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DOI:
10.1016/j.jum.2023.01.004

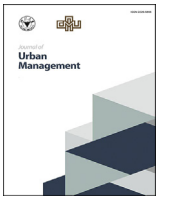
Journal of Urban Management 12 (2023) 57–73

HOSTED BY

Contents lists available at ScienceDirect

Journal of Urban Management

journal homepage: www.elsevier.com/locate/jum



Research Article

Leadership for responsible digital innovation in the built environment: A socio-technical review for re-establishing competencies

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ARTICLE INFO

Keywords:
Competencies
Socio-technical framework
Responsible leadership
City managers and built environment professionals
Digital innovations
Smart cities

ABSTRACT

Digitalisation in cities offers new opportunities and challenges for city planners and managers to re-shape their roles and create public value through responsible innovation. However, there is a lack of understanding of the competency requirements to foster leadership capacity for digital innovation with social coherence and responsibility. Based on a socio-technical perspective, this paper presents a multi- and inter-disciplinary framework to identify and evaluate the competencies necessary for leading digital innovation in the built environment. The framework incorporates three dimensions: digital and technical, governance and management, and ethical and responsible innovation. A review of existing competency frameworks for digitalisation in the urban built environment is presented to identify competency gaps across the three dimensions. The results show that existing frameworks rarely strive for comprehensiveness and are limited in their scope to certain competencies along a single dimension. In addition, studies addressing the need for multi- and inter-disciplinary competencies across the three dimensions are lacking. The paper thus demonstrates that our three-pronged framework is a useful and much needed tool to identify competency requirements for local public, private and community stakeholders to steer place-based digital innovation and ensure public value creation.

1. Introduction

The application of digital technologies in the built environment presents significant challenges for urban planning and management. The development of digital cities is a socio-technical and dynamic change process that involves socio-technical transitions and incremental improvements (Carvalho, 2015; Nochta et al., 2019). Many cities have adopted innovative technologies such as Digital Twins (Nochta et al., 2021), Big Data (Lim et al., 2018), Artificial Intelligence (AI) (Batty, 2018), Machine Learning (Zekić-Sušac et al., 2021), and IoT (Marques et al., 2019) to enhance community satisfaction and quality of life. The integration of digital technologies with urban infrastructures enables urban planners and managers to collect, monitor, process, analyse, and share data among the various

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https://doi.org/10.1016/j.jum.2023.01.004
Received 9 October 2022; Received in revised form 27 January 2023; Accepted 30 January 2023
Available online 13 February 2023

stakeholders (D'Amico et al., 2021). Extracting and connecting information from infrastructure data across various city domains (e.g. energy, transport, water, housing, environment, communication) can help to make better-informed decisions on how to design, manage and operate current and future infrastructures (e.g. buildings, roads, bridges, traffic lights). This requires professional planners with interdisciplinary competencies (i.e. abilities and knowledge) to achieve a collective vision and facilitate stakeholders collaboration (Viale Pereira et al., 2017). Such cooperation and the improvement of associated public services enabled by digital technologies can facilitate public value creation (Criado & Gil-Garcia, 2019).

Public value is a multi-dimensional construct that describes the value that public and private organisations contributes to society (MacLean & Titah, 2022; O'Flynn, 2007). Kelly et al. (2002) stresses three dimensions of public value, including (1) services as vehicles for delivering public value, (2) outcomes as high-level aspirations, and (3) trust, legitimacy and confidence in government as critical aspects to public value creation. Public value paradigm is seen as a way of understanding government activity, informing policy-making and constructing service delivery (Bryson et al., 2014; O'Flynn, 2007). The adoption of such public value perspective implies city managers working collaboratively to respond to the needs of citizens and their collective preferences, achieving multiple goals and expected outcomes, using diverse accountability systems, managing advanced digital technologies, and selecting providers pragmatically to deliver enhanced public services (Bryson et al., 2014). This entails a considerable shift in the roles of city managers and their required competencies to promote integrative leadership and effective public value creation (Hartley et al., 2019; O'Flynn, 2007).

Digital cities require strong leadership to govern (i.e. plan, manage, operate, and use) digital technologies through responsible innovation as a crucial aspect to create public value and mitigate social harms (Vlok et al., 2019). The adoption of innovative technologies can affect the organisational structures, processes, people, and city systems of local authorities that need to be adapted in consequence. Governance allows for a broad understanding of social coordination of such organisational elements which, as a result, can improve decision-making, institutional integration and interoperability, and trust-building between different stakeholders (e.g. public sector, private sector, and citizens) (Nochta et al., 2019). At the same time, urban digital innovation brings new risks and effects of developing, adopting, deploying, and monitoring emerging technologies (Yigitcanlar et al., 2021). Urban managers need to deal with the complexity of digital solutions and the implications to deploy them effectively and safely, considering the negative effects on the society and environment (Martinuzzi et al., 2018; Wan et al., 2019). Such complexity makes it difficult to plan and manage digital innovation projects and requires leaders with the right competency set to deliver new roles and successfully transform cities digitally.

Policy-makers, industry and academia have recognised the need for re-establishing existing roles and competencies to be a successful leader for responsible digital innovation in the built environment (Construction Innovation Hub, 2021; Verhoef et al., 2021; Li et al., 2016). Such reestablishment implies both refining existing roles and competencies and discovering new ones. City managers and built environment professionals should be equipped with the right set of competencies to address the right digital cities projects. However, there is a lack of understanding of the competency requirements to foster leadership capacity and public value creation through responsible innovation. This paper introduces various aspects and visions for leading digital innovation based on a socio-technical perspective according to the technology, governance, and responsible innovation dimensions. A comprehensive review of existing competency frameworks for the urban built environment is conducted to identify competency gaps in such socio-technical dimensions. Results indicate that only a few frameworks directly investigate the role of responsible innovation in urban digital transformations, and barely any studies address the need for interdisciplinary competencies throughout these three socio-technical dimensions. These gaps lead to siloed training which is incompatible with the requirement for *trans*-disciplinary professional roles to deliver responsible digital innovations in the built environment. The results can help to re-think competencies of professional planners in the digital era in order to re-establish existing core competencies and roles and develop new ones.

The remainder of the paper is organised as follows: Section 2 introduces the socio-technical dimensions for leading responsible digital innovation in the urban built environment. Section 3 presents the methodology followed by this study. Section 4 explores and reviews existing competency frameworks from such socio-technical dimensions. Section 5 discusses the main findings and Section 6 concludes the paper.

2. Responsible digital innovation in the urban built environment: A socio-technical viewpoint

Although smart city projects are often presented as the vehicles for tackling various urban challenges and delivering better public value through improved decision-making, outcomes have been identified as underwhelming (Nochta et al., 2019, 2021). Critics argue that the shortcomings are underpinned by overemphasis on technical aspects of smart cities and a lack of multidisciplinary competencies among city managers who are responsible for smart city projects. Nochta et al. (2021) argue that beyond the technical (e.g. deploying sensors, data analytics algorithms), smart city projects have integral social (governance and management, and responsible innovation and ethics) aspects that need to be considered if desired public value outcomes are to be realised. Existing studies show how concerns and problems related to these dimensions of city-scale digitalisation projects are often interrelated; addressing one might hold consequences for another. For instance, high-profile smart city projects like the unsuccessful Sidewalk project by a Google subsidiary failed mainly due to an inability to anticipate and manage important trust issues related to its data-heavy ideology for the planned neighbourhood Austin and Lie (2021). Based on a review of city governance and digital innovation issues in Toronto and London, Kleinman (2016) concludes by stressing the need for city leaders to review and build the needed capacity to ensure efficient deployment of digitalisation initiatives that will serve the purpose of delivering public value. In addition to the technical dimensions of smart city projects, effectively evaluating and incorporating these three dimensions of the social requires city managers to possess multi-disciplinary competencies to achieve the wished-for public value outcomes (Hambleton & Howard, 2013; Panagiotopoulos et al., 2019). Therefore, this study draws on key components from various studies (OECD, 2017; Plummer et al., 2021; Woodruffe, 1993) to define a competency as the repertoire of knowledge and abilities that define how an individual should function effectively in a specific

role to create public value with responsible digitalisation in the urban built environment.

We take as a point of departure the socio-technical nature of smart city projects and argue that a siloed lens – e.g. with emphasis on technical optimization only – would constrain efforts to identify the multi-disciplinary competencies needed to deliver public value through such initiatives (Nochta et al., 2021). In contrast, a growing body of studies emphasize the need to view digital innovation projects as part of smart city initiatives through lenses that take into consideration both social and technical components (e.g. Nochta et al. (2021); Mora and Deakin (2019)). According to Solman et al. (2022), the delivery of a city-scale digital twin, for instance, entails interactions between multiple stakeholders across sectoral boundaries and involve a confluence of business, social and technological dimensions which will engender several multifaceted and evolving complexities. The context specificity of digital innovations in urban built environments, and the multi-party involvements identified also underscore how their development and implementation are inaccurately understood if examined mainly through lenses that privilege either social or technical dimensions only (Nochta et al., 2021; Wan et al., 2019).

From a review of relevant studies Nochta et al. (2021) suggest that three principles guide a socio-technical perspective. First, going beyond an examination of technical functionalities to unpacking aspects of trustworthiness and trust between proponents (e.g. local government, the public sector and private sector actors, investors) and citizens. Undertaking the latter entails an articulation of the approaches used by representative actors in framing policy objectives to shape context-specific model design and utilization to address urban challenges. Second, laying emphasis on how the technical design of digital innovations reflects context-specific characteristics (e.g. governance structures, processes) to enable successful implementation. This principle brings forward the need to understand the social (local) identity of digitalisation initiatives, and not treat their technical components as detached from their origins and final place of use. Finally, a highlight on resource provision and local adaptations is needed to ensure that its implementation is successful. Doing so comprises detailing the human and organisational resources needed to equip a locality with what is needed to deliver desired outcomes related to public value from a digital innovation project as part of a smart city initiative. These three principles draw attention to the role of various actors, how they draw on contextual elements (e.g. local and national policies) and use them to frame city-scale digitalisation projects in ways that engender trust among the network of actors engaged (including citizens), the localised identity of such projects, and adjustments that need to be made within local structures to ensure success, and implications that might arise where they will be deployed. For city managers to successfully undertake these activities as part of delivering public value, they need to be adequately equipped with the right competencies. Although socio-technical studies of smart cities are growing, they are yet to focus on these competency needs of city managers that can be identified.

In the existing literature, few discrete studies drawing attention to competency needs can be usefully grouped around the digital and technical, governance and management, and ethical and responsible innovation dimensions of digital innovations in smart cities projects. The majority of the existing research on smart cities focused on these three dimensions is siloed and therefore falls short in accounting for their interrelatedness. Based on a socio-technical perspective, we propose a framework in which these dimensions are connected and constitute a network that is not limited to engagement from a single discipline of professionals involved in city management (see Fig. 1).

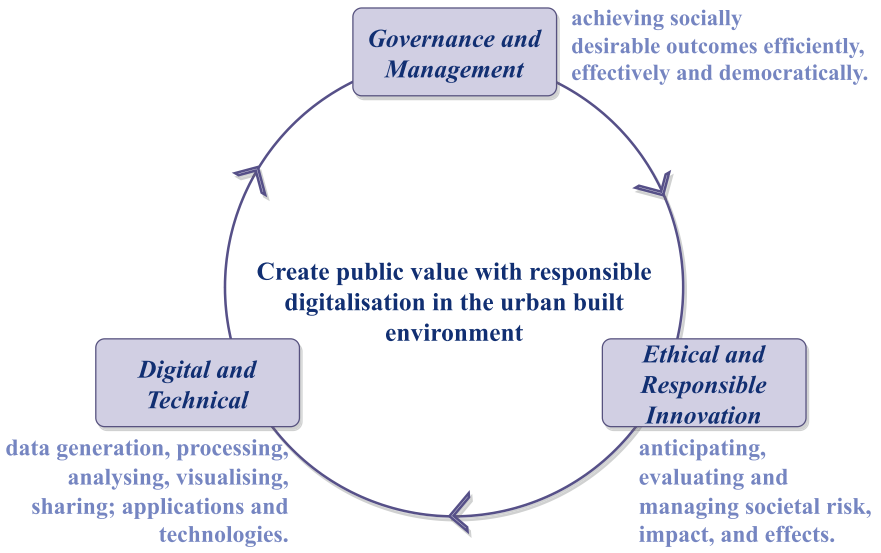

Fig. 1. Socio-technical framework for responsible urban digital innovation. Source: Authors' work.

2.1. Digital and technical

The technical dimension of digital innovations in the urban built environment is arguably the most studied in the literature, and this is echoed across several review papers (Albino et al., 2015; Mora & Deakin, 2019; Nochta et al., 2019). Studies focused on the technical dimension of digital innovations are often premised on the idea that the future of urban systems will be defined by those with superior levels of functionality, performance, and efficiency. There is therefore a lot of attention to complex analytics, modelling, and optimization of data capture and analysis technologies to inform decision-making Albino et al. (2015); Austin et al. (2020). The literature in this category tend to focus on aspects of digitalisation including optimizing technological components, with emphasis on emphasize their functionalities and predictive abilities (e.g. Deng et al. (2021)), as well as improving data structuring, browsing, searching, evaluating, storing, filtering and transfer, and increasing performance of digital twin communications (Austin et al., 2020). Others also focus on understanding information and digital content in various formats and types, and how to integrate data-driven content into existing workflows (e.g. Dembski et al. (2020)).

Growing technocentrism and prevalence of technology optimism bias in smart cities literature poses risks to widely expressed aspirations of smart city proponents to deliver public value using digitalisation in the urban built environment. First, there is the risk of obscuring the practical challenges of city managers taking into consideration the interrelatedness of digital and technical, governance and management, and ethical and responsible innovation dimensions that are embedded in digitalisation initiatives in the urban built environment. Questions about the relationships involving complex analytics and modelling with possible biases in city management decision making and resource distribution, for instance, cannot be addressed if technology-centric studies remain dominant. Second, the persistence of technology optimism bias as the common starting point for several existing studies is limiting for critical studies that will evaluate possible unintended consequences arising from the deployment of data capturing sensors in urban settings. Artificial intelligence linked to facial recognition technologies for crime detection and prevention, for instance, has been found to profile ethnic minorities owing to biases built into their algorithms Engin et al. (2020); Ibänescu et al. (2022); Just and Latzer (2017). For digitalisation to contribute to the creation of public value, an expansion in literature on the digital and technical dimension of smart cities to critical studies of technology is essential. Such studies hold the potential to situate, more clearly, the contextual specificity of deploying technological innovations, and to highlight unintended consequences in society.

Competency requirements of actors involved in city-scale digitalisation, for example, are yet to be discussed in detailed in the existing literature. Nonetheless, few studies indicate, often implicitly, that technical competencies need to be developed among city managers for a successful delivery of digitalisation projects. Snow (2021) found that city managers do not possess the needed capabilities to effectively examine and utilise algorithmic decision tools in smart city technologies and are often averse to them. Other fields (e.g. organisation studies and project management) have benefited from critical studies in better understanding how technological innovations could be deployed to yield desired outcomes and minimize possible negative outcomes. Thus, expansion in this area of studies on smart cities hold the potential to help advance towards developing comprehensive knowledge to facilitate the creation of public value using digital innovations in a way that embraces its embedded socio-technical nature.

2.2. Governance and management

In contrast to technology-focused studies, another section of existing literature argues for the need to focus on the governance and management aspects of conceptualizing, developing and implementing wide-ranging urban scale digital innovations. Such digital innovations are complex socio-technical transitions (Nochta et al., 2019) that involve different sectors, multi-actor governance, high interdependency, inter-departmental coordination, and multiple and conflicting goals (Bastidas et al., 2017). These socio-technical transitions encapsulate strategic (e.g. digital strategies and goals), structural (e.g. institutionalised processes, procedures), human (e.g. multiple stakeholders) and contextual (e.g. laws, culture, regulations) elements that are related to, affected by and/or impact digitalisation initiatives. Proponents of this view argue for the need to focus on these elements owing to the contextual specificity of digitalisation projects, and take as a point of departure not just the physical and technical aspects of these transitions but also their governance (Nochta et al., 2019). Here, the governance and management of these urban-scale digital innovations are key to achieve social outcomes effectively, efficiently and democratically. This means facilitating participation and collaboration across a broad range of relevant stakeholders (e.g. local authorities, service providers, citizens) to achieve common and specific goals, and create public value overall.

Several studies focus on the engagement and participation of citizens as central actors of these urban digital innovations. For instance, Sharp et al. (2022) underscore the need for participatory citizen engagement in the development of smart city initiatives, and valuing plurality in engaging citizens for data governance based on their study of a $135m net-zero sustainability initiative in Melbourne, Australia. Studying smart city projects in the Netherlands (van Zoonen, 2020), concluded that although city managers aspire to deliver ‘public good’, they lack the capabilities to do so owing to data governance weaknesses, contributing to privacy and data protection breaches (Biswas et al., 2019). quantitatively analyse ‘good’ governance indicators from 22 frameworks for urban management in an attempt to establish universality and comparability across geographies based on experts' opinions. These frameworks include those developed by the United Nations Development Programme (UNDP) and from national governments from three continents. From a set of 72 elements drawn from across the frameworks, the criteria found important for judging good urban governance are accountability, transparency, participation, effectiveness, equality, sustainability, vision & planning, legitimacy & bureaucracy, civic capacity, service delivery, efficient economy, relationship and security.

City managers and planners are required to lead these participatory and collaborative processes for and with digitalisation. This implies that city administrators have interdisciplinary competencies to break down the silos of knowledge, data and practices, with the

collaboration of all actors and stakeholders, and the participation of citizens (Gil, 2020). Such competencies should also be complemented with knowledge to manage structural changes in city governance practices, ensuring citizen privacy where data is gathered, implementing measures to avert any unintended disempowering of citizens, instituting data management protocols to safeguard against exploitation, and enforcing data protection regulations. Based on a study in Australia (Barns et al., 2017), discovered a "significant mismatch" between the often-limited capabilities of local governments and the scope of technology adopted in the creation of smart cities. Indeed, based on a review by da Cruz et al. (2019), capacity shortcomings among local governments for urban governance is one of the most prominent topics discussed in the literature. This gap is exacerbated by the introduction of technological innovations that are increasingly becoming popular in several cities around the world, and challenging local governments to evolve how they might achieve socially desirable outcomes (Meijer & Thaens, 2018). To successfully address these challenges, da Cruz et al. (2019) suggest the need for "governance solutions that are inclusive but that nonetheless meet the technical challenges of the 21st century". Reflecting on the problem of capacity gaps earlier noted brings forward the need to focus on how relevant capabilities can be developed by city managers for the preceding vision to be realised.

2.3. Ethical and responsible innovation

Another category of growing literature emphasizing social aspects of urban scale digitalisation initiatives is increasingly drawing attention to issues related to ethical and responsible innovation. The $73m Virtual Singapore project, Papyshev and Yarime (2021) highlighted that the competencies to guide the ethical use of granular human behaviour modelling in addition to historical data-based modelling and predictive analysis of future infrastructure provision are missing among city decision-makers. Despite several calls emphasizing the criticality of principles of ethical and responsible innovation, only a few studies spotlight this dimension of digitalisation projects in the urban built environment. This budding group of studies are based on the premise that the ongoing transition from a period of relative data scarcity to an era of digital abundance under the 'fourth industrial revolution' ought to be approached from an angle that begins by anticipating, evaluating and managing societal risks, impacts and effects from digitalisation. This change, Martinuzzi et al. (2018) reveal, holds implications for inequalities, exclusion, and marginalization. Indeed, Kitchin (2014) and Batty (2018), for example, have argued that the deployment of digital twins as part of a city's smartification agenda holds the potential to deepen marginalization, and further disempower disadvantaged members of society (e.g. persons who experiencing poverty). Although critiques highlighting these issues have emerged, empirical evidence in existing literature confirming or rebutting whether decision-making driven by different digital tools (e.g. city-scale digital twins) (dis)empower and marginalise citizens remains mixed. Widening citizen participation to include under-represented groups, as stakeholders, as part of digitalisation projects has therefore been identified as critical for any 'smart' city initiative (Juvenile Ehwi et al., 2022). How community goals co-evolve with digitalisation projects towards a desired outcome is another area related to the ethical and responsible dimension which studies call for more attention.

As an emerging body of studies, there remains vast potential for various ethics and responsible innovation elements to be explored, including the area of competencies. Urban-scale digitalisation studies should emphasize unpacking how city managers can anticipate, evaluate and manage risk, impacts and effects of digitalisation on society when using digital innovations to deliver public value. In the UK, a set of concepts that come close to suggesting how this might be achieved is the Gemini Principles (Bolton et al., 2018). These offer a template that borders ethical and responsible innovation principles, offering guidance for how digitalisation projects must deliver public good whilst being trustworthy. How this might be achieved through clear capacity building on the part of city managers is however nonexistent (Juvenile Ehwi et al., 2022). also emphasize the need for citizen involvement in smart city projects from their case study in Cambridge, UK, calling upon city managers to be responsible and ethical. This call is based on the background that ethical decision-making is one of the least discussed dimensions of smart city developments, despite being argued to hold far reaching implications for potentially widening citizen inequalities and further entrenching marginalization of minority groups, for instance (Batty, 2018; Engin et al., 2020; Ibănescu et al., 2022). Despite the relevance of this finding, the competencies needed to incorporate ethical and responsible innovation principles in the delivery of digitalisation projects is yet to be discussed in the literature. Studying smart city projects in the Netherlands, van Zoonen (2020) concluded that although city managers aspire to deliver 'public good', they lack the capabilities to do so owing to data governance weaknesses, contributing to privacy and data protection breaches.

3. Methodology

This study conducts a critical review with systematic efforts to identify competency gaps in existing competency frameworks for the urban built environment. The authors sought to follow the guidelines suggested by (Briner & Denyer, 2012) and the concept-centric approach proposed by (Webster & Watson, 2002) to provide a more comprehensive and conceptual structuring of the review. The methodology phases applied are described in the following.

3.1. Identifying the research hypothesis and objectives

This paper presents a socio-technical framework for responsible digital innovation that incorporates three dimensions: *Digital and Technical, Governance and Management, and Ethical and Responsible Innovation.* This review explored the hypothesis that current competency frameworks are mainly focused on certain competencies along a single socio-technical dimension. The main objective of this study is to uncover competency gaps in existing competency frameworks according to these three dimensions. Achieving this objective required a critical assessment of selected competency frameworks and an examination of their coverage of each of the three dimensions.

Table 1
Critical Review of Existing Competency Frameworks from a Socio-technical (S-T) Perspective (Key:✓ = Covered, – = Partially covered, = Not covered).

Competency Frameworks			S-T Dimensions		
Reference	**Short Name**	**Purpose**	Digital and Technical	Governance and Management	>Ethical and Responsible Innovation
Commission et al. (2022)	The Digital Competence Framework for Citizens (DigiComp)	Improve citizens' digital competence and help policy-makers support digital competence building.	✓	–	–
Plummer et al. (2021)	Skills and Competency Framework	Support the implementation of the Information Mgmt. Framework and the National Digital Twin.	✓	✓	–
Shahruddin et al. (2021)	Competency Framework for Local Government	Redefine the BIM competencies of architects serving an architectural institutional environment.	–	✓	–
Olorunfemi et al. (2021)	Competencies and the Penetration Status of BIM	Assess the competencies of built environment professionals in the use of BIM for improvement.	–	✓	
Karsenti et al. (2020)	The Digital Competency Framework	Define the set of skills required for the use of digital technologies, learning, and participation in society.	–	–	✓
GAUC (2019)	The Urban Competency Framework	Develop the competencies that underpin effective humanitarian action in urban crisis.		✓	–
Wedlake et al. (2019)	Digital skill sets for diverse users	Create digital equity research resources to be used for policy, design, and curriculum development.	✓	–	–
Coward and Fellows (2018)	Digital Skills Toolkit	Ensure that young people are equipped with and further develop job-ready digital skills.	✓	–	
UK Department for Education (2018)	Essential Digital Skills	Support providers and employers who offer training for adults to enhance their essential digital skills.	–	–	–
RICS (2018)	RICS Requirements and Competencies Guide	Define the knowledge, skills and competencies required by built environment professionals.	–	✓	–
Law et al. (2018)	Global Framework of Reference on Digital Literacy Skills	Serve for monitoring, assessment and further development of digital literacy in different countries.	✓	–	–
Paschou et al. (2018)	Competences in Digital Servitization	Establish the competencies that should be developed by individuals facing the digital servitization.	–	–	–
OECD (2017)	Core Skills for Public Sector Innovation	Improve the competencies of civil servants to enable innovation in public sector organisations.	–	✓	
Shubha (2017)	E-Governance Competency Framework	Bridge the talent gap between the public and the global industry standards in India.		✓	
Bacigalupo et al. (2016)	The Entrepreneurship Competence Framework (Entre-Comp)	Provide a framework to foster entrepreneurial capacity of European citizens and organisations.		✓	–
IAEA (2016)	IAEA Competency Framework	Align staff's skills, capabilities and knowledge with organisational priorities.		✓	
CEN (2016)	European e-Competence Framework (e-CF)	Provide a common language for describing digital competences of IT professionals.	✓	–	
Van der Waldt (2016)	E-Gov Competency Framework for Public Service Managers	Provide the competencies for civil service managers based on existing competency models and practices.	–	✓	
Jasiewicz et al. (2015)	The Framework Catalogue of Digital Competences	Raise digital activity to allow fully use possibilities of high-speed Internet and new public e-services.	–	–	
UK Government (2012)	Civil Service Competency Framework	Outline of the skills, behaviours, and values expected of civil servants.		✓	
Hunnius and Schuppan (2013)	E-Government Competency Framework	Provide new core e-government skills and competencies related to e-government and public sector.	–	–	
Staff Commission for North Ireland (2012)	Competency Framework for Local Government	Support the delivery of councils' vision, values, corporate plan and strategic framework.		✓	–

3.2. Search strategy and scholarly sources

The search strategy followed a structured approach to determine the source material for the review. The selection of available material was carried out according to the problem investigated, using a variety of both academic and grey literature on digitalisation in the urban built environment and competency frameworks. Google Scholar was used for the preliminary selection of the material, Semantic-scholar was used to refine the search of scientific literature, and Google as a database was used to identify relevant grey literature that presented competency frameworks.

3.3. Key words, inclusion and exclusion criteria

The keywords used in the search process are specified in the following structure: *competency(e) framework* + *domain and/or users*. The list of *domains* includes: smart city(ies), sustainable city(ies), digital city(ies), urban, city(ies), (e−)government, built environment, civil engineering, construction environment, construction engineering, and construction sector. The list of *users* comprised: city managers, city planners, urban planners, civil servants, civic servants, city authorities, urban professionals, and city professionals. For instance, one of the searches was specified as: "competency framework" + digital cities + city managers. The keywords were derived based on an initial search, especially considering the overview and content of the articles. The keywords were searched in the title, abstract, and keywords terms. The date of publication was considered as an additional criterion to shape the initial collection of papers. In particular, the selected articles were published between 2010 and 2022, providing the most recent timespan with a complete set of research on digital and smart cities.

The papers included in the selection are relevant competency frameworks that focus on at least one of the socio-technical dimensions. Articles were excluded if they did not present a comprehensive specification of the competencies for the urban built environment. Successively, additional relevant papers were identified through a snowballing approach by reviewing the citations of the identified articles, as well as reviewing the citations of the identified articles. In total, publications on 22 competency frameworks were identified and reviewed in depth for this paper, which are subsequently examined.

3.4. Structuring the review

The logical approach developed for grouping and presenting the findings of the literature review is as follows. First, we explored the selected competency frameworks and the main purpose of each framework. Second, we critically analysed the coverage of the frameworks in each dimension. Third, we extracted and grouped the set of competency areas for each dimension. In total, 27 competency areas were uncovered: 10 in the *Digital and Technical* dimension, 13 in the *Governance and Management* dimension, and 4 in the *Ethical and Responsible Innovation* dimension. Fourth, we provide a more detailed review of the selected competency frameworks by extracting the set of competencies for each of the uncovered competency areas as presented in the appendices.

4. Competency frameworks for the urban built environment: A multi-perspective review

The review explores existing competency frameworks from a socio-technical perspective. It is presented under the same logic as in the previous section and it is therefore divided into three different dimensions: *Digital and Technical*, *Governance and Management*, and *Ethical and Responsible Innovation*.

Table 1 compiles the list of reviewed frameworks, the main purpose of each framework and the coverage of each socio-technical dimension. It shows that the *Digital and Technical* dimension was addressed by several of these frameworks, while some of these works do not cover any competencies in this dimension. The *Governance and Management* dimension were partially or completely addressed by all the reviewed competency frameworks. In contrast, results indicate that only a few frameworks directly investigate the role of *Ethical and Responsible Innovation* in the urban built environment, and barely any studies address the need for multidisciplinary competencies across the three socio-technical dimensions. Moreover, only a few frameworks focus on leadership capacity, and value creation is conceived primarily as value created through urban data platforms rather than public value created with responsible digitalisation in the urban built environment.

A more detailed review of existing competency frameworks explores the set of competencies for each socio-technical dimension as presented in the following subsections.

4.1. Digital and technical

Digital and technical competencies should capture the main characteristics to describe the capabilities, knowledge and abilities needed for leading digital innovation in the urban built environment. They must imply the confident, critical and responsible use of, and engagement with, digital technologies (Commission et al., 2022). The reviewed competency frameworks focus on various digital and technical competency areas, as described below.

Data Literacy and Management: Demonstrates the ability to create, use, and communicate data in context (i.e. built environment context), and incorporate data into decision-making to improve urban systems and public service delivery (Karsenti et al., 2020; OECD, 2017; Plummer et al., 2021).

Data Modelling: Applies a system thinking method as a way to plan, design, manage and enhance data flow, considering the conceptual modelling of data (e.g. metamodels and taxonomies) and its semantics (e.g. ontologies), which can impact on data sharing and interoperability (Plummer et al., 2021).
Lifecycle Assurance and Quality Management: Understands the dependencies between data quality, its supporting processes, along with lifecycle management and how together they inform data quality and requirements to build trust and transparency (CEN, 2016; Plummer et al., 2021).
Analytics and Intelligence: Specifies quality requirements necessary to produce and analyse data using statistical analysis techniques and data science methods. Uses visualisation and sense-making processes to serve problem-solving and decision-making tasks (Plummer et al., 2021).
Digital Content and Solutions: Creates solutions that solve complex problems with multiple interacting factors regarding content creation. ICT architecture design is key to maintaining alignment between city service evolution and digital solutions development (CEN, 2016; Commission et al., 2022; Paschou et al., 2018).
Digital Technologies and Tools: Uses and applies digital technologies (e.g. machine learning, big data, blockchain, cloud computing, IoT) and digital tools (e.g. tool ecology) to create urban digital platforms (e.g. BIM software tools, digital twins) (Commission et al., 2022; Plummer et al., 2021; Shahruddin et al., 2021).
Career-specific Digital and Technical Competences: Operates specialised digital technologies and analyses and evaluates specialised data, information, and digital content for a particular field. It involves the use of learning management systems to deliver online education content (Jasiewicz et al., 2015; Law et al., 2018).
Experience and Application: Designs intuitive and engaging user experience interfaces through user research and testing. Closes the gap between data, technology, and users (e.g. using assistive technologies to ensure the participation of people with disabilities in society) (Coward & Fellows, 2018; Plummer et al., 2021).
Devices and Software Operations: Identifies and uses the functions and features of the hardware tools and technologies. Knows and understands the data, information and digital content that are needed to operate software tools and technologies (Law et al., 2018).
Security: Understands the requirements for governance and compliance to inform how data is accessed, used, and shared. Administrates risks and threats in digital environments and incorporates a secure-by-design approach to cybersecurity (Plummer et al., 2021; UK Department for Education, 2018).

Appendix A provides a more detailed view of these digital and technical competencies proposed by the reviewed frameworks.

4.2. Governance and management

Governance and management competencies should include the capabilities, knowledge and abilities required to govern (i.e. plan, manage, operate and use) digital technologies through responsible innovation. They must imply a comprehensive understanding of social coordination among organisational elements in order to improve decision-making, institutional integration and interoperability, and trust-building between different stakeholders (Nochta et al., 2019). The reviewed competency frameworks focus on several governance and management competency areas, as described below.

Strategic Management and Policy: Demonstrates knowledge of urban policy and strategy planning along with the core areas of developing, assessing, and articulating digital programmes within complex governance structures (Coward & Fellows, 2018; GAUC, 2019; Olorunfemi et al., 2021; Shahruddin et al., 2021).
Innovation Appetite: Understands the impact and potential of new technologies, and has the capacity to evaluate costs, benefits and any risks related to their use for business purposes and service delivery innovation (Paschou et al., 2018; Van der Waldt, 2016).
Iteration: Develops policies, products, and services incrementally and experimentally. This iterative approach to digital projects includes different phases such as rapid and incremental development, prototyping and refinement, and experimentation and testing (OECD, 2017).
Business Analysis and Management: Identifies business needs and determines solutions using collected data that is analysed, assessed, and interpreted. Anticipates long-term business requirements, influences the improvement of efficiency and effectiveness of business processes (CEN, 2016; Plummer et al., 2021; RICS, 2018).
User Centricity: Identifies the needs of users and designs policies and services that meet those needs. Adopts participative approaches that involve users in the different phases of digital innovation projects and incorporates opportunities to undertake research and testing with users (OECD, 2017; Shubha, 2017; Van der Waldt, 2016).
Problem Solving and Critical Thinking: Understands the needs and complexity of problems in urban digital environments. Critically assesses and selects digital tools and possible technological responses to solve the identified problems (Commission et al., 2022; Shahruddin et al., 2021).
Communication and Sharing: Provides an opportunity to listen to various stakeholders in order to understand data requirements and ensure commitment to digital innovation initiatives. Shares data, information and digital content using appropriate technologies (Commission et al., 2022; Plummer et al., 2021; Shahruddin et al., 2021).
Collaboration: Enables an environment of data flows, sharing and interoperability with trust among city stakeholders. Uses digital tools and technologies for collaborative processes, and for co-construction and co-creation of data, resources and knowledge (Commission et al., 2022; Plummer et al., 2021).

Transformational Leadership: Promotes and supports the value of data and associated digital assets to meet the purpose and vision of cities. Influences and leads cultural change to effectively implement digital transformation projects (Paschou et al., 2018; Plummer et al., 2021; Shahruddin et al., 2021; Shubha, 2017).
Adaptability: Reflects ways of thinking that enable innovation, resilience, flexibility, and agility to address problems within the complexity and diversity of urban settings (e.g. deal with resistance to change) (Commission et al., 2022; GAUC, 2019; Plummer et al., 2021).
Commercial Mindset: Understands how to specify business cases driven by data governance and sharing, considering the economic and societal outcomes for communities (e.g. the environmental and financial gains of waste reduction) (Olorunfemi et al., 2021; Plummer et al., 2021; RICS, 2018).
Urban Environments: Embraces the use of digital innovation as a vehicle to enhance service efficiency and organisational effectiveness in complex and dynamic systems influenced by social factors, directives, regulations, and policies (GAUC, 2019; Shubha, 2017; UK Government, 2012; Van der Waldt, 2016)
Sustainability and Resilience: Determines relevant sustainable design strategies in order to deal with the possible risk of environmental impact. Promotes resilience of urban communities and actors to manage, adapt to and recover from disasters (GAUC, 2019; Shahruddin et al., 2021).

Appendix B provides a more detailed view of such governance and management competencies extracted from the reviewed frameworks.

4.3. Ethical and responsible innovation

Ethical and responsible innovation competencies should comprise the capabilities, knowledge and abilities required to anticipate, evaluate and manage risks, impacts and effects of digitalisation on society when using innovations to deliver public value. It is required to involve the understanding of the safety and critical development, adoption, deployment and monitoring of digital technologies (Yigitcanlar et al., 2021). The reviewed competency frameworks focus on a few ethical and responsible innovation competency areas, as described below.

Safety: Understands how to protect personal data and privacy within urban digital innovation projects and complies with relevant regulations. Is aware of digital technologies for social well-being, inclusion and positive environmental impact (Commission et al., 2022; GAUC, 2019).
Diversity, Inclusion and Teamworking: Demonstrates the knowledge of behavioural norms in online and virtual interactions and to be aware of cultural and generational diversity. Engages with diverse stakeholders to promote collaboration and defuse conflict when it arises (Karsenti et al., 2020; Shahruddin et al., 2021).
Social and Ethical: Act in an ethical manner, considering the social, cultural and philosophical diversity of the people (e.g. city planners, citizens) who use digital technologies and the context where people interact (Bacigalupo et al., 2016; GAUC, 2019; Karsenti et al., 2020; Shahruddin et al., 2021).
Personal and Professional Empowerment: Uses existing and emerging technologies to discover, acquire, maintain and develop competencies (e.g. entrepreneurial competencies) for personal and professional empowerment (GAUC, 2019; Karsenti et al., 2020).

Appendix C provides a more detailed view of these ethical and responsible innovation competencies proposed by the reviewed frameworks.

4.4. Summary and gaps in the review

The review of both academic and grey literature on digitalisation in the urban built environment and competency frameworks in the previous sections highlights some gaps.

First, there is a clear gap in terms of the lack of competencies that are defined with a socio-technical understanding and cut across the three key dimensions of digitalisation in the urban built environment. This multi-perspective review reveals the lop-sided focus of existing competency frameworks on the *Digital and Technical* and *Governance and Management* dimensions. Fewer frameworks take into account the *Ethical and Responsible Innovation* dimension. For instance, GAUC (2019) addresses the interrelated needs in urban populations and outlines the ethical competencies that underpin effective humanitarian action (e.g. facilitating equitable access to urban services). Nonetheless, this framework does not include the digital aspects of urban innovations. In contrast, other competency frameworks (more technically oriented) are concerned with the financial impact (i.e. money and time) of urban innovation projects (OECD, 2017) and the risk associated with existing IT infrastructure (e.g. risk to web, cloud and mobile resources) (CEN, 2016). However, these works do not consider the similar competencies regarding anticipating impact (e.g. adverse effects that represent harm to public value) and assessing risk to people (e.g. the risk of exclusion in providing digital public services).

Second, despite the existence of competencies on single dimensions, they are not comprehensively brought together, or even jointly referenced and discussed. Hence, approaches to defining competencies and associated roles remain siloed. For example, the *Skills and Competency Framework* published by the Centre for Digital Built Britain (Plummer et al., 2021) proposes the skills and competencies needed to adopt the Information Management Framework (IMF) and support the National Digital Twin (NDT) guided by the Gemini Principles (Bolton et al., 2018). It defines business and digital roles for the adoption of these programmes at both an organisational level

(e.g. cyber security specialist, data architect, data consumer, process modeller) and the national level (e.g. policy maker, business analyst, industry leader, data regulator, sector regulator). The framework highlights other roles (e.g. data quality analyst, enterprise architect, process owner, user researcher) needed to address these digital innovation projects in the urban built environment. However, it focuses primarily on a business perspective towards physical assets and digital twins and does not consider any ethical and responsible innovation role profile.

Third, existing competence frameworks tend to be static, without considering the progressive nature of digital projects. The relationship between competencies and roles, and how such dynamic relationship evolves as a digital city project progresses are not clear. These issues identified are potentially due to the complexity of integrating the three dimensions in developing multidisciplinary competencies which make adopting narrow discrete lenses more attractive in the existing literature. While convenient, such lenses fail to address the socio-technical practicalities of planning, delivering and implementing digitalisation projects in the urban built environment, and fall short when seeking to develop multidisciplinary competencies for city managers. For example, the *European e-Competence Framework (e-CF)* (CEN, 2016) proposes five (5) stages, derived from the Information and Communication Technology (ICT) business processes: plan, build, run, enable and manage. This framework defines a set of reference competencies for each phase, with a generic description of each competency. However, these phases and associated competencies are established from a technical angle, with a weak focus on first establishing the need for such a digital intervention, and less emphasis on urban planning, management, and public service delivery.

5. Discussion: the underpinnings of a competency framework for leading digital innovation in the urban built environment

The previous section reviews the competencies city leaders need to govern digital technologies through responsible innovation in order to create public value and mitigate social harms. As a result of this review, existing gaps are summarised and discussed from a socio-technical perspective. In this section, we address these gaps by outlining the foundations and approach of a competency framework for city managers to be effectively guided by socio-technical understanding when leading digital innovations in the urban built environment.

5.1. Redefine competencies

Digitalisation in the urban built environment is inherently socio-technical and the definition of the competencies required should be more comprehensively approached. There is a need to redefine existing competencies which are fragmented, encompassing a range of disciplines and different competency frameworks even within one discipline and without reference to other interacting disciplines. Digitalisation initiatives, as part of city smartification, are multi-faceted and can be usefully grouped under social (governance and management, and ethical and responsible innovation) and technical (digital and technical) dimensions. It is necessary to redefine interdisciplinary competencies in these areas so that digital innovations to truly transform the public sector into an instrument for creating public value. For instance, there is a trend to apply data analytics and machine learning in diverse digital innovation projects. Many companies recognise the need and benefits of skills in these areas. However, such skills are mainly concentrated on report creation, data analytics, and information visualisation, with less attention to data quality and its impact on trust building (Plummer et al., 2021). This lack of data trust can risk the creation of public value due to the inability to meet the expectations of public-sector stakeholders and citizens.

5.2. Discover multidisciplinary leadership roles

Key roles as specific profiles with cross-disciplinary competencies are needed to achieve the main purpose of creating public value with responsible digitalisation. Towards the reestablishment of roles, it is crucial to develop strategic and operational roles that must be defined by transversal competencies related to the *Digital and Technical*, *Governance and Management*, and *Ethical and Responsible Innovation* Dimensions. However, discovering new roles should not correspond to job roles or individuals; rather, they should be built around groups of relevant competencies that cut across the three dimensions. Worth noting here is that some roles may require teams, while individuals may also be able to undertake multiple roles, depending on the institutional and organisational context and needs. Similarly, competency clusters will feature more strongly in some roles than in others depending on the central focus. Building on the preceding, our main proposition here is that identifying and developing key strategic and operational roles that are based on multidisciplinary competencies are essential if city managers are to be better equipped to consider a balance across the three dimensions of digital innovation projects in the urban built environment.

Strategic roles relate to setting vision and goals that have the delivery of public value at the centre, and directing the management of resources. This involves monitoring the evolution of what comprises public value over time and adapting the kinds of digitalisation initiatives implemented to meet those changes in a way that anticipates and avoids negative unintended consequences. This could include an ecosystems manager/coordinator and an information and data environment manger. An ecosystems manager/coordinator would function as an intermediary between citizens, local authority, councillors, and central government. Such a role would intermediate between local authority departments and managers, and liaise with other local authorities/cities for collaboration and to establish best practices in using digital innovation to deliver public value. This role would require, with varied emphases, competencies including understanding theories of change in socio-technical systems, network management (*Governance and Management*), landscape of digital tools and technologies, data collection tools and analytical methods, data sharing ecosystems (*Digital and Technical*) and forecasting impact, deliberating options, bias in data collection, landscape of data ethics frameworks (*Ethical and Responsible Innovation*).

Operational roles focus on the day-to-day activities related to the delivery and implementation of a digitalisation project. Core values underpinning the development of a digitalisation initiative are instilled in processes, procedures and activities implemented in the delivery of digital innovation projects. At the operational level, roles could include project manager, sectoral manager, experts in diversity and inclusion, cybersecurity, and digital training coordinator. A sectoral manager, for example could be a relatively more complex role and would require varied combinations of competencies. Without privileging any disciplinary professional background, such a role would require competencies to understand interdependencies between various urban infrastructures (transport, communication, buildings), predict the interrelated impacts of digitalisation on existing infrastructure and their users, potential exclusionary impacts on other citizens, and business ecosystems that could emerge at the nexus of the networked infrastructure as a result of digitalisation in order to manage potential risks accordingly. Like the earlier example, these role-defining competencies cut across several dimensions of urban-scale digitalisation and extend beyond the capabilities of an individual professional.

5.3. Define the tasks of the digital innovation process

Implementing innovative technologies in the public sector requires a clear process and well-defined associated tasks that city leaders with the right set of competencies can perform. The development of digital and smart cities is seen as a dynamic change process that extends to both the technological aspects of cities and the social environment that produces, maintains and uses them (Nochta et al., 2021). The planning and management of digital city projects depend often on experience from other methodologies and sectors. For instance, continuous improvement methodologies have been used for many years in some governments to manage operational services (OECD, 2017). At the same time, iterative approaches and project management methods can enable city managers to test prototypes initially at a small scale and then upscale to a broader urban context. The application and adoption of new technologies in the urban built environment are challenging and a digital innovation process and associated tasks are as yet largely unspecified. These tasks should be defined as specific actions and activities considered particularly important in the digital innovation process to fulfil the overall objective of public value creation through responsible innovation, as specified below.

- Planning tasks are required to consider a more strategic, foresight and planning approach to direct innovative experiments, understand their impact, as well as their contribution to creating public value.
- Testing tasks are required to consider the potential and importance of experimentation and prototyping in delivering successful digital innovation.
- Embedding tasks are required to evaluate the outcomes of the pilot experimentation in order to reach a decision whether a particular digital innovation can be embedded into the broader urban context.
- Enabling tasks are required to support a variety of parallel digital innovation processes in order to enable these process cycles to kick-off and deliver expected results.

5.4. Practical implications and challenges

This study introduces a socio-technical and three-pronged framework for leading responsible digital innovation and conducts a review of existing competency frameworks based on this socio-technical perspective. The review shows the need for re-establishing existing roles and competencies to successfully lead responsible digital innovation in the built environment. Such a re-establishment implies both refining existing competencies and roles and developing new ones in organisations responsible for the delivery of digital innovation projects to create public value. This requires critically rethinking the core competencies of professional planners and city managers to promote integrative leadership and effective public value creation and holds implications for catalysing institutional and professional changes.

From an institutional perspective, widespread change and transitions agenda is characterised by the introduction of new logic, and consequently contests between incumbents and the new (Lounsbury & Boxenbaum, 2013; Oliver, 1991; Pache & Santos, 2010). It can therefore be expected that the call for re-establishing competencies that take the three main dimensions into consideration would catalyse changes in how city managers and built environment professionals are trained. The established silo approach of training is put into focus for change, and the relevance of a new interdisciplinary form of training is being argued. This transition is likely to create tensions in areas including professional identities. On the one hand, the status quo encourages siloed training with little to no hybrid knowledge creation across disciplines. On the other hand, the development of cross-disciplinary competencies demands an interdisciplinary approach to training urban built environment professionals and city managers. A collective embrace of the latter is not guaranteed immediately, as insights from the institutional complexity literature suggest (Pache & Santos, 2010). Nonetheless, with growing evidence that there is a significant need for competencies that consider the digital/technical, governance and management, and responsible innovation dimensions of digitalisation initiatives, steady progress can be expected in the provision of such training and education to stimulate changes in professional practice (Construction Innovation Hub, 2021; Li et al., 2016).

The re-establishment of professional competencies holds a direct implication on how digitalisation projects will be planned and implemented, creating better prospects for expected outcomes. With the proposed competencies, city managers and built environment professionals will be well-placed to plan, test, and enable digital innovations not as one-off pilot projects (Nochta et al., 2019, 2021), but as an embedded component of change. This understanding would consequently create a refined view of digitalisation for the creation of public value with well-defined processes, tasks, and roles and their combined inter- and multi-disciplinary competencies requirements. A corollary of the foregoing is the need to refine training and upskilling requirements. Evidently, there is a need for new programs and training for city managers and professional planners to facilitate the promotion of multi- and inter-disciplinary competencies (i.e.

abilities and knowledge) across the three socio-technical dimensions proposed by this study. This places the challenge largely within the urban built environment change and will have an impact on education, practice and professional development to adopt broader schemes for responsible urban digital innovation.

As part of the future work, the results of this study provide the basis for two directions of future work. First, designing a framework to help urban planners identify, develop, and expand the competencies they need to effectively steer responsible digital innovation and ensure public value creation. Secondly, the development of educational offerings for training qualifications following an interdisciplinary approach to help break down the professional silos that currently exist in cities and among built environment professionals involved in digitalisation initiatives and city management.

6. Conclusion

The development of digital cities is a socio-technical and dynamic change process that involves socio-technical transitions and incremental improvements (Carvalho, 2015; Nochta et al., 2019). Digitalisation in the urban built environment is therefore inherently socio-technical and needs to be comprehensively approached as such.

Following such socio-technical understanding, this paper introduces a socio-technical framework to identify and evaluate the competencies necessary for leading digital innovation in the built environment. The framework incorporates three dimensions: digital and technical, governance and management, and ethical and responsible innovation. A review of existing competency frameworks for the urban built environment is presented to explore the set of competencies across the three socio-technical dimensions. This review reveals that most of the frameworks tend to focus on skill requirements on single dimensions and very few investigate inter-disciplinary and intersectional competencies, which are crucial for managing the wider socio-economic and political impact of digital innovations. To address these gaps, we argue that re-establishing the competencies of city leaders requires: (i) redefining competencies from a three-dimensional point of view; (ii) discovering inter-disciplinary leadership roles that currently remain isolated and affect intersectoral collaboration and participation; and (iii) defining the tasks of the digital innovation process that city leaders equipped with the right set of competencies should perform to ensure the ultimate goal of creating public value.

This research helps us to understand that the competencies required by city managers and their delivery partners to tackle interrelated issues across the three main dimensions are better envisaged with their multi-faceted and cross-disciplinary natures in mind. The three-pronged framework proposed by the authors of this paper, while not exhaustive, it certainly is a useful tool to highlight discrepancies in existing competency frameworks and avenues for further research to move towards a more comprehensive, multi- and inter-disciplinary understanding of competency requirements. These results create promising opportunities for researchers and practitioners to develop new competency requirements and re-establish competencies for local authorities and industry stakeholders involved in delivering urban digital innovations and creating public value. In addition, the results will underpin the design of a novel competency framework and the development of educational outcomes to train future digital-city leaders.

Declaration of competing interest

All authors declare that we have no conflicts of interest.

Acknowledgement

The study is part of the Digital Cities for Change Programme at the Centre for Smart Infrastructure and Construction (CSIC), Department of Engineering, University of Cambridge. The project is funded by The Ove Arup Foundation [RG89525].

Appendix A. Digital and Technical Competencies

Table A1 presents the digital and technical competency areas as described in section 4.1 and provides a detailed set of competencies extracted from the competency frameworks explored.

Table A1
Digital and technical competencies.

Competency Areas	Competencies	Competency Frameworks (References)
Data Literacy and Management	● Finding data, information and digital content ● Evaluating data, information, and digital content ● Managing data, information, and digital content ● Generating value from data ● Making decisions with data ● Data-driven public services	Commission et al. (2022); Plummer et al. (2021); Karsenti et al. (2020); Coward and Fellows (2018); RICS (2018); Law et al. (2018); Paschou et al. (2018); OECD (2017); Hunnius and Schuppan (2013)
Data Modelling	● Ontology ● Taxonomy and semantics ● Reference data ● Systems architecture and integration	Plummer et al. (2021)

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Table A1 (*continued*)

Competency Areas	Competencies	Competency Frameworks (References)
Lifecycle Assurance and Quality Management	● Data validation ● Information requirements and governance ● Quality analysis and improvement ● Process improvement and modelling	Plummer et al. (2021); CEN (2016); Hunnius and Schuppan (2013)
Analytics and Intelligence	● Analytics tools and techniques ● Data requirements ● Statistical analysis ● Visualisation and sense-making	Plummer et al. (2021)
Digital Content and Solutions	● Developing digital content ● Integrating and re-elaborating digital content ● Copyright and licences ● Computational thinking and programming ● Developing, testing and reviewing solutions ● Designing and developing software and hardware ● Systems Engineering ● ICT Architecture Design	Commission et al. (2022); Plummer et al. (2021); Shahruddin et al. (2021); Olorunfemi et al. (2021); Karsenti et al. (2020); Wedlake et al. (2019); Coward and Fellows (2018); Law et al. (2018); Paschou et al. (2018); CEN (2016); Hunnius and Schuppan (2013)
Digital Technologies and Tools	● Tool ecology ● BIM (Building Information Modelling) software tools ● GIS (Geographical Information Systems) ● Web and mobile applications ● Developing greater awareness of emerging issues concerning digital technology ● Developing a general understanding of artificial intelligence and its impact ● Critically evaluate technology	Commission et al. (2022); Plummer et al. (2021); Shahruddin et al. (2021); Olorunfemi et al. (2021); Karsenti et al. (2020); Wedlake et al. (2019); Coward and Fellows (2018)
Career-specific Digital and Technical Competences	● Operating specialised digital technologies for a particular field ● Interpreting and manipulating data, information and digital content for a particular field	Law et al. (2018); Jasiewicz et al. (2015)
Experience and Application	● User interface design and accessibility ● User requirements and experience ● User research methods and techniques ● User testing ● Assistive technologies	Plummer et al. (2021); Wedlake et al. (2019); Jasiewicz et al. (2015); Coward and Fellows (2018)
Devices and Software Operations	● Physical operations of digital devices ● Software operations in digital devices	Law et al. (2018)
Security	● Legal ● Protecting devices ● Business Continuity ● Managing threats ● Information Security Management	Commission et al. (2022); Plummer et al. (2021); Wedlake et al. (2019); UK Department for Education (2018); Law et al. (2018); Paschou et al. (2018); CEN (2016)

Appendix B. Governance and Management Competencies

Table B1 presents the governance and management competency areas as described in section 4.2 and provides a detailed set of competencies extracted from the competency frameworks explored.

Table B1
Governance and management competencies.

Competency Areas	Competencies	Competency Frameworks (References)
Strategic Management and Policy	● Policy and strategic planning ● Building legislation, regulations and standards ● Managing people and processes ● Managing knowledge and information ● Operating with complex governance structures ● Developing and assessing digital policies and programmes ● Spatial planning policy and infrastructure	Shahruddin et al. (2021); Olorunfemi et al. (2021); GAUC (2019); Coward and Fellows (2018); OECD (2017); Shubha (2017); Bacigalupo et al. (2016); IAEA (2016); UK Government (2012); Hunnius and Schuppan (2013)
Innovation Appetite	● Managing projects for the introduction of new/digital technologies ● Service delivery innovation ● Innovation and continuous learning	Paschou et al. (2018); Van der Waldt (2016)

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Table B1 (*continued*)

Competency Areas	Competencies	Competency Frameworks (References)
Iteration	● Using prototypes to explore approaches ● Conducting tests and experiments ● Taking risks, but not with time or money	OECD (2017)
Business Analysis and Management	● Analysing information to make decisions ● Calculating risk/reward ratio ● Process and workflow mapping ● Requirements definition ● IS and Business Strategy Alignment ● Forecast Development	Plummer et al. (2021); RICS (2018); CEN (2016)
User Centricity	● Solving user needs ● Focusing on users at every step ● Considering how users think and act ● Involving users in projects ● Adopting a holistic people-centred approach	OECD (2017); Shubha (2017); Van der Waldt (2016); Staff Commission for North Ireland (2012)
Problem Solving and Critical Thinking	● Solving technical problems ● Identifying needs and technological responses ● Creatively using digital technology ● Identifying digital competence gaps ● Research and development ● Developing critical thinking ● Curiosity	Commission et al. (2022); Shahruddin et al. (2021); Olorunfemi et al. (2021); Karsenti et al. (2020); UK Department for Education (2018); Paschou et al. (2018); OECD (2017); Shubha (2017); Bacigalupo et al. (2016); IAEA (2016); Van der Waldt (2016); Staff Commission for North Ireland (2012)
Communication and Sharing	● Active listening ● Persuasion and influencing ● Storytelling ● Teaching lessons ● Engaging stakeholders ● Interacting through digital technologies ● Translating technical into everyday language ● Confirm and check quality of information ● Sharing and resharing the right data ● Selecting digital collaboration tools based on needs and context	Commission et al. (2022); Plummer et al. (2021); Shahruddin et al. (2021); Karsenti et al. (2020); Wedlake et al. (2019); Coward and Fellows (2018); UK Department for Education (2018); Law et al. (2018); Paschou et al. (2018); OECD (2017); Shubha (2017); IAEA (2016); UK Government (2012)
Collaboration	● Engaging citizenship digitally ● Collaborating through digital technologies ● Managing digital identity ● Building trusting relationships ● Manage and resolve conflicts ● Seizing opportunities for collaboration and even co-creation ● Working with unusual partners	Commission et al. (2022); Plummer et al. (2021); Shahruddin et al. (2021); Olorunfemi et al. (2021); Karsenti et al. (2020); Law et al. (2018); OECD (2017); UK Government (2012)
Transformational Leadership	● Championing the value of a quality data culture ● Creating a vision and sense of purpose ● Developing and empowering others ● Identifying digital competence gaps ● Driving ownership and accountability ● Develop office culture	Plummer et al. (2021); Shahruddin et al. (2021); Paschou et al. (2018); Shubha (2017); Van der Waldt (2016); UK Government (2012); Hunnius and Schuppan (2013); Staff Commission for North Ireland (2012)
Adaptability	● Continuous improvement ● Embracing innovation ● Results orientation, time and stress management ● Personal resilience ● Scenario planning	Plummer et al. (2021); Karsenti et al. (2020); GAUC (2019); Paschou et al. (2018); Staff Commission for North Ireland (2012)
Commercial Mindset	● Developing strategy and plans ● Identifying use cases ● Taking an enterprise view ● Writing business cases ● Planning finance and budget ● Financial modelling ● Procurement and tendering	Plummer et al. (2021); Shahruddin et al. (2021); Olorunfemi et al. (2021); RICS (2018); Bacigalupo et al. (2016); UK Government (2012)
Urban Environments	● Working in built-up areas	GAUC (2019); Shubha (2017); Van der Waldt (2016); UK Government (2012)

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Table B1 (*continued*)

Competency Areas	Competencies	Competency Frameworks (References)
Sustainability and Resilience	● Working across sectors and industries ● Systems thinking ● Systems dynamics ● Complexity theory ● Management of networks ● Integrating a sustainable assessment method ● Applying sustainable design strategies ● Promoting resilience and sustainability ● Thinking sustainably	Shahruddin et al. (2021); GAUC (2019); Bacigalupo et al. (2016); IAEA (2016)

Appendix C. Ethical and Responsible Innovation Competencies

Table C1 presents the ethical and responsible competency areas as described in section 4.3 and provides a detailed set of competencies extracted from the competency frameworks explored.

Table C1
Ethical and responsible innovation competencies.

Competency Areas	Competencies	Competency Frameworks (References)
Safety	● Protecting personal data and privacy ● Protecting health and well-being ● Assessing risk in the urban environment ● Being safe and legal online	Commission et al. (2022); Plummer et al. (2021); Karsenti et al. (2020); GAUC (2019); Wedlake et al. (2019); UK Department for Education (2018); Law et al. (2018)
Diversity, Inclusion and Teamworking	● Netiquette ● Developing interpersonal skills to interact respectfully and effectively with others ● Defusing conflict between stakeholders with competing interests ● Considering the social, cultural and philosophical diversity of digital society	Commission et al. (2022); Shahruddin et al. (2021); Karsenti et al. (2020); GAUC (2019); Wedlake et al. (2019); RICS (2018); Law et al. (2018); Bacigalupo et al. (2016); Staff Commission for North Ireland (2012)
Social and Ethical	● Exercising ethical citizenship ● Using digital tools to foster inclusion and address diverse needs ● Considering risks associated with the use of digital technology ● Promoting social cohesion ● Facilitating equitable access to urban services ● Maintaining high standards of behaviour in pressured and dynamic environments	Shahruddin et al. (2021); Karsenti et al. (2020); GAUC (2019); Paschou et al. (2018); Bacigalupo et al. (2016)
Personal and Professional Empowerment	● Using digital technology to acquire, maintain and develop competencies for professional life ● Developing entrepreneurial competencies and autonomy via digital technology	Karsenti et al. (2020)

References

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