Chapter 2
A Conceptual Framework for the Alignment of Infrastructure Assets to Citizen Requirements in Smart Cities

James Heaton and Ajith Kumar Parlikad

Abstract With the predicted world population growth of 83 million people per year (increasing 1.09% year on year) compounded with a strong trend for migration to urban centres, there is a developing interest by academics, industry and government to the digitalisation of the built environment and its potential impact on private enterprises, public services and the broader context of society. Governments around the world are aiming to guide and standardise this process by developing an array of standards to support this digitalisation, most notably on Building Information Modelling (BIM) and Smart Cities. Furthermore, the advancement of the Internet of Things (IoT) is creating a highly flexible, dynamic and accessible platform for the exchange capture and of information. There is a risk that this information on the built environment is quickly becoming unmanageable, and the value of that information is quickly becoming lost. This chapter presents a smart asset alignment framework that creates an alignment between the information captured at the infrastructure asset level and citizen requirements within a Smart City. The framework contributes to the debate on designing and developing Smart City solutions in a way that will deliver value to the citizens.

Keywords Smart cities · Asset management · Building information modelling · BIM · Smart cities framework · Citizen requirements · Smart assets

1 Introduction

The concept of using data within a city environment to inform economic, social and environmental policy decisions is not new. During the Cholera outbreak of 1854 in London Dr. John Snow theorised that the disease was being spread through contaminated water and collected data on the location of pumping stations and nearby cholera deaths [1]. John quickly realised that there were geospatial clusters of death

J. Heaton · A. K. Parlikad (✉)
Institute for Manufacturing, University of Cambridge, 17 Charles Babbage Road, Cambridge CB30FS, UK
e-mail: ajith.parlikad@eng.cam.ac.uk

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around specific water pumps and despite the scepticism from the local authority, the pumps' handles were removed, and the deaths quickly subsided. One of the first attempts to document the Social status of citizens within a city was from Charles Booth, who mapped every street of London between 1889 and 1903 and documented the average "social class" of families on those streets [2]. Even though the maps and associated data capture techniques were considered revolutionary at the time, there is little evidence to suggest they helped inform policy and decisions regarding the city's development. During the 1940s the Los Angeles Department for Planning had developed a computer stamp-card system that they hoped could track and analyse all of the properties within the city including information on ownership, number of bedrooms and location [3]. After World War two (1939–1945) there was a growing awareness that the poorly maintained housing stock threatened the prospective health and morals of the city [4], and the planning department while alone could not address this problem. During the 1950s and '60s, the city started to investigate the integration of other data sources such as US census, police department, county assessor, aerial photos and other private and public sources [5]. This exercise was hugely successful in gaining federal funding to support the redevelopment of Los Angeles during the 1950/60/70s.

One of the initial mentions of Virtual and Digital Cities within academic literature was in 1997 by Graham and Aurigi [6], who discussed the nature and potential value of the virtual city within a social and inclusive context. The first Digital City practice was developed in Amsterdam in 1994, that gave the Internet to a large group of people for the first time and is cited as creating the first online community within a specific city and including the general public (not just computer experts, which was common at the time) [7, 8]. These examples show the first concepts of a Smart City, and the advancement of modern technology is evolving of the concept of Smart City that engages with cities' stakeholders and encompasses all of the built and natural environment.

It is accepted that the built environment including infrastructure within a city has a direct impact on the quality of life for citizens that live, work and visit the city. This relationship is generally understood at a high level but not when considering the performance of individual assets to the citizen requirements, specifically within a Smart Cities framework. This chapter addresses this gap by proposing an addition to the existing Smart Cities framework that examines the functional output of infrastructure assets and systems to create an understanding of how a city's infrastructure comes together to deliver services and meet citizen requirements. The fundamental objectives of this research are: (1) to investigate the impact of individual infrastructure asset functions and systems performance on city services and citizen requirements, (2) to investigate the relationship between citizen requirements and cities services and (3) suggest how to underpin the development of Building Information Modelling (BIM) within the concept of Smart Cities. The material presented in this chapter was first published by the authors in the Cities journal.

The chapter is structured as follows. Section 2 sets the context by reviewing Smart Cities standards and specifications alongside the current academic literature in the domain of Smart Cities which informs the smart asset alignment framework presented in Sect. 3. Finally, Sect. 4 summaries the approach and proposes future research opportunities.

2 Literature Review

2.1 Method

A systematic literature review allowed clear understanding of the cross-functional nature and the diversity and complexity of Smart Cities and BIM. Firstly, standards and specifications directly and indirectly related to BIM and Smart Cities were reviewed. Secondly, grey literature such as reports and organisational white papers were analysed. Specifically focused on Smart City ranking and rating reports and white papers focused on Smart Cities management services, technology platforms and implementation and integration offerings. Finally, academic literature was reviewed, utilising the research databases of Google Scholar, Direct Science and Scopus too source both peer reviewed journals and conference papers. The key search terms included Smart Cities frameworks/governance, Building Information Modelling, Engineering Asset Management, physical asset classification, Internet of Things and citizen requirements. Three discreet parts were discovered including governance (government and policy), technology (software, hardware and platforms) and people (educations and stakeholder engagement). These domains were used to structure the following two research questions (1) How can the emerging domains of BIM and infrastructure asset management aid in the development of a Smart Cities framework? (2) How does the performance of infrastructure assets impact on the city services and citizen requirements within a city?

2.2 Smart Cities Standards, Specifications and Guidance

Cities are either planned or evolved organically, often over a timeline of hundreds of years [9]. As an example, Saint Petersburg is a planned city with a specific date of foundation (1st of May 1703) and designed for specific function, as being the new capital of Russian political and military power. Saint Petersburg from its foundation, had a city master plan with construction rules and registrations [10]. While in contrast, Venice is a city that has evolved organically over thousands of years that has been occupied and exploited many times, with little thought to the city planning requirements [11]. While Saint Petersburg had the advantage of a well-structured top-down planning process that provided a structured approach to the city's development, it is often cited that these cities lack a sense of place, culture and community feeling due to their structured development. Because Venice had no structured approach to its development, it created a chaotic and ad hoc approach to the city's development, and history, community and culture playing a key role in the city's development [12]. This dynamic nature of cities makes it impossible to develop a "one size fits all" approach to the development of Smart Cities. The published standards, specifications and guidance have focused on the conceptual framework for how each city should develop its own Smart City objectives and strategies.

Several organisations have started developing an array of Smart Cities related standards, specification and guidance, most notably British Standards Institute (BSI), International Standards Organisation (ISO) and the International Telecommunication Union (ITU). The BSI has developed a comprehensive set of ad hoc standards that are in the form of Publicly Available Specifications (PAS) and Published Documentation (PD) that focus on developing a Smart Cities framework [13]. The ITU has primarily focused on the development of Key Performance Indicators (KPIs) to allow cities to have a credible measure of their Smart City transformation. Furthermore, based on the research developed by ITU study group the KPIs were categorised into ICT, environmental sustainability, productivity, equality and social inclusion, quality of life and physical infrastructure [14–16]. ISO, as the leading international organisation for the development of standards, have a comprehensive array of standards that directly or indirectly aid the development of a Smart City by developing specific standards for specific needs within a city including but not limited to energy, urban mobility, water, infrastructure, security and health [17–22]. The BSI specification PAS 182 (model for data interoperability within a Smart Cities framework) has been adopted as an ISO standard [23].

Even though there is a growing set of documentation around Smart Cities, there are very few enforceable standards,[1] and most of the documentation is guidance, specifications and technical reports. This is partly due to the confusion around the definition of a Smart City and the challenges in developing standards from a holistic point-of-view while still maintaining the required detail. With that being said, there are Smart Cities related standards being developed by ISO, most notably ISO 21972 developing an upper-level ontology for Smart Cities indicators and ISO 27550/1 focusing on information security within a Smart Cities framework [24]. There is no direct and official alignment between the different organisations' standards being developed, but they tend to fall under one of three categories as summarised below (see Table 1 and Fig. 1).

- **Strategic**—Aid in establishing strategies, plans and objectives for Smart Cities, providing a high-level framework for decision-making to agree and develop a holistic Smart Cities strategy with a well-defined vision and purpose, focusing on management progresses and implementation, not the technical processes.
- **Processes**—Support the development of a framework within the city that aids in the data interoperability, normalisation and classification of different datasets that can be combined to create greater informed decisions.

[1] Standard that have a measurable performance rating.

Table 1 Summary of Smart City related standards and documentation

Title	Description	Category	Reference
British Standards Institute			
Smart Cities—Vocabulary	A collection of a diverse range of terms and expressions used in discussions around Smart Cities	Strategic	PAS 180 [25]
Smart City Framework—Guide to establishing strategies for Smart Cities and communities	Proposes a Smart City Framework allowing leaders of a city to develop a Smart City strategy with a vision, objectives and success factors	Strategic	PAS 181 [26]
Smart City concept model—Guide to establishing a model for data interoperability	Guide to establishing a model for data interoperability supporting the classification of information from many data sources within a city	Technical	PAS 182 [27]
Smart Cities—Guide to establishing a decision-making framework for sharing data and information services	guide to establishing a decision-making framework for the sharing of data and information for the creation of information services to support decision-making processes	Process	PAS 183 [28]
Smart Cities—Developing project proposals for delivering Smart City solutions—guide	Guides and case studies for developing a project proposal for Smart Cities solutions.	Strategic/process	PAS 184 [29]
Smart Cities—Specification for establishing and implementing a security-minded approach	a framework for establishing Smart Cities with a security-minded approach aligns to PAS 1192-5	Technical/process	PAS 185 [30]
Smart Cities overview—Guide	Provides general guidance and approach for adoption of Smart Cities processes, focused on rapid development	Process	PD 8100 [31]
Smart Cities—Guide to the role of the planning and development process	Guide for city planning departments on how to advise and plan for the implantation of Smart Cities, including innovative technologies and approaches	Strategic	PD 8101 [32]

(continued)

Table 1 (continued)

Title	Description	Category	Reference
Automatic resource discovery for the Internet of Things—Specification	Specifies a common catalogue format that IoT sensors can be used to recognise each other	Technical	PAS 212 [33]
International Organization Standards			
Guidance on social responsibility	Provides guidance on the underlying principles of social responsibility, recognising the social responsibility and engaging stakeholders.	Strategic	ISO 26000 [34]
Sustainable cities and communities—Vocabulary	A collection of a diverse range of terms and expressions used in discussions around Smart Cities	Strategic	ISO 37100 [35]
Sustainable development in communities—Management system for sustainable development—Requirements with guidance	Establishes requirements for a management system for sustainable development in communities, including cities, using a holistic approach	Process	ISO 37101 [36]
Sustainable development of communities—indicators for city services and quality of life	Establishes definitions and methodologies for a set of city indicators to steer and measure delivery of city services and improved quality of life	Process/technical	ISO 37120 [37]
Smart community infrastructures—Review of existing activities relevant to metrics	An overview of the current metrics and processes used to measure digital infrastructure in a Smart City	Process	ISO/TR 37150 [38]
Smart community infrastructures—Principles and requirements for performance metrics	Provide principles and specifics requirements for community infrastructures performance metrics.	technical	ISO/TR 37151 [39]
Smart community infrastructures—a Common framework for development and operation	A framework for developed of smart community infrastructure, considering their characteristics	Process	ISO/TR 37152 [20]

(continued)

Table 1 (continued)

Title	Description	Category	Reference
Asset Management	Framework for establishing and adopting an asset management system for infrastructure assets	Strategic/process	ISO 55000 [40]
Master data: Quality management framework	Provides a framework for improving data quality that can be used independently or in conjunction with quality management systems	Strategic	ISO 8000 [41]
Quality management systems	Framework for a quality management system with organisations	Strategic	ISO 9000 [42]
International Telecommunication Union			
Key performance indicators for smart Internet of things and Smart Cities	Recommends KPI's for Smart Cities, which guidance on how to measure/achieve them	Process	Y.4903/L.1601/2/3 [14–16]

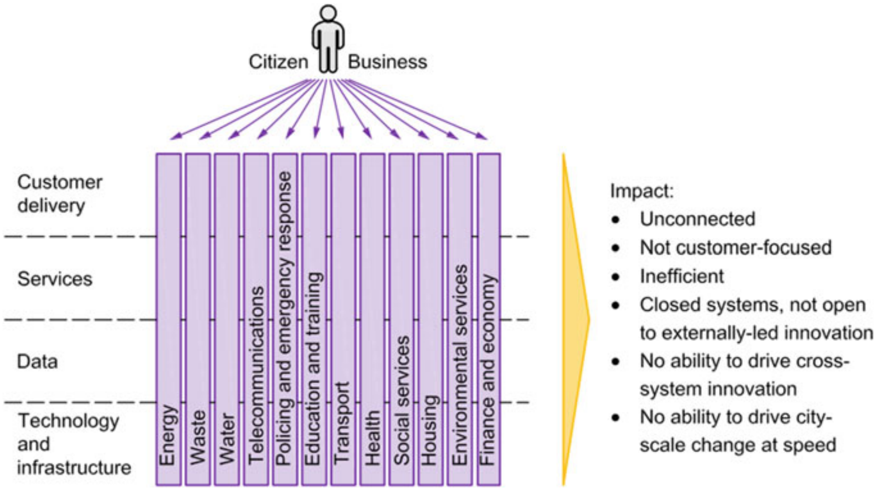

Fig. 1 Tradition cities operating model [26]

- **Technical**—Technical support and guidance on how best to develop the digital infrastructure for Smart Cities, including communication, internet protocols and sensors development.

Whilst not directly related to Smart Cities, the emergence of Building Information Modelling (BIM) is providing a catalyst for the development of Smart Cities. BIM provides a collaborative information management framework used to inform integrated decisions throughout the whole lifecycle (design, construction, operational & maintenance and disposal/renew) of built environment assets. BIM has been widely adopted in the design and construction phase, but its adoption is limited in the operational & maintenance phase [43]. BIM information management processes are governed by a set of standards and specifications that lay down the foundation for how information should be defined, collected, stored, exchanged, used and disposed of in the context of the engineered assets. The key BIM standards are summarised in Table 2 and categorised along the associated asset lifecycle.

Tables 1 and 2 provides an extensive overview of current Smart Cities and BIM related standards, specification and guidance. As can be seen within Table 1, there has been a considerable amount of work completed in developing Smart Cities specifications including strategic guidance on developing a Smart City vision and strategy, process guidance for developing an information decision framework and technical guidance for developing a city data model. Furthermore, KPIs have also been developed to validate Smart Cities' performance. While not all of the references within Table 1 are directly Smart Cities related (such as ISO 8000, 9000, 55000) they will ultimately have an impact on implementing a Smart Cities framework. While the standards within Table 1 are extensive, the Smart Cities framework proposed lacks sufficient guidance for its implementation and fails to align with current and emerging

Table 2 BIM Related Standards Summary

Title	Description	Lifecycle	Reference
Collaborative production of architectural, engineering and construction information	Provides the framework for the development of a Common Data Environment (CDE), an environment to freely share design and construction related data. The owner or principal contractor manage the CDE	Design/construction	BS 1192 [44]
Specification for information management for the capital/delivery phase of construction projects using building information modelling	Guidance in the management of BIM related data within a CDE. A strong focus on BIM management and required documentation, e.g. BIM Execution Plan	Design/Construction	PAS 1192-2 [45]
Specification for information management for the operational phase of assets using building information modelling	proposes the information management framework for the use of BIM within the operational phase, including developing organisational requirements within a BIM-enabled environment	Operational and Maintenance	PAS 1192-3 [46]
Fulfilling employer's information exchange requirements using COBie	UK government requirement for the exchange of information from project to the end user/client, in the format of organised spreadsheets	Exchange from Construction to Operational	BS 1192-4 [47]
Specification for security-minded building information modelling, digital built environments and smart asset management	Guidance on how to support BIM processes with security sensitive information and models		PAS 1192-5 [48]
Briefing for design and construction Code of practice for facilities management	Guidance on operational briefing requirements within the design and construction phase	Operational and Maintenance	BS 8536-1 [49]
Building construction—Organization of information about construction works	Defines a framework for classification of construction-related information, e.g. cost, time, models, ETC	Design	ISO 12006-2 [50]

(continued)

Table 2 (continued)

Title	Description	Lifecycle	Reference
Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries	An opensource information model allowing for the exchange and transfer of 3D geometry, between different enterprise systems	All	ISO 16739 [51]
Building Information Modelling—Information Delivery Manual	A methodology to highlight the exchange of information between different actors for a specific task	All	ISO 29481 [52]
Government soft landings	Guide on how to successfully deliver built asset related information throughout the lifecycle of an asset	All	GSL [53]

processes such as BIM within the construction/operational and maintenance domain within cities.

Table 2 provides the key specifications and standards for the development of BIM information management processes throughout an engineered asset's whole-life. Furthermore, the standards provide a structured approach for the exchange of data throughout the different lifecycles and stakeholders including key milestones for when to exchange data, and the open source format this data should be in, e.g., IFC. Similar to the Smart Cities standards, the BIM standards lack any alignment with current and emerging processes within Smart cities, despite the overlaps within interoperability data models and information decision frameworks. It can be seen that both BIM and Smart City standards have been developed in parallel but in isolation to each other. Furthermore, as BIM spans the whole-life of engineered assets in the contents of information management processes, data structure and exchange protocols, it is well placed to act as an enabler to support the development of a Smart Cities framework.

2.3 Review of Smart Frameworks

The purpose of this review is to gain a comprehensive understanding of the current state of the concept of Smart Cities and informs the development of the Smart Asset Alignment to Citizen Requirements Framework.

Whilst there is not a single solution, there are recurring components in the literature that support the strategic development, implementation and support of a Smart City. The most recurring components can be categorised as technology (software, hardware and platforms), people (education, innovation and creativity) and institutes (government, policy and organisations). Al-Hader [54] specifies the specific components of technology within a Smart City develop as a graphic user-interface (dashboards, reports, web interface, maps), control systems (common platforms, automatic control elements) and database resources (big data, data warehouse, exchange platforms) [54]. The application of IoT has been proposed as a solution to provide a holistic platform to integrate the cities' services under one technology platform [55]. The people component is critical to the success of developing a Smart City, but it is often neglected at the expense of technology and strategic development. It is essential to understand the individual's needs within a city but also the needs of the communities, groups and neighbourhoods of the city [56]. A strong focus is required on education that will foster the knowledge and required innovation to develop and operate within a Smart City. These individuals will form smart communities that deploy ICT solutions in a consensus and agreed-upon approach to aid in meeting the requirements of the community. Institutes are essential for providing leadership, governance, guidance and lead the development of the overall vision [57]. Smart Cities and more specifically the deployment of ICT can enhance the democratic process and provide the community with a more dynamic and alternative relationship with institutes. Governance is a significant challenge for the development of a Smart

City; some traditional challenges include limited transparency, accountability, isolated city services and lack of human resources [58]. A Smart City and therefore smart governance need to address these limitations and incorporate collaboration, communication, partnership, leadership and data exchange/integration solutions.

A growing amount of research is developing (most notably, coming out of the European Commission Horizon 2020 research grants) that focus on the engagement of the stakeholders within the development of Smart, most notably in the use of digital solutions to address the city challenges. These stakeholders include citizens, businesses, city management teams and technology providers. Organicity has developed a seven-step service framework for collaboration within a city based upon Experimentation as a Service [59]. Several case studies have been developed that show how the collaborative approach of the Organicity framework enables the city communities to engage with technology providers and city management support experiments that address a specific city challenges with a digital solution [60, 61]. A more technology-focused development is the City Platform as a Service (CPaas.io). The goal of CPass.io is to provide a solution that enables Smart City innovations for all of the city stakeholders by using the platform to combine the capabilities of IoT, big data analytics, cloud services with government open data approaches and linked data approaches [62]. The platform is then made available for interested parties to engage with. CPass.io, has taken a novel approach to the management of personal data which they called citizen engagement. This uses the human-centred personnel data management processes of MyData [63] and then visualises this in a citizen privacy dashboard that allows the citizen to see when and how their data is being used [64].

The abovementioned Living Labs institutes support the development of Smart Cities frameworks by proving several approaches that aid the technical communities to develop Smart Cities frameworks in engagement with non-technical communicates. Furthermore, a core focus of the tools developed within the Living Labs is providing feedback from the non-technical communities to the technical communities to ensure that non-technical communities needs and wants are addressed within the technical solution. Living Labs is a user-centric approach to integrate current research and innovation processes often within a private-public-city partnership [65]. Several Smart Cities Living Labs have been developed over the years with the specific goals of bring together city management, city planners, sociologists, local community groups and the technical community. There are many similarities within the recent and ongoing research efforts that aim to align the wants and requirements of non-technical local community groups within the technical developments. Furthermore, the references within this section demonstrate that the technical community are testing and putting into practice several aspects of the approaches proposed.

3 Smart Assets/Cities Alignment Framework

This research integrated the industry and academic literature to generate a Smart Asset Alignment to Citizen Requirements Framework for the development of Smart Cities to incorporate the relationship and influences between the citizen's requirements within a city and the functional outputs of the cities infrastructure assets. The framework utilises the Smart Cities operational model within PAS 181 that illustrates the requirement within a Smart City to integrate all the city services through city-wide governance enabled by ICT. This is moving away from the traditional model where the citizen would have to interact with the individual service providers within the city. Figure 1 illustrates the traditional operating model within a city, where services are purely based around the service they provide and are not designed around the citizen requirements. These services are traditionally in vertical silos where organisational processes such as budget-setting, operational delivery, accountability and decision-making processes happen in isolation to the other city services and embedded within the silos of their delivery chain. This traditional approach provides two fundamental challenges in developing a Smart cities framework. Firstly, data and therefore information has typically been siloed within the individual services, both technically such as different data structures and at an organisational level, such as different data quality management processes. This limits the potential for collaboration and alignment across the city services. Secondly, individual citizens and business are required to engage with each siloed service in isolation, having to make connections themselves, rather than receiving a connected service that meets their requirements.

To support the alignment between the services and the citizen requirements it is proposed that within a Smart City framework the services have to be linked to the infrastructure assets (e.g., transport infrastructure) that support the operational requirements of that service. This is achieved by viewing the infrastructure assets within a city as a system, that when combined provide a functional output that aids to support the operational requirements of the city services. The infrastructure assets hierarchy structure follows the industry standard ISO 12006-2 for the classification of infrastructure assets [50]. Several international organisations have aimed to classify infrastructure assets functions, systems, sub-systems and products, the most comprehensive being Omniclass [60] and UNIClass [66, 67]. Figure 2 illustrates the parent-child relationship as defined within ISO 12006-2 and example definitions from UNIClass.

One key advantage for a city to classify its infrastructure assets is to understand the many different asset systems and products that support a function output and the relationship they form. For example, the functional output of heating is partly supported by the gas boiler asset system in which the thermostat is a product/component. Furthermore, as the services provided within a city as defined by PAS 182 [27] are primarily supported by infrastructure assets, it is required to create a relationship between the functional output of the assets to the city services. As an example, a Smart City must provide the service of education, which is supported by multiple functional outputs such as heating, water supply and electricity supply which are

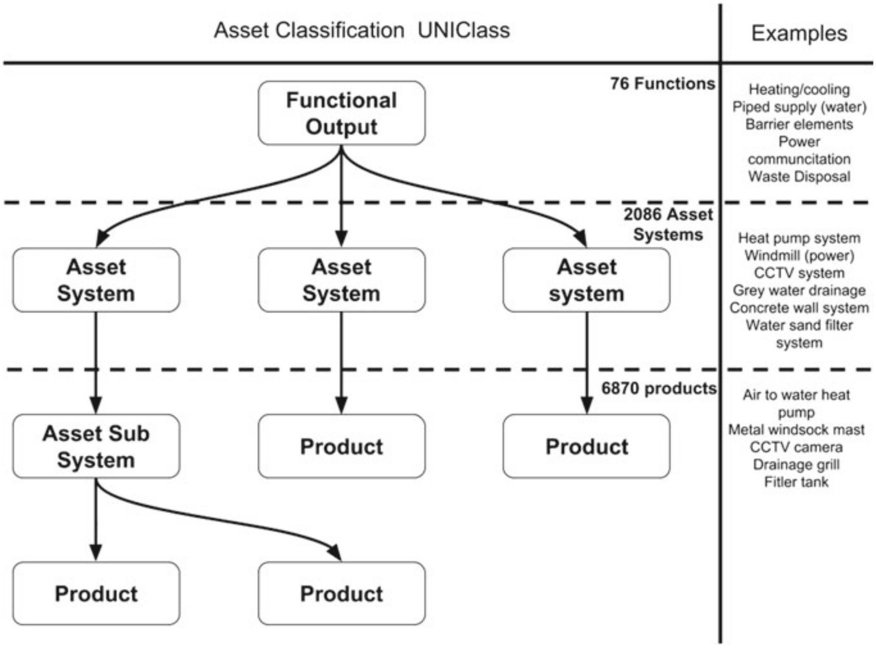

Fig. 2 Infrastructure asset classification system

themselves supported by an array of asset systems and products. Within this example, you could monitor the performance of education via the performance of the infrastructure assets that support that service. Furthermore, you could also monitor/predict the impact that the failure of infrastructure assets will have on the city services. Within this example, the failure of the water supply will have a direct impact on the performance of providing the education service and will result in lost educational hours, as you cannot operate a school without a running water supply. Classification of cities infrastructure assets makes it possible to create a tangible link between the city services and the infrastructure assets that support them.

While the classification of infrastructure assets within a part-child hierarchy relationship is not a new concept, the classification of infrastructure assets within the concept of a Smart Cities framework has not been widely explored. When classifying infrastructure assets from the point-of-view of a Smart Cities framework, the highest functional output of the infrastructure assets should be identified such as transport, communication and waste disposal that align to support the city services. By a city adopting such an approach within its framework, it enables the alignment of BIM related data and the city services, as asset classification is a key step within the BIM processes. As stated within the literature review (Sect. 2). BIM has been widely adopted within the design and construction phases, but with limited use within the operation and maintenance phases. A Smart City framework that aligns itself to BIM related classification will support the seamless transfer of BIM related data into the cities' operational services. Traditionally there is a time-lag between the completion of infrastructure assets such as a new train platform, water pump or school complex within a city and integration into the city services due to the complex nature of infrastructure asset data and information handover over from projects to the city services. A Smart Cities framework that follows BIM enabled classification processes will support a structured approach for the exchange of new infrastructure assets to the city services by providing a common structure for infrastructure asset-related data.

Creating the alignment between asset functions and city services has added benefits. Firstly, it allows the owner of the city services to have a holistic understanding of the assets that support that service and the multiple stakeholders that develop, operate and maintain them. This is especially important when cities assets have public and private owners. Secondly, it provides a scalable platform for data analysis and modelling tools that can focus on individual infrastructure assets performance impact on the cities' services and ultimately the citizen's requirements.

Figure 3 illustrates how the infrastructure assets can be amalgamated within the city services via a data integration layer. The Data Model Integration Layer (DMIL) acts as a data amalgamation platform that supports the exchange of asset related information. The arrows from the functional output to the DMIL represents the flow of asset related data into the DIML. This flow of data should be in an open-source format, ideally in one of the BIM enabled formats such asIFC or COBie, as highlighted in Sect. 2.2. If a BIM-enabled format is not possible, for example if BIM has not been widely adopted within the country, then open source formats as XML, JSON or CSV should be considered. The remaining arrow flowing from the DMIL into the city services represent the flow of data and information from the DMIL directly into their enterprise systems. Examples of such enterprise systems include reporting systems, information technology management, resource planning and fiscal management. The DMIL provides a single point of access to all infrastructure asset related data in a structured approach. As an example, the health services within a city could monitor the performance of public transport related infrastructure assets and feed this data into their appointments management and resource scheduling to respond dynamically to their performance, such as reschedule or cancel the appointment if patients are delayed due to a failed rail signal or rolling stock. Furthermore, the health department could utilise the DMIL to gain greater insight on its resilience by monitoring the performance of the water supply, energy supply, communion and environmental services within one holistic point-of-view and utilise it within their risk management processes.

The DMIL development takes concepts from BIM in the operational phase specification PAS 1192-3 that specifies the development of an Asset Information Model (AIM) [46]. The AIM acts as a single source of amalgamated information for infrastructure asset related data including graphical, non-graphical and documentation. While the DMIL does not encompass all of the concepts of the AIM, the concept of acting as a data store for infrastructure related data and exchange this with enterprise systems is a crucial concept of the DMIL.

To ensure that the Smart Cities development framework is citizen-centric and not the traditional city operational model where citizens have siloed interaction with

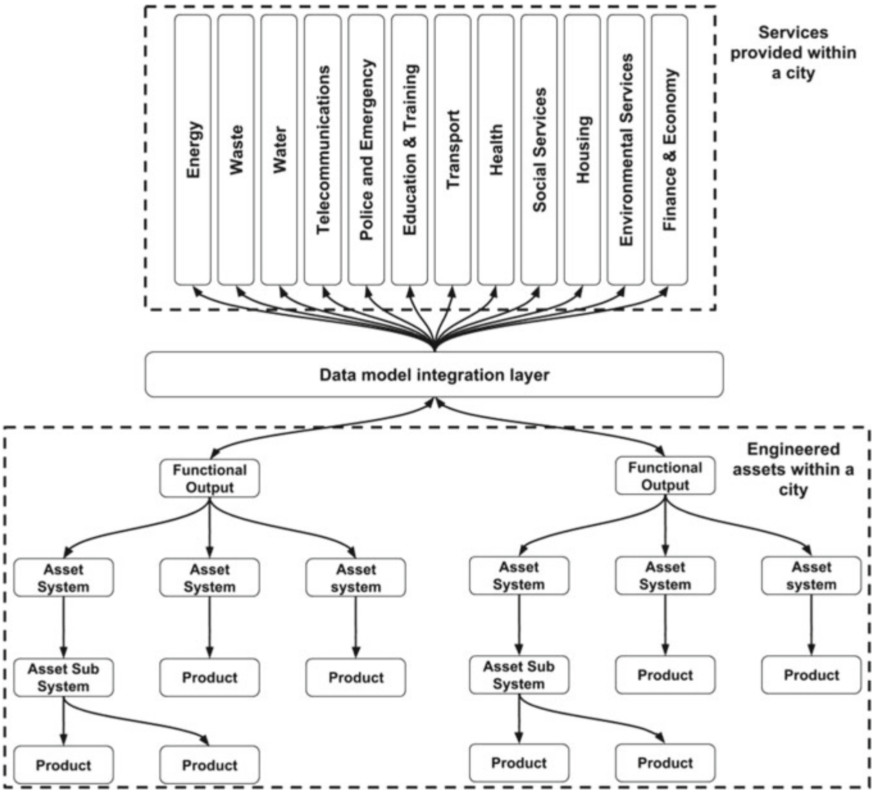

Fig. 3 Alignment of infrastructure assets to the services provided by a city

individual city services, this research has identified the need to understand the citizen requirements in the contents of a Smart Cities framework. Many of the cities citizens requirements will be supported by multiple city services, which in turn are supported by multiple infrastructure assets.

To support the development and classification of citizen requirements it is proposed to use The United Nationals Statistics high-level Classification of the Function of Government (COFOG) [68] as a reference point. The COFOG goal is to identify and classify high-level functions that a stable government should provide to its citizens. Where appropriate these functions have been adopted into citizen requirements, Table 3 summarises the high-level COFOG and associated citizen requirements were applicable.

Classifying citizen requirements in alignment to government functions aids in supporting the integration of city services, as they no longer support individual service requirements but aid to support the holistic requirements for the citizens. While there are vastly different cities around the world due to their development (organic growth or planned), culture and demographics, they must all meet a set of citizen

Table 3 Alignment of government functions with citizen requirements

Functions of government [68]	Citizen requirements
General public service	N/A
Defence	N/A
Public Order and Safety	All
Economic affairs	Work, Invest
Environmental Protection	All
Housing	Live
Health	Heal
Recreation, Culture and Religion	Socialise, play
Education	Learn
Social Protection	Grow-up, ageing (die)

requirements. Understanding citizen requirements is a complex exercise due to the diverse nature of people within cities, especially global cities such as London, New York and Beijing. The citizen requirements developed within this framework are deliberately a high-level concept that addresses all the citizen requirements, no matter the city in question. Furthermore, the high-level nature of these requirements allows for a more holistic alignment of city services to the citizen requirements.

As an example, the United Nationals within the COFOG stated that a functional government needs to provide the service of education, which as a citizen requirement is the need to learn. This citizen requirement is supported by multiple city services such as fresh drinkable water supply, transport services to get to and from the place of learning and telecommunication. The high-level nature of the requirement for learning allows this holistic point-of-view and enable city services integration. The degree to which the individual cities will value and measure the performance of each citizen requirements will depend on the current policy and objectives within the city. As an example, a newly-elected mayor who campaigned on the policy of creating a higher performing education service will result in an increase in the benchmark for performance in learning.

Figure 4 illustrates the final Smart Cities framework that incorporates the three discussed selections of infrastructure asset classification, integration of city services and categorising citizen requirements. A core advantage of implementing such a framework is providing the direct line-of-sight from the citizen requirements through the city services and alignment to the performance of the infrastructure assets. Ultimately the city could analyse the impact of poor performing or failing infrastructure assets on meeting the citizen requirements. As an example, the failure of a rail signal results in a series of cancellations of trains during the morning rush of students travelling to school. This results in students being delayed for school and impacts the level of performance that the city provides in education and ultimately impacts on the students' requirement to learn. Within the traditional Smart Cities framework, this kind of citywide impact analytics would not be possible as they don't consider the performance of infrastructure assets on providing city services.

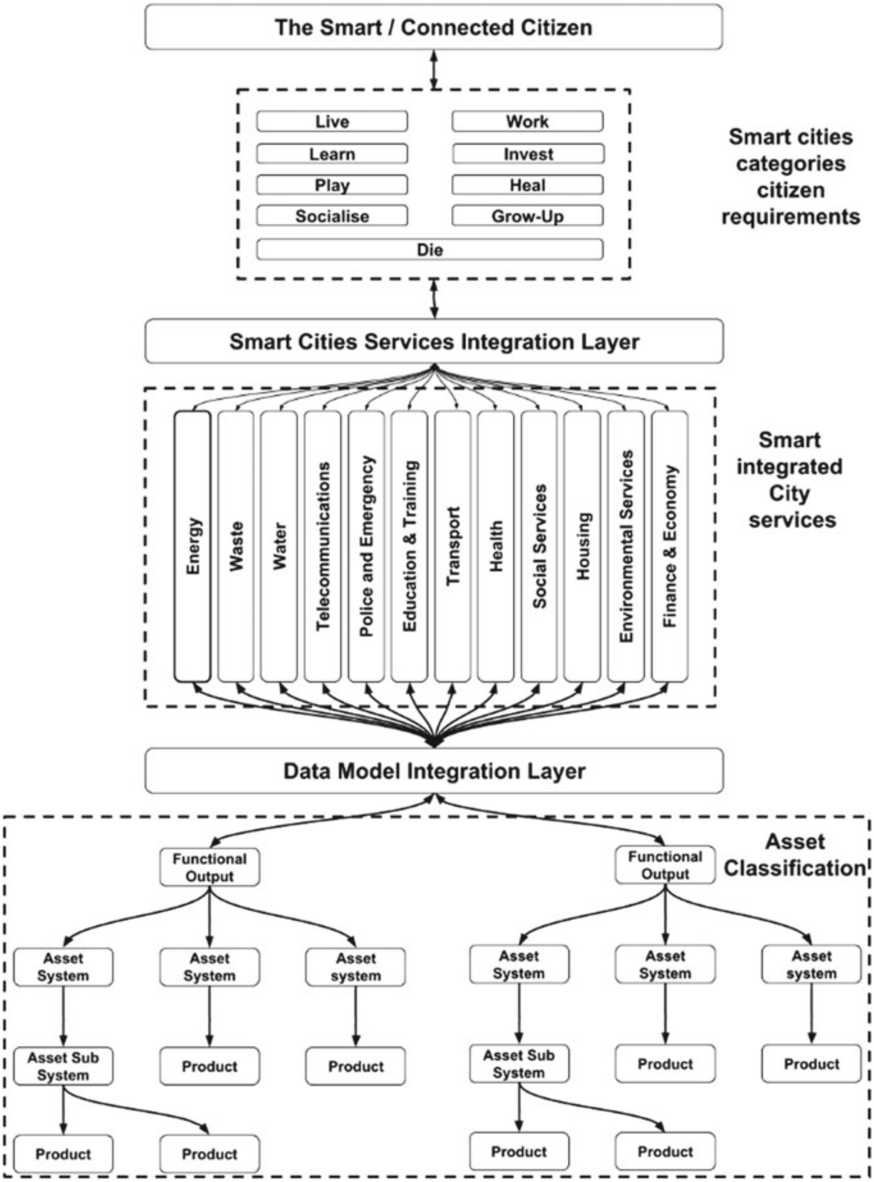

Fig. 4 Smart asset alignment to citizen requirements framework (SAACRF)

The Smart Cities Integration Layer (SCIL) acts as an amalgamation between the city services and the citizen requirements. Focusing on the arrows flowing from the city service to the SCIL, the SCIL integrates all of the city services performance data into a single standardised platform. Much like the DMIL, in a BIM-enabled Smart City this should take the form of a BIM format such as IFC or COBie as highlighted within Sect. 2.2, alternatively an open source format such as JSON, XML or CSV. While the DMIL enables the push of data from the infrastructure assets to the enterprise systems within the city services, the SCIL supports the pull of data out of the individual enterprise systems within the city services. Focusing on the arrow between the SCIL and the citizen requirements, this illustrates the integrated flow of data from the SCIL to the citizen requirements, using the data pulled in by the CSIL to validate if the performance requirements for the citizen requirements are being achieved. Ultimately the CSIL acts as the integration later and gateway to aligning the city services with the citizen requirements and the citizen themselves.

The Smart/Connected citizen is one that can seamlessly connect with the city services in an integrated and holistic solution. Instead of the traditional model where the citizen has individual interaction with the city services, the Smart/Connected Citizen can have access to multiple services through one point of interaction and the value generated from connecting the services is realised. As an example, if a new health problem impacts the mobility of a citizen, this will impact the ability for them to attend school and will need the support of a carer from social services. The proposed framework would support the seamless connection between the health service, education service and social services, without the citizen having to engage with the individual services. Ultimately, this will also allow the city leaders to validate if the citizen requirements are meant to meet by the city services.

Given the recent highly publicised events of data breaches within financial and commercial organisational and more specifically the "hijacking" of personal data for exploitation, it is important to consider the data governance and privacy within such a proposed framework. All personal data should be protected under a data privacy framework, the European Union (EU) development of the General Data Protection Regulation (GDPR) [69] is an example of a data privacy framework that organisations which store personal data within the EU must follow. Furthermore, citizen engagement is critical to ensure transparency and provide assurance that their data is being used for what they approve, Sect. 2 provides examples of Living Labs, which aims to integrate the technical community with the city citizens to provides a citizen-centric smart city solution. The data privacy framework should be implemented within the city services, as they will collect and store the bulk of personnel-related data. The infrastructure assets themselves will not collect, store or use personal data—only operational and performance data will be collected. Care should be taken with the governance of this data to ensure that security, safety and commercial dimensions of the data are highlighted and processes put in place to protect them from malicious exploitation.

The Smart Asset Alignment to Citizen Requirements Framework is a combination of a collection of research domains that have developed in isolation and aims to align key elements of those domains, most notably BIM and Smart Cities. Asset classification is derived from the domain of BIM. A BIM referenced international standard ISO 12006-2 defines the parent-child relationship for infrastructure assets structure and classification that provides the foundation for this section [50]. Furthermore, key literature from the domain of construction management, engineering asset management and information technology in construction provides examples of infrastructure assets part-child relationships and hierarchy [70, 71]. The Smart Integrated City Services is derived from Smart Cities specification PAS 181 [26], which demonstrate the often siloed services provided within a city. Finally, the citizen requirements are derived from The United Nationals Statistics high-level Classification of the Function of Government (COFOG) [68], which states the high-level functions a government must provide.

4 Discussion and Conclusion

This chapter attempts to extend the current Smart Cities frameworks. The concept of a Smart City is becoming increasingly popular, both in academic literature and in industrial applications. The review of the current standards, specification and guidance in the domain of Smart Cities revealed that various international organisations are developing Smart City-related standards within their given domains, but little focus is given to the citizen requirements within a Smart City framework. Furthermore, infrastructure assets within a city have also been neglected from Smart Cities frameworks. This is partly due to the multi-faceted concept of Smart Cities and the complexity of developing citizen requirements. The developed standards, specifications and guidance have been categories into the groups of strategic, process and technical, to describe their focus areas. The most notable and comprehensive Smart Cities standards have been developed by the BSI within the PAS 18X series, focusing on establishing strategies development, establishing an interoperability data model, establish a decision-making framework, developing project proposals and establishing a security-minded approach to Smart Cities. Furthermore, it was noted that the BIM and IoT standards are not directly related to the Smart Cities development but can act as an enabler for the development of Smart Cities throughout the infrastructure assets lifecycles.

The academic literature review discovered that there are many definitions of a Smart City, initially with a strong focus on ICT development but more recently with a focus on citizens and smart communities. Furthermore, many variations exist by replacing smart with alternatives such as digital, intelligence, knowledge and innovation. It is noted that cities are complex, unique and dynamic, led by their history, culture and citizen requirements. Due to this complex nature, it is unrealistic to assume a single framework for Smart Cities development or a one-size-fits-all solution. The most recurring themes include technology (software, hardware and platforms), people (education, innovation and creativity) and institutes (government, policy and organisations). Finally, it was noted that there are many different ways to score and rate the smartness of cities. Most reviewed indicators where ICT focused, but there was a growing need to be able to measure citizen satisfaction and wellbeing within a Smart Cities context.

The proposed smart asset alignment framework within this chapter builds on existing Smart City frameworks (notably PAS 181), it was noted that two components are missing from this framework. Firstly, it fails to identify the citizen requirements within the city. Secondly, it fails to consider the functional output of the cities' infrastructure assets and the impact of this on the citizen requirements.

The existing Smart City framework was first expanded to include infrastructure assets aligned to the city services. To support this, it is proposed to classify infrastructure assets as per the functional output they provide, this follows an industry classification standard. This supports the alignment of thousands of individual asset systems and products that support a function output and ultimately aid in support of city services.

Secondly, many of the citizen requirements are supported by multiple city services, the citizen must manually interact with individual services to meet their requirements. To support the holistic integration requirements of city services within a Smart City framework, it is needed to categorise the city citizen requirements. The high-level governance functions as defined by the United Nations was used as a framework to transform into citizen requirements.

When adding the two proposed components to the current Smart Cities framework, it will provide a direct line-of-sight from citizen requirements, the services used within the city to meet that requirements and the infrastructure assets that support the used services and ultimately validate if the citizen requirements have been fulfilled.

This chapter demonstrated that the performance of a city service is dependent on the performance of multiple different asset functions that are not traditionally considered, as an example, providing the service of health care is impacted on the performance of the public train network to get staff and patients into the hospital. Furthermore, it was noted that a single citizen requirement is often supported by multiple city services. As an example, the citizen requirements 'to learn' is support by the service of education but also by the services of transportation to support teachers and students to travel to a school. Finally, BIM was highlighted as an enabler to support the development of a Smart Cities framework by providing a structured approach for the developed, storage and transformation of built environment data throughout its whole-life cycle.

While there have been significant advancements in the Smart Cities technology solutions (such as IoT), there are still limitations in current technology and data analytics processes to support the data capture, integration and exploitation required within the proposed framework. Furthermore, the understanding of the interaction with these technologies both at the individual level and the collective level is not well understood and could limit the implementation of the framework. Often fractured national government of local policies do not provide the needed transparency and leadership required. Furthermore, the established bureaucracy in city services will be reluctant to expose their services processes and associated data to the other city services and the broader city management. A political, city services culture, technical and social transformation is required to support the development and implementation of the proposed framework. Privacy and concerns of impact on democratic governments within a Smart Cities framework need to be addressed as it becomes a growing concern for cities and society as a whole. This includes both technology-related concerns such IT safeguards of personnel data and governance concerns around the separation of power between governments, technology provides and the citizens. These concerns must be addressed for successful implementation of a Smart Cities framework.

Future research should focus on exploring the scalability of the proposed framework to incorporate the alignment to the broader regulation and government objectives and strategies. This will support line-of-sight from government policy to citizens requirements and the performance of infrastructure assets. Furthermore, due to the diverse nature of cities, the dynamic and changing aspect of citizen requirements should be investigated and inform changes in government functions. Finally, investigating the commercial business requirements might differ from individual citizen requirements and provide new insight into the relationship between business, city services and the infrastructure assets.

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