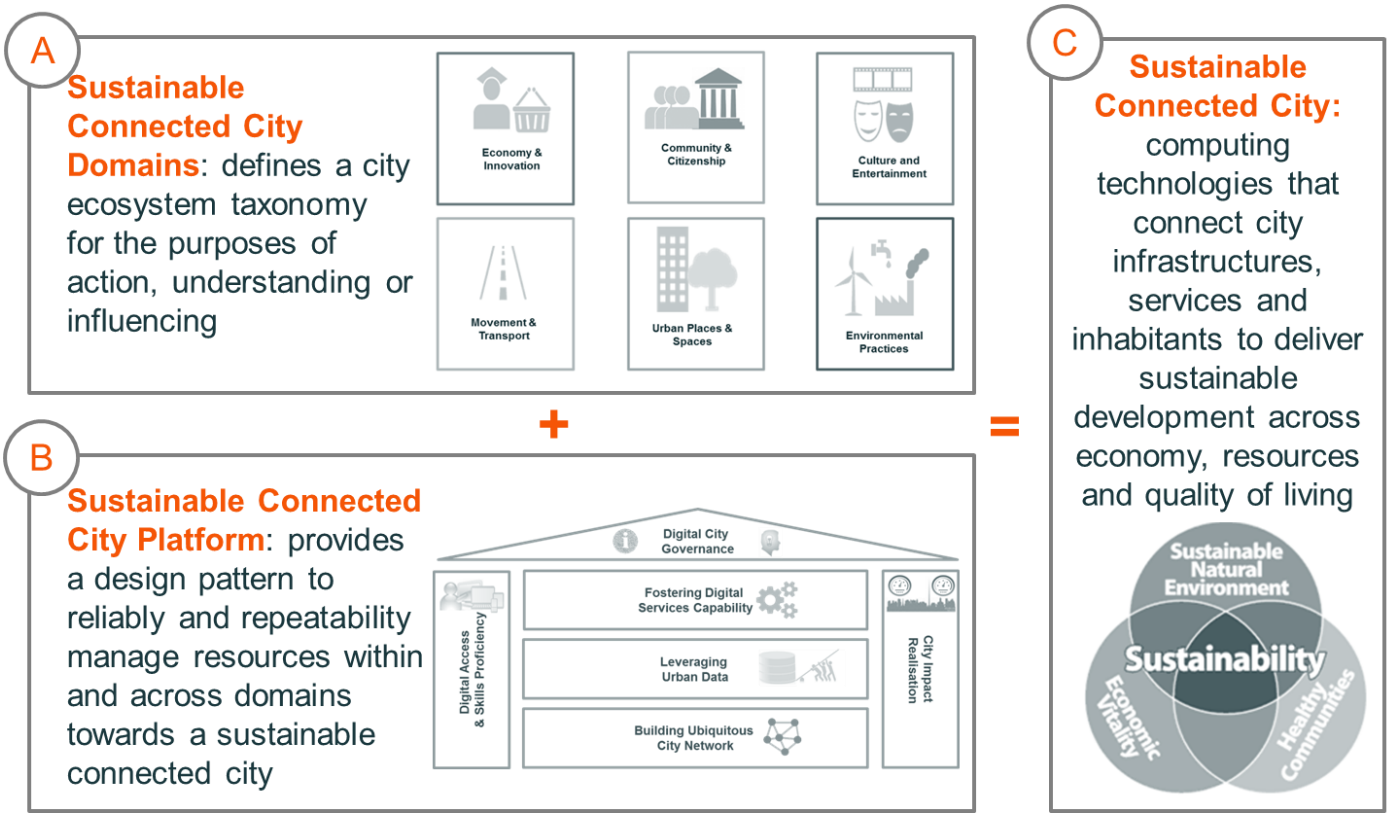

Figure 1: Sustainable Connected Cities Capability Maturity Framework – Overview

The SCC-CMF's objective is to present a 'whole systems perspective' towards achieving sustainable cities, enabling joined up thinking and co-ordination on key issues across interests groups such as city inhabitants, municipalities, businesses, local/national legislation, policy makers, etc. It can offer a city-wide guiding structure to co-ordinate and provide direction towards the achievement of sustainable city outcomes.

6. Sustainable Connected City Domains

The domains of SCC-CMF are generically defined as an:

> *city ecosystem classification, according to their homogeneity for the purposes of action, understanding or influencing advancement towards a sustainable connected city.*

More specifically, they are designed to represent a city taxonomy; namely

- Economy & Innovation: facilitating human capital[7] towards knowledge economy, commerce vitality, entrepreneurship, employment, and flexibility.
- Community & Citizenship: improving social capital[8] towards individual and community well-being, participation, inclusion, health and safety.
- Culture & Entertainment: promoting cultural heritage, involvement and accessibility.
- Movement & Transport: managing transport systems and services for accessible and sustainable travel behaviour choices.
- Urban Places & Spaces: managing vitality and viability of open spaces, residential and commercial buildings towards a coherent urban structure.
- Environmental Practices: managing environmental and biodiversity impact.

[7] Human capital: How people's skills and knowledge can contribute to economic and social value.

8 Social capital: How the attitude, spirit and willingness of people to network, engage, and co-operate with each other in achieving collective activities such as community improvement and civic engagement. In this way social capital represents the value and power of the social bonds and social networks created between individuals and their communities.

Applying a combination of design science research and grounded theory method [20], these domains describe a broad range of characteristics associated with Sustainable Connected Cities (SCC) – Figure 2 - where computing technologies intelligently connect a city for the sustainable development of its economy, environment and quality of living.

Figure 2: Sustainable Connected City Domains and Objectives

A rigorous review of academic publications and international city trends informed the definition of SCC Domains and the characteristics within them, including consulting Dublin City's Development Plan [21] and Giffinger et al [22]. However, SCC Domains are adaptable for adding to and subtracting from; based on individual city context and circumstances. A full examination pertaining to the development of these domains is beyond the scope of this paper, refer to Maccani et al [23] which covers this topic in more detail.

7. Sustainable Connected City Enabling Platform

To achieve sustainable connected city outcomes within and across each of these six domains, the SCC Enabling Platform provides a design pattern[9] - Figure 3 - to

> *manage (deploy, develop, marshal and mobilize) key resources (both tangible and intangible) towards achieving sustainable connected city outcomes.*

This design pattern can be used within a single domain and across all domains, for an entire city or within a single city neighbourhood or city project. The remainder of this section outlines the philosophies, together with examples, for each element of the enabling platform.

[9] Design pattern is generally reusable template solution to commonly re-occurring challenges

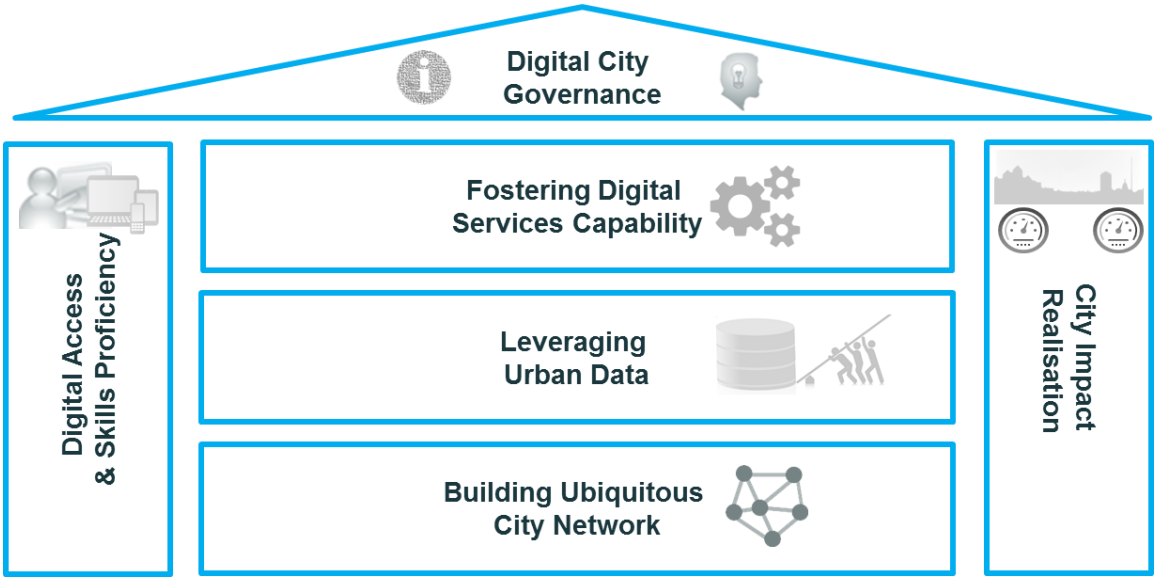

Figure 3: Sustainable Connected Cities – Enabling Platform

7.1. Digital City Governance:

To achieve SCC goals, managerial interoperability across a city's resources is required. This means putting issues of sustainability and digital transformation at the centre of city governance. The traditional boundaries between national and city authorities will need to be increasingly more permeable to exercise the efficacy of direct or indirect governance levers over how a city's infrastructure and resources are utilized. Those governance levers can come in the form of either; direct ownership or operational control of city infrastructure and services, authority to set or enforce polices and regulation, ability for budgetary control or set levies, and defining a vision for a community to rally around [24]. Promoting unified approaches to how these levers are applied across city departments and municipalities can be a key enabler for management towards sustainable connected cities. For example, integrated uses of policy levers, such as tax, regulatory, or procurement policies, can spur greater IT innovation and transformation in key sectors of the city.

Additionally, computing technologies are opening up participatory democracy opportunities for including meaningful contributions from city inhabitants on sustainable city management decision-making. This form of 'open source governance' represents a political philosophy that promotes the citizen's role and participation in governance; in particular on using the wisdom and knowledge of citizens collectively to inform policy. Leveraging information technology can effectively increase the scale of civic representation and participation in the city's democratic processes.

A unified city-wide approach to governance offers opportunities to create coordinated city-wide approaches across municipalities, private sectors and citizens. A city could increase its focus on aligning governance levers towards incentivising sustainable connected city outcomes, both within and across the SCC domains. For example metropolitan areas, like London and Stockholm, are using city-wide governance policies and technologies to institute road-pricing schemes to dramatically improve traffic flow [25].

7.2. Digital Access & Skills Proficiency:

To leverage the IT revolution to deliver SCC outcomes will require promoting digital inclusion for all city dwellers and city employees i.e. advancing human and social capital. However, with the challenged state of public, private and personal purses; new partnership and collaboration models involving national, state and local government sectors together with the for-profit and non-profit, working with city inhabitants will be required to bridge the digital divide. These new forms of collaboration can take many forms, one such form called quadruple helix model of innovation, "where civic society joins with business, academia, and government sectors to drive changes far beyond the scope of what any one organization can do on their own" [26]. These type of collaboration examples are many and varied,

including public IT skills programs[10], crowd-sourcing and hackathon campaigns[11], municipal Wi-Fi[12], leveraging unused radio spectrum for data transmission, etc. These programs are not exclusively targeted at city dwellers but also extend to employees of the various city municipalities and private-sector service providers – promoting IT access and skills development needs to be engrained across a city's various operating and service delivery models e.g. using GPS and modelling techniques to optimise most efficient waste collection routes.

By promoting an egalitarian approach to IT access and skills development for city dwellers and city employees using innovative forms of collaboration, a key building block is laid towards achieving SCC outcomes. For example, Intel's World Ahead programme aims to use technology to improve education in both the developing and developed world by "Connecting People to a World of Opportunity." Additional efforts involve Intel working with a wide range of partners using technology to improve access to and quality of STEM[13] education to enable greater social and economic opportunities for people everywhere.

7.3. Building Ubiquitous City Network:

Historically, national and local governments have relied heavily on the use of electro-mechanical machines to boost productivity of city resources. However today in an economy increasingly focused on sharing information for intelligent decision-making; complementary use of computing technologies can connect and extend the productivity of city resources, manage environmental impact and promote social well-being. For example, Intel Labs is investigating research on architecture principles for the Enernet (Energy Internet / smart grid) to optimise energy generation and use based on real-time electricity prices, weather patterns, people's schedules, etc; contributing towards a balanced grid, optimal use of renewables, improved costs, etc. One such Intel Labs research collaboration with SAP and ESB has demonstrated by using smart scheduling algorithms for charging, approximately 100,000 additional electronic vehicles can be connected the energy grid of Ireland without need for significant increase in energy generation [27].

If cities are to benefit from increased connectedness, a ubiquitous city-wide communications and information processing network is required. Underlying this concept are the fundamentals of instrumentation (e.g. sensors) and interconnectedness (many networked devices integrated to a city network or network of networks) to provide necessary intelligence [28], [29]. Intelligence may manifest itself locally at the 'edge', centrally or a combination of both for responsive decision-making and action. As sensing devices grow more powerful, inexpensive, smaller and connected; their use will become more ubiquitous and potential for generating SCC outcomes greater. More than 30 billion devices (consumer and industrial) are expected to be wirelessly connected to the 'Internet of Things' (aka Internet of Everything) by 2020 [30]. These ubiquitous city networks will be "characterised by a high degree of autonomous data capture, event transfer, network connectivity and interoperability" [31]. The ubiquitous city network provides the sense and respond platform to achieve the SCC outcomes.

7.4. Leveraging Urban Data:

EU Commissioner Neelie Kroes previously stated "Data is new oil for a digital era" [32], where management of data can be the new fuel to drive progress and sustainability. However, data, like crude oil, needs to be extracted, stored and processed to be of value. Modern cities generate huge amounts of data, unfortunately much of it often going unprocessed or even uncollected, resulting in lost opportunities for increasing urban sustainability. Furthermore, IT systems involved in city management were often built using proprietary technologies, leaving inflexible and expensive bespoke systems that cannot easily interoperate with one another. Promotion of city-wide defined standards for data management across city departments can facilitate better integration and leveraging of city data.

[10] Coderdojo is one such activity, a world-wide initiative providing free and open learning to young people, especially in programming technology

[11] USA recently held 'National Day of Civic Hacking', with 11,000 people participating to help build technology solutions that can help address challenges faced by communities across America

[12] Dublin - Ireland – is one of many cities offering free wifi in certain areas of city centre

[13] Science, Technology, Engineering, Mathematics

Enabling data interoperability across city data repositories enables innovation that can keep a city's legacy IT systems current while also offering platform opportunities for new services. One such activity includes making national[14] and city[15] level data open and available, though official websites. Cities, like San Francisco - https://data.sfgov.org/ and New York - https://data.ny.gov/, - are posting city data online, offering access to vast quantities of information featuring economic development, health, recreation, and public services information.

However, initiatives like these most likely require considerable efforts beyond just posting data online; policies for regulatory, privacy, security and data sharing may need to be considered, as well as data synchronisation and interoperability across different data sources. However, by opening up data, it is hoped innovative new services will spring forward for modernising city living and sustainability. For example, open data from London city public transport is improving journey planning of city inhabitants through third-party mobile Apps [33] which use this data.

These open-data initiatives allow the metabolism of cities to be studied using techniques such as Big Data analytics, where mass amounts of city information can be analysed to find hidden patterns to city living, predict trends and even reengineer the way we live. In Rockfort (IL, USA) for example [34], one such demonstration is identifying when communities breach 15% threshold levels for poverty. From historical analysis, breaches of this threshold often result in higher crime levels, property dilapidation, escalating school dropouts and unemployment levels. By managing urban data across municipalities and related service providers based on open and secure standards (e.g. accuracy, completeness, timeliness, relevance, consistency, reliability, integrity, protection, accessibility), the platform is laid for generating analysis to feed into strategic and informed decisions about a city's social, economic, and environmental well-being. Addressing technical aspects to data management will be necessary however unlikely to be sufficient, the readiness of city stakeholders to open data up may flourish or flounder based on the ability to foster a culture of mutual respect, trust and benefit across industry, academia, municipalities, government departments/agencies and city inhabitants.

The Intel Collaborative Research Institute for Sustainable Connected Cities (ICRI Cities) with Imperial College London and University College London – has multiple research themes including how to 'connect the invisible city' by utilising data flows of urban environments for informed decision making by city managers, businesses and citizens [35]. The ICRI Cities combines both technical and human centred approaches, having multi-disciplinary teams of experts in user experience, interaction design, and ethnography, together with experts in the built environment, commerce, engineering, anthropology, interaction design, and social psychology.

7.5. Fostering Digital Service Capabilities:

Having a city-wide 'digital-first' mantra in place can help a city overcome sustainability challenges by consistently exploring and evaluating how computing technologies can be applied. Davenport [36] provides such a description of generic service capabilities that computing technologies can support - Table 2.

Table 2: Computing Technology' Generic Service Capabilities

Capabilities	Description
Automational	Eliminating human labour from a process
Informational	Capturing process information for purposes of understanding
Sequential	Changing process sequence, or enabling parallelism
Tracking	Closely monitoring process status and objects
Analytical	Improving analysis of information and decision-making
Geographical	Coordinating processes across distances
Integrative	Coordination between tasks and processes
Intellectual	Capturing and distributing intellectual assets
Disintermediating	Eliminating intermediaries from a process

[14] E.g. http://www.data.gov.uk, http://www.data.gov/
[15] E.g. http://www.dublinked.ie/, http://data.dc.gov/

Systematically applying the generic service capabilities of computing technologies (together with city-wide adoption of open data standards) can provide a platform across city municipalities for delivering new services towards achieving SCC outcomes. Moreover, open data standards can provide new engagement models for bottoms-up innovation by city inhabitants and emerging start-ups. Historically, innovation was almost exclusively considered a top-down approach due to the amounts of capital required, which individuals and start-ups often struggled to assemble. Today, the pervasiveness of consumer technologies, open source movements, and Cloud technologies are reversing this, making innovation equally as likely, if not more-so, to come from bottoms-up as top-down [37].

These trends are presenting new opportunities to maximise a city's 'cognitive surplus' towards sustainable city living causes i.e. by maximising the free time that people have on their hands to engage in collaborative activities for creative acts rather than consumptive ones [38]. For example, CitySensing and CityWatch, are Intel Labs research collaborations to explore autonomic responses in an urban setting with Trinity College Dublin and Dublin City, by combining ambient sensor technologies with city inhabitants' participation to continuously record numerous variables across a city from temperature, humidity and air quality to slowing traffic, burst water mains, or fallen trees. Using consumer technologies, a city's inhabitants can be powerful augmenters[16] to an ambient dataset, as blanketing the whole of a city with sensors is rarely practical or financially affordable.

Promoting digital service capabilities and platforms like these, a city can encourage, enable and support city dwellers to apply their cognitive surplus towards SCC opportunities, allowing a city to more economically substitute physical atoms for information bits (e.g. dematerialization), or optimise consumption rather maximise production (e.g. servitisation or product-service systems)[17]. These new forms of digital city service capabilities are characterised by the use of computing technologies to firstly; enable new collaboration forms amongst local and regional governments, municipalities, universities, citizens and businesses, and secondly; facilitate higher levels of service co-creation with citizens.

7.6. City Impact Realisation:

The move towards triple bottom line accounting expands traditional reporting by acknowledging, in addition to the economic performance, also the ecological and social impact when measuring success. The United Nations and ICLEI standards for urban and community accounting in early 2007, endorsed triple bottom line accounting as the common approach to public sector full cost accounting [39]. However, the realization of triple bottom line impact can often become thwarted by perceived imbalance amongst certain stakeholders of 'all pain, no gain' [40].

More so for cities and urban areas which are complex ecosystems of diverse stakeholder interests whose priorities may vary across economic, environmental, and societal, - a challenge summarised by the parable 'tragedy of the commons'. In it, farmers individually benefit more by grazing additional cattle on the commons while suffering only a fraction of the costs, however collectively the mass over-grazing ruins the commons for everyone. Today, command and control policies, embodied in legislation, regulation, taxes and penalties, are often applied to inhibit such tragedies from occurring – with varying degrees of success.

Even with compelling imperatives to change, sometimes organisations' or individuals' actions can deviate from expected or 'rational choices'. These deviations are progressively being illuminated by examining social, cognitive and behavioural factors affecting our decision-making. In 2009 for example, the UK government installed a Behavioural Insights Team (BIT)[18] to consider the application of behavioural economics[19] to policy design, evaluation and execution. BIT's philosophy is drawn from Thaler and Sunstein [41], who advocate the use of 'nudges' or choice architecture, where decisions are influenced by how choices and information are presented - without taking away

[16] To make (something already developed or well under way) greater, as in size, extent, or quantity
[17] Dematerialization and servitisation are identified as merging traits of Open Innovation 2.0 [26]
[18] https://www.gov.uk/government/organisations/behavioural-insights-team
[19] Behavioural economics uses dual approaches of economics and psychology to understand and predict human choices

freedom of choice but providing timely feedback on consequences of the choices we make. For example, using data from smart meters to provide people with feedback on their home energy usage patterns, plus comparisons with similar households or even other communities can help conserve energy use [42].

Intel Labs is researching real-time energy monitoring systems called Wireless Energy Sensing Technology (WEST) a simple plug-in device that helps manage energy use of all the devices in your home [43]. Similarly, Personal Office Energy Monitor (POEM) which allows office workers to monitor in real time the energy consumed by their PC, printer, heating, lighting and other such devices. Additionally, the Intel Collaborative Research Institute (ICRI) is researching how using various combinations of policies and technologies can have a more enduring impact on behavioural change for a city's sustainability.

Such initiatives possess the potential for contributing towards sustainability of cities e.g. buildings represents 40% of the European Union's (EU) total energy consumption [44], and increasingly, buildings are now required to obtain energy certifications, some go further with public displays of real-time energy usage dashboards. Because our use of energy is traditionally not obvious (at least not until monthly bills arrive), approaches like these provide timely feedback on the consequences of our actions (or inactions) and 'encourage, support and enable' firms and individuals make better choices for themselves and society, much of it achievable without mandating such reductions.

Additionally, successful sustainability approaches are can be increasingly designed as a 'win-win' across shareholders, a concept Porter and Kramer call 'shared value'[20]. This focuses on realizing value propositions that can mutually boost a firm's results and the well-being of communities and environments in which it operates [45]. It differs from corporate social responsibility (CSR), which some regard as a cost of doing business [46], and subject to the vagaries of economic downturns when CSR is often most needed. While CSR fulfils many deserving needs, pursuing programs based on shared value can generate more non-obvious opportunities for win-win and more enduring relationships to addressing pollution, large-scale inefficiencies, and underserved markets regarding social or environmental ills.

As well as identifying shared value opportunities, being able to measure them is also a key aspect to realising city impact, after all 'if you can't measure it, you can't manage it'! While a myriad of measurement approaches exist, a selection of pragmatic methodologies to express and measure value are available [47], [48], [49], [50], [51], [52], [53]. Moreover, the Intel co-founded Innovation Value Institute (not-for-profit entity) researches, advises and disseminates proven approaches for managing IT for value and innovation [54].

Acknowledging that successful SCC impact realisation is multi-faceted, complex, and dynamic, imposing disincentives on harmful behaviours can have its place e.g. green taxes on use of plastic shopping bags. However, to promote more enduring[21] and self-reinforcing[22] methods of sustainable city living may require looking beyond policies of 'command and control' to policies that leverage informed choices, timely feedback, and shared value, all of which can support, encourage and enable organizations and citizens to voluntarily adopt more sustainable approaches because of the utility, convenience, cost and/or social advantage provided over traditional approaches'[23].

8. SCC-CMF Dynamic Feedback Loop

SCC-CMF is architected as a dynamic feedback loop, to be applicable at any level of managing a sustainable connected city hierarchy; from city-wide, to subset of city districts, a single community, to delivery teams or at individual project level. By applying SCC-CMF, maturity can be calibrated, appropriate actions selected and executed. Maturity can be recalibrated by running the feedback loop once more, every loop stimulating new maturity actions

[20] An emerging characteristic of open innovation 2.0 [26]
[21] Often once policies based on disincentives are relaxed or removed, the original harmful behaviours can return
[22] Feedback that results in amplification or growth of desirable behaviours e.g. network effects, or chain reactions
[23] Personal conversations with Martin Curley, Intel Corporation, 2013

that move closer to overall SCC goals. These feedback loops can run in macro and micro cycles amongst all elements of the framework[24]. Figure 4 illustrates the feedback loop, plus identification of nascent key activities associated with driving maturity within each of the enabling platform elements.

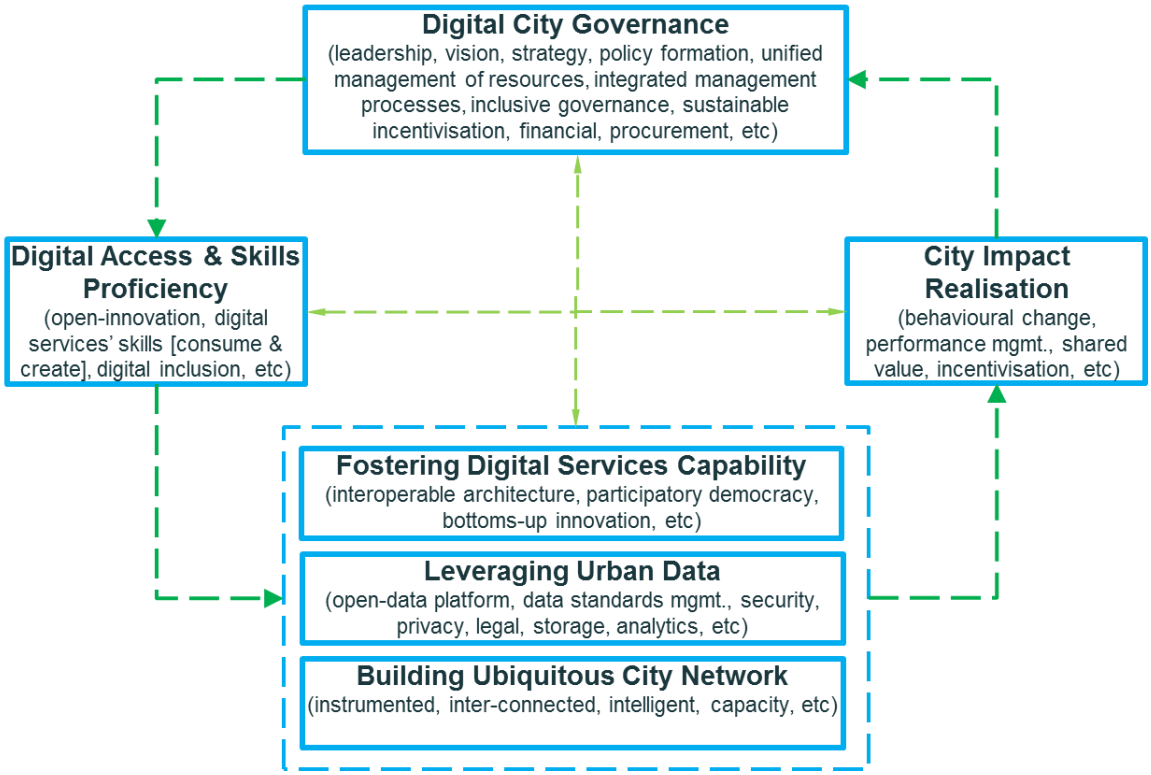

Figure 4: Sustainable Connected City – Enabling Platform Feedback Loops

The intent is to incrementally evolve a city, where computing technologies intelligently connect a city for the sustainable development of its economy, environment and quality of living. Maccani et al [13] summarise key published literature on the impact from employing computing technologies towards better city management of its economy, environment, and society, including improved outcomes across traffic, education, health and well-being, employment, entrepreneurship, e-government, waste management, public safety, food, water and energy supply.

9. Dublin City Case Study Application of SCC-CMF

Dublin City was seeking a management artefact that would help shape the city's digital future and provide a guide for the city to leverage new technologies that will enhance the city's economic vitality, social well-being and environmental balance. The development of SCC-CMF involved intense collaboration from Dublin City officials. This collaboration used a combination of means when developing SCC-CMF, including expert (or face) validity[25], construct validity[26], and empirical validity[27]. Regarding expert and construct validities, a great deal of attention was given to ensuring the various artefacts were clear, easy to comprehend and that all the relevant factors were comprehended. This involved leveraging relevant academic and international practitioner approaches, together with informed and reasoned discussions to develop the design science artefacts outlined in Table 1 and expanded upon in subsequent sections of this paper.

[24] SCC-CMF architecture leverages the Innovation Value Institute's IT Capability Maturity Framework (IT-CMF). The research team would like to thank Martin Curley (originator of IT-CMF) for suggestions in blueprinting SCC-CMF

[25] Face validity is often used to assess whether artefacts appear to make sense

[26] Construct validity relates to whether all the relevant factors are captured and whether all the appropriate relationships between those factors have been identified and incorporated

[27] Empirical validity is used to assess, describe, and recognise causal patterns at work through empirical analyses.

To test empirical validity, a city workshop involving city stakeholder representatives including municipalities, service providers, business groups, transport bodies, environmental agencies, community organisations, councils, etc, and city dwellers to assess the current level of Dublin's SCC maturity and to define how Dublin city can improve its maturity for city sustainability. A maturity scoring rubric was employed to evaluate Dublin City on the SCC Enabling Platform within each of the six SCC domains.

Figure 5 summarises quantitative data collected across the six SCC domains. Leading maturity domain are 'Movement & Transport', 'Community & Citizenship' & 'Environmental Practices', while lagging domains are 'Culture & Entertainment'.

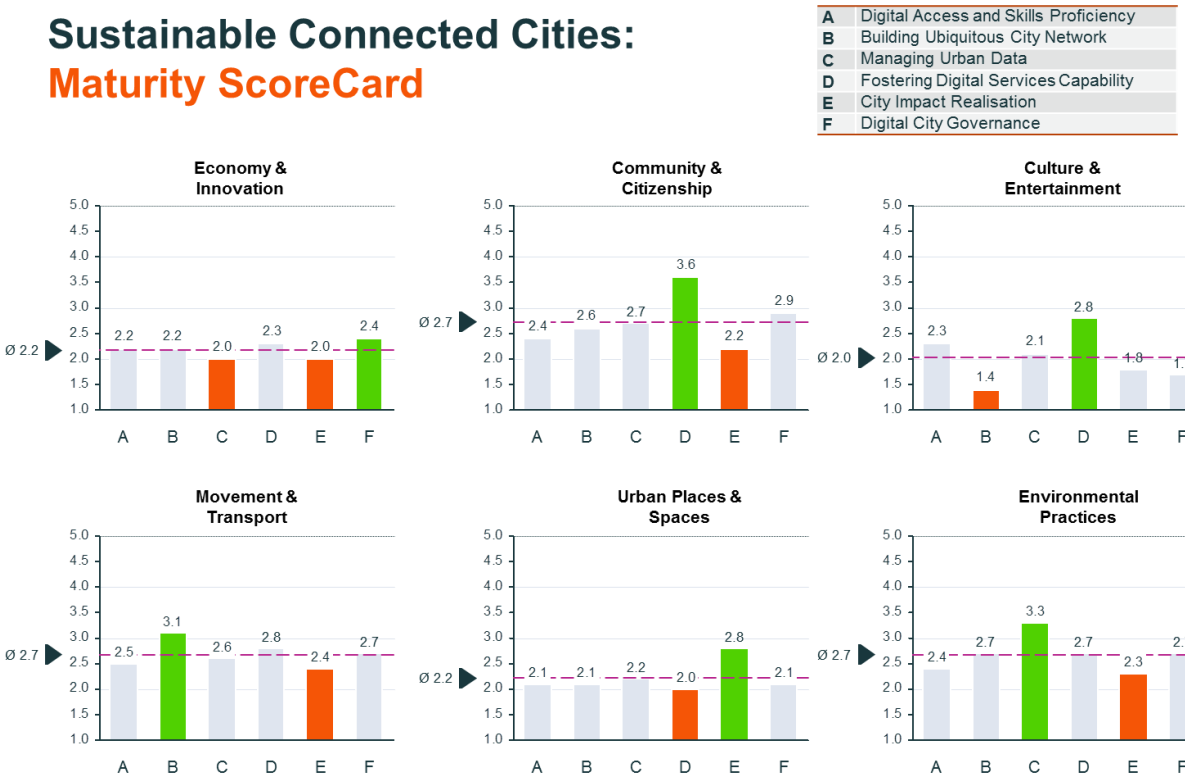

Figure 5: Summary results from Dublin City SCC maturity workshop

As well as quantitative data collected, arrays of qualitative information were solicited using expert facilitators and the SCC-CMF to guide dialogue. The qualitative and quantitative insights from the workshop provided the foundation for creating Dublin's first Digital MasterPlan, unveiled by EU Commissioner Neelie Kroes and Dublin's Lord Mayor in June 2013 - this Digital MasterPlan defines a roadmap for making Dublin a dynamic and technology enabled city [55].

10. Conclusion

The challenge for cities will be to redefine the city as a platform for innovation to shape its own sustainable future leveraging innovative computing technologies. What is required is a form of city-wide swarm intelligence where the collective behaviour of a city's decentralized nature can be coordinated according to universal principles and consistent approaches. This paper outlines the nascent potential of the Sustainable Connected City Capability Maturity Framework to enhance a city's capacity to identify more meaningful approaches towards effectively leveraging computing technologies across its city ecosystem for sustainable outcomes.

Further research is underway on extending the SCC-CMF including, growing international city case studies, researching best practices within the SCC Enabling Platform, cataloguing of world-wide city projects in each SCC domain, defining key-performance-indicators (KPIs) for benchmarking across cities, and expanding SCC maturity assessment instruments outside a workshop delivery.

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Disclaimer

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