ArchiSmartCity: Modelling the Alignment of Services and Information in Smart City Architectures

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A thesis submitted in fulfillment of the requirements for the degree of
Doctor of Philosophy

July 2021

This thesis is dedicated to my parents, in loving memory. Thank you for the gift of life and your love. Blessings to you in the immensity of heaven and the company of God.

Declaration

I declare that this thesis is my own work and has not been submitted in any form for another degree or diploma at any university or other institution of tertiary education. Information derived from the published or unpublished work of others has been acknowledged in the text and a list of references is given.

Viviana Bastidas
July 2021

Acknowledgements

This thesis was made possible thanks to the support of many people. First, I would like to thank my main supervisor, Professor Markus Helfert, for his valuable assistance, guidance, great commitment, and enthusiasm during my research process. Thanks to him for giving me the opportunity to start an academic career. I would like to thank the cosupervisors of my research, Dr. Hao Wu and Dr. Marija Bezbradica. Thanks to them for their support, help, and useful advice throughout my studies. I would like to acknowledge Professor Iris Reychav from Ariel University. Thanks to her for the dedicated guidance, encouragement, and extreme support during my research in Israel. I would like to thank the Head of the Computer Science Department at Maynooth University, Dr. Joseph Timoney, for his assistance and support.

I am grateful for the financial support of the Science Foundation Ireland grant 13/RC/2094 and co-funded under the European Regional Development Fund through the Southern & Eastern Regional Operational Programme to Lero - the Science Foundation Ireland Research Centre for Software (www.lero.ie). I am also thankful for the financial support of the Council for Higher Education in Israel through a fellowship program at Ariel University.

Many thanks to all Business Informatics Group (BIG) members for their help and support. Special thanks to Dr. Zohreh Pourzolfaghar for her useful advice, encouragement, and friendship. I would like to thank my colleagues Manoj Kesavulu and Dr. Qishan Yang. Thank you for all your help over these years and the learning that we shared.

I would like to thank my parents with all my heart. Thanks to my mom, Lidia Melo, for her love, support, and sacrifices. Thanks to her for teaching me the importance of education. Her motherly care and smile will be the inspiration for my life. Thanks to my dad, Silvio Bastidas, who has been my motivation for every day. I always feel his love and I remember his words and his example. God bless them in heaven. Thanks to my brother Giovanny Bastidas, for his love and support. Last but not least, I would like to thank my beloved and admired, Dr. Christian Cabrera, for his constant encouragement and endless support. Thank you for always being there.

Abstract

Digital transformation in the public sector describes the shift from traditional creation and delivery of services, into the massive use of digital technologies to enhance public services. The digitalisation of public administration presents significant challenges for many municipalities in the social, economic, environmental, and sustainable dimensions. Cities take advantage of the rapid advances in information and communication technologies capabilities to make the provision of city services (e.g., health service, transport service, air-quality service, education service) more efficient. These modern urban environments are commonly referred to as Smart Cities, where advanced and innovative services are offered to improve the overall quality of life for the citizens. Smart Cities are complex systems that involve diverse stakeholders and concerns, use heterogeneous information systems and technologies, and aim to fulfill multiple and conflicting goals. Such complexity challenges the provision of services that may fail to achieve city goals and meet the needs of citizens due to the lack of alignment between city services and the information systems that support them. Evidence of this is the existence of city services and systems that fail to address the real needs of stakeholders, and are not perceived as valuable by them because they do not interoperate, leading to duplication of work and incompatible solutions.

Enterprise Architecture (EA) is an established planning and governance approach to manage the complexity of corporate systems. EA presents a holistic view of organisational business strategies and IT initiatives to achieve organisational goals by adopting a comprehensive perspective on the overall architecture. Smart Cities can be seen as urban enterprises with more complex and multi-dimensional systems that require integration among smarter services from different domains (e.g., mobility, energy, public safety, emergency, education, culture, etc.) to respond to diverse interests and objectives from a range of stakeholders. Existing research on EAs for Smart Cities uses the concept of layers and views to describe architecture content and guide its implementation. However, these approaches do not identify the concepts to describe and model the relationships between the service and information layers which are essential to address the strategic alignment. Furthermore, there is an absence of such concepts in languages and metamodels for Enterprise Modelling. These architectures and metamodels mostly emphasize technical aspects that constitute Smart Cities and they rarely focus on city services and their strategic aspects towards delivering the cities vision and objectives.

This research introduces *ArchiSmartCity*, a metamodel that addresses the alignment between city services and information systems according to Smart City strategies to assist in the digitalisation of public city services. In this thesis, design principles and design requirements are defined and instantiated by designing the *ArchiSmartCity* metamodel that explicitly expresses this alignment, following a design science research approach. Further, *ArchiSmartCity* is developed and implemented as a coherent extension of an EA metamodel to describe an expository instantiation and its application. *ArchiSmartCity* is evaluated in an iterative manner within multiple-case studies, by creating real-world services models that are validated by Smart City domain experts. Moreover, this thesis demonstrates and evaluates *ArchiSmartCity* by developing a computer-based solution for semantic alignment analysis. Ex-post evaluation results demonstrate the quality and practical relevance of the developed metamodel extension for cities and municipalities. This study contributes to the current understanding of how city strategies should be aligned with Smart City implementations by providing a prescriptive view and metamodel to guide coherent and unambiguous architecture design in the Smart Cities field.

List of publications

1. **Bastidas Viviana**, Reychav Iris, Ofir Alon, Bezbradica Marija, and Helfert Markus. "Concepts for Modelling Smart Cities: An ArchiMate Extension". Business & Information Systems Engineering Journal. Under Review.

   Contribution to the dissertation. Understanding of the different concepts for modelling Smart Cities to provide a coherent Enterprise Architecture description of this field.

2. **Bastidas Viviana**, Bezbradica Marija, Bilauca Mihai, Healy Michael, and Helfert Markus. "Enterprise Architecture in Smart Cities: Developing an Empirical Grounded Research Agenda". Journal of Urban Technology, Under Review.

   Contribution to the dissertation. Understanding of the application of Enterprise Architecture in Smart Cities, focusing on the identified issues in practice and the need for further research.

3. Pourzolfaghar, Zohreh, **Bastidas Viviana**, and Helfert Markus (2019). "Standardisation of Enterprise Architecture Development for Smart Cities". Journal of the Knowledge Economy, pp. 1-22. Springer, 2019.

   Contribution to the dissertation: Outlining the relationships among architecture layers to support the development of a reference architecture for Smart Cities.

4. **Bastidas Viviana**, Helfert Markus, and Bezbradica Marija (2018). "A Requirements Framework for the Design of Smart City Reference Architectures". In Proceedings of the 51st Hawaii International Conference on System Sciences, pp. 2516-2523, 2018.

   Contribution to the dissertation: Understanding the requirements associated with the design of Smart City reference architectures and associated Smart City systems.

5. Helfert Markus, **Bastidas Viviana**, and Pourzolfaghar Zohreh (2018). "Digital and Smart Services - The Application of Enterprise Architecture". In International Conference on Digital Transformation and Global Society, pp. 277-288. Springer, Cham, 2018.

   Contribution to the dissertation: Understanding the concepts related to the service and information layers within an Enterprise Architecture reference framework proposed for Smart Cities.

6. **Bastidas Viviana**, Bezbradica Marija, and Helfert Markus (2017). "Cities as Enterprises: A Comparison of Smart City Frameworks based on Enterprise Architecture Requirements". In International Conference on Smart Cities, pp. 20-28. Lecture Notes in Computer Science, vol 10268. Springer, Cham, 2017.

   Contribution to the dissertation: Identifying essential requirements of Enterprise Architecture in Smart Cities and understanding the alignment issues in this field to guide future research.

7. Pourzolfaghar, Zohreh, Helfert Markus, **Bastidas Viviana**, and Khalilijafarabad Ahmad (2017). "Proposing an Access Gate to Facilitate Knowledge Exchange for Smart City Services". In IEEE International Conference on Big Data (Big Data), pp. 4117-4122. IEEE, 2017.

   Contribution to the dissertation: Understanding the need for the interconnection of city services to make data accessible to different users in the context of Smart Cities.

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Nomenclature

Acronyms / Abbreviations

AMME Agile Modelling Method Engineering

DS Design Science

DSRM Design Science Research Methodology

EA Enterprise Architecture

EAML Enterprise Architecture Modelling Language

EM Enterprise Modelling

ICT Information Communication Technology

IoT Internet of Things

IS Information Systems

IT Information Technology

UML Unified Modeling Language

Chapter 1

Introduction

The digital transformation and innovation of public services in Smart Cities take advantage of the rapid progress in the development of Information Technology (IT) capabilities (Zhuhadar et al., 2017). The public sector is enabled with the advance in IT solutions that make the provision of city services more efficient (Pérez González and Díaz Díaz, 2015). Smart Cities are urban spaces where advanced and innovative services are offered to improve the quality of life for the citizens (Piro et al., 2014). These cities have a high degree of complexity where offered city services must respond to the concerns and goals of diverse stakeholders (Al-Nasrawi et al., 2015). Citizens demand the improvement of services from multiple domains (e.g., natural resources and energy, transport and mobility, living, buildings, government, etc.) where social, economic, sustainable, and technological changes are required (Neirotti et al., 2014). Additionally, city managers must be able to use a large amount of information to support the planning, operations, and optimal management of cities (Schleicher et al., 2016). Deploying these innovative technologies in the public sector requires a structured approach to digitally enable public services transformation, while also managing the increasing complexity (Helfert et al., 2018).

Enterprise Architecture (EA) presents a holistic view of organisational business strategies and IT initiatives to achieve organisational goals and manage the complexity of corporate systems (Ahmad et al., 2018). EA can be used to structure the digital transformation of public services and, consequently, manage complexity in Smart Cities, which can be viewed as Urban Enterprises (Mamkaitis et al., 2016; Ylinen and Pekkola, 2019). Smart cities have organisational aspects, governance and information capabilities, and multidimensional issues as any enterprise (Anthopoulos and Fitsilis, 2014). EA is an established planning and governance approach to manage the change and address the alignment between those various aspects by adopting a comprehensive perspective on the overall architecture (Buckl et al., 2010). Existing research on EAs for Smart Cities uses the concept of layers and views to describe architecture content and guide its implementation (Cox et al., 2016; Kakarontzas et al., 2014; Lnenicka et al., 2017; McGinley and Nakata, 2015; Pourzolfaghar et al., 2019). These architectures present, among other layers, the service and information layers to support the development of services in urban environments. The service layer describes the closest level of a city service (e.g., air-quality service, transport service, health service, etc.) to the stakeholders, while the information layer describes the applications and data to automate city services. However, these architectures do not identify the concepts to describe and model the relationships between such architecture layers which are essential to align the city strategies and goals with the Smart City implementation and solutions. Smart Cities are likely to fail to offer the required services to citizens because of this lack of alignment that negatively impacts the achievement of city goals and objectives (Manville et al., 2014). This results in Smart City systems that do not provide city services to respond to the concerns of stakeholders and meet the needs of citizens.

This research introduces *ArchiSmartCity*, a metamodel that addresses the alignment between city services and information systems to support Smart City strategies. This thesis defines the design principles and design requirements to supopoort this alignment in the Smart Cities domain, following a design science research approach. Such principles and requirements are instantiated by designing the *ArchiSmartCity* metamodel to explicitly express this alignment. *ArchiSmartCity* is developed and implemented as an extension of the ArchiMate language to describe an expository instantiation and its application. ArchiMate (The Open Group, 2017) is an EA modelling language that complies with the Open Group TOGAF framework and is used in this thesis as a base language to describe and visualise EA models. The rest of this chapter presents the theoretical background and formalises the problem of this thesis as follows: Section 1.1 introduces the information on the concepts of Enterprise Architecture, Business and IT alignment, and Enterprise Architecture Modelling. Section 1.2 presents a brief review of the alignment of services and information in Smart Cities. Section 1.3 presents the observations that drives this research and research gap identified. Section 1.4 formulates the problem, motivation, and hypothesis of this research. Section 1.5 presents the research challenges and objectives. Section 1.6 formalises the research questions. Section 1.8 provides an overview of the structure of this thesis.

1.1 Research Background

1.1.1 Enterprise Architecture

Organisations need architectures to manage their complexity, strategies, processes, and systems (Lankhorst et al., 2009). Architecture is defined as "the fundamental organisation of a system embodied in its components, their relationships to each other, and to the environment, and the principles guiding its design and evolution” (ISO/IEC/IEEE 42010, 2011). The purpose of architecture is to align organisational strategies with their business processes, information systems and the coordination of their resources (Janssen and Van Veenstra, 2005). Enterprise Architecture (EA) is an engineering approach and strategy to determine the required enterprise capabilities and subsequently designing the organisation, processes, services, information, and technologies to provide those capabilities (Giachetti, 2012; Rouhani et al., 2015). Organisations use EA to manage their complexity and align business and IT resources (Kurniawan et al., 2013). The benefits of applying EA approaches include increasing IT flexibility and efficiency, supporting complexity management, improving strategic achievement, and reducing management costs (Alaeddini et al., 2017; Boucharas et al., 2010; Niemi and Pekkola, 2016; Shanks et al., 2018). These benefits help to manage constant corporate change and transformation in complex systems, to improve strategic agility and alignment with business and IT. (Kurniawan et al., 2013).

EA is implemented using various frameworks that coordinate different fundamental aspects of an enterprise in a holistic manner (Bhattacharya, 2017; Varaee et al., 2015). These frameworks usually offer guidance for creating and managing EA as well as for the form in which an EA should be described. The Zachman Framework is one of the first frameworks for Information Systems (IS) architecture that was subsequently extended to model the entire EA (Zachman, 1987). This framework is based on the principles of architecture that establish a common vocabulary and set of dimensions or perspectives to describe complex enterprise systems. A number of similar frameworks were developed due to the increasing importance of EA, including the Federal Enterprise Architecture Framework (FEAF) (Chief Information Officers Council, 1999), the Department of Defense Architecture Framework (DoDAF) (Chief Information Officer, U.S. Department of Defense, 2010), the Treasury Enterprise Architecture Framework (TEAF) (Department of the Treasure, Chief Information Officers Council, 2000) and The Open Group Architecture Framework (TOGAF) (The Open Group, 2011, 2018). These frameworks provide a guide to create architecture descriptions for specific concerns of stakeholders through layers and viewpoints organised in various architecture views.

TOGAF is recognized as one of the key and widely accepted frameworks of EA (The Open Group, 2018). This framework is based on interrelated areas of specialization called architecture domains: business, data, application, and technology (Desfray and Raymond, 2014). Business architecture covers strategy, goals, business processes, functions, and organisation structure. Data architecture concerns the organisation and management of information. Application architecture presents applications, software components, and their interactions. Technology architecture describes the technical components and physical infrastructure to support applications and data sources. The TOGAF Architecture Development Method (ADM) is a core element of the framework and describes a method for developing and managing these domains within an architecture lifecycle. The TOGAF content metamodel defines a set of concepts (e.g., business, data, application and technology concepts) to support consistency, completeness, and traceability among architecture domains and layers (The Open Group, 2018). TOGAF artefacts and architecture content can be used by organisations for designing EA that ensures the alignment of business and IT strategies (Kurniawan et al., 2013).

1.1.2 The Alignment of Business and Information Technology

One of the most important issues on information systems (IS) research is the need to align business and information technology (IT). The alignment is conceptualized in the academic literature using various terms such as fit, bridge, integration, harmony, linkage and fusion (Aversano et al., 2012). Business and IT alignment is defined as a means to quantify the extent to which business needs are met with solutions provided by IT (Pereira and Sousa, 2005). The objective of business and IT alignment is to apply Information Technology (IT) in an appropriate and timely way, in harmony with business strategies, goals and needs (Luftman, 2004). Organisations are required to align their business and IT in order to reach business goals and strategies, acquire competitive advantages, and communicate IT performance in business relevant language (Chan and Reich, 2007). Alignment must focus on how IT and business are aligned with each other and how IT can enable business change (Luftman and Kempaiah, 2007).

The business and IT alignment is supported by different approaches that offer a holistic and prescriptive view of its elements and interactions (Chan and Reich, 2007). Henderson and Venkatraman (1993) state that alignment is the degree of adjustment and integration between business strategy and organisational infrastructure on the one hand, and IT strategy and IT infrastructure on the other hand. They propose the Strategic Alignment Model (SAM), which is based on four related key domains of strategic choice, namely business strategy, organizational infrastructure and processes, IT strategy, and IT infrastructure and processes. Luftman

(2004); Luftman et al. (1993) describes alignment as interrelated capabilities that can be measured by assessing six components: communications, value, governance, partnership, scope and architecture, and skills. These six components are placed in a five-level maturity model, where Level 5 is the highest maturity. This model is used as a tool to evaluate the business and IT alignment maturity in a formal manner, identifying necessary actions to ensure the alignment. Labovitz and Rosansky (1997) emphasise the horizontal and vertical alignment dimensions of an organisation. Vertical alignment describes the relation between the strategy at the top and the people at the bottom, whereas horizontal alignment describes the relation between internal processes and external customers. Ross et al. (2006) propose a strategy for the business and IT alignment with three main elements, including the definition of an operating model, the adoption of an IT engagement model, and the design and implementation of EA. The operating model is one of the key elements to understand organisations and design the basis for execution by providing an actionable view of companies. The operating model must be implemented via EA to guide the adoption of IT and ensure the business and IT alignment.

The proposed approaches (e.g., methods, techniques, and tools) to address the business and IT alignment issues involve strategies ranging from modelling to measurement (Aversano et al., 2012). The modelling of alignment is required to capture the information necessary for analysing the alignment and understand whether enough knowledge is available for the analysis. The models can then be used to assess the degree of alignment of the concepts considered and determine if the alignment reaches a satisfactory level for organisations.

1.1.3 Enterprise Architecture Modelling Languages

Enterprise Architecture Modelling Languages (EAMLs) address business and IT alignment in a comprehensive manner by describing the appropriate concepts and defining the relationships between those concepts within a formal language (Desfray and Raymond, 2014; Horkoff et al., 2018). Applying and modelling EA require coherent EAMLs to provide the techniques, languages, tools, and best practices for using models (Chiprianov et al., 2014). An EAML is a formal language, aiming at creating integrated EA models to represent the current and future state of an enterprise at the early stages of design (Sandkuhl et al., 2014). Enterprise Modelling Languages (EMLs) are defined as graphical or textual languages for visualising, specifying, constructing, and documenting the artefacts of a system (Chiprianov et al., 2014). Graphical modelling languages are widely used in EA modelling and specify modelling language aspects by graphical means. The specification of a graphical language comprises two different levels of formality, including the definition of the abstract and concrete syntax (Bork et al., 2020). The abstract syntax defines a set of modelling concepts and the relationships between these concepts that must correspond with the concepts in the semantic domain. The concrete syntax specifies the notation and semantics of the modelling language. Notation refers to the graphical representation of syntactic concepts while semantics specify the meaning of them. Moody (2009) introduces a set of nine principles for designing cognitively effective visual notations and graphical qualities (e.g., layouts, color, size, etc.). The graphical notation of the syntactic concepts in modelling languages contribute significantly to the communication and understanding by domain experts.

Enterprise Modelling Languages (EMLs) such as ArchiMate, MEMO, ARIS, and other EMLs have a high level of abstraction, which can lead to miss the needs of specific modelling scenarios (Lara et al., 2019). Domain specific languages are created to solve this lack of specificity within a defined domain, by creating the vocabulary and notations to describe the domain (Pfeiffer, 2007). Domain specific modelling methods can allow to define domain-specific requirements and formalise them by means of conceptual modelling (Visic et al., 2015). The Open Group especially proposes ArchiMate as an EAML dedicated to TOGAF for modelling integrated EA models (Desfray and Raymond, 2014). This language describes the relationships to model the link between the business, applications, and technology layers (i.e., cross-layer dependencies), which contributes to support the business and IT alignment through a model-based approach (Lankhorst et al., 2009; Lankhorst, 2004). These relationships facilitate the traceability of dependencies between concepts across EA. Concepts and relationships are organised in an EA metamodel which defines the underlying language of the Architecture Content Framework of TOGAF (Arbab et al., 2007; Rurua et al., 2019). The ArchiMate language contains a number of layers to describe architectures (The Open Group, 2017). The core part of the ArchiMate language defines the concepts and relationships from three core layers: business, application, and technology. The strategy and motivation concepts are used to model the strategic direction and motivation behind the core concepts. The implementation and migration concepts are used to support the architecture implementation and migration.

1.2 The Alignment of Services and Information in Smart Cities

Smart Cities are complex systems where Information and Communication Technologies (ICT) play a significant role to address the needs of multiple stakeholders and ensure the delivery of required city services (Khatoun and Zeadally, 2016; Zanella et al., 2014). The Smart City implementation assumes applying ICT to improve the quality of life, the efficiency of urban operations and services, and competitiveness with respect to economic, social, environmental as well as cultural aspects (ITU, 2010; Pourzolfaghar and Helfert, 2017). Smart Cities should be composed by a well-defined strategic plan and innovative solutions that serve the needs of the citizens and urban environments (Agbali et al., 2019; Kakarontzas et al., 2014). Cities and municipalities have to face the challenges for the development and implementation of smarter cities. They need to move from a traditional model to offer the services to a more citizen-centric services, contributing to the success of Smart City initiatives (King and Cotterill, 2007).

City services are traditionally designed and delivered within vertical silos where organisational processes and decision-making happen in isolation to other city services (British Standard Institute, 2014; Heaton and Parlikad, 2019). Smart Cities are required to integrate city services from multiple-domains (e.g., health, education, mobility) to respond to the goals and objectives of diverse stakeholders (e.g., city authorities, service providers and citizens). City managers belong to diverse departments of city councils where different legacy data, applications, and systems need to be integrated (Kuk and Janssen, 2011). These managers are responsible for leading Smart City initiatives and projects to enhance several city services, ranging from services to manage and operate buildings and multimodal traffic management, up to services for the citizen participation driven by social media and Artificial Intelligence (AI) (Schleicher et al., 2016). Furthermore, citizens demand accurate responses to complex requests using composed services, which involves the integration of systems and the exchange of relevant data across such vertical domains (Cabrera et al., 2018; Hefnawy et al., 2015; Ma et al., 2016; Wenge et al., 2014). Therefore, Smart Cities need to respond to a more citizen-centric approach to design and deliver city services.

Fig) 1.1 depicts a sample of the expected alignment between the service and information layers. The service layer presents three city services from different domains which aim to achieve various goals in the city while the information layer presents the applications and data that support each service. The footfall-counter service from the mobility domain offers information on the number of people in various points of the city. The air-quality service from the environment domain provides the air-quality data to the public. The public-safety service from the living domain detects critical safety places in the city. For someone planning a walking trip, Smart City systems must integrate the data from all the three services of these vertical domains. The systems might merge the planned trip information on the pedestrian traffic, air quality data, and safety data, consequently suggesting the best route for the trip. These city services can also have common goals in order to make the city smarter and respond to the needs of citizens. However, each city service involves particular people, processes, decisions, quality properties, data, and applications that must be integrated horizontally among those domains. Smart Cities face different challenges to align the services and information systems that support them, including citizen centricity, multi-domain services, diverse stakeholders and goals, and heterogeneous systems and technologies. The lack of alignment between services and information leads Smart Cities to provide services that may fail to achieve city goals and meet the needs of citizens.

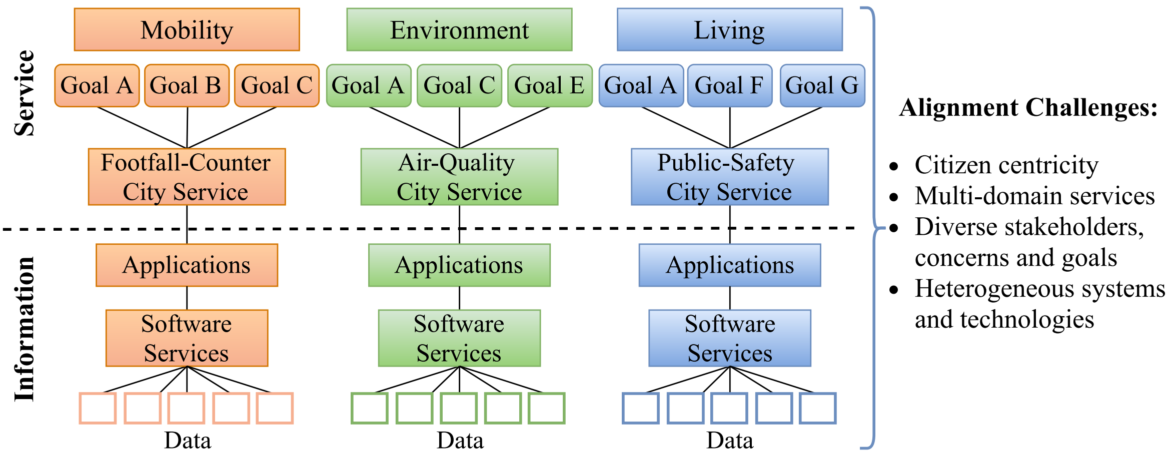


Fig. 1.1 Service and Information Alignment in Smart Cities.

EA is suitable to manage the complexity of large enterprises where multiple stakeholders and heterogeneous systems and technologies coexist and interact (Ylinen and Pekkola, 2019). Smart Cities can be viewed as Urban Enterprises, with organizational aspects, governance and innovation capabilities, and multidimensional issues (Anthopoulos and Fitsilis, 2014; Mamkaitis et al., 2016). A multi-layered framework is proposed as a reference on applying EA to Smart Environments (Helfert et al., 2018; Helfert and Ge, 2017; Pourzolfaghar et al., 2019; Pourzolfaghar and Helfert, 2017). The approach helps to address the complexities associated with service systems in the public sector. The authors augment the traditional EA view of multi-layered frameworks by adding the elements of context and services which are central to Smart Cities. The framework presents, among other layers, the service and information layers to support the development of services in urban environments. *The Service Layer* describes the structure and interaction between the city services, strategy, organization structure, functions, decisions, and information needs. *The Information Layer* describes the information systems and data to support the realization and automation of city services. However, there is a lack of alignment between these layers in existing Smart City architectures. EA concepts that support this alignment and allow the management of these architectures are still missing.

Smart Cities architectures can provide a common framework for stakeholders and a guide to model their concerns (Anthopoulos and Fitsilis, 2014). These concerns require models to cover multiple aspects that need to be captured in a coherent and explicit manner (Sandkuhl et al., 2018). Smart Cities are required to achieve city goals and objectives and provide the desired services to citizens, with challenging implications in the management and design of services (Cicirelli et al., 2017b). A more detailed overview of the alignment between the service and information layers within existing Smart City architectures is presented as follows.

1.2.1 Enterprise Architectures for Smart Cities

Existing EAs for Smart Cities follow a multi-layered architecture to model all possible services (Anthopoulos and Fitsilis, 2014). Kakarontzas et al. (2014) present an architecture based on architecture patterns which address the identified quality requirements of Smart Cities (e.g., interoperability, usability, security, availability, recoverability and maintainability). The framework includes a business logical layer with diverse public or private services. The information layer uses the messaging pattern to gather data from different applications and interfaces. The proposed framework makes suggestions for the service aspects, however, it focuses mainly on information aspects. McGinley and Nakata (2015) present a Community Architecture Framework for Smart Cities based on the Zachman framework. This proposal aims to tackle the complexity that represents the management of multiple stakeholders, their inter-relationships and the conflict of interest resolution. The community architecture framework consists of different dimensions or perspectives, including data, function, network, organization, schedule and strategy. However, the connection between architecture artefacts and models related to the service and information layers are not represented. Cox et al. (2016) adopt TOGAF and a reference model for the Internet of Things (IoT) as frameworks for the definition of a reference architecture for Smart Cities. The architecture layers are represented through different types of services such as business/city services, application services, data services, and sensing services. However, this architecture does not explicitly describe how these different services are connected among architecture layers in order to address the Strategic alignment in this domain.

1.2.2 Business and IT Architectures for Smart Cities

A business and information architecture is presented as an approach to analyse the connection between the business models and information systems of Smart Cities (Kuk and Janssen, 2011). A blueprint is used to describe the information architecture, focusing on the use of Web 2.0 technologies to integrate the information sources in the web browsers of clients. However, the architecture presents only generic relationships between the front-end (e.g., final users of the systems) and back-end components (e.g., databases and application servers). Various information systems architectures for Smart Cities are defined to provide public services to citizens in an efficient manner. Those architectures principally focus on data (Wenge et al., 2014), software services (Bawany and Shamsi, 2015), and Smart City platforms (Kuk and Janssen, 2011; Zdraveski et al., 2017) to integrate, share and govern data from a wide range of services. Several IT architectures for Smart Cities are proposed to support the development and implementation of IT solutions and services (Al-Hader et al., 2009; Cicirelli et al., 2017b; Hernández-Muñoz et al., 2011; Massana et al., 2017). These architectures mostly place on the information aspects (e.g., applications, notifications of events, warnings, and alerts) and technical aspects (e.g., servers, virtual objects, sensors, and actuators) to create technical solutions for cities and municipalities. The above architectures rarely focus on the concepts that constitute the service layer (e.g., city services, strategy aspects, stakeholders, and other concepts) and its alignment with the other architecture layers (Pérez González and Díaz Díaz, 2015).

1.2.3 Limerick Enterprise Architecture Project

Limerick City and County Council (LCCC) is selected as an initial case study of this research in order to explore current and future services. Limerick, the River City, has a digital strategy to become a Smart City (Limerick City and County Council, 2017). One of the main aims is to support the digital transformation and innovation of public services aligned to the needs of the citizens by using digital technologies. Limerick City has a service catalogue to provide to its citizens a comprehensive list of services across across 6 domains, including economy and innovation, community and citizenship, culture and entertainment, movement and transport, urban places and spaces, and environmental practices. However, outdated service data, information silos, unused city dashboards and disconnected domains are common examples of the lack of alignment between services and information observed during this case study.

We developed the Limerick Enterprise Architecture project to add value to public services and illustrate how Enterprise Architecture (EA) can be applied in Smart City contexts. This project adopts EA best practices (e.g., The TOGAF standard) to provide a set of EA guidelines for any local government-related project that guide its involvement with business process, application, data and technology architecture in the region. The project involves the modelling of architecture diagrams for the Urban Architecture Repository in order to guide the design of services and develop the foundations for "Insight Limerick" – the portal for information sharing. The ArchiMate language was adopted for modelling those services following the TOGAF Architecture Development Method (ADM). However, during the design of the models, and based on practical observations, the main conclusion was that both TOGAF ADM and ArchiMate need to be extended to meet the needs of the Smart Cities domain. In addition, the precise and unambiguous specification of the concepts (e.g., domains, city service indicators, sensors, etc.) and the relationships between them according to the particularities of these types of cities are crucial to support the digitalisation and transformation of city services at the early design phase.

1.3 Observations and Research Gap

There are three observations that drive this research. First, Enterprise Architectures are mostly derived from experience in the corporate sector, with limited consideration of the concepts of the Smart Cities domain. These architectures do not identify the concepts to describe and model the relationships between architecture layers which are essential to address the strategic alignment. Second, IT architectures for Smart Cities mostly emphasise on the information and technical aspects that constitute Smart Cities, however, they rarely focus on city service concepts (e.g., strategy aspects, decisions, service qualities, and other concepts) and its alignment with the information concepts (e.g., data, applications, software services, and other concepts). Smart Cities are likely to fail to offer the required services to citizens because of this lack of alignment that negatively impacts the achievement of city goals and objectives (Manville et al., 2014). This results in Smart City systems that do not provide city services to respond to the concerns of stakeholders and meet the needs of citizens. Third, Enterprise Architecture Modelling Languages have a high level of abstraction, which can lead it to miss specific modelling scenarios needed for the Smart Cities domain. Moreover, these languages lack expressiveness for modelling specific concepts that are necessary to express the alignment between city services and information systems. EAs and modelling approaches for Smart Cities should address this alignment by providing:

1. *Vertical and Horizontal Alignment.* Smart Cities are required to support a vertical alignment within existing domains (e.g., energy, transport, health, education), and a horizontal alignment in order to enable the integration among services from various domains. Architecture principles and a common language can provide the required harmonization and alignment of architectures for Smart Cities (Bhatt et al., 2017; Heaton and Parlikad, 2019).

2. *Domain Specific Concepts.* Additional domain specific concepts of Smart Cities should be introduced to properly model city service and information systems scenarios (Bork et al., 2016). Domain specific modelling languages can solve this lack of

specificity, by creating the vocabulary, semantics, and notations to describe the defined domain (Pfeiffer, 2007).

3. *Cross-Layer Dependencies and Relationships*. The relationships of concepts among layers (i.e., cross-layer dependencies) should be modelled and described to address the alignment by using a model-based approach (Lankhorst et al., 2009; Lankhorst, 2004). These relationships can provide a means to link the different layers resulting in coherent models to support the strategic alignment.

1.4 Problem Statement, Motivation and Hypothesis

The wide use of novel and emerging technologies brings both opportunities and challenges for the development of Smart Cities. However, in practice, cities must shift from using traditional service design and delivery to more integrated processes for the provision of public services. This makes it challenging to support the alignment between city services and the underlying information systems according to Smart City strategies. EA concepts that support this alignment and allow the management of these architectures are still missing. Therefore, Smart Cities are likely to fail to offer the required services to citizens because this lack of alignment negatively impacts the achievement of city goals and objectives. This results in Smart City systems that do not provide city services to respond to the concerns of stakeholders and meet the needs of citizens. This research focuses on modelling the alignment between city services and information systems to support Smart City strategies, as a reference that will assist city authorities, planners, and designers in the design and digitalisation of public services. The motivation for this research is to create integrated services that respond to the needs of citizens, considering the challenges faced with the digital transformation. The hypothesis to address the identified problem of this thesis is as follows:

> **Hypothesis:** *The service and information layers in Smart City architectures can be aligned by explicitly specifying the concepts of Smart Cities to ensure that services meet the needs of citizens.*

Fig 1.2 illustrates the general process for how to model the alignment between the service and information layers in Smart City architectures. First, it is necessary to identify the design principles that are used to guide the design of this alignment. Then, design requirements are identified and defined as the basis to represent the Smart Cities domain. Both design principles and design requirements are extracted from the literature and validated with

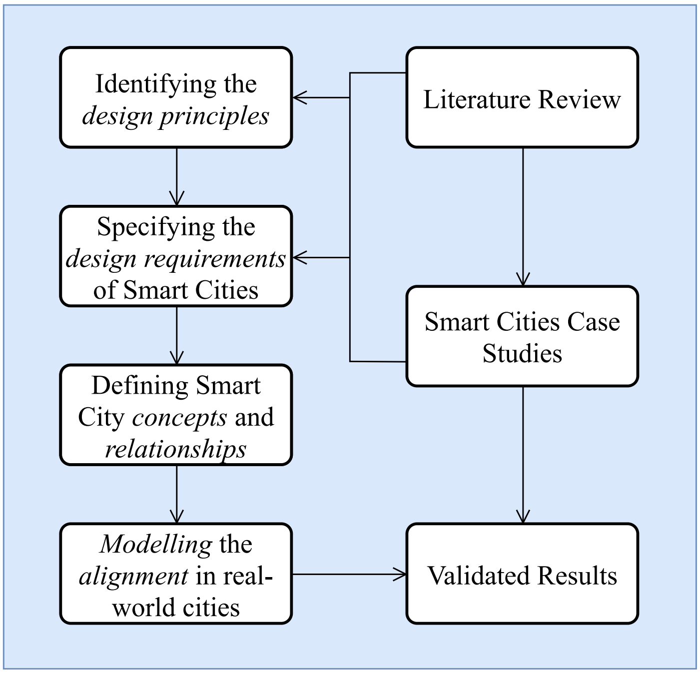


Fig. 1.2 The Overall Process for Modelling the Alignment.

practitioners by conducting multiple case studies. They are subsequently used to define and structure the concepts and relationships that support the alignment between city services and the underlying information systems. Finally, these concepts and relationships are applied by modelling architectures of real-world city services that are validated with domain experts.

1.5 Research Challenges and Objectives

Smart Cities have significant challenges for providing services aligned with Smart City visions and goals, thus improving the quality of life for the citizens. In particular, the alignment of services and information to support the strategic alignment in Smart City architectures faces the following challenges:

Challenge 1: How to *define* the *design principles* for addressing alignment between the service and information layers.

Challenge 2: How to properly *capture and specify* the *concepts and relationships* of the Smart Cities domain which are required to address the alignment between the service and information layers.

Challenge 3: How to formally *design and structure* the *concepts and relationships* of Smart Cities that express the alignment between the service and information layers.

Challenge 4: How to *apply and evaluate* the research proposal to support the alignment between the service and information layers within real-world cases.

The following objectives are proposed based on the hypothesis and the challenges faced by this research:

Objective 1: Identifying the *design principles and design requirements* for addressing alignment between the service and the information layers.

Objective 2: Defining the Smart City *concepts and relationships between them* for addressing the alignment between the service and information layers based on a set of design requirements and the identified design principles.

Objective 3: Creating a coherent *metamodel* to formally represent the defined concepts and relationships between them, together with its syntax, semantics, and graphical notations of the Smart Cities domain.

Objective 4: Providing results of the *application and evaluation* of the proposed metamodel in real-world Smart Cities.

1.6 Research Questions

The following research question is formulated in order to address the identified problem and achieve the research objectives described above:

Main Research Question: *How to support a suitable alignment between the service and information layers in Smart City architectures to meet the needs of citizens?*

The main research question is divided into three sub-reseach questions (RQs). Research question one aims to identify the principles that support the alignment between the service and information layers from the literature and practitioner point of view.

RQ.1 *What are the design principles that support the alignment between the service and information layers in Smart City architectures?*

1.1 What are the design criteria to satisfy the alignment between the service and information layers?

Research question two aims to consider the principles resulting from research question one, to create and design a coherent metamodel for Smart Cities.

RQ.2 *What are the concepts of Smart Cities that support the alignment following the identified design principles?*

2.1 What are the design requirements that capture the specific knowledge of the Smart Cities domain to address the alignment between these layers?

2.2 What concepts and relationships are required to express the alignment in the Smart Cities domain?

2.3 How can these concepts and relationships be added and structured into a coherent metamodel?

Research question three aims to apply and evaluate the concepts and their relationships resulting from research question two.

RQ.3 *How reliable are the proposed concepts to support a suitable alignment between the service and information layers in Smart City architectures?*

3.1 What are the requirements and criteria to evaluate the metamodel?

3.2 Are the concepts and the relationships between them considered of high-quality and usefulness from the point of view of practitioners?

1.7 Thesis Contributions

This research proposes the *ArchiSmartCity* metamodel to explicitly specify the alignment between the service and information layers in Smart City architectures. This section summarises and presents the research contributions of this study as well as its implications for practitioners.

Impact for Research

- This research contributes to the current understanding of how city strategies should be aligned with Smart City implementations by providing a prescriptive view to guide a coherent architecture design and support the fulfillment of the Smart Cities vision. This prescriptive view ensures that Smart City implementations are built according to city goals and the needs of citizens.
- This research builds an understanding of the different concepts and relationships from the Smart Cities domain that together provide a coherent and unambiguous Enterprise Architecture (EA) description of this domain. Such concepts and relationships are

understandable for domain experts and allow city planners and designers to manage the complexity of these cities and support continuous alignment.

- This research enhances the understanding of the role of the alignment to support and manage transformation and change in dynamic urban contexts. For this purpose, this thesis outlines what information (e.g., quality of service) is necessary for the alignment analysis and how to perform and automate the analysis in the Smart City context.

Impact for Practice

- The proposed concepts and relationships have a referential character, meaning that they together provide a guide for a coherent architecture design of the desired services to assist cities and municipalities in the digitalisation and transformation of public services.
- This research proposes an approach to extend ArchiMate for Smart Cities where domain-specific elements are required, thus expanding EA modelling capabilities into this field. Our case studies show that the proposed extension is valuable for practice as it enables Smart Cities managers and designers to use a common language between them.
- Our case studies lead us to understand that digital transformation in these cities is a significant strategic challenge. The proposed strategic concepts help city managers to identify during city service design, the reasons why these services exist or why they need to be changed before developing new application platforms and solutions or hiring new service providers.
- City services need to be integrated within the same or different domains (e.g., mobility, environment, livability, etc.) from the early stage of design to contribute to the achievement of common city goals. Thus this study can help cities and municipalities to tackle this challenge.
- Our case studies show that early identification of city actors and their requirements regarding the data for decision making contributes to the design of added-value services and assist city functional departments in improving the ability to collaborate in the provision of more citizen-centric services.

1.8 Thesis Structure

This thesis follows a design science research approach and research method due to the relevance to the domain of information systems (IS) and the applicability to the design of an artefact which is an essential activity in this research work. The chapters of this thesis are organised according to the main concepts and processes of design science. The remainder of this thesis is structured as follows:

Literature Review Chapter 2 analyses how the literature on architecture for Smart Cities addresses the alignment among architecture layers. This chapter analyses the concepts and relationships between them proposed by different Enterprise Architectures, business architectures, information technology architectures, and information systems architectures for Smart Cities. This analysis provides a detailed description of the complexity and problems that exist to align the service and information layers in these architectures.

Research Methodology Chapter 3 presents the importance of a research methodology as the rationale and the philosophical assumptions that underlie a particular study. It introduces the research methodology and the concepts, theories and techniques used to systematically answer each research question identified in Chapter 1. This chapter outlines a justification for the research methodology selection.

Design Principles Chapter 4 presents a set of design principles that ensure the alignment between the service and information layers in Smart Cities architectures in order to answer RQ.1. The design rationale and justification behind each design principle are provided. These design principles will be instantiated in the form of concepts and relationships to make them actionable in Chapter 5.

ArchiSmartCity Design Chapter 5 introduces the concepts of Smart Cities that ensure the alignment between the service and information layers in Smart City architectures in order to answer RQ.2. It extracts the design requirements from the literature and formalise them by means of conceptual modelling. Design principles and design requirements are instantiated to construct the ArchiSmartCity metamodel.

ArchiSmartCity Implementation Chapter 6 describes the implementation of the ArchiSmartCity as an extension of the ArchiMate language according to the metamodel design outlined in Chapter 5. It details the context, functional, and deployment views of the architecture to describe the ArchiSmartCity implementation.

Demonstration and Evaluation Chapter 7 presents the application and evaluation approach of the research proposal in order to answer RQ.3. The demonstration consists of two parts; the demonstration in the real-world by conducting multiple case studies and the demonstration and artificially evaluation of ArchiSmartCity by developing a computer-based solution for semantic alignment analysis. Moreover, it presents and analyses the evaluation criteria and results showing how this research proposal is a suitable approach for addressing the alignment of services and information in the Smart Cities domain.

Conclusion Chapter 8 concludes this thesis and the contributions to prove that this research achieves the objectives and answers the main research question. It presents the limitations and future directions of this research work.

Chapter 2

Literature Review

This chapter presents the literature review on the alignment in Smart City architectures. Existing literature concentrates on the business and IT alignment in the corporate and profit sector (Jia et al., 2018; Zhang et al., 2019). This chapter extends these reviews by exploring and analysing the alignment in the public sector with the main focus on Smart Cities. This literature review follows the structure presented in the Fig 2.1. Existing Enterprise Architectures (EAs) for Smart Cities are reviewed and analysed in order to identify whether they offer alignment between city services and information systems to support Smart City strategies. Information Technology (IT) Architectures perform similar integrative tasks on lower levels and therefore are reviewed and considered parts of an extended EA for Smart Cities (Gampfer et al., 2018). The review of IT Architectures for Smart Cities determines if these architectures provide alignment between city services and their underlying Information Systems (IS) to enable Smart City strategies. Smart City architecture concepts are reviewed to describe the architecture content of existing EA and IT architectures for Smart Cities. This review is used to establish whether these concepts are inter-related among architecture layers to support their alignment with Smart City strategies. Finally, metamodels for Smart Cities are reviewed to explore the representation of the syntax, semantics, and notations that support the alignment in the Smart City domain. The search strategy follows a structured approach proposed by (Webster and Watson, 2002) and pragmatically applied by (Corradini et al., 2018) in order to determine the source material for the review. This method focuses on how to conduct the literature review process in the IS field and how to structure and compile the results. Section 3.6.2 describes the overall application process of this structured approach within this thesis. Appendices are used to detail the literature review process for the following themes: Appendix A - Smart City Architectures Alignment; Appendix B - Design Principles; and Appendix C - Design Requirements. In the following, this chapter presents the results of the review focusing on high-quality journals and conference papers related to

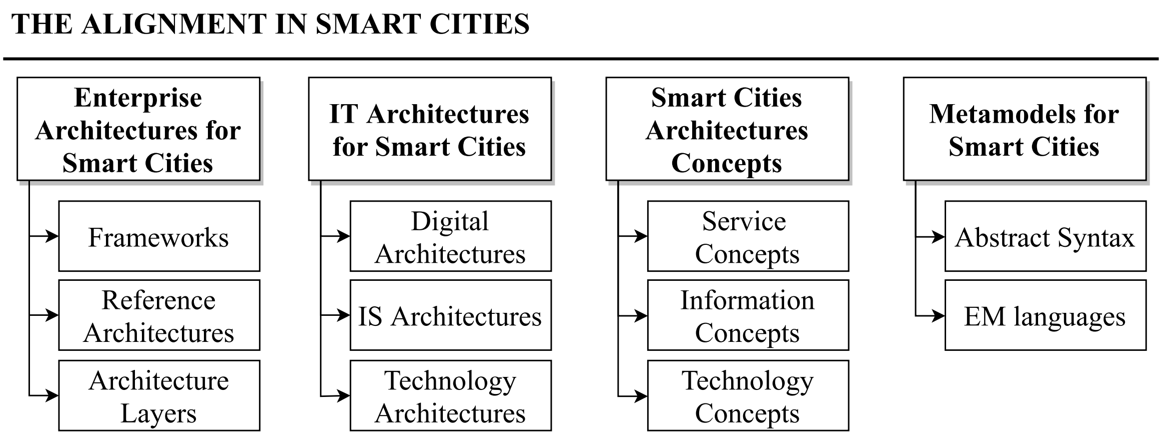


Fig. 2.1 Literature Review Structure.

EAs, IT architectures, Smart Cities architecture concepts, and metamodels for Smart Cities. A concept-centric matrix is used to summarize the findings and to present the gaps in the literature.

2.1 Enterprise Architectures for Smart Cities

Smart Cities can be viewed as Urban Enterprises, with organisational aspects, governance and innovation capabilities, and multidimensional issues (Anthopoulos and Fitsilis, 2014; Mamkaitis et al., 2016). Public services transformation affects various aspects of these cities, including strategy, stakeholders, organisational structure, information systems, and technological infrastructure. EA is an established planning and governance approach to manage the change and address the alignment in complex systems by adopting a comprehensive perspective on the overall architecture (Buckl et al., 2010). Numerous researchers describe concepts and frameworks for EA and highlight its benefits such as strategy achievement, complexity management, business, and IT alignment, and many others (Boucharas et al., 2010; Niemi and Pekkola, 2016; Shanks et al., 2018). A number of EAs for Smart Cities are proposed to face the challenges of digitalising and transforming public services (Cox et al., 2016; Kakarontzas et al., 2014; Lnenicka et al., 2017; McGinley and Nakata, 2015). The suggested approaches use the concept of views and layers to manage architecture complexity and describe architecture content (Rouhani et al., 2015). In this section, this study reviews existing reference architectures, frameworks, and layers of EA for Smart Cities in order to identify whether they offer alignment between city services and information systems to support Smart City strategies.

2.1.1 Reference Enterprise Architectures for Smart Cities

The ESPRESSO Smart City reference architecture (Cox et al., 2016) is an EU-funded initiative that adopts the TOGAF framework and an IoT reference model as the foundation for its definition. The reference architecture represents the consumers (e.g., stakeholders or systems) that can interact with different types of services such as business services, application services, data services, sensing services, and positioning services. The proposal includes several cross-cutting services, such as security services, technology services, and supporting services that provide the capabilities required for any horizontal services (e.g., data services, application services, etc.). For instance, security services include a set of standard security capabilities such as identify management, authentication, authorisation, encryption, and auditing to provide data only to authorised parties. The authors underline the exploitation of city data ranging from the definition of high-level city goals to the specification of use-cases and requirements. Hidayat and Supangkat (2014) propose a reference EA for Smart Cities by applying the TOGAF Architecture Development Method (ADM). The reference architecture covers the phases of motivation and strategy, design, and implementation and migration. Architecture principles are used as a reference for making decisions in information systems management and ICT support. These principles serve as a guide to determine the evaluation criteria relevant to Smart City initiatives and programs. The authors suggest that EA can serve as a means of communication between city stakeholders, allowing the understanding of how ICT is implemented to improve the performance of the city in delivering services.

2.1.2 Enterprise Architecture Frameworks for Smart Cities

Kakarontzas et al. (2014) present a conceptual EA framework for Smart Cities. The framework is based on architecture patterns that address the identified quality requirements of Smart City architectures such as interoperability, usability, security, reliability and availability. For instance, interoperability is achieved by providing web services interfaces at the business logic layer of software applications. This architecture framework focuses on information and technical aspects and provides some suggestions on the connections between software applications and sensor networks. The authors highlight the need to manage and coordinate a multitude of potential city goals and applications that co-exist and can grow in various directions in the future. An alternative community architecture framework (CAF) for Smart Cities (McGinley and Nakata, 2015) is presented as a participatory approach for the development of information systems to support Smart City design. This research work augments the EA Zachman framework (Zachman, 1987) for supporting diverse stakeholder perspectives and classifying the artefacts developed in EA. The community architecture framework generally describes each architecture artefact of the collaborating perspective of each stakeholder, including, data, function, network, organisation, schedule, and strategy. The authors propose a community architecture development methodology (CADM) to complement the framework. They emphasize the consideration of multiple views of stakeholders with the primary focus on the interests of citizens represented during the planning and design of Smart Cities services. Lnenicka et al. (2017) propose a conceptual framework to analyze the requirements of big and open linked data (BOLD) analytics in Smart Cities. The conceptual framework proposes different layers that represent the overall components that need to meet the requirements of BOLD analytics for Smart Cities. For example, the requirements overview highlights the importance of smart network infrastructure and its availability, which provides computing resources, data transport, and necessary storage capacity for data streaming and processing platforms. The main contribution of the conceptual framework is on the link between business and application architecture in the public sector, which is realized using open government processes. The authors stress especially the importance of involved stakeholders and their roles shaping the city processes and services provided.

Sobczak (2017) presents a model framework based on EA management for Smart Cities, defining its main components as the capabilities to perform the city transformation. The framework includes areas such as governance, strategy and architecture, portfolio, maintenance, and mechanisms of measuring the achieved results within the implementation of Smart City initiatives. The authors argue that a Smart City is not only the ICT structure or information systems. The implementation of Smart Cities should be considered as a consistent portfolio of coordinated IT and organisational projects and programs that implement changes in all aspects of cities operation. Petersen et al. (2019) propose an EA framework for Smart Cities for managing data and creating value-added services through a variety of virtual enterprises. The work is conducted within the EU H2020 Smart City project +CityxChange to support data exchange in a service-based ecosystem. The central element of the framework is the DataxChange layer which provides an overview of all available data and systems involved. The framework includes two main perspectives, including the stakeholder perspective to represent different stakeholders and their roles; and the data perspective to address specific principles and guidelines of services. These services are likely to be delivered by collaboration between one or more public and private organisations. The authors emphasize that adding value to the services to its citizens can be achieved by leveraging the exchange of data.

2.1.3 Enterprise Architecture Layers for Smart Cities

Enterprise Architecture presents various perspectives at different layers of abstraction (e.g., business, information systems, and technology layers) (Barbosa et al., 2019). Layers decompose a system into distinct but interrelated components, key concerns, and inter-related layers. However, digital transformation affects EA (e.g., EA layers and concepts) (Julia et al., 2018). Hence, there is a need to refine EA to support the management of IT within Smart Cities and the wider public sector. A multi-layered framework is proposed as a reference for applying EA to Smart Environments (Helfert et al., 2018; Helfert and Ge, 2017; Pourzolfaghar et al., 2019; Pourzolfaghar and Helfert, 2017). The authors augment the traditional EA view of multi-layered frameworks by adding the elements of context and services which are central to Smart Cities. The main architecture layers (e.g., Service, Information and Technology) proposed to support the service design process in urban environments are described as follows.

- **The Service Layer:** This layer represents the closest level of a city service (e.g., air-quality service, transport service, health service, etc.) to the stakeholders. This layer defines city services, city actors, service qualities, motivations, decision-making processes, etc., to support the Smart City vision and facilitate and optimize intelligent decision making. City services must respond to the needs of citizens by utilizing ICT to improve existing services. These services should be more efficient, more user-friendly and, in general, more citizen-centric (Hefnawy et al., 2016; Lee and Lee, 2014; Mohamed et al., 2017)

- **The Information Layer:** This layer describes information systems and data that automate city services. This layer defines information components such as applications, software services, and data to support the automation or realisation of city services. Applications are responsible for interacting directly with the stakeholders to present the data through interactive interfaces. Software services make possible the usability of the data collected from heterogeneous data sources in a transparent way. Data components describes the data of the city which will have governance, management, analytics, and a maintenance process (Massana et al., 2017; Singh et al., 2017; Wenge et al., 2014).

- **The Technology Layer:** This layer defines hardware and software infrastructures such as networks, storage structures, and physical devices to support the daily activities of citizens and the Smart City operation. This layer includes sensors, actuators, gateways, and IoT devices that collect and produce useful information. Data is collected by monitoring devices within the network and is sent back to data warehouses, databases, or cloud platforms. City actors (e.g., city authorities, citizens, retailers) can make decisions and take actions based on the collected data from the required services. (Anthopoulos and Fitsilis, 2014; Bawany and Shamsi, 2015; da Silva et al., 2013).

2.1.4 Discussion

Reference Enterprise Architectures for Smart Cities describe a high-level overview of the Smart City field primarily as a set of IT service capabilities. These reference architectures follow a layered and service-oriented approach, using generic concepts and blocks. For instance, the ESPRESSO reference architecture (Cox et al., 2016) proposes a layered architecture that includes business services at the top and IT services (i.e., application services, data services, sensing services) at the bottom. However, this reference architecture does not consider the city services that are central to Smart Cities. Furthermore, this reference architecture does not explicitly describe how such business and IT services can be linked between architecture layers to support city goals and objectives. Helfert et al. (2018); Helfert and Ge (2017); Pourzolfaghar et al. (2019); Pourzolfaghar and Helfert (2017) propose an EA framework that can be used as a methodology to manage EAs in Smart Cities. In contrast to other proposals, this framework presents a service layer to describe city services. However, more refined service concepts and their relationships with other architecture components (e.g., relationships with information systems concepts) are required to address the strategic alignment in Smart Cities. The description of such concepts and the relationships between layers is recognised as a useful instrument to achieve goals and meet the needs of different stakeholders (Jonkers et al., 2004).

EA frameworks and reference architectures for Smart Cities adopt the TOGAF and Zachman frameworks to assist cities and municipalities in digitising and transforming public services (Cox et al., 2016; Hidayat and Supangkat, 2014; McGinley and Nakata, 2015; Pourzolfaghar et al., 2019). However, traditional EA layers (e.g., business, information systems, and technology) are suitable for structuring an EA for Smart Cities, but not optimal for this purpose. EA frameworks in Smart Cities must be adapted for domain-specific needs and also to determine where specific solutions can be generalized to support different services. The perspective of citizens should be considered when refining architecture layers and concepts, since the point of view of citizens and the improvement of their quality of life is crucial. Smart City reference architectures and frameworks describe citizens as consumers of services (Cox et al., 2016; Kakarontzas et al., 2014). However, citizens have a more active role in the planning of Smart Cities. For example, they can participate in shaping the urban design processes and services provided in a collaborative environment with local authorities (McGinley and Nakata, 2015).

2.2 Information Technology Architectures for Smart Cities

The Smart City notion has been evolved from Digital Cities to urban spaces for business opportunities and service delivery (Anthopoulos and Fitsilis, 2010). The Smart City concept is approached as part of the term of digital city by (Anthopoulos and Tsoukalas, 2006), introducing a generic Information Technology (IT) architecture for digital cities. These types of cities are required to establish an IT architecture that describes Smart City solutions and end-systems (e.g., traffic management systems) to support the development of modern urban spaces. Traditionally, IT Architectures involve Data, Application, and Technology Architectures that are part of the target EA (Gampfer et al., 2018; Ross et al., 2006). Existing IT architectures for Smart Cities follow a Service Oriented Architecture (SOA) and a multi-layer approach to design all possible city services (Anthopoulos, 2015; Santana et al., 2017). A number of IT companies such as IBM, Cisco, and Accenture propose IT solutions and platforms for Smart Cities based on a set of operating models and models for individual city systems (e.g., public safety, citizen health, energy) (van den Buuse and Kolk, 2019). Smart Cities are applications fields of the IoT, which allow city information systems to detect, integrate, share, and control data from a wide range of devices (Gaur et al., 2015; Silva et al., 2018). These services are located and offered in centralised, distributed and hybrid environments with challenging implications in their design and management. In this section, this study reviews existing digital architectures, information systems architectures, and technology architectures, since they are an integral part of IT architectures for Smart Cities (Anthopoulos, 2017). This will help to determine if these architectures provide alignment between city services and their underlying information systems to enable Smart City strategies.

2.2.1 Digital Architectures

Digital architectures integrate urban information (both digital archives and real-time) and in the cities based on Internet technologies (Ishida, 1999). Digital architectures deal with digital applications (e.g., cities websites and government platforms) and software services which offer relevant news, community resources, entertainment, and commerce for locals, businesses, and visitors. These architectures mainly represent the physical space of cities, as well as their people, local businesses and processes. Anthopoulos and Tsoukalas (2006) propose a multi-layer architecture to support the diffusion of activities (e.g., local economy and employment, education, culture, etc.) to the community. The architecture deals with interoperability issues in an e-government environment that offers applications and digital services to the community. These digital services aim to provide a framework for communication between citizens and public organizations, covering individual and public needs. Komninos (2006) presents an architecture for digital cities to enhance knowledge and innovation in cities. The architecture mainly deals with concepts and layers at the digital, institutional and physical levels based on ICT to provide digital services (e.g., commerce service, health service, education service, and governmental service). Anthopoulos and Fitsilis (2010) define an architecture for digital cities to achieve sustainability and continuous evolution of digital projects. The digital architecture presents an architecture blueprint with concepts related to stakeholders, software services, data repositories, and storage infrastructure.

2.2.2 Information Systems Architectures

Information Systems (IS) in the context of Smart Cities includes key factors related to information security, data processing, and storage and many of the themes regarding cloud computing and big data (Costa and Santos, 2016; Ismagilova et al., 2019). Several IS architectures for Smart Cities are defined from a one or more IS perspectives (i.e., data and applications) to provide public services to citizens in an efficient manner. Kuk and Janssen (2011) present an analysis of the information architecture of two cities in Netherlands. The information architecture of each city is described through an architecture blueprint with generic relationships between the front-end and back-end of the system. Wenge et al. (2014) propose a data architecture that includes the transmission, management, analysis, presentation, and interaction of data gathered from deployed sensors. The research work presents an overview of the architecture for data processing which includes event-driven applications, domain services, data storage, and other data components. Bawany and Shamsi (2015) define an architecture for the integration of software services across public sector departments and other parties via an open data model. The architecture includes concepts such as stakeholders, software services, e-governance, and infrastructure to address the challenges for Smart City information system management. Massana et al. (2017) present an architecture to support data-driven methods for energy efficiency monitoring in Smart Cities. The authors specify the implementation of the architecture through a use case related to forecasting electrical energy using data-driven models. The architecture represents the required software services for support energy efficiency in urban infrastructures such as buildings. Zdraveski et al. (2017) propose a cloud platform architecture based on the ISO 37120 standard that establishes indicators for city services and quality of life. The architecture supports the data integration from heterogeneous data sources such as sensors networks, social networks, news, blogs, and other city systems. The data is transformed using an ontology model and then presented at the application front-end to final users such as city authorities and citizens. Citizens require many different services to support different situation which leads to the emergence of heterogeneous data sources. Data can be presented in various protocols and formats (e.g., JSON, CSV, relational DB, XML, SPARQL endpoints). Teslya et al. (2019) compare different Smart City platforms (e.g., Km4City, FIWARE, MKSmart, DataTank, IES City) that address the issue of information consolidation by combining and unifying different information sources. The authors also propose a platform architecture for citizens mobility support to connect information sources using the description of services from a shared knowledge base.

2.2.3 Technology Architectures

Technology architectures for Smart Cities are proposed to support the Smart City implementation and ensure the delivery of desired city services. These architectures are based on the IoT that provides essential building components to sense, process, and transmit data from smart devices (e.g., motion sensors to regulate the street light) (Badii et al., 2017a; Gaur et al., 2015). Al-Hader et al. (2009) propose an architecture to support data integration with geospatial data warehouse solutions for Smart Cities. The architecture is based on infrastructures and networks connected to a system administration work-frame. The system administration comprises of a cluster of server applications, database servers, and communication servers. Filipponi et al. (2010) present an event-driven architecture for monitoring and managing heterogeneous sensors in public spaces. The architecture represents an interoperable platform for the interaction between end-users and smart environments. This architecture includes notifications to the citizens and technical components such as sensors, devices, appliances and embedded systems in general. Hernández-Muñoz et al. (2011) propose a high-level architecture for urban platforms based on Ubiquitous Sensor Networks to integrate heterogeneous and distributed systems. The architecture fulfills basic principles of open, federated and trusted platforms at two different levels: the infrastructure level (IoT support), and at the technology service level. The authors stress the use of experimental test facilities such as the SmartSantander EU project which supports experimentation of IoT architectures and their applications. Cicirelli et al. (2017b) present an edge-based distributed architecture for the management of heterogeneous physical devices in Smart Cities. The architecture represents the links or communication connections between middlewares, agent-servers, and virtual objects. Such architecture is characterized by the combination of software services with heterogeneous physical devices and protocols. Badii et al. (2019) presents a Smart City architecture to enable the integration and implementation of IoT in the context of mobility and transport. This platform architecture includes various building blocks such as IoT devices like (i.e., sensors and actuators) that send/received information from/to a gateway or aggregator. The data is processed and exposes by the Smart City platform using microservices APIs.

This platform allows citizens to interact with their infrastructure (in terms of streets, roads, cycle paths, public transport stations, parking, etc.), and city operators of the mobility and transport to configure and monitor the transportation infrastructure.

2.2.4 Discussion

Although Smart Cities were initiated as information-based systems (i.e., digital cities), they soon evolved to large IT systems that deliver different kinds of services to local communities (Anthopoulos and Fitsilis, 2009). The conception of services in such systems is principally related to software services such as web services, geospatial services, and location-based services (Anthopoulos and Fitsilis, 2010; Badii et al., 2019; Cicirelli et al., 2017b). IT architectures for Smart Cities are mainly based on the information and technical aspects, missing the elements related to city services and their alignment with Smart City strategies. For example, Anthopoulos and Fitsilis (2010) define who are going to use the services (i.e., city stakeholders) and how to consume the services (i.e., policies, operating rules). However, the authors exclude the rationale for the services (i.e., city goals and objectives) or any motivation for their digitalization. Zdraveski et al. (2017) propose an architecture to support city indicators, but they do not define how these indicators are used to measure the performance of cities and their connection with Smart city goals and objectives. A few architectures present generic building blocks, omitting the representation of concepts (e.g., domains, city services, city goals, etc.) and the link and connections among architecture layers (Massana et al., 2017; Wenge et al., 2014). A number of architectures propose blueprints with various concepts and their intra-layers relationships (Bawany and Shamsi, 2015; Hernández-Muñoz et al., 2011; Komninos, 2006). However, they do not represent the relationships across layers which are important to ensure the alignment in the early design phase of services. This lack of connection of IT concepts with city strategies and goals may cause IT architectures to fail to provide a solid foundation to develop city services and solutions which meet the needs of citizens.

2.3 Smart City Architectures Concepts

A coherent description of Enterprise Architectures (EAs) and IT architectures for Smart Cities comprises architecture models and views to enable communication among stakeholders. Architecture models are composed of a collection of concepts and the relationships between them (ISO/IEC/IEEE 42010, 2011). Architecture views use these concepts to represent different perspectives of the overall architecture. The TOGAF framework, for example, defines a set of concepts to describe each EA domain (e.g., business, data, information, and technology domains). TOGAF structures the data architecture and its enterprise sources of data in concepts related to logical data assets, physical data assets, and data management resources (The Open Group, 2018). Such EA concepts are particularly beneficial when designing Smart Cities architectures. However, the complexity of Smart Cities with diverse interests and goals from a range of stakeholders makes it difficult to adopt these EA concepts in this field (Helfert et al., 2018). In this section, this study extracts the concepts from existing EAs and IT architectures for Smart Cities in order to identify the concepts described within each architecture and establish whether these concepts are inter-related among architecture layers to support the strategic alignment. These concepts are defined as Service Concepts, Information Concepts, and Technology Concepts.

2.3.1 Service Concepts

In this section, the focus is on the *Service Concepts* from existing EAs and IT architectures for Smart Cities. They capture the main characteristics to describe city services as follows.

- **City service:** A city service is a service offered to the citizens by the city government and private institutions (e.g., public bus service, weather forecast service, health service) (Cabrera et al., 2018; Nesi et al., 2016).
- **Stakeholder:** A person, group or organization with an interest or concern in the operations of the city and its agencies or institutions (e.g., city authorities, citizens, communities, retailers) (Comerio et al., 2013; Lnenicka et al., 2017).
- **City goal:** A common outcome among city leaders and stakeholders. For example, aiming at efficient solutions that reduce energy consumption and CO2 emissions (Dameri, 2017; McGinley and Nakata, 2015).
- **Consumer:** A person (e.g., pedestrian, cyclist, patient, student) who consumes services offered by local authorities or services providers (Comerio et al., 2013).
- **Location:** A place where city services are deployed and offered to citizens. Categories of locations involve roads, bridges, airports, hospitals, government buildings, etc. (Gil-Garcia et al., 2015).
- **Business unit:** A government organisation unit of a city, for example, a department of a city council that delivers the electricity service to citizens (Cox et al., 2016).
- **Indicator:** A measure of city performance regarding social, economic, and environmental qualities (Zdraveski et al., 2017).

2.3.2 Information Concepts

In this section, the focus is on the *Information Concepts* from existing EAs and IT architectures for Smart Cities. They capture the main characteristics to describe the data and applications that automate city services as follows.

- **Software service:** A software functionality or a set of software functionalities which provide useful information to the citizens (e.g., the location of nearby hospitals, the number of people in a bus station, the amount of Carbon dioxide CO_2 in the street, etc.) (Santana et al., 2017).
- **Domain software service:** A software service which belongs to a particular domain such as education, health, mobility, living, environment (Gaur et al., 2015; Neirotti et al., 2014; Wenge et al., 2014).
- **Monitoring application:** A software tool or another deployable software component designed to perform a group of coordinated functions, tasks, or activities to monitor the status of city environment. For example, an application to monitor city pollution to avoid health risks (Hefnawy et al., 2016).
- **Application front-end:** The front-end includes software components to support city processes that are used to interact directly with citizens and/or businesses. Front-end integration can be described as a user-based integration that presents heterogeneous content and data (Kuk and Janssen, 2011).
- **Application back-end:** The back-end includes software components to support city processes that do not directly involve customer interactions. Back-end integration can be described as a semantic and syntactic standardization and integration of resources that makes information available (Kuk and Janssen, 2011).
- **Software module:** A module that is part of a program or a software component and contains one or more routines in order to provide the data requested by users in a transparent means (Massana et al., 2017).
- **Middleware:** A software that offers common services for applications and easy application development by integrating heterogeneous computing and communications devices. A middleware supports the interoperability of diverse applications and services running on such devices (Razzaque et al., 2016).
- **Reasoner:** A software component that contains an ontology model to represent the semantic data model required for data transformation and reasoning rules. For example,

gathered data can be transformed by a reasoner to present city indicators to citizens, city authorities and foreign users at the application front-end (Zdraveski et al., 2017).

- **Notification:** A software component or software functionality that provides a message on city events (e.g., earth motion detection) produced by sensors according to the requirements of cities. Notifications are published through enabled client applications (Filipponi et al., 2010).

- **Public and private data:** Data in various formats exist and are valuable in Smart Cities, and as such require particular attention. Data sets need to be governed, managed and maintained to provide application developers with the opportunity to design services efficiently (Cox et al., 2016; Helfert et al., 2018).

- **Information:** A representation of the data processed, interpreted, organized and structured to be meaningful and useful to end-users (Jin et al., 2014).

- **Document:** A document provides information generated by public agencies or private sector in accordance with data protection regulations for personal and confidential information (Anthopoulos and Tsoukalas, 2006).

- **Digital tool:** A online application and resource that can be used to create and enhance a digital learning environment and innovation in the cities. Digital tools support the developing of a global market with new products and services for a specific and well-defined segment of the population (Komninos, 2006).

2.3.3 Technology Concepts

In this section, the focus is on the *Technology Concepts* from existing EAs and IT architectures for Smart Cities. They capture the main characteristics to describe the technology infrastructure that supports city services as follows.

- **Virtual Object:** An abstraction of a physical device such as a sensor of humidity, temperature, luminosity, electricity, etc. Virtual objects provide a uniform Application Programming Interface (API) for the exploitation of the capabilities of heterogeneous physical devices (Cicirelli et al., 2017a).

- **Agent server:** A server that provides the runtime support for the execution of agents. Agents are defined as network software programs that can perform particular tasks for a user and have a degree of intelligence to perform parts of the tasks autonomously and to interact with the environment in a useful manner (Cicirelli et al., 2017b; Fortino et al., 2012).

- **Hardware and software infrastructure:** A physical infrastructure (e.g., application servers, network equipment) and technical computing infrastructure (e.g., operating software systems) necessary for the city operation (Anthopoulos and Tsoukalas, 2006).
- **Communication infrastructure:** A technology protocol and network connection that allows the operation of broadcasting and telecommunication services to ensure the interconnection of devices and data transmission (Komninos, 2006; Massana et al., 2017).
- **Storage structure:** A physical storage structure to support large-scale complex data with high reliability and scalability. The data storage in Smart Cities can follow a centralised, distributed or hybrid approach to support the daily operation (Massana et al., 2017; Wenge et al., 2014).
- **Physical network:** A computer network topology that includes the computer devices, locations, and cable installation to support a wide range of services (Massana et al., 2017).
- **Cloud storage service:** A cloud computing model in which data is stored on remote servers accessed from the internet using virtualization techniques. Cloud computing offers large-scale data storage and computational services to smart cities (Mohamed et al., 2017).
- **Gateway:** A computer that links the smart devices at the edges of the network to a core network infrastructure. Gateways allow the communication and connectivity between the devices and the network and the management of these devices (Sánchez et al., 2013).
- **Sensor:** A device that detects events or changes in the environment and sends the information to other electronics, frequently a computer processor (e.g., gateway). Sensors impact the quality of life for the citizens in terms of their transportation, activities and wellbeing (Samaras et al., 2013).
- **Actuator:** A device responsible for moving or controlling other mechanisms, systems or equipment. Actuators can control parameters such as lights, temperature, and humidity in order to improve the level of comfort of public buildings and reduce the costs of heating or cooling (Zanella et al., 2014).

Table 2.1 Service, Information, and Technology Concepts

Concepts	**Service Concepts**							**Service and Information Alignment**	**Information Concepts**													**Information and Technology Alignment**	**Technology Concepts**									
References	City service	Stakeholder	City goal	Consumer	Location	City business unit	Indicator		Software service	Domain software service	Monitoring application	Application front-end	Application back-end	Software module	Middleware	Reasoner	Notification	Public and private data	Documents	Information	Digital tool		Virtual object	Agent server	Hardware and software infrastructure	Communication infrastructure	Storage structure	Physical network	Cloud storage service	Gateway	Sensor	Actuator
Anthopoulos and Tsoukalas (2006)		X							X									X	X			X			X							
Komninos (2006)		X		X																	X	X				X						
Al-Hader et al. (2009)			X	X		X					X											X						X				
Filipponi et al. (2010)																	X					X			X							
Anthopoulos and Fitsilis (2010)		X		X					X		X							X		X		X			X							
Hernández-Muñoz et al. (2011)									X		X				X		X					X								X	X	X
Kuk and Janssen (2011)		X							X			X	X																			
Kakarontzas et al. (2014)									X		X	X	X									X									X	
Piro et al. (2014)	X	X			X					X		X	X	X				X				X				X	X	X			X	
Wenge et al. (2014)									X	X							X								X		X	X	X		X	
Zanella et al. (2014)				X					X			X	X					X				X	X		X	X	X	X	X		X	X
Bawany and Shamsi (2015)				X					X	X	X											X										
McGinley and Nakata (2015)			X		X	X			X		X							X							X	X	X	X				
Costa and Santos (2016)					X				X		X	X	X					X	X	X							X					
Cox et al. (2016)	X	X		X				X	X		X							X	X						X		X		X		X	
Cicirelli et al. (2017b)																							X	X						X	X	X
Lnenicka et al. (2017)		X	X						X		X		X					X				X			X	X		X	X			
Massana et al. (2017)									X		X			X								X			X	X	X			X	X	X
Nitti et al. (2017)				X					X			X	X					X				X	X		X	X	X	X	X		X	X
Santana et al. (2017)				X					X			X	X					X				X	X		X	X	X	X	X		X	X
Silva et al. (2017)		X							X		X				X			X							X	X	X	X	X	X	X	X
Zdraveski et al. (2017)							X	X	X		X	X	X			X																
Sharma and Park (2018)									X		X							X				X				X		X	X		X	
Sholla et al. (2018)		X								X								X				X					X	X	X		X	
Silva et al. (2018)				X						X	X							X								X	X	X	X		X	X
Simmhan et al. (2018)				X					X		X							X							X	X					X	X
Tanaka et al. (2018)		X	X						X		X			X				X							X	X						
Ahlers et al. (2019)				X					X		X	X	X					X	X							X		X	X		X	X
Badii et al. (2019)				X					X		X	X	X			X		X				X	X		X	X	X	X	X	X	X	X
Petersen et al. (2019)	X	X				X			X									X							X						X	
Tot.	3	11	4	12	3	3	1	2	23	5	18	10	11	3	2	2	3	19	4	2	1	17	5	1	16	15	13	14	12	5	18	11
Tot. per Type	37							2	103													17	110									

Table 2.1 compiles and synthesises the service, information, and technology concepts outlined above. The concept-matrix includes the service and information alignment and the information and technology alignment to represent existing relationships between intra-layer concepts. It indicates that EAs and IT architectures for Smart Cities mostly represent information and technical concepts such as monitoring applications, sensors, actuators, hardware and software infrastructure. However, they rarely focus on service concepts (e.g., city services, city goals, stakeholders, indicators) and their relationships with information

concepts (e.g., software services, applications, public and private data) which are essential to align the city strategies and goals with the Smart City implementation and solutions. The literature review indicates that a limited number of architectures (Cox et al., 2016; Zdraveski et al., 2017) cover strategic aspects of Smart Cities such as city goals and indicators within the literature. Particularly, (Cox et al., 2016) presents the realisation of high-level goals (e.g., enhance the user experience, orchestrate city data, make city data available and safe) through use cases and requirements specification. However, this approach does not present details on the information concepts (i.e., data and application concepts) that will automate city services and their alignment with such city goals. At the same time, city goals and objectives can be high level, therefore, it is important to link them to existing city indicators which measure the performance of cities (Falconer and Mitchell, 2012). However, just one of the reviewed architectures defines indicators as part of its information architecture platform (Zdraveski et al., 2017). Finally, Smart City application domains are used to represent domain software services as information concepts, without taking into account that these domains also involve people, processes and decisions, and other key service concepts.

Relationships between Concepts

Fig 2.2 depicts a graph with the Smart City Architectures Concepts (nodes) and their relationships (edges) extracted from the literature as summarised in Table 2.1. Each node of the graph represents a concept with a particular colour as follows: yellow for ***Service Concepts***; blue for ***Information Concepts***; and green for ***Technology Concepts***. Each line (edge) denotes a relationship between two concepts (nodes). A concept that has fewer relationships with other concepts is represented as a smaller node size and vice versa. For instance, several ***Service Concepts*** are smaller and isolated in the graph, including *City Goal, Consumer, Business Unit, and Location*. This makes it difficult to understand how to link these concepts to support Smart City Strategies and goals. Additionally, a few ***Service Concepts*** such as *City Service, Stakeholder, and Indicator* have a small number of relationships with ***Information Concepts***. In contrast, the reviewed architectures mainly describe the relationships between ***Information and Technology Concepts***, such as *Software Service, Domain Software Service, Monitoring Application, Digital Tool, Storage Structure, and Hardware and Software Infrastructures*. This suggests that current architectures are mostly focused on the implementation of the information and technology aspects of Smart Cities with little attention on how to achieve *City Goals*. This study focuses on modelling the relationships between the ***Service and Information Concepts*** of Smart City architectures to support the strategic alignment in this field. Therefore, existing ***Service and Information Concepts*** and their relationships will

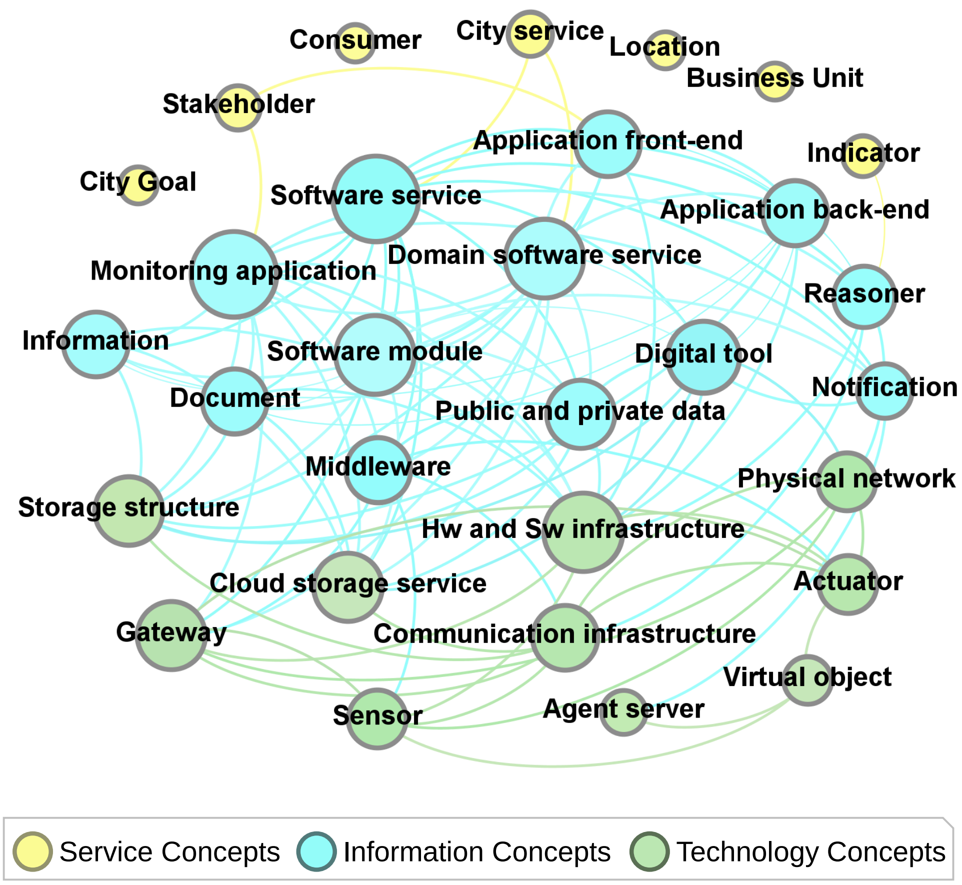


Fig. 2.2 Service, Information, and Technology Concepts and their Relationships.

be refined and modelled according to the particularities of these types of cities to guide a coherent architecture design.

2.3.4 Discussion

The design of architectures for Smart Cities must start with city goals and objectives as its base, against which all initiatives are then measured (Dameri, 2017; Falconer and Mitchell, 2012). City managers must define actions or initiatives by their impact on the stated Smart City vision and strategy (Falconer and Mitchell, 2012; Mannaro et al., 2017). Existing research on EAs and IT Architectures for Smart Cities uses concepts and relationships to describe the content of architecture views and models that represent the perspectives of different stakeholders (Anthopoulos, 2015; Cox et al., 2016; Komninos et al., 2014; Zdraveski et al., 2017). Yet, these architectures mostly describe information and technology concepts and their relationships. They do not consider critical service concepts and their relationships with the information concept to support the alignment with Smart City strategies. Smart Cities are likely to fail to offer the required services to citizens because of this lack of alignment that negatively impacts the achievement of city goals and objectives (Manville et al., 2014). Moreover, although these architectures mainly represent stakeholders and consumers as general concepts, the representation of city actors and their roles (e.g., service provider, domain expert, data manager, data user, service operator) is lacking. This can lead to the overlooking of relevant concerns and views from various perspectives of city services which are important for their delivery and operation.

2.4 Metamodels for Smart Cities

A metamodel defines a language for describing a specific domain of interest (Bézivin, 2004). Metamodels describe and organise the abstract syntax (e.g., concepts, attributes, and relationships) of a Domain-Specific Modeling Language (DSML). They define constraints and static semantics that provide additional information on the modelling language for a formal specification (Cho and Gray, 2011). This specification comprises two different levels of formality, including the definition of the abstract syntax (i.e., syntax), and concrete syntax (i.e., semantics and notation) (Bork et al., 2020). In practice, metamodels provide designers with a versatile and effective tool to support modelling activities using a common and reusable vocabulary (Jonkers et al., 2004). EA metamodels can provide a means to handle the increasing complexity in Smart Cities contexts. Enterprise architects need metamodels and modelling tools to express architecture models for their own understanding and for communication with other stakeholders, including city managers, service owners, service providers, service developers, and end-users (Hefnawy et al., 2015; Lankhorst et al., 2009). In this section, this study reviews the abstract syntax of existing metamodels and presents EMLs for Smart Cities. This identifies whether abstract syntax and EMLs provide a sufficient set of elements (i.e., syntax, semantics, and notations) to address the alignment between city services and information systems that support Smart City strategies.

2.4.1 Abstract Syntax for Smart Cities

Bellini et al. (2015) present a Smart City ontology, called KM4City (Knowledge Model for City). The KM4City model describes macro-classes (e.g., administration, street-guide, point of interest, local public transport, sensors, temporal, and metadata) and the relationships between them. The model represent multiple city services (e.g., busses, parking, traffic flows) and enables the interconnection, storage and the inquiry of data from a variety of sources. This data is mapped to the KM4City model and stored into an RDF store where it is available for applications via SPARQL queries to provide new services to the users via specific applications of the city public administration. Abu-Matar (2016) propose a reference architecture metamodel for Smart City projects (SmartCityRA) that contains architecture building blocks, best practices, and patterns. The metamodel provides multiple architecture views, including capability, participant, service, data, business process, application, analytics, place, and infrastructure. For instance, the service view focuses on the exposed interfaces (APIs) of the capability view which represents business requirements offered by a Smart City project. All views are presented along with their stakeholders, concerns, and model type (e.g., use case diagram, service architecture diagram, activity diagram, and data flow diagram). Cicirelli et al. (2017a) propose the Smart Environment Metamodel (SEM) framework from the Functional and Data point of view. Functional concepts represent smart environments which provide cyber-physical functionalities to end-users (e.g., usage, sensing, actuation, communication, monitoring, and prediction). Data concepts describe data sources required in a smart environment and their relationships with the smart functionalities. For instance, these relationships can model proximity, statistical correlation, mutual physical influence, and temporal synchronization. The authors also provide a set of general guidelines to conduct the analysis, design, and implementation of the metamodel. Abu-Matar and Mizouni (2018) propose a metamodel to manage variability in Smart City ecosystems (SmartCityML). The authors classify the different types of variabilities (e.g., diverse stakeholders, varied sensors types, multiple deployment platforms) which allow representing models of diverse Smart Cities scenarios. The SmartCityML presents different classes (e.g., feature, place, infrastructure, service, etc.) and the relationships between them to describe variability information.

2.4.2 Enterprise Modelling Languages for Smart Cities

Modelling EA requires coherent EMLs to provide the techniques, languages, tools, and best practices for using models (Chiprianov et al., 2014). EM languages are defined as graphical or textual languages for visualizing, specifying, constructing, and documenting the artefacts of a system (Chiprianov et al., 2014). Bork et al. (2015) present an approach for modelling different scenarios faced in the Smart Cities domain (e.g., emergency and waste management services) by applying conceptual modeling as part of the Next-generation Enterprise Modeling Summer School (NEMO). The scenarios are developed to create a graphical Smart City Modelling Language (SmartML) by using the metamodelling development and configuration platform ADOxx[1]. SmartML enables, for example, the creation of conceptual models using the notations and semantics of Smart Cities and the development of model queries to find a doctor in proximity to a car accident. The modelled concepts and notations include, among others, crossings, street lights, pedestrians, ambulances, and smart trash cans. In the same way, Bork et al. (2016) use the ADOxx metamodelling platform to develop domain-specific concepts and properties related to Smart Cities emergency response and marathon planning (e.g., air-quality index sensors, paths, drinking stations, volunteers and roles, decision nodes, and other city concepts). The resulting models are mainly focused on the operation of Smart Cities and their changing requirements. Tanaka et al. (2018) propose a framework for ICT governance in Smart Cities. They present a partial view of the use of the ArchiMate modelling language by designing the motivation and migration aspects of a case study in the area of education.

2.4.3 Discussion

A limited number of abstract syntaxes for Smart Cities have been proposed in the literature, however, there is no single and accepted syntax for modelling the strategic alignment in the Smart Cities domain. Despite existing syntax representing the various concepts of Smart Cities and the explicit relationships among them, the majority of their definitions are focused on the information, technical and physical factors of Smart Cities (Bellini et al., 2015; Cicirelli et al., 2017a). The metamodels, SmartCityRA and SmartCityML, represent different architecture views regarding the concerns of citizens, city officials, developers, and service providers (Abu-Matar, 2016; Abu-Matar and Mizouni, 2018). The multiple views are interrelated with each other and are unified by a generic Capability view that models the provided capabilities of a Smart City application domain. However, these metamodels do not represent any concern about the alignment of services and information with city goals and objectives. Moreover, the definition of city services and their application domain (e.g., health, energy, mobility, living, buildings) is fundamental in Smart Cities. The KM4City model (Bellini et al., 2015) represents such concepts. However, the model mainly relates those concepts to the data and information concepts to address the integration of data from heterogeneous sources, missing, for example, the city objectives that can be achieved with that integration. EM languages are used to represent different Smart City scenarios by applying conceptual modelling. However, these languages are predominantly focus on technical and physical aspects of Smart City solutions (e.g., sensors, streets, vehicles, stations) (Bork et al., 2016, 2015). ArchiMate allows the creation of different EA models and cross-layer

[1]Metamodelling development and configuration platform - (http://www.adoxx.org)

dependencies to addresses the business and IT alignment in an enterprise domain (Lankhorst et al., 2009; Lankhorst, 2004). However, this language has a high level of abstraction that leads to it missing the key concepts of Smart Cities (e.g., city services, domains, indicators, sensors, and other concepts). The precise specification of the syntax, semantics, and notations of an EML for Smart Cities is crucial to support the digitalization and transformation of city services at the early design phase.

2.5 Summary

This chapter analysed current research in EAs, IT Architectures and Metamodels for Smart Cities from the perspective of city services and their underlying information systems to address the strategic alignment. The most related research concerning the specification of city service concepts includes approaches for knowledge models for cities (Bellini et al., 2015) and the alignment of infrastructure assets to citizen requirements (Heaton and Parlikad, 2019). The most related work with regard to the specification of information concepts includes IT architectures (Bellini et al., 2015; Heaton and Parlikad, 2019; Zdraveski et al., 2017) and EA for Smart Cities (Cox et al., 2016; Kakarontzas et al., 2014; Lnenicka et al., 2017; McGinley and Nakata, 2015). The most related research respecting the specification of Smart City strategy concepts such as city goals are the architectures proposed by (Cox et al., 2016; McGinley and Nakata, 2015) and the description of city service indicators is the architecture platform proposed by (Zdraveski et al., 2017). The most related work with regard to the alignment mechanism for the explicit specification of the relationships among architecture layers are proposed by (Bellini et al., 2015; Kakarontzas et al., 2014; Zdraveski et al., 2017). The most related research regarding horizontal alignment in Smart Cities is presented by (Heaton and Parlikad, 2019), which aligns the information captured at the infrastructure asset level and citizen requirements.

Fig 2.3 presents to what extent the most relevant studies satisfy a set of criteria defined from the thesis observations and research gaps (Section 1.3). The figure illustrates that to date a number of EA and IT architectures for Smart Cities (Cox et al., 2016; Heaton and Parlikad, 2019; Lnenicka et al., 2017; Nesi et al., 2016; Zdraveski et al., 2017) have concentrated on information concepts which include software services (e.g., web services), applications (e.g., mobile applications, dashboards, software application platforms) and data (e.g., public and private data) in this domain. However, the service concepts such as domains and city services have not been consistently identified and represented within these architectures (Kakarontzas et al., 2014; Zdraveski et al., 2017). These architectures define service concepts by focusing mainly on organisation structures concepts which include citizens only as consumers of

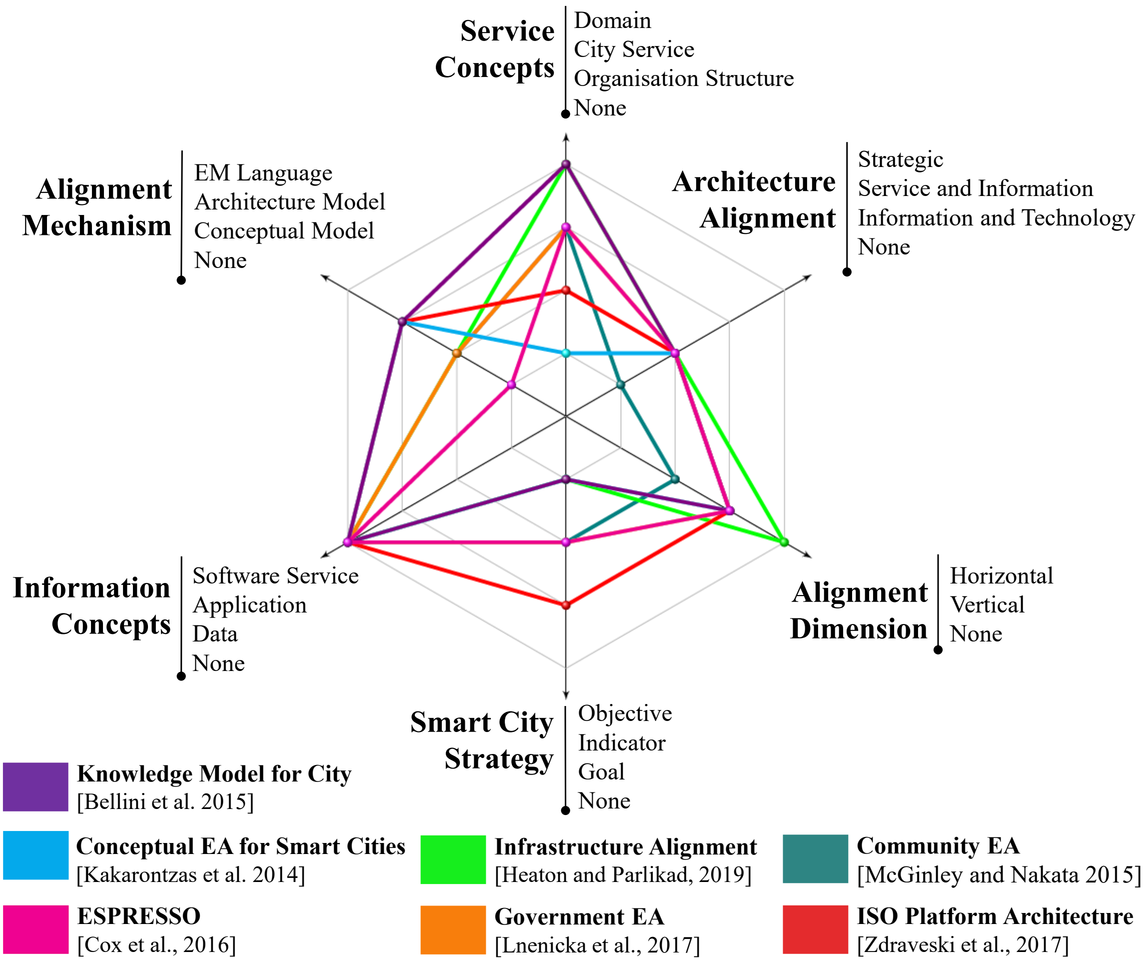


Fig. 2.3 Literature Review Diagram.

services. Furthermore, they do not specify the management characteristics of city services such as city authorities, city processes and decisions, and the domain where the city services belong to such as environment, transport, health, education, or energy. This makes it difficult, for example, to know what APIs are required to support the processes and decisions made by different city authorities, and how city services involved are integrated or affected by the services from other domains.

Several architectures for Smart Cities have been proposed to enable social, environmental, economic, and cultural progress, but they mainly focus on the relationships between information and technology (Bellini et al., 2015; Heaton and Parlikad, 2019; Kakarontzas et al., 2014; Zdraveski et al., 2017). Cox et al. (2016); McGinley and Nakata (2015) use the TOGAF and Zachman frameworks respectively as a foundation for creating their EAs for Smart Cities. They describe city goals as part of the architecture content, but they do not represent how to address the strategic alignment in Smart Cities. Falconer and Mitchell (2012); Mannaro et al. (2017) have stressed the importance of the connection between more specific strategic concepts such as city objectives and indicators, yet, existing EAs for Smart Cities tend to define high-level city goals. As a result, the lack of alignment of city services, their information systems and their multiple and conflicting goals remains an open gap in this domain (Sánchez-Corcuera et al., 2019).

Vertical alignment in Smart Cities represents the alignment of city services within a domain (e.g., environment), whereas, horizontal alignment, needed in Smart Cities, represents the alignment among various domains (e.g., health, culture, mobility, economy) (Bhatt et al., 2017). Bellini et al. (2015); ISO37120 (2018); Kakarontzas et al. (2014) tend to concentrate on the vertical alignment of city services, representing Smart City concepts, their relationships and properties within conceptual and architecture models. This can lead to the development and delivery of vertical applications that can rapidly increase and become disconnected silos (Bhatt et al., 2017). Heaton and Parlikad (2019) propose a conceptual framework to support the horizontal alignment of the requirements of citizens and infrastructure assets in Smart Cities. However, this proposal does not consider strategic aspects of Smart Cities or a more formal specification of the horizontal alignment (i.e., architecture model or EM language). Moreover, despite the significant industrial and research activity in Smart Cities, there is no single, accepted EM language for supporting the strategic alignment, making it difficult for the management of city services and the achievement of city goals and objectives.

The analysis of EM languages focuses on the different EM languages (including ArchiMate) for Smart Cities as presented in Section 2.4.2 and discussed in Section 2.4.3. Hence, ArchiMate is not individually represented in Fig 2.3, but it is considered within the group: *EM Language* in *Alignment Mechanism*. ArchiMate was used in this thesis to model different scenarios of Smart Cities because this language allows the creation of EA models with cross-layer dependencies to addresses the strategic alignment (Jonkers et al., 2004), which is crucial in this study. However, based on our practical observations (see Section 1.2.3), the main conclusion was that ArchiMate needs to be extended to meet the needs of the Smart Cities domain. This was confirmed with other studies (Lara et al., 2019; Rurua et al., 2019) that stressed that existing EM languages such as ArchiMate have a high level of abstraction, which can lead to miss the representation of the syntax, semantics, and notations of particular scenarios in various fields.

In summary, open gaps and possible solutions to answer the research questions (Section 1.6) within the current study on the alignment of city services and information systems in Smart Cities are:

1. The lack of an EA perspective to create integrated city services among different domains (i.e., horizontal alignment). Considering this from the design phase of city services can help to achieve common city goals, prevent locked city processes and decisions, and reduce information silos. Thus, it is needed to specify what principles can guide the design of an EA perspective in the context of Smart Cities in order to close this gap and answer RQ.1.

2. The disconnection between city services and their underlying information systems to support the strategic alignment in Smart Cities. The definition of the relationships between the service and information layers has the potential to create architectures that align Smart City strategies (i.e., city goals and objectives), thus responding to the needs of citizens. Hence, it is necessary to understand how to support a suitable alignment between the service and information layers in Smart City architectures in order to close this gap and answer both RQ.1 and RQ.2.

3. The limitation of EM languages which lack the domain-specific concepts of Smart Cities to support the alignment of services and information systems. Domain specific modelling languages (DSML) can offer, through appropriate syntax, semantics, and notations, a common language to help the communication and understanding of stakeholders. Therefore, it is required to define and validate the domain-specific concepts of Smart Cities that support this alignment in order to close this gap and answer both RQ.2 and RQ.3.

Chapter 3

Research Methodology

The literature review in Chapter 2 identified a number of limitations in the current alignment between city services and information systems to support Smart City strategies. We followed an approach proposed by (Webster and Watson, 2002) and pragmatically applied by (Corradini et al., 2018) in order to determine the source material for the literature review, which is detailed in the appendix: Appendix A - Smart City Architectures Alignment. This method focuses on how to conduct the literature review process in the IS field and how to structure and compile the results.

This chapter describes the approaches used to address the questions stated by this research. First, this chapter presents the importance of a research methodology as the rationale and the philosophical assumptions that underlie a particular study. Next, this chapter examines the research paradigms, methodologies, and methods involved in the Information Systems field. This chapter then examines a number of methodological requirements that are fundamental in order to address this research in a rigorous and consistent manner. It continues with an analysis of IS research methods that are appropriate to this study in accordance with the research themes identified in the literature review. Next, this chapter presents the Design Science Research Methodology (DSRM) as the selected research methodology as well as the different methods for its application in order to answer the research questions formulated by this study and guide the research process. For instance, Section 3.6.2 describes the literature review method applied during the design phase of this thesis, which is detailed in the appendices: Appendix B - Design Principles and Appendix C - Design Requirements. Finally, Table 3.1 summarises the applied techniques and methods in order to address both the validity and reliability of this study.

3.1 The Importance of Research Methodology

An appropriate methodology or approach is required to address the research questions and systematically solve a problem. Research is defined as a process for the collection and analysis of data to improve knowledge and understanding of a topic or issue in order to solve a perceived problem (Bell et al., 2018; Creswell John, 2012; Johnston, 2014; Walshaw, 2012). It is used to identify or confirm facts, reaffirm the results of previous work, address existing or emerging problems, support theorems, or generate new theories (Mehta, 2017). The goal of the research is to investigate and find answers to a research question following a systematic process that is designed to be unbiased and objective (Kumar, 2019). This research process consists of a set of logical steps to formalize a research question, collect data to answer the question, and present an answer to this question (Creswell John, 2012). A research methodology is a way to solve a research problem in a systematic fashion. In a research methodology, researchers study the various steps that are generally adopted along with the logic behind them (Kothari, 2004). They are required to select a suitable methodology to consistently guide the research processes and ensure scientific outputs.

Research methodology refers mainly to the rationale and the philosophical assumptions that underlie a particular study (Knight and Ruddock, 2009). Kamba (2009) describes a methodology as a guideline for systematically solving a problem by logically following various phases and tasks and encompassing a body of methods and tools. It is necessary to select among multiple research methods or techniques which are adequate to achieve the research objectives during each phase of the research methodology (Kumar, 2019). Research methods are understood as approaches or techniques that are used to conduct the research work (e.g., collecting and/or analysing data) (Collis and Hussey, 2013). They are closely related to the behaviour and instruments used in research, such as selecting and constructing research techniques to make observations and analyse data (Cohen et al., 2013). It is important to distinguish between the tools for investigation (i.e., methods) and the principles that determine how such tools are deployed and interpreted (i.e., methodology). In the following sections, several research methodologies and methods are discussed in order to select a set of appropriate research methodologies and methods for this thesis.

3.2 Methodologies for Research Guidance

Information Systems (IS) is a discipline that encompasses technical research on IT, the application and business use of IT, and the natural, social, and behavioural scientific dimensions of IT (Baskerville et al., 2018). This section describes behavioural science and design science as the major paradigms in the IS field. Research methodologies are divided into qualitative, quantitative, and mixed research in the main. Individual approaches and methods are presented under this classification as follows.

3.2.1 Design Science and Behavioural Science Research

In Information Systems research two paradigms are utilised to describe the processes of research: behavioural science and design science (Hevner and Chatterjee, 2010b; Hevner et al., 2004). The *behavioural science paradigm* has its origin in natural science research methods. It aims to develop and justify theories (i.e., principles and laws) that explain or predict organisational and human phenomena around the analysis, design, implementation, and use of information systems (Hevner et al., 2004). Such a research paradigm seeks to find the truth, usually starting with a defined hypothesis. The *design science paradigm* originates in engineering and the science of the artificial (Hevner and Chatterjee, 2010b). It seeks to construct artefacts (i.e., socio-technical artefacts) that improve effectively and efficiently the analysis, design, implementation, management, and use of information systems (Gregor and Hevner, 2013; Helfert et al., 2012). This research paradigm uses an objective-oriented approach to create artefacts (e.g., decision support systems, modeling tools, governance strategies, methods for IS evaluation, and IS change interventions) which must be designed and evaluated (Gregor and Hevner, 2013; Helfert et al., 2012).

Whereas *behavioural science* attempts to understand the truth and reality, *design science* focuses on creating artefacts that serve a specific human purpose and address urgent problems or improve practice (Carlsson, 2005; Hevner et al., 2004). Both paradigms are fundamental to the IS discipline, involving people, organisations, technology, and their interactions.

3.2.2 Qualitative Research

Qualitative research is particularly relevant in the behavioural sciences where the objective is to discover the fundamental motives of human behaviour. For example, when the interest is in investigating the reasons for human behaviour (i.e., why people think or do certain things) (Kothari, 2004). This kind of research crosscuts the social, as well as the humanities and the physical sciences (Denzin and Lincoln, 2017). In qualitative research, researchers need to learn more from participants and their environment by exploring a problem and developing a detailed understanding of a central phenomenon. The exploration is related to the need to better know how the phenomenon occurs (Creswell John, 2012). On the other hand, the understanding of the social is associated with the need to better comprehend the complexity involved through an examination of the interpretation of that world by its participants (Bell et al., 2018). The main research methods associated with qualitative research include ethnography, qualitative interviewing, focus groups, language-based approaches (discourse analysis and conversation analysis), and the collection and qualitative analysis of texts and documents (Bell et al., 2018). Qualitative research uses the theoretical assumptions of the participatory perspective to study the phenomenon of interest. For instance, it suggests strategies and approaches such as phenomenology, grounded theory, ethnography, action research, and case study (or multiple-case studies) which are described as follows (Kamba, 2009; Suter, 2012).

- **Phenomenology:** The phenomenology is associated with understanding the basic structure of an experience and interpreting the meaning it has from the point of view of a person or group. It is used when there is interest in how that experience becomes embedded in consciousness and what meaning that carries (e.g., in the field of consumer behaviour) (Lee et al., 2005; Suter, 2012).

- **Grounded Theory:** A systematic qualitative research approach involving the construction of theories through methodical gathering and analysis of data (including open coding techniques, or line-by-line analysis). It is used by researchers to develop a theory based on the understanding of the multiples sources of data (e.g., observations, conversations, and interviews) (Lee et al., 2005; Martin and Turner, 1986).

- **Ethnography:** A type of qualitative research that involves immersion in a culturally distinct group to study everyday life. Ethnography relies on participant observation as the main data collection method. It is used when there is a need of study social interactions, behaviours, and perceptions that occur within groups, teams, organisations, and communities (Fortino et al., 2012; Suter, 2012).

- **Action Research:** A systematic qualitative research approach that enables researchers and practitioners (acting together) to find effective solutions to the problems they confront in their everyday life in a social context. It is used to provide a means for people to understand and formulate solutions concerned with issues of organisational, informational and technical change (e.g., in the field of IS) (Goldkuhl, 2012; Stringer, 2013).

- **Case Study:** An approach to qualitative research that focuses on the study of a single situation (or person) or multiple cases using various data sources. It is used when the focus of the study is on a contemporary phenomenon within a real-life context. Multiple cases are often more informative, given their potential to replicate findings (in different contexts) and test (or exclude) rival explanations (Suter, 2012; Yin, 2009).

3.2.3 Quantitative Research

Quantitative research is related to the measurement of quantity and involves the generation of data which can be subjected to rigorous quantitative analysis. This kind of research is applicable to phenomena that can be expressed in terms of quantity (Kothari, 2004). For instance, instruments for quantitative data collection include survey questionnaires, tests, and checklists that researchers can use to observe behaviors. These instruments involve the collection of numeric data from a large number of people with predetermined questions and responses that would produce statistical data (Creswell John, 2012). Quantitative methods aim to establish whether the predictive generalisations of a theory are true by using quantitative methods (Kamba, 2009). Hence, researchers examine the relationship among variables and formulate this in terms of questions or hypotheses. Quantitative research questions are used commonly in social science research and especially in survey studies, whereas quantitative hypotheses are predictions the researcher makes on the expected relationships among variables (Creswell and Creswell, 2017). The major research methods associated with quantitative research include experimental research and non-experimental research (e.g., causal-comparative method and correlational design) (Creswell and Creswell, 2017; Kamba, 2009). These common quantitative research methods are outlined as follows.

- **Experimental Research:** In this quantitative research method, the researcher designs and conducts controlled experiments to demonstrate a known truth or validate a hypothesis. It is used by researchers in order to control the environment as much as possible and only concentrate on those variables that the researcher want to study (e.g., all variables that influence the outcome) (Creswell John, 2012; Muijs, 2010).
- **Non-experimental Research:** A quantitative research method that needs no further effects in setting up experiments to manipulate data and find relationships between variables (e.g., a survey). It is used by researchers in order to explore the relationships (e.g., the degree of the relationships and cause-effect relationships) between two or more quantifiable variables (Creswell and Creswell, 2017; Johnson, 2001).

3.2.4 Mixed Research

Mixed methods research is becoming increasingly relevant in several scientific areas (e.g., behavioural and design science) (Ågerfalk, 2013; Gregor et al., 2007). Mixed research methodologies take advantage of the strengths of both qualitative and quantitative research to address complex problems. The research process can comprise interdisciplinary teams with individual methodological interests and approaches (Creswell and Creswell, 2017). Mixed research integrates both qualitative and quantitative methodologies to gain more insight from this combination within a single study. Researchers can focus on understanding a problem by applying both qualitative and quantitative methods as a strategy for inquiry (e.g., for extensive data collection). For instance, a mixed research approach can be used to evaluate the internal technical quality of an artefact by means of cognitive–instrumental rationality through an automated test (Ågerfalk, 2013). At the same time, a qualitative method (e.g., case studies, surveys, and field studies) can be used to understand the user experience of the artefact in its social context (Gregor et al., 2007). A number of reasons are highlighted for using mixed research methods, such as triangulation, complementarity, initiation, development, expansion, diversity (Ågerfalk, 2013). For example, El Amrani et al. (2006) use both a survey based on quantitative methods and case studies to complement each other within a study on the effects of an enterprise resource planning implementation.

3.3 Methodological Requirements

An appropriate research methodology or approach is required to address research questions. The methodology selection underpins the research work and methods used in order to conduct the research. It should guide the various steps that will be adopted in studying this research problem along with the logic behind them (Kothari, 2004). This section examines and describes the requirements that a research methodology should consider in order to answer the research questions of this study as follows.

3.3.1 A Foundation for Inquiry

A deep understanding of the phenomenon associated with the main problem of this research (i.e., the alignment of city services and their information systems to support Smart City strategies) requires an examination from various perspectives. The socio-technical nature of these systems (i.e., Smart City systems) requires the researcher to examine in more detail the environment that the IS operated in (Backhouse and Cohen, 2014). Hence, since the initial phases of this research, it is required to actively engage with the Smart City environment, its initiatives, systems, and participants. This can provide, for example, a deeper understanding of current alignment issues in a real-world environment at the organisational, information, and technical levels.

3.3.2 Design-Based Research

The main research question and sub-research questions have analytical elements related to what and how the concepts of Smart Cities ensure the alignment between city services and their information systems. These are practical challenges (e.g., alignment concepts/aspects and their architectural considerations) that demand some concrete illustration of the possible outcomes (Lankhorst et al., 2009). This also influences in this research for the need to include design-based research where the iterative refinement of the final artefact is a key methodological approach to improve design (Barab and Squire, 2004; Hoadley, 2002; Zinger et al., 2017). Therefore, it is required that this research includes the iterative nature of design to create a tangible design that works in complex social settings such as Smart Cities.

3.3.3 A Research Framework

Alignment has been consistently ranked highly as a key issue for IS managers (Leonard and Seddon, 2012; Zhang et al., 2018). How alignment is perceived in an organisation environment by practitioners is widely acknowledged in the literature (El-Mekawy et al., 2015). Combined with the necessity to the practical perspective in the IS community is the need for the representation of the alignment based on a metamodel-based approach (Lankhorst, 2004; Leonard and Seddon, 2012). This requires an engineering approach that guides the design and development of a technological artefact. This research also conducts an artificial evaluation to examine how architecture models express the alignment using semantic analysis. Consequently, the application of more than one research approach requires a research framework that incorporates a set of mixed methods.

3.3.4 High Quality Standards

The followed methodologies must have professional credibility. In this way, the research results have perdurable values (Collis and Hussey, 2013). The rigor of the methodological process should be fully respected. This would ensure that the research, within the parameters of the (accepted) methodology, was valid and reliable. Validity and reliability represent prominent factors and criteria that are relevant to the quality of the research process (Creswell John, 2012; Kumar, 2019). Validity means that correct procedures have been applied to find answers to a question and generate conclusions. Reliability is concerned with the quality of a measurement procedure that provides repeatability and accuracy. Accordingly, it is required to ensure the validity and reliability of the research process conducted.

3.4 Research Methodology Selection

Research methodologies involve a coherent, active, and systematic process of inquiry (Bell et al., 2018). They are more than a simple set of methods; rather they refer to the rationale and the philosophical assumptions that underlie a particular study. In this section, the Design Science Research Methodology (DSRM) is selected as the main research methodology to guide this research within the Information Systems (IS) and Smart Cities fields. In the following, the DSRM is placed in context and the reasons for its selection are detailed.

3.4.1 Information Systems and Methodology Selection

The Information Systems (IS) field traditionally has attended to the interactions between specific classes of information technology and their social and organizational effects (Tilson et al., 2010). The digitalization of public services in Smart Cities is a socio-technical process of applying digitizing techniques to broader social and institutional contexts (Lindgren et al., 2019). IS researchers tend to understand Smart Cities as being about the provision of a broad range of services (e.g., healthcare monitoring, green sustainability, intense social interaction, transportation) to improve the daily life of the citizens (Backhouse and Cohen, 2014). This research perceives the interactions between Smart City stakeholders (e.g., citizens, city authorities, service providers), city services and end-systems as being part of a social-technical system. The examination of a particular technical or social aspect of research allows for the choice of a definitive research methodology from the quantitative or qualitative perspective.

As explained earlier in this chapter, behavioural science and design science characterise much of the IS research (Gregor and Hevner, 2013; Hevner et al., 2004; March and Smith, 1995). Hevner et al. (2004) argue that behavioural science and design science paradigms are essential to IS research as they address the socio-technical nature of systems namely the confluence of people, organisations and technology. Behavioural science aims to understand reality and consists of creating and justifying theories, whereas design science adopts an engineering approach to create artefacts that serve a particular human purpose and solve urgent problems. Behavioural science seeks to comprehend reality, this is realised by the development and verification of theories that explain or predict human or organisational behaviour (Hevner et al., 2004). Design science on the other hand seeks to extend the boundaries of human and organisational capabilities by providing intellectual as well as computational tools. Design science is technology and process oriented and its outcomes (i.e., artefacts) have to be assessed against criteria of value and utility (March and Smith, 1995). Examples of artefacts include, among others, constructs, methods, models, design principles, and initiations (Gregor and Hevner, 2013).

This research adopts the design science research methodology and paradigm (Gregor and Hevner, 2013; Hevner et al., 2004) for the following reasons. First, design science is an established and recognised research methodology in the IS field which aims to extend the ability of people and organisations in solving IS problems, thus adding knowledge to the IS research field (Drechsler and Hevner, 2016; Walls et al., 2004). Second, the main objective of this research is to define the Smart City concepts and relationships between them for addressing the alignment between the service and information layers in Smart City architectures. These concepts and relationships are structured within an artefact (metamodel) which is the product of the design science research. Third, design science methodology defines a process on how to evaluate and demonstrate artefacts, which are crucial steps for this research to iteratively enhance the final artefact. Finally, design science research methodology provides a framework for integrating methods (both qualitative and quantitative), and tools developed from multiple fields that are used to improve the design science artefact (Peffers et al., 2007).

3.5 The Design Science Research Methodology (DSRM)

Several types of Design Science Research Methodologies (DSRM) can be found in the literature, providing different approaches to organize the process of research. In the following, this section describes different DSRM and presents the design science (DS) framework selected to direct the design process of this research.

3.5.1 Design Science Framework

A three-cycle view of design science research comprises the relevance, design, and rigor cycles to manage research projects (Hevner, 2007). A design science process with five steps (e.g., awareness of problems, suggestion, development, evaluation, and conclusion) is presented to establish a computable design process model (Takeda et al., 1990). An approach to design research is divided into steps covering three general phases: problem identification, solution design, and evaluation (Offermann et al., 2009). A two-dimensional framework is driven by the distinction between research outputs (e.g., representational constructs, models, methods, and instantiations) and research activities (e.g., build, evaluate, theorize, and justify) (March and Smith, 1995). Hevner and Chatterjee (2010a); Peffers et al. (2007) provide a set of phases for implementing DSRM following a sequential process with six steps including (1) problem identification and motivation, (2) definition of the objectives for a solution, (3) design and development, (4) demonstration, (5) evaluation and, (6) communication. This thesis follows the DSRM proposed by (Hevner and Chatterjee, 2010a; Peffers et al., 2007) as a DS reference framework to conduct this study. The selected DSRM contributes to IS research by providing a commonly accepted framework for successfully carrying out DS research and a mental model for its presentation. This framework represents a reference process structured in six defined phases which are explained in more detail below.

Problem Identification and Objectives Definition

The identification of the specific research problem and motivation is used to justify that an artefact can effectively provide a solution. The resources required for the problem identification and motivation involve knowledge of the state of the problem (e.g., conducting a literature review) and the relevance and importance of its solution. The objectives should be derived rationally from the problem specification and they can be qualitative or quantitative (Hevner and Chatterjee, 2010a; Peffers et al., 2007).

Design and Development

Moving from the objectives to the design and development, the creation of an artefact in this research is a key activity in the research process. This design activity includes determining the required functionalities of the artefact and its architecture. Then, the artefact can be developed based on such specifications. The resources required for the design and development include knowledge of the theory that can be applied to the solution (Hevner and Chatterjee, 2010a; Peffers et al., 2007).

Demonstration and Evaluation

The demonstration of the use of the artefact implies to solve one or more instances of the problem by using experimentation, simulation, case study, or other appropriate activities. The evaluation involves observing and measuring how well the artefact supports the solution to the problem. It requires comparing the objectives of the solution to actual observed results from the use of the artefact in the demonstration. It is necessary to decide whether to iterate back to the design phase and improve the effectiveness of the artefact or to move to communication (Hevner and Chatterjee, 2010a; Peffers et al., 2007).

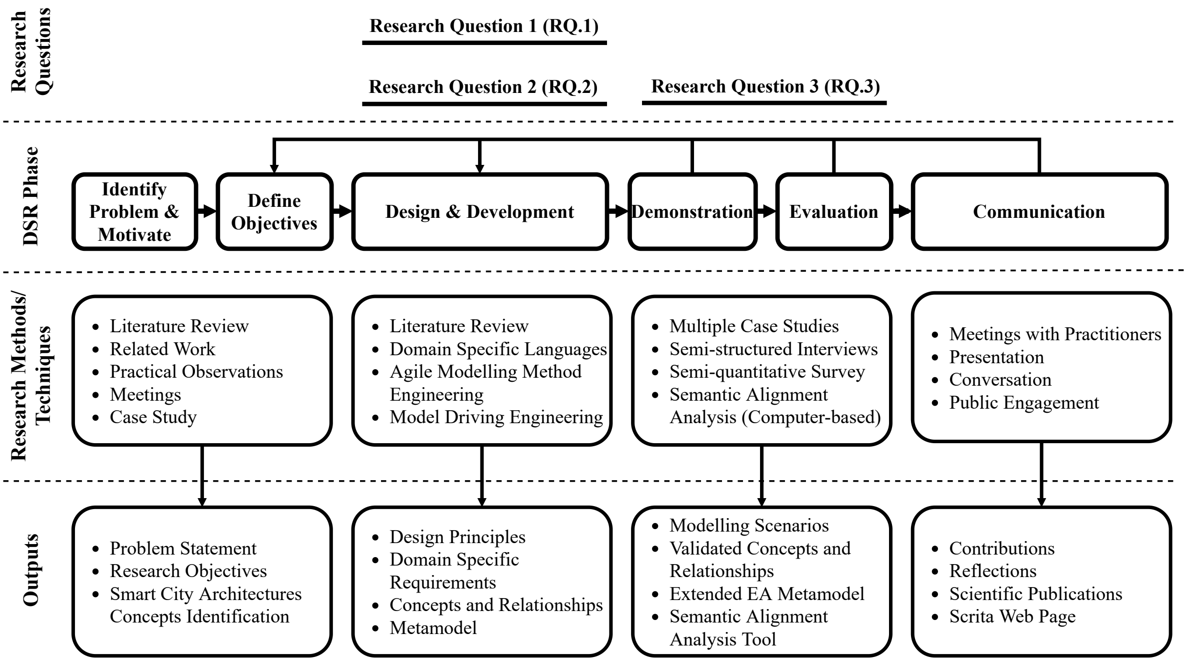


Fig. 3.1 The Research Methodology Adopted for this Research.

Communication

The communication with researchers and practitioners is essential to present the problem and its importance, the artefact, its utility and originality, the rigor of its design, and its effectiveness to researchers and practitioners. Research publications could comprise the problem definition, literature review, hypothesis development, data collection, analysis, results, discussion, and conclusion as a common structure for empirical research process. (Hevner and Chatterjee, 2010a; Peffers et al., 2007).

3.6 Design Science Application in this Thesis

This section presents how to apply the different phases of the selected framework in this thesis. Figure 3.1 depicts an overview of the DSRM applied to the current research and illustrates the outputs of each research question along the Design Science (DS) research process. It includes the research methods and techniques that address the research questions of this study.

3.6.1 Problem Identification and Objectives Definition

The identification of the research problem and motivation, and the definition of the research objectives are presented in Chapter 1 and Chapter 2. During the problem identification and motivation, Section 1.2 presents a review of the literature on the alignment of services and information in Smart Cities. An overview of an initial case study is presented in Section 1.2.3 in order to explore current and future city services and alignment issues in practice. Observations and research gaps are defined in Section 1.3. The research problem and motivation are specified in Section 1.4. Research objectives are derived from the problem definition in Section 1.5. Chapter 2 presents the literature review and related work on the alignment in Smart City architectures, following a concept-centric approach for the literature reviews (Corradini et al., 2018; Webster and Watson, 2002). Open research gaps are presented in Section 2.5 which are beneficial to identify the key elements associated with the problem and motivate this research, based on the literature review conducted. These research gaps are formalised with the research questions defined in Section 1.6. The research gap related to the lack of an EA perspective in the context of Smart Cities is formalised with RQ.1. The research gap regarding the disconnection between city services and their underlying information systems in Smart Cities architectures is formalised with both RQ.1 and RQ.2. The research gap associated with the limitation of EM languages that lack the domain-specific concepts of Smart Cities is formalised with both RQ.2 and RQ.3.

3.6.2 Design and Development

This thesis focuses on modelling the alignment between the service and information layers to support Smart City strategies and assist the design and digitalisation of public services. The design and development of the artefact (metamodel) in this research is a key activity in the research process. This study provides the details of the artefact design and description both in conceptual and technical terms. Chapter 4 defines the design principles to address this alignment in order to answer the RQ.1. Chapter 5 presents the design of the artefact and Chapter 6 details its development and technical implementation in order to answer the RQ.2. The artefact has been refined based on an iterative design process by using the feedback provided by Smart City domain experts during the demonstration and evaluation phases. The research methods and techniques employed during the design and development phases are outlined as follows.

Structured Literature Review

The review of relevant literature is a key characteristic of this research to facilitate theory development. This research follows a snowballing method described by (Corradini et al., 2018; Webster and Watson, 2002) as a guide on how to execute a structured literature review for research in the Information Systems (IS) field. This method uses a structured and concept-centric approach that is suitable for the purpose of this thesis. The method is used to review and identify relevant articles on the design principles to answer RQ.1, and define the modelling requirements and concepts of the Smart City domain to answer RQ.2. Corradini et al. (2018); Webster and Watson (2002) present the general process followed during the literature review process. This method suggests to start from an initial set of papers manually identified according to specific criteria (keywords) in order to identify the set of relevant research papers to consider in the next phases. Additional relevant papers are consecutively identified by proceeding backward and forward in time. It uses respectively the related works section when available (backward snowballing), and the "cited by" functionality provided by digital libraries (forward snowballing). The literature is summarised by compiling a concept matrix as each article is read and presenting each identified concept. Chapter 2 outlines the review process and presents the relevant literature of this study.

Domain Specific Modelling Languages (DSML)

This research uses a domain specific modelling language (DSML) to capture the concepts of Smart Cities and design the artefact (metamodel). DSML are used for modelling purposes and incorporate concepts that represent domain-level knowledge (Frank, 2010). They contribute to model integrity and reuse due to the incorporation of semantics and constraints that would otherwise have to be added manually (Clark et al., 2015). A DSML includes a metamodel that specifies the abstract and concrete syntax of the domain specific language. This supports the comprehension of models and improves the communication of domain stakeholders. Modellers generate fewer errors in models when a modelling language includes more domain specific semantics (Overbeek et al., 2015). DSML can be created by using the extension mechanisms of existing modelling languages. For example, BPMN extends the elements of business process domain specificity, including simulation mechanisms attributes (i.e., different kinds of costs, times, resource consumptions) and semantic relationships (i.e., to a responsible role from a related organisational chart) (Karagiannis et al., 2016).

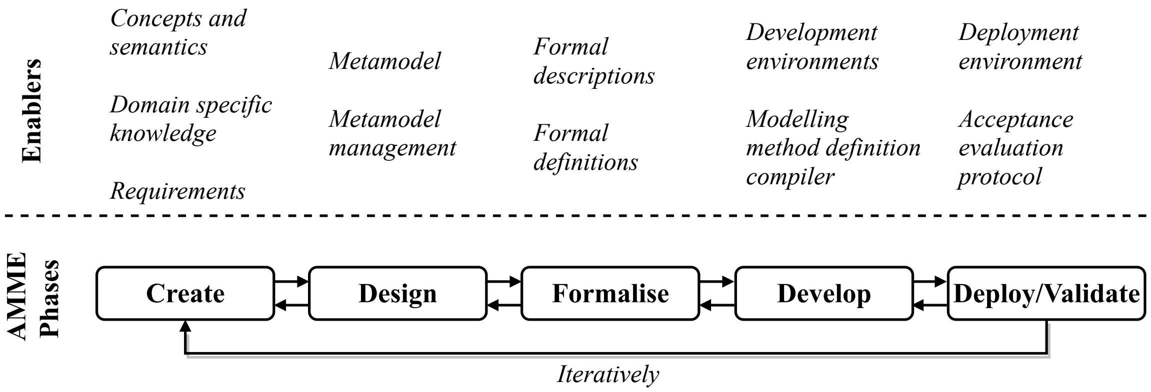


Fig. 3.2 Agile Modelling Method Engineering (Karagiannis, 2015).

Agile Modelling Method Engineering (AMME)

Designing and developing an artefact (metamodel) for a domain specific purpose requires a modelling method. This research follows the Agile Modelling Method Engineering (AMME) to design and develop the artefact in the Smart Cities domain. The AMME is driven by evolving requirements and motivated by emerging paradigms and research initiatives such as Enterprise Modelling, Internet of Things, and Cyber-physical Social Systems. This method has been used to build tools and models in particular domains, such as requirements engineering, business process modelling and Enterprise Architecture. The AMME defines a cycle of iteration which follows the agility principles defined in software engineering. The phases of the AMME cycle are illustrated in Figure 3.2 and are described below (Karagiannis, 2015, 2016).

- **Create:** The creation phase aims to define and specify the requirements that capture the knowledge of a domain (e.g., Smart City domain).
- **Design:** The design phase aims to specify the metamodel, its language grammar, notation, functionality, syntax, and semantics.
- **Formalise:** This phase aims to describe the outcome of the previous phase in non-ambiguous descriptions (e.g., UML) for presenting results in a scientific community.
- **Develop:** The development phase aims to create concrete modelling prototypes by using a metamodel platform that allows tools to be built that can leverage models.
- **Deploy/Validate:** The deployment and validation phase aims to involve the stakeholders in practice and evaluate the metamodel to feed back into the next interaction of the metamodel.

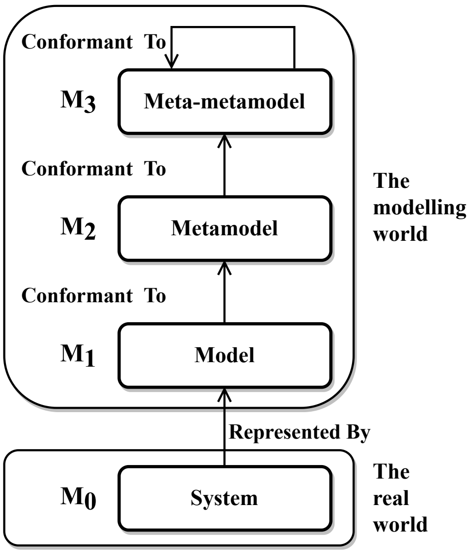


Fig. 3.3 The 3+1 Model Driving Architecture (Bézivin, 2004).

Model Driving Engineering (MDE)

This thesis follows a Model Driving Engineering (MDE) approach to implement the software architecture of the artefact (metamodel). Figure 3.3 introduces the 3+1 architecture defined by the Object Management Group (OMG) (Bézivin, 2004).

The M0 layer is the real system. The M1 layer is the model that represents this system. The model conforms to its metamodel defined at level M2 and this metamodel conforms to the meta-metamodel at level M3. The meta-metamodel conforms to itself. In this study, the layer M3 includes the metamodel Meta Object Facility (MOF) which is a standard of the OMG for MDE that allows the creation of metamodels in the layer M2. The Eclipse Modelling Framework (EMF)[1] is selected as a modelling framework and code generation facility for describing class modelling concepts and building the artefact.

3.6.3 Demonstration and Evaluation

This study demonstrates the use and application of the artefact in the real-world by conducting multiple case studies. The evaluation consists of an iterative process by observing and measuring how well the artefact addresses the identified problem in the real-world. The design of the artefact is improved based on the feedback provided by Smart City domain experts from the evaluation phase. Chapter 7 details the demonstration and evaluation phases of this thesis. The research methods and techniques using for this purpose are described as follows.

[1]Eclipse Modelling Framework - https://www.eclipse.org/modeling/emf/

Multiple Case Studies

Understanding an IT artefact in context requires an understanding of the constituents of the subjective and social worlds and how these relate to the constituents of the objective world (Bézivin, 2004). Case Studies help researchers to develop generalisable concepts and models which underpin the theoretical debate, add to existing knowledge, and inform the research agenda. Multiple case studies explore differences within and between cases by replicating findings across them (Yin, 2014). This thesis demonstrates and evaluates the artefact by conducting multiple case studies in two real-world cities, including Limerick City and County Council in Ireland, and Netanya Municipality in Israel. These case studies were selected because of their essential principle of prioritizing the needs of citizens as part of their Smart City strategies. Moreover, these cities were required to digitalise public services by applying a formal architecture approach (i.e., Enterprise Architecture and Enterprise Modelling) to model and design the transformation of public services. These case studies rely on multiple sources of evidence (meetings, semi-structured interviews, internal documents, digital strategy), with data that converge in a triangulating fashion.

Survey

The evaluation of the artefact consists in assessing the utility and quality of the artefact, following (Helfert et al., 2012). The evaluation includes the application of two semi-quantitative surveys that are systematically judged by a group of Smart City domain experts. A first survey aims to corroborate the need for the concepts for modelling the alignment of city services and their underlying information systems. The participants include the Smart City domain experts of Tel Aviv-Yafo Municipality and Netanya Municipality. A second survey aims to evaluate the artefact (e.g., abstract, concrete syntax and semantics) and its instances (e.g., the modelling scenarios created within the case studies). The participants involve the Smart City domain manager of Netanya municipality and five senior directors and managers of the Federation of Local Authorities in Israel. They were selected because of their expertise in the public sector and their work in the field of Smart Cities that impacts different aspects of daily life for all Israeli citizens (e.g., urban planning and management, education, transportation, and more urban aspects).

Semantic Alignment Analysis

This thesis demonstrates and artificially evaluates the artefact by developing a computer-based solution for semantic alignment analysis. The artificial evaluation is used to examine how architecture models express the alignment using semantic analysis from an Enterprise

Architecture (EA) perspective. This solution presents and visualises the alignment between city services (e.g., city service qualities) and their information systems (e.g., application services qualities) to support Smart City strategies, including city goals and objectives. It aims to offer a solution to identify and analyse the alignment by using the Resource Description Framework (RDF), which is a standard for semantic analysis. This solution is able to examine the knowledge of the models created (e.g., XML format) and visualise the alignment between city services and their underlying information systems. The analysis uses a top-down approach starting from city goals, objectives, or city services. This analysis is critical for city managers who need alignment information to support the decision-making process (Cañas et al., 2015; Őri, 2017a).

Validity and Reliability

The examination of this research from the technical and social aspects allows for the choice of methods and techniques from both quantitative or qualitative perspectives. This research follows DSRM as the methodology to guide the research process to address a problem that has emerged in the socio-technical context of Smart Cities. This implies to ensure that research work is both valid and reliable (Aken, 2004; Golafshani, 2003; Morse et al., 2002). Validity means that correct procedures have been applied to find answers to a question. It can be divided into construct validity, internal validity, and external validity (Runeson and Höst, 2009; Teegavarapu and Summers, 2008). Reliability refers to the quality of a measurement procedure that provides repeatability and accuracy (Creswell John, 2012; Kumar, 2019). Table 3.1 presents the research techniques and methods used during the research process of this study in order to address both validity and reliability.

Construct validity reflects how the operational measures studied really represent what the researcher has in mind and what is investigated according to the research questions (Runeson and Höst, 2009). Validation efforts were conducted with Smart City domain experts within each of the cases in an iterative fashion. This research uses multiple sources of evidence and individual case study reports in accordance with (Runeson and Höst, 2009; Teegavarapu and Summers, 2008; Yin, 2009) to address the construct validity. Internal validity seeks to assure that the research investigates what it is mean to (Malterud, 2001). The Internal validity aspect of this research is concerned with the causal relations investigated during the case studies and factors influencing the design process. The considered factors that influence the design phase include architectural standards, Enterprise Architecture (EA) guidelines, and modelling techniques used for creating the artefact (Bézivin, 2004; ISO/IEC/IEEE 42010, 2011; The Open Group, 2018).

Table 3.1 Validity and Reliability in this Thesis

Characteristic	Technique	Addressed in this Research
Construct Validity	• Multiple sources of evidence (data triangulation) • Individual case study reports (Allow key informants to review case study reports)	• Case Study Research (Hancock and Algozzine, 2017) • Case Study Design and Method (Runeson and Höst, 2009; Yin, 2014)
Internal Validity	• Enterprise Architecture guidelines, architecture standards, modelling techniques • Structured literature review • Interviews with Smart Cities domain experts	• TOGAF (The Open Group, 2018) • Systems and software engineering — Architecture description (ISO/IEC/IEEE 42010, 2011) • Concept Centric Approach for Literature Reviews (Corradini et al., 2018; Webster and Watson, 2002) • Case Study Design and Method (Runeson and Höst, 2009; Yin, 2014)
External Validity	• Replication logic in multiple case studies • Structured literature review	• Case Study Research, Design and Method (Hancock and Algozzine, 2017; Runeson and Höst, 2009; Yin, 2014) • Concept Centric Approach for Literature Reviews (Corradini et al., 2018; Webster and Watson, 2002)
Reliability	• Case study database (NVivo database) • Case study protocol • Modelling method engineering	• Computer assisted qualitative data analysis (Bell et al., 2018) • Case Study Design and Method (Hancock and Algozzine, 2017; Runeson and Höst, 2009; Yin, 2014) • Agile Modelling Method Engineering (Karagiannis, 2015, 2016)

Additionally, internal validity is addressed by conducting a structured and concept centric literature review to gather the design principles and requirements from the Smart City domain. The external validity of an artefact is concerned with to what extent the findings can be generalised (Malterud, 2001). This research conducts multiple case studies and applies the artefact by modelling different scenarios, i.e., city services from different cities in Ireland and Israel. This research addresses the external validity by building the solution on established theories and techniques from the existing knowledge base on business and IT alignment and EA.

Finally, we extracted the design principles and design requirements from the literature and defined them in a high-level abstraction description to meet the requirements of various Smart Cities. Reliability is concerned with the repeatability of the research findings. Repeatability of this research process is addressed by following standard guidelines, formulating a case study protocol and following the same for multiple cases. This criterion is satisfied by developing a case study database (e.g., NVivo database), formulating a case study protocol, and following a clear and transparent engineering method to design the final artefact. More details on the evaluation of the validity and reliability of this research is presented in Section 7.3.3.

3.6.4 Communication

Design science research must be presented effectively to both technology-oriented and management-oriented audiences (Hevner and Chatterjee, 2010a). The results of this research have been presented in a complementary way allowing for their technical and management application. This research provides the details that allow for the technical implementation of the artefact and a process to guide the implementation of the artefact from a Smart Cities management perspective. Hence, scientific conference and journal papers have been presented and published within the IS and Smart Cities fields. At the same time, different meetings have been held to present and discuss the results of this research with Smart City domain experts in various cities, including Limerick in Ireland, and Tel-Aviv, Jerusalem, and Netanya in Israel. Additionally, the results of this research have been published on a Smart City web page[2] which presents the research on EA management by developing a Reference Methodology to digitalise and transform public services. This aims to share and disseminate the results of the research with the public as part of an initiative in public engagement and research stakeholder engagement.

[2] A Reference Methodology for Developing and Transforming Public Services - https://scrita.lero.ie/

3.7 Research Methodology Summary

This chapter presents the research methodology selected to guide and conduct the research process, including rationale and justification. It presents an overview of the methodologies for research guidance and describes in detail the research framework employed to conduct this research. The methodological requirements of this research were outlined. The DS framework and its process to design the artefact (metamodel) was also discussed. The individual methods and techniques selected to answer each of the research questions were identified and detailed. Finally, this chapter presents also how this study addresses both the validity and reliability of the research process. The remainder of this thesis describes the design, development, demonstration, and evaluation phases of this research. Chapter 4 presents the design principles to ensure the alignment between city services and information systems in Smart Cities architectures in order to answer RQ.1.

Chapter 4

Design Principles

The research methodology presented in Chapter 3 describes the research approach and process used to answer each research question identified in Chapter 1. This chapter is related to the design principles that support the alignment between the service and information layers in Smart Cities architectures in order to answer RQ.1. Hence, six distinct design principles are derived from literature and the experience gained from working with cities in Ireland and Israel. These principles are explicit prescriptions on how to address the alignment in the Smart Cities domain. Conceptual models are used to formulate and better explain each design principle. Further, this chapter presents the rationale and justification behind each design principle.

4.1 The Need for Design Principles

It is necessary that city services and their information systems support a continuous strategic alignment during digital transformation and change. The effective transition of strategy into IT requires extensive design activity on both organisation design and information systems design (Hevner et al., 2004). Henderson and Venkatraman (1993) present a Strategic Alignment Model (SAM) which defines the different perspectives for the integration between business and IT. In this model, business strategy drives both the organisational design choices and the design of IS, while IT enables new or enhanced business strategies. Several analytical methodologies are available to make the strategic alignment operational: critical success factors, IS business systems planning, and Enterprise Modelling (EM) (Chan and Reich, 2007; Henderson and Venkatraman, 1993; Luftman, 2004; Ross et al., 2006). Unlike the existing research that considers strategic alignment in organisations, the alignment of Smart City strategies (e.g., city goals) is still an open challenge in the Smart Cities domain (Sánchez-Corcuera et al., 2019). Citizen centricity influences the design and delivery of city services

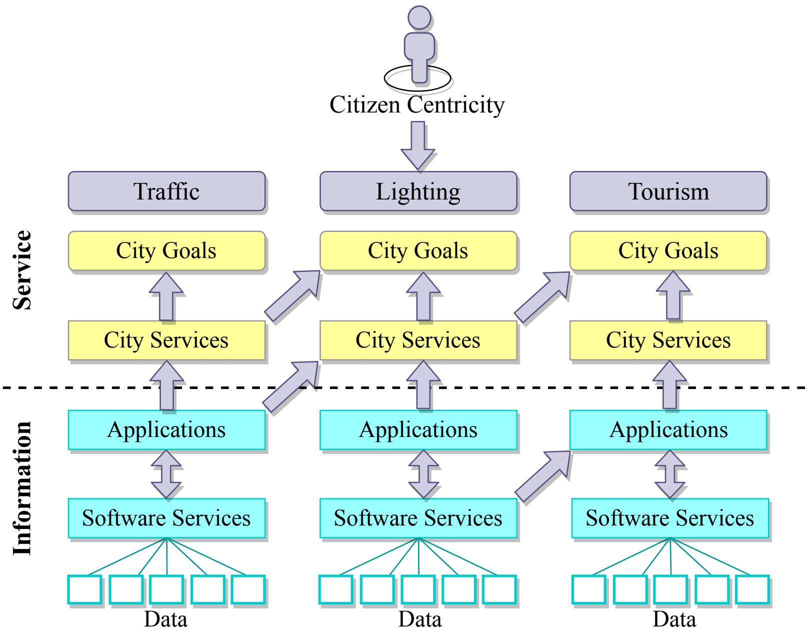


Fig. 4.1 Service and Information Alignment to Support Smart City Strategies.

driven by the needs of citizens (e.g., residents, visitors and businesses) (ISO37106, 2018). Figure 4.1 illustrates how information systems should support city services according to common city goals and the needs of citizens. As we can see in the figure, software services support applications, such applications support city services, and these city services support city goals, from similar or different domains. Hence, design principles are necessary as general design considerations to address the alignment in the Smart Cities domain. This can provide a solid foundation to break the existing silos and ensure the interoperability of Smart Cities at various levels (e.g., strategic, organisational, city services, applications, data) (Bhatt et al., 2017).

This thesis defines a set of design principles as a key input and starting point to define the concepts and relationships that ensure the alignment between the service and information layers in Smart City architectures. These design principles are explicit prescriptions on how to address this alignment in the Smart Cities domain. They are formulated following the structure and approach suggested by (Chandra et al., 2015), focusing on how an artefact should be built (i.e., materiality oriented design principles). These design principles will be instantiated in the form of concepts and relationships to make them actionable, for more information see Chapter 5.

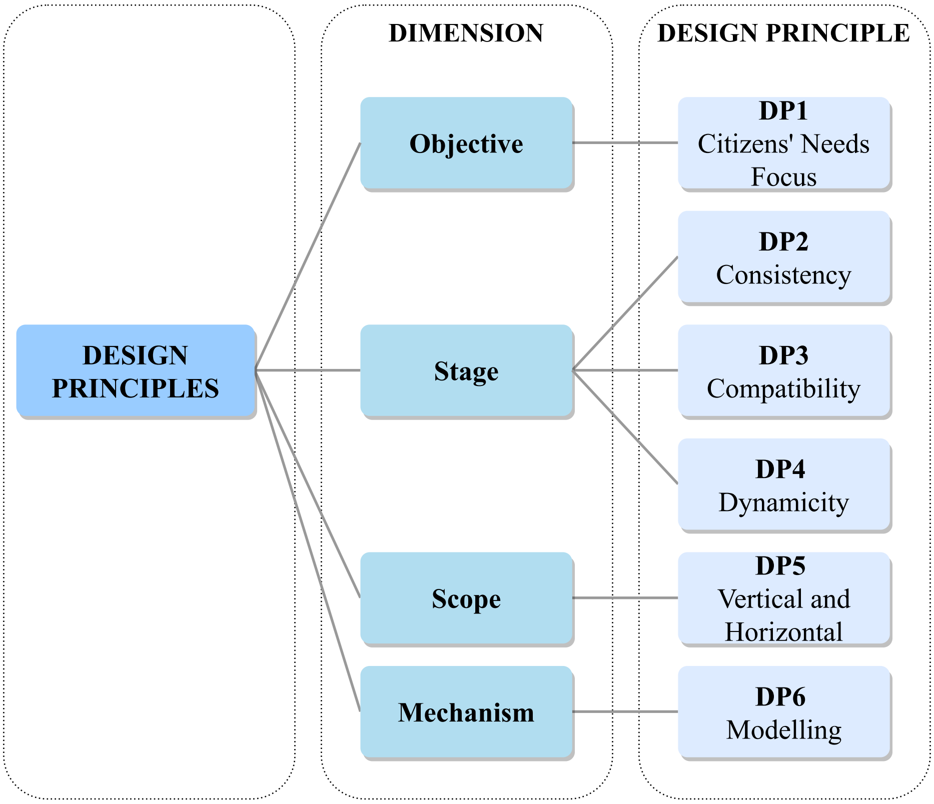


Fig. 4.2 Design Principles to Address the Alignment.

4.2 Design Principles Definition

This section defines a set of design principles for alignment between the service and information layers in Smart City architectures in order to answer the RQ.1. These design principles are derived conceptually, deducing their necessity argumentatively from the literature and the experience gained from working with real cities (Chapter 7). Appendix B - Design Principles specifies the literature review process followed to select the set of design principles. The practical experience includes the modelling of complex real-world public service scenarios from different domains. Figure 4.2 presents the set of design principles identified. The design principles are grouped along four dimensions: Objective, Usage, Scope, and Mechanism, and are outlined as follows.

4.2.1 Dimension: Objective

One main design principle is identified as specifying the objective of the alignment between the service and information layers in Smart City architectures: Citizens' Needs Focus.

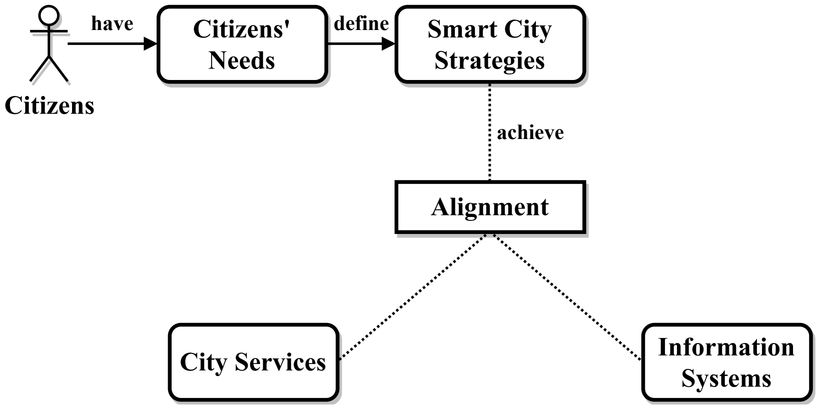


Fig. 4.3 DP1: Citizens' Needs Focus. Alignment Objective.

DP1 - Citizens' Needs Focus: ***Support the alignment of the service and information layers in order to meet the needs of citizens.***

The objective of the alignment between city services and the underlying information systems in Smart Cities is to develop IS solutions according to city strategies and goals, thus responding to the needs of citizens. Smart Cities should develop a well-defined strategic plan, and innovative solutions that serve the needs of citizens (Agbali et al., 2019; Kakarontzas et al., 2014). The needs of citizens involve the needs of individuals, but also the needs of communities, groups, neighborhoods, and businesses of the city (Chourabi et al., 2012; ISO37106, 2018). City services should be built around these needs rather than the cities organisational structures (i.e., internal municipalities structures) (Lee and Lee, 2014). Smart cities are required to develop new ways of working across vertical silos to deliver more citizen-centric services, contributing to the success of Smart City initiatives among different domains (ISO37106, 2018; King and Cotterill, 2007).

From the practitioner point of view, this citizen-centric approach is fundamental in all aspects of service design and delivery, thereby reflecting the needs and expectations of their residents and visitors, and meeting city goals (Al-Nasrawi et al., 2015; Simonofski et al., 2019). For instance, one of the Smart City principles of Limerick City and County Council is related to the needs of citizens: *"While support for customers is paramount, any initiatives will put the citizen's interest first. Any design must start with the citizen's needs as far as it is practical. Current practices will be changed to suit the citizen and only then can the organisation issues be addressed"*. Figure 4.3 presents a conceptual model to represent the Design Principle 1. The model illustrates how the needs of citizens define the Smart City strategies that are achieved through the alignment between city services and their information systems.

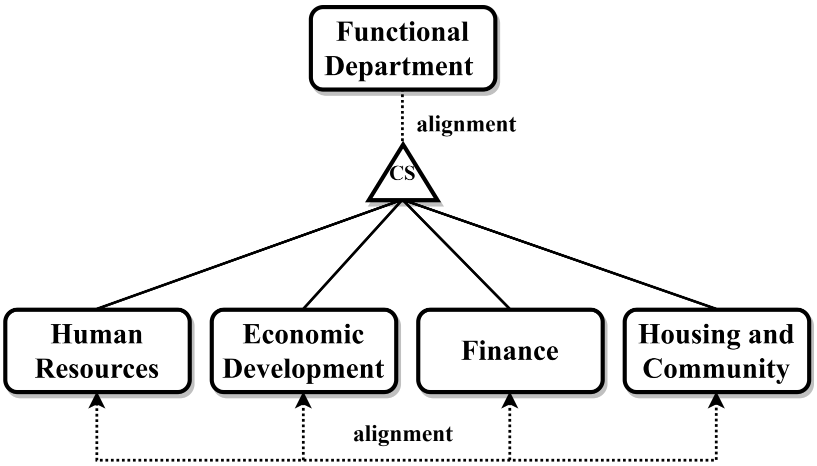


Fig. 4.4 DP2: Consistent Alignment. City Council Functional Departments.

4.2.2 Dimension: Stage

Three main design principles are associated with the notion of the alignment between the service and information layers in Smart City architectures: Consistency, Compatibility, and Dynamicity.

DP2 - Consistency: ***Provide a consistent alignment that allows a coherent architecture specification of concepts within each layer.***

The first stage of alignment concerns the development of a consistent architecture layer specification. The specification of the components within each Smart City architecture layer (e.g., the service layer and the information layer) must be mutually supportive (ISO/IEC, 2015; Morabito et al., 1999). Addressing the consistency of alignment should involve two main dimensions. The first concerns selecting the appropriate components to satisfy the intent of the designer. The second is related to the correspondence among those components. The implementation of a Smart City architecture is more likely to be successful if the specifications of each architecture layer component are consistent (Jonkers et al., 2004; Morabito et al., 1999).

Figure 4.4 illustrates a sample of consistent alignment between functional departments in a city council. In this example, Human Resources, Economic Development, Finance, and Housing and Community are concept specializations (CS) of the overall concept: Functional Department. When designing a city service that involves various city council departments, each functional department may be specified at the same hierarchical level. This enables functional departments to be more easily supported by information covering all functional

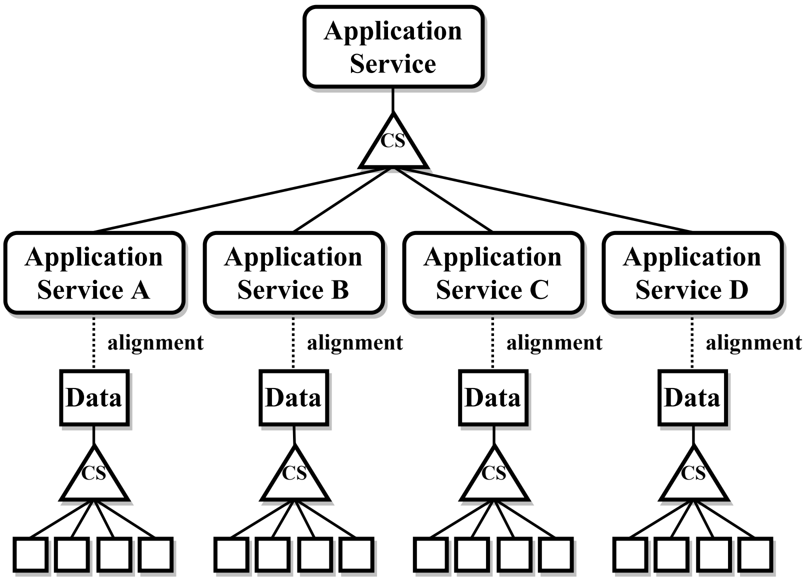


Fig. 4.5 DP3: Compatible Alignment. Multiple Application Services.

departments involved rather than information for each functional department. For instance, in the case of car accidents, different city council functions need to be triggered in real-time using information, such as transportation (routing traffics), health (finding nearby emergency hospitals with rooms) and welfare (getting insurance information) (Lee and Lee, 2014). Each functional department, then, should support every other functional department.

DP3 - Compatibility: ***Provide a compatible alignment that allows appropriate architecture specification of concepts across architecture layers.***

The next stage is related to the compatibility of alignment. This involves the definition of compatible specifications across the selected components (Jonkers et al., 2004; Morabito et al., 1999). For instance, a city service may be designed with the expectation of aggregated information from different city devices or smart objects that need to communicate and collaborate with software components (Huber et al., 2019). However, if the city does not have a data aggregation system to combine data or open interfaces that allow for a more dynamic form of orchestrating services, city stakeholders will not have the required information (Böhmann et al., 2018). The specification of the city service will therefore not be compatible with the city information systems.

Figure 4.5 illustrates a sample of compatible alignment between multiple application services and data collected. In this example, different application services (e.g., Application Service A, B, C, and D) are concept specializations (CS) of the concept: Application Service.

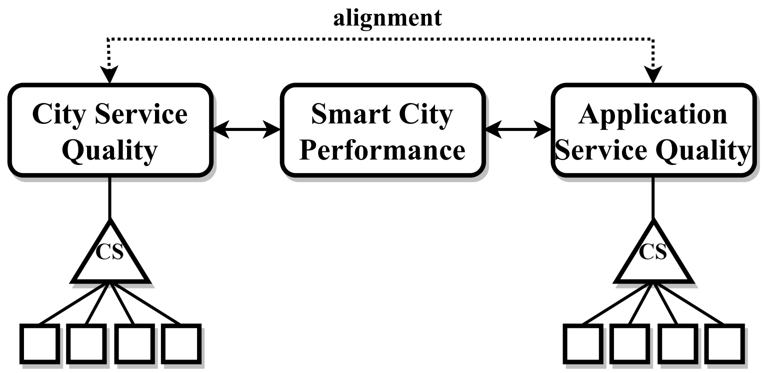


Fig. 4.6 DP4: Dynamic Alignment. Quality Perspectives.

Each application service should be aligned with the data required to support the service at the application level. Then, multiple alignment ensures that a local specification is compatible with the specifications of the entire Smart City.

DP4 - Dynamicity: ***Provide a dynamic alignment of concepts that allows a flexible architecture specification that can be adjusted over time.***

The next stage concerns dynamic alignment. This is related to the required flexibility of the alignment approach (Jonkers et al., 2004; Morabito et al., 1999). This recognises, for example, that changing one component at the city service level affects other components at the information systems level. Dynamic alignment assumes that changes happen in a Smart City and as a result all alignments progress over time (Sen and Sinha, 2011). Dynamic alignment in Smart Cities seeks to ensure that alignment principles (consistent and compatible) are adjusted over time, responding to the dynamic nature of Smart Cities. This can impact the strategy, structure interactions, and information systems (Sabherwal et al., 2001).

Quality perspectives are important for an adequate dynamic alignment (Zimmermann et al., 2015). Figure 4.6 illustrates a sample of the dynamic alignment in terms of Smart City quality levels and their performance implications. In this example, the Smart City performance depends on the alignment of both city service qualities (e.g., efficiency, flexibility, decision-support) and application service qualities (e.g., interoperability, availability, usability). These quality characteristics can easily change due to the dynamic nature of Smart Cities (e.g., a car accident that affects public transport schedules, a flooding that affects pedestrian and cycling mobility, or any unexpected city event that affects city services). It is important to consider, then, the dynamic alignment for the adaptation (e.g., in real-time) of these qualities in order to provide the required Smart City performance.

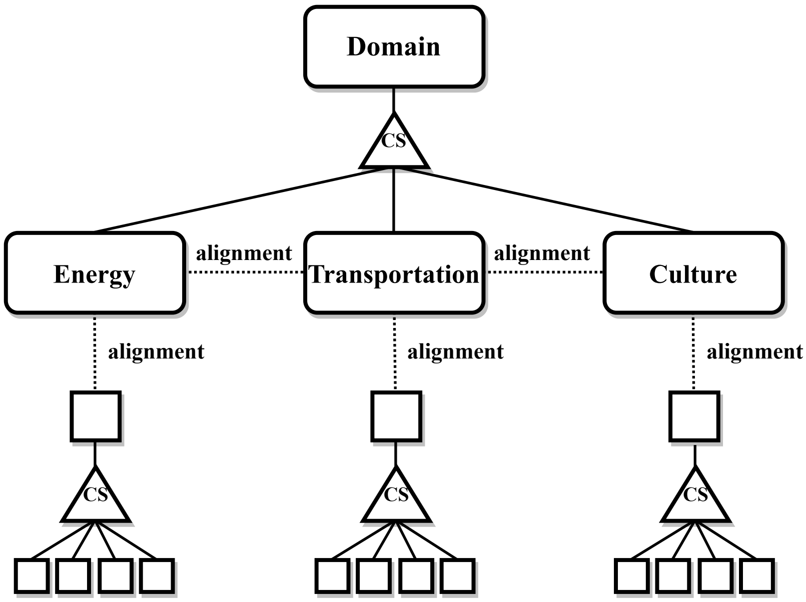


Fig. 4.7 DP5: Vertical and Horizontal Alignment. Smart City Application Domains.

4.2.3 Dimension: Scope

The scope refers to the level of the alignment between the service and information layers in Smart City architectures. One scope design principle is identified: Vertical and Horizontal.

DP5 - Vertical and Horizontal: ***Enable the vertical and horizontal alignment of Smart Cities since the architecture specification.***

The alignment in Smart Cities involves the design and delivery of city services driven by the integration of domains rather than services within the silos of a city (ISO37106, 2018). Understanding how a city operates is one of the key elements in designing the foundation for execution via Enterprise Architecture (EA) by providing an actionable view of a city (ISO37106, 2018; Ross et al., 2006). A smart city operating model, as the basis for the alignment, enables cities to drive innovation and collaboration across these vertical domains and hence operationalises their vision and strategy (ISO37106, 2018). Many city solutions are vertically locked, where the data collection, processing, analysis, and the resulting decisions and accumulated knowledge are normally locked within the boundaries of a particular domain: education, energy, transport, buildings, government, etc., (Hefnawy et al., 2015, 2016).

Figure 4.7 illustrates the vertical and horizontal alignment in Smart Cities. In this example, Energy, Transportation, and Culture are concept specializations (CS) of the concept: Domain.

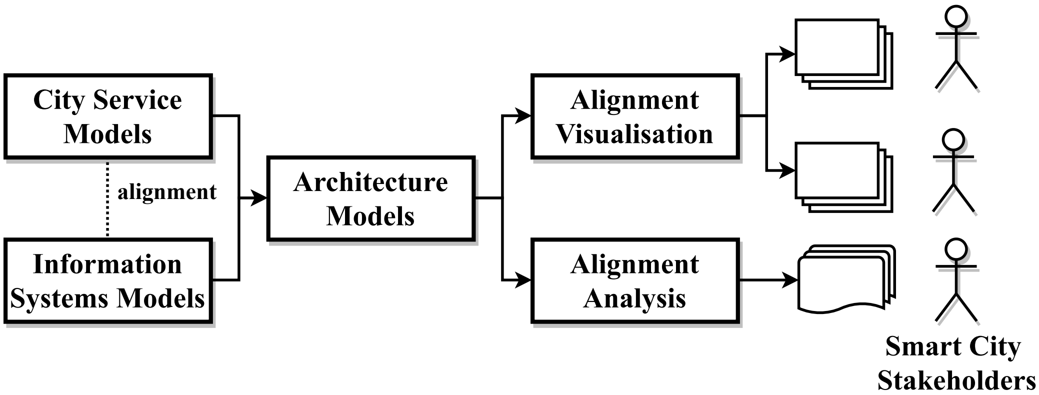


Fig. 4.8 DP6: Modelling. Alignment Mechanism.

Smart Cities are required to provide vertical alignment within such domains, and horizontal alignment to enable the integration among services from various domains (Bhatt et al., 2017; Heaton and Parlikad, 2019). Vertical and horizontal alignment can be expressed in terms of the relationships among layers (e.g., the service and information layers) (Boucké et al., 2008). Vertical relationships are either conducted between layers at different levels of abstraction (e.g., refinements) or with other representations (e.g., strategy, requirements, organisation structure, applications, data). Horizontal relationships refer to relationships between layers at the same level of abstraction (e.g., city services).

4.2.4 Dimension: Mechanism

One main design principle is identified as a mechanism for the alignment between the service and information layers in Smart City architectures: Modelling.

DP6 - Modelling: ***Provide a modelling mechanism to express the alignment between architecture layers.***

All the concepts involved in the alignment between the service and information layers in Smart City architectures should be modelled (Aversano et al., 2012). Modelling is necessary to understand what information is considered for alignment analysis. Modelled concepts should be mapped to facilitate concept traceability and perform alignment analysis. This involves the definition of the relationships between the concepts that need to be traced across Smart City systems (Tekinerdogan and Erata, 2017). De Castro et al. (2011) describe Model Driven Engineering (MDE) as a tool to support the alignment between architecture layers and views, and metamodels to represent the concepts involved in the alignment analysis. Smart Cities standards and specifications together with the current academic literature in the

Table 4.1 Design Principles (DP) and Design Rationale.

DP	Design Rationale	Supporting Source
DP1	**Citizens' Needs Focus.** Support the alignment of the service and information layers in order to meet the needs of citizens. *Justification: The alignment of city services and underlying information systems will be required to respond to city goals, thus meeting the needs of citizens.*	Agbali et al. (2019); Al-Nasrawi et al. (2015); Chourabi et al. (2012); ISO37106 (2018); Kakarontzas et al. (2014); King and Cotterill (2007); Lee and Lee (2014); Simonofski et al. (2019)
DP2	**Consistency.** Provide a consistent alignment that allows a coherent architecture specification of concepts within each layer. *Justification: The alignment of city services and underlying information systems will be required to define mutually supportive concepts.*	ISO/IEC (2015); Jonkers et al. (2004); Lee and Lee (2014); Morabito et al. (1999)
DP3	**Compatibility.** Provide a compatible alignment that allows an appropriate architecture specification of concepts across architecture layers. *Justification: The alignment of city services and underlying information systems will require the definition of concepts compatible with the specification of the entire architecture.*	Böhmann et al. (2018); Huber et al. (2019); Jonkers et al. (2004); Morabito et al. (1999)
DP4	**Dynamicity.** Provide a dynamic alignment of concepts that allows a flexible architecture specification that can be adjusted over time. *Justification: The alignment of city services and underlying information systems will require management and adaptation.*	Jonkers et al. (2004); Morabito et al. (1999); Sabherwal et al. (2001); Sen and Sinha (2011); Zimmermann et al. (2015)
DP5	**Vertical and Horizontal.** Enable the vertical and horizontal alignment of Smart Cities since the architecture design phase. *Justification: The alignment of city services and underlying information systems will be required to enabling the Smart Cities operating model.*	Bhatt et al. (2017); Boucké et al. (2008); Heaton and Parlikad (2019); Hefnawy et al. (2015, 2016); ISO37106 (2018); Ross et al. (2006)
DP6	**Modelling.** Provide a modelling mechanism to express the alignment between architecture layers. *Justification: The alignment of city services and underlying information systems will require a modelling approach for a coherent architecture description.*	Aversano et al. (2012); De Castro et al. (2011); Heaton and Parlikad (2019); Jonkers et al. (2003); Őri (2017b); Tekinerdogan and Erata (2017)

Smart City domain should be considered when defining the required alignment (Heaton and Parlikad, 2019).

Figure 4.8 illustrates a sample of the alignment mechanism by creating integrated architecture models (e.g., city service models and information systems models). These models and modelling tools must support the visualisation and analysis of the alignment within and across architecture layers (Jonkers et al., 2003). Coherent architecture models enable communication among different stakeholders (e.g., citizens, city managers, architects, data managers) and guide city service transformation processes. Additionally, analysis techniques (e.g., alignment analysis) provide ways to determine the state of alignment and areas for architecture improvement (i.e., re-architecture) (Őri, 2017b).

4.3 Design Principles Rationale

The reasons for defining these principles are that they are crucial to support and guide the alignment of city services and their information systems in order to achieve Smart City strategies. They are defined as statements that describe how the alignment should be designed or built or what it should comprise. Table 4.1 presents each design principle and the design rationales for why they were included.

4.4 Design Principles Summary

This chapter presented the design principles that support the alignment between the service and information layers in Smart City architectures. It started by presenting the need for the design principles and and was followed by the approach for their definition and conceptualization. The literature review process and the selection of articles as sources of support are detailed. Six design principles are defined and grouped along four dimensions: Objective, Usage, Scope, and Mechanism. These definitions rely on the existing literature and the experience of the design of public services in real cities. A conceptual model then describes how each design principle is understood in the Smart City domain. The design rationale justifies the selection and definition of each design principle. These design principles will be instantiated in the form of concepts and relationships to make them actionable in the next Chapter.

Chapter 5

ArchiSmartCity Design

The literature review in Chapter 2 identified a number of limitations in the current alignment of city services and information systems in Smart Cities which are: i) the disconnection between city services and their underlying information systems to support the strategic alignment in Smart Cities; ii) the lack of an EA perspective to create integrated city services among different domains (i.e., horizontal alignment); iii) the limitation of EM languages which lack the domain-specific concepts of Smart Cities to support the alignment of city services and information systems.

This chapter introduces the concepts of Smart Cities that support the alignment between the service and information layers in Smart City architectures in order to answer RQ.2. These concepts are derived from literature and the experience gained from working with cities in Ireland and Israel. First, this chapter describes in detail the design requirements that, along with the design principles defined in Chapter 4, are used to define the concepts. These concepts are further instantiated by designing the ArchiSmartCity metamodel that explicitly expresses this alignment to support Smart Cities strategies, following a conceptual modelling method (Visic et al., 2015). The ArchiSmartCity design includes the definition of the syntax, semantics, and notations, to create a common language to help the communication and understanding of Smart City stakeholders. Finally, this chapter discusses the main contributions.

5.1 Metamodel Construction Overview

This chapter defines the concepts of Smart Cities that ensure the alignment between the service and information layers in Smart City architectures. Engineering a solution to represent and describe these concepts requires the construction of a metamodel suitable for the Smart City domain where none previously existed. This research designs the ArchiSmartCity

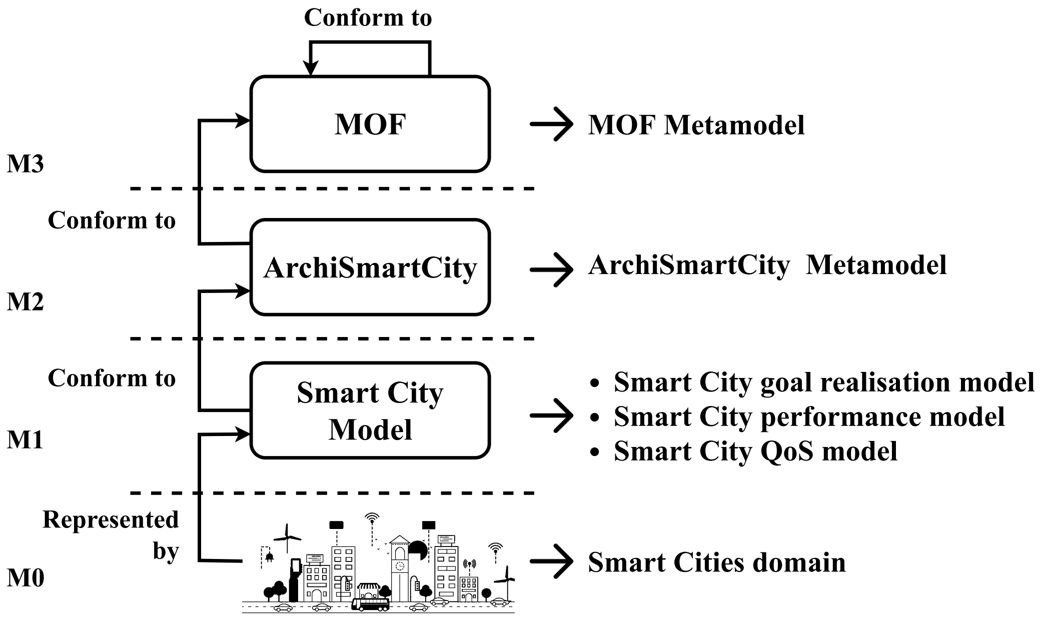


Fig. 5.1 ArchiSmartCity Model Driven Architecture 3+1.

metamodel as an expository instantiation of the concepts through explicit prescriptions in the form of Design Principles (see Chapter 4) and Design Requirements (see section 5.2).

Designing and developing a metamodel for a domain specific purpose requires an engineering modelling approach and method. This thesis follows a Model Driving Engineering (MDE) approach to design and implement the ArchiSmartCity metamodel. Figure 5.1 introduces the architecture of the proposed metamodel based on the 3+1 architecture defined by the Object Management Group (OMG) (Bézivin, 2004). The layer M0 presents the Smart Cities domain from the real world. The layer M1 includes the Smart City models that represent city services offered to citizens and the information systems than automate them to address the alignment. The layer M2 represents the ArchiSmartCity metamodel to explicitly model the alignment between the service and information layers in Smart City architectures. ArchiSmartCity defines the language that end-users (e.g., enterprise architects, Smart City managers) use to create Smart City models (i.e., Smart City models that conform to ArchiSmartCity). These models involve, for example, the Smart City goal realisation model, the Smart City performance model, and the Smart City QoS model. The layer M3 includes the metamodel Meta-Object-Facility (MOF) (OMG, 2016) which is a standard of the OMG for MDE to create metamodels in the layer M2 (i.e., ArchiSmartCity is conform to the MOF metamodel).

Figure 5.2 illustrates the phases and tasks that this thesis follows to define the concepts and build the metamodel. This process follows the Agile Modelling Method Engineering

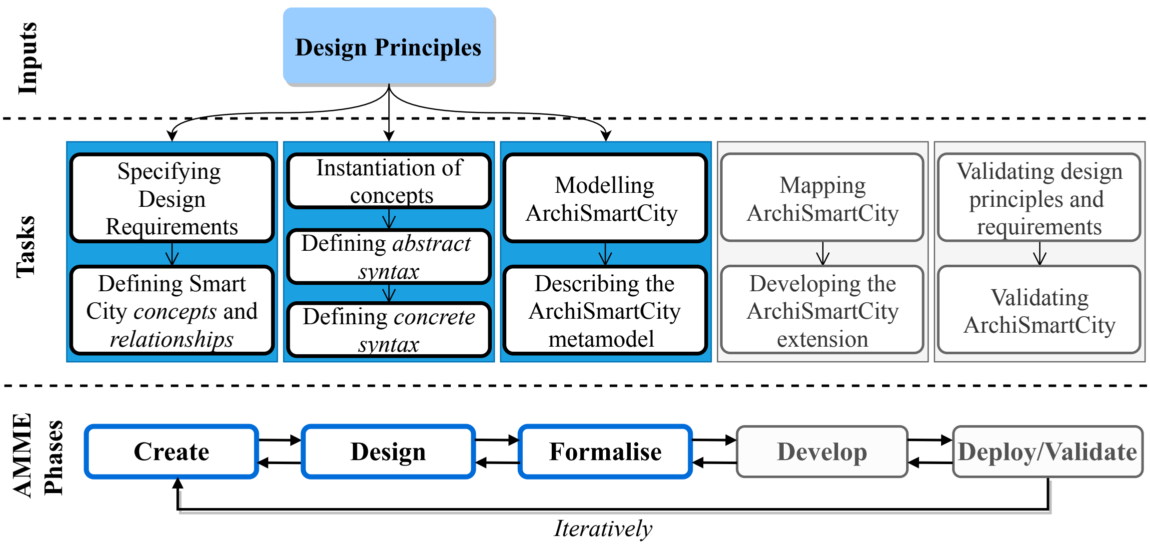


Fig. 5.2 ArchiSmartCity Metamodel Design and Construction Method.

(AMME) (Visic et al., 2015). The AMME includes six iterative phases to create, design, formalise, develop, and deploy/validate the metamodel. This iterative approach, then, is appropriate and complementary to the Design Science Research Methodology (DSRM) selected for this research (Peffers et al., 2007). This chapter focuses on the three first phases to create, design, and formalise the metamodel.

During the *creation phase* and with the design principles defined (see Chapter 4), design requirements were identified to capture the specific knowledge of the Smart Cities domain. Both design principles and design requirements were used to derive appropriate concepts and relationships in the context of Smart Cities (see Section 5.2.2). During *the design phase*, the ArchiSmartCity metamodel is defined as an instantiation of these concepts and relationships. During *the formalisation phase*, ArchiSmartCity is formally described using the UML notation. Each of these phases is outlined below.

- **Create:** The creation phase includes activities of knowledge acquisition and requirements elicitation. These activities capture the specific knowledge of the Smart Cities domain in the form of design requirements extracted from the literature. Both design principles and identified design requirements are used to derive the concepts and relationships that ensure the alignment of city services and underlying information systems. The design rationale is presented to justify why and how concepts from the literature were included.

- **Design:** The design phase specifies ArchiSmartCity as an instantiation of the concepts and relationships. It includes the definition of the abstract syntax and concrete syntax to represent the concepts in the Smart Cities domain. The abstract syntax defines a set of concepts and relationships between these that must correspond with their equivalent in the semantic domain. The concrete syntax specifies the notation and semantics of the modelling language. Notation refers to the graphical representation of syntactic concepts while semantics specify the meaning of them (Bork et al., 2020).
- **Formalise:** The formalisation phase describes the outcome of the previous phase in non-ambiguous descriptions with the purpose of presenting and sharing the results to a scientific community. This research uses a UML class diagram to represent the final metamodel, depicting the concepts and the relationships between them with the UML notation. The Unified Modeling Language (UML) is a visual modelling language that is typically used in software engineering to formally represent metamodels (Wu, 2016).

The development phase of the ArchiSmartCity metamodel will be presented in Chapter 6. Design Science research requires that, after construction of the artefact, the evaluation must be clearly demonstrated (Hevner et al., 2004). The validation and evaluation phase will be provided in Chapter 7. The phases to create, design, and formalise the metamodel are further elaborated in the next sections.

5.2 Phase I: Create

This phase defines the design requirements that capture the specific knowledge of the Smart Cities domain extracted from the literature and based on the experience gained in the design of city services in real-world cities (Chapter 7). The design requirements are used to derive the concepts and relationships that can assist cities and municipalities to support the alignment of city services and their information systems.

5.2.1 Design Requirements

This section identifies the design requirements from the literature, focusing on the main characteristics for modelling the alignment between city services and information systems to support Smart City strategies. The search strategy follows a structured approach to determine the source material for the review (Corradini et al., 2018; Webster and Watson, 2002). Appendix C - Design Requirements details the literature review process. The design requirements are formulated following the structure and approach suggested by (Chandra et al., 2015), focusing on what an artefact should allow for. These design requirements prescribe the functionalities that the metamodel should meet. Thereby, the design requirements exhibit a clear focus on the interaction with Smart Cities stakeholders as is described as follows.

- **DR1: It is required to provide dedicated concepts to represent Smart City application domains.**

  The definition of Smart City application domains and their alignment must start from the design phase of the services (Ma et al., 2016). Smart City application domains represent the most critical development fields for more intelligent usage of urban resources (Neirotti et al., 2014). Giffinger et al. (2007) provide an initial classification of six domains to characterise Smart Cities, including smart economy, smart governance, smart mobility, smart environment, smart life, and smart people. Neirotti et al. (2014) propose a classification domains and associated sub-domains based on the degree of importance of ICT as an enabling factor for the development of Smart City initiatives. Each domain consists of a set of services, for example, the transport and mobility domain may include public transport services and emergency vehicle monitoring services. (Ma et al., 2016). Smart City managers are responsible for leading Smart City initiatives and projects in such vertical domains which need the integration of services from different or similar domains (Gaur et al., 2015; Michelucci et al., 2016). The seamless flow of information between cross-domain services can help to realise the horizontal interoperability of city systems and applications to support multiple stakeholders (Hefnawy et al., 2015). It is necessary to establish the relationships between these domains and other Smart City concepts (e.g., city services, application services, city locations) in order to meet different requests from citizens (Cabrera et al., 2018).

- **DR2: It is required to provide dedicated concepts to represent Smart City strategy management.**

  The realisation of a Smart City and its strategies requires the management and coordination of city goals and the underlying information systems (Kuk and Janssen, 2011). Smart Cities should develop a well-defined strategic plan, and innovative solutions to enhance city performance, economy, and sustainability (Agbali et al., 2019; Kakarontzas et al., 2014). Designing and managing a common vision and strategy of cities requires the understanding of the needs of the community (e.g., residents, businesses, organisations) to inspire the vision and address the local challenges (Letaifa, 2015). A comprehensive vision and strategy define all city goals that should be clearly quantified to measure the public value created and Smart City performance (Dameri, 2017). Although the main goal of Smart Cities is to improve the quality of life for the citizens, well-defined city goals must be considered to achieve this, e.g., the Sustainable Development Goals (Griggs et al., 2013). These goals are generally defined at a high level (e.g., aiming at efficient solutions reducing CO2 emissions, addressing sustainable mobility and alternative fueling vehicles) (Dameri, 2017; Falconer and Mitchell, 2012). Goals should be decomposed into more specific and low-level objectives, providing more detailed planning and implementation (Object Management Group, 2015). For example, the goal "aiming at efficient solutions reducing CO2 emissions" can be refined into the objective: "cut CO2 emissions by at least 80% in the city centre by the end of 2022", and then it can be measured with appropriate indicators (see DR3). City managers should coordinate and interconnect the multitude of city goals and supporting applications from different domains that co-exist and can grow in various directions in the future (Kakarontzas et al., 2014).

- **DR3: It is required to provide dedicated concepts to represent Smart City performance measurement.**

  Smart City initiatives enhance urban performance by using IT to provide more efficient services to citizens and to monitor and optimise existing infrastructure (Marsal-Llacuna et al., 2015). The measurement of Smart City performance is essential in order to document, demonstrate and explain the smartness and progress of such urban ecosystems to stakeholders (Komninos et al., 2014). Key performance indicators should be established to chart the progress towards desired Smart City goals and objectives and to detect stakeholder priorities (Loo and Tang, 2019). Different indicator models are proposed to measure the performance of Smart Cities that reflect the level of intelligence, efficiency and sustainability (Al-Nasrawi et al., 2015; Carli et al., 2013). ISO37120 (2018) proposes standardised indicators for city services and quality of life to achieve sustainable development of cities. This standard follows the framework of the Global City Indicators Facility (GCIF), which is structured fundamentally around city services themes (e.g., education, finance, governance) and the quality of life dimensions (e.g., civic engagement, environment, economy). Quality of life is an essential element for the development of Smart Cities that can be influenced by government actions (De Guimarães et al., 2020). Smart City indicators should reflect these qualitative characteristics and quantitative data that are acquired from heterogeneous data sources and displayed on application platforms and dashboards (Zdraveski et al., 2017). It is necessary to offer a truthful and realistic model representations of these indicators and their relationships with other Smart City concepts such as goals and objectives to which Smart Cities are moving (Lombardi et al., 2012).

- **DR4: It is required to provide dedicated concepts to represent city services and their relevant types.**

  The public sector has shifted towards a service orientation paradigm (Bifulco et al., 2016). Services are central to cities and municipalities, focusing on the needs of citizens and their quality of life (Lee and Lee, 2014). Three key features of services are considered crucial: functionality, behavior, and quality (Bouguettaya et al., 2017). Functionality refers to the operations offered by a service. Different types of services (e.g., city services and application services) are specified according to the functionalities provided and the level of abstraction in Smart City architectures (service and information layers) (Bawany and Shamsi, 2015; Oktaria et al., 2017; Piro et al., 2014; Yeh, 2017). Behavior reflects how the service operations are invoked. Smart City services can be invoked through different application interfaces such as Application Programming Interfaces (APIs) that generally are described, published and located over a network (i.e., Web Services) (Badii et al., 2017b; Nesi et al., 2016). Web services are a key technology in this domain and Smart City managers are required to select the most appropriate web services to obtain the desired service functionalities (Purohit and Kumar, 2019). The design of service systems should be based on a formal service model that enables efficient access to a large service space (Bifulco et al., 2016).

- **DR5: It is required to provide dedicated concepts to represent the quality of services.**

  Expressing the quality of service is needed to allow requesters (e.g., citizens) to specify service quality expectations; providers to advertise quality levels that their services achieve; and service composers to finely compare alternative services (Jureta et al., 2009). The quality of city services is closely associated with the customer satisfaction and overall well-being of citizens (Aleksic et al., 2019). Since service quality is a multi-dimensional construct, schematic representation of quality dimensions of city services (e.g., reliability, customer satisfaction, responsiveness, assurance) are essential to represent the quality expectations (Sá et al., 2016; Schulte et al., 2017). For instance, the reliability quality dimension refers to the ability of service providers in handling customer service issues (Engdaw, 2019). Regarding application services, it is necessary to express the quality attributes or non-functional properties of services such as accuracy, availability, and interoperability (Kyriazopoulou, 2015; Santana et al., 2017; Weber and Podnar Žarko, 2019). The definition and representation of these qualities during the service design enable the development and improvement of both city services and their correspondent application services.

- **DR6: It is required to provide dedicated concepts to represent the decision-making process.**

  Smart Cities improve decision-making through the use of data for all stakeholders (e.g., city authorities, businesses, and residents). Many interacting subsystems and multiple stakeholders compose a Smart City. Both make decisions at different levels to achieve diverse city goals (Carli et al., 2016). Modelling decisions can improve the visibility and focus of decisions based on information (input data) required by the key stakeholders (Janssens et al., 2016). City authorities use data-driven dashboards that visualize the necessary information collected from multiple data sources (e.g., real-time APIs, social media, sensor networks, gateways) (Matheus et al., 2018). A city dashboard is a web-based decision support tool designed to satisfy the city goals, objectives, and services (Barns, 2018; Mannaro et al., 2017). Dashboards support strategic, tactical, and operational decision-making (Sarikaya et al., 2018). They are becoming an important instrument for the government to create transparency, achieve accountability, and stimulate citizen engagement (Harrison and Sayogo, 2014). Moreover, dashboards allow city authorities and citizens to monitor the city and support the decision-making (e.g., strategic and operational decisions) based on real-time information about the weather, air pollution, public transport, delays, public bike availability, river level, and electricity (Kitchin, 2014).

5.2.2 Concepts Definition

This section defines the concepts and their relationships to formalise the design principles outlined in Chapter 4 and the design requirements defined in section 5.2. These concepts and relationships are crucial to support the alignment of city services and their information systems. They are defined in a high-level abstraction description to meet the requirements of various Smart Cities.

In the following, design principles and design requirements are used to derive appropriate concepts. These concepts are derived as features or specific ways to implement the design principles and design requirements in an actual artefact (Meth et al., 2015). In this sense, each concept and its relationships are described from Table 5.1 to Table 5.14 where they are assigned to its corresponding design principle(s) and design requirement(s). Additionally, each table includes the stakeholders interested in the concepts, the design rationale to justify why and how the concepts were included, and supporting sources from the literature. These concepts and relationships are implemented in an expository instantiation (i.e., the ArchiSmartCity metamodel) in the next section.

Table 5.1 Concept Definition - Domain.

Design Principles	DP2, DP3, DP4, DP5, DP6
Design Requirement	DR1. It is required to provide dedicated concepts to represent the Smart City application domains.
Concept	*Domain*
Relationships	• *belongs to (city service, domain):* The relationship between a city service that belongs to a domain. • *compose of (domain, domain):* The relationship between a domain and its sub-domains.
Stakeholders	City authorities, citizens, service providers, and service developers.
Design Rationale	A stakeholder should be able to identify the Smart City application domains (e.g., education, health, mobility, living, environment) to which city services belong when designing or managing a Smart City.
Supporting Sources	Cabrera et al. (2018); Gaur et al. (2015); Giffinger et al. (2007); Hefnawy et al. (2015); Ma et al. (2016); Michelucci et al. (2016); Neirotti et al. (2014)

Table 5.2 Concept Definition - Goal.

Design Principles	DP1, DP2, DP3, DP6
Design Requirement	DR2. It is required to provide dedicated concepts to represent the Smart City strategy management.
Concept	*Goal*
Relationships	• *belongs to (goal, domain):* The relationship between a city goal that belongs to a domain.
Stakeholders	City authorities, citizens.
Design Rationale	A stakeholder when it is designing or managing a Smart City should be able to represent a city goal as a common outcome of multiple stakeholders.
Supporting Sources	Agbali et al. (2019); Dameri (2017); Falconer and Mitchell (2012); Griggs et al. (2013); Kakarontzas et al. (2014); Kuk and Janssen (2011); Letaifa (2015); Object Management Group (2015)

Table 5.3 Concept Definition - Objective.

Design Principles	DP1, DP2, DP3, DP6
Design Requirement	DR2. It is required to provide dedicated concepts to represent the Smart City strategy management.
Concept	*Objective*
Relationships	• *quantifies (objective, goal):* The relationship between a city objective that quantifies a city goal. • *belongs to (objective, domain):* The relationship between a city objective that belongs to a domain.
Stakeholders	City authorities, and citizens.
Design Rationale	A stakeholder should be able to identify a feasible, time-targeted, and measurable target that a Smart City seeks to reach in order to achieve its city goals.
Supporting Sources	Agbali et al. (2019); Dameri (2017); Falconer and Mitchell (2012); Griggs et al. (2013); Kakarontzas et al. (2014); Kuk and Janssen (2011); Letaifa (2015); Object Management Group (2015)

Table 5.4 Concept Definition - Indicator.

Design Principles	DP1, DP2, DP3, DP4, DP6
Design Requirement	DR3. It is required to provide dedicated concepts to represent the Smart City performance indicators.
Concept	*Indicator*
Relationships	• *measures (indicator, objective):* The relationship between an indicator that measures a city objective. • *demonstrates performance (indicator, city service):* The relationship between an indicator that demonstrates the performance management of city services. • *belongs to (indicator, domain):* The relationship between an indicator that belongs to a domain.
Stakeholders	City authorities, citizens.
Design Rationale	A stakeholder should be able to measure the city performance in terms of both city services and quality of life when designing or managing a Smart City.
Supporting Sources	Al-Nasrawi et al. (2015); Carli et al. (2013); De Guimarães et al. (2020); ISO37120 (2018); Komninos et al. (2014); Lombardi et al. (2012); Loo and Tang (2019); Marsal-Llacuna et al. (2015); Zdraveski et al. (2017)

Table 5.5 Concept Definition - Quality of Life Dimension.

Design Principles	DP1, DP2, DP3, DP4, DP6
Design Requirement	DR3. It is required to provide dedicated concepts to represent Smart City performance indicators.
Concept	*Quality of Life Dimension*
Relationships	• *impacts (indicator, quality of life dimension):* The relationship between an indicator that impacts a quality of life dimension.
Stakeholders	City authorities, citizens.
Design Rationale	A stakeholder should be able to explicitly define the quality of life dimension impacted (e.g., civic engagement, environment, economy, culture, social equity) with Smart City initiatives and city services.
Supporting Sources	Al-Nasrawi et al. (2015); Carli et al. (2013); De Guimarães et al. (2020); ISO37120 (2018); Komninos et al. (2014); Lombardi et al. (2012); Loo and Tang (2019); Marsal-Llacuna et al. (2015); Zdraveski et al. (2017)

Table 5.6 Concept Definition - City Service.

Design Principles	DP1, DP2, DP3, DP4, DP5, DP6
Design Requirement	DR4. It is required to provide dedicated concepts to represent city services and their relevant types.
Concept	*City Service*
Relationships	• *belongs to (city service, domain):* The relationship between a city service that belongs to a domain.
Stakeholders	City authorities, citizens, service providers, and service developers.
Design Rationale	A stakeholder should be able to identify city services (e.g., health service, transport service, air-quality service, education service) from different domains offered to the citizens when designing or managing a Smart City.
Supporting Sources	Badii et al. (2017b); Bawany and Shamsi (2015); Bifulco et al. (2016); Bouguettaya et al. (2017); Cabrera et al. (2018); Lee and Lee (2014); Nesi et al. (2016); Oktaria et al. (2017); Piro et al. (2014); Purohit and Kumar (2019); Yeh (2017)

Table 5.7 Concept Definition - Application Service.

Design Principles	DP2, DP3, DP4, DP5, DP6
Design Requirement	DR4. It is required to provide dedicated concepts to represent city services and their relevant types.
Concept	*Application Service*
Relationships	• *automates (application service, city service):* The relationship between an application service that automates a city service.
Stakeholders	City authorities, citizens, service providers, service developers.
Design Rationale	A stakeholder should be able to identify the application services that support and automate city services (e.g., the application service that provides information on nearby hospitals with available rooms supports the health care city service) when designing or managing a Smart City.
Supporting Sources	Badii et al. (2017b); Bawany and Shamsi (2015); Bifulco et al. (2016); Bouguettaya et al. (2017); Cabrera et al. (2018); Lee and Lee (2014); Nesi et al. (2016); Oktaria et al. (2017); Piro et al. (2014); Purohit and Kumar (2019); Yeh (2017)

Table 5.8 Concept Definition - Web Service.

Design Principles	DP2, DP3, DP4, DP5, DP6
Design Requirement	DR4. It is required to provide dedicated concepts to represent city services and their relevant types.
Concept	*Web Service*
Relationships	• *provides interface (web service, application service):* The relationship between a web service that provides an interface to an application service. • *provides data (web service, dashboard):* The relationship between a web service that provides data to a dashboard. • *belongs to (web service, domain):* The relationship between a web service that belongs to a domain.
Stakeholders	City authorities, citizens, service providers, service developers.
Design Rationale	A stakeholder should be able to identify and select appropriate web services to access, process, and exchange data when designing or managing a Smart City.
Supporting Sources	Badii et al. (2017b); Bawany and Shamsi (2015); Bifulco et al. (2016); Bouguettaya et al. (2017); Cabrera et al. (2018); Lee and Lee (2014); Nesi et al. (2016); Oktaria et al. (2017); Piro et al. (2014); Purohit and Kumar (2019); Yeh (2017)

Table 5.9 Concept Definition - Middleware.

Design Principles	DP2, DP3, DP4, DP5, DP6
Design Requirement	DR4. It is required to provide dedicated concepts to represent city services and their relevant types.
Concept	*Middleware*
Relationships	• *supports (middleware, application service):* The relationship between a middleware that supports an application service.
Stakeholders	City authorities, citizens, service providers, service developers.
Design Rationale	A stakeholder should be able to identify the software to supports the interoperability of multiple applications and services running on heterogeneous systems when designing or managing a Smart City..
Supporting Sources	Badii et al. (2017b); Bawany and Shamsi (2015); Bifulco et al. (2016); Bouguettaya et al. (2017); Cabrera et al. (2018); Lee and Lee (2014); Nesi et al. (2016); Oktaria et al. (2017); Piro et al. (2014); Purohit and Kumar (2019); Razzaque et al. (2016); Yeh (2017)

Table 5.10 Concept Definition - Quality of Application Service.

Design Principles	DP1, DP2, DP3, DP4, DP5, DP6
Design Requirement	DR5. It is required to provide dedicated concepts to represent the quality of services.
Concept	*Quality of Application Service*
Relationships	• *meets (application service, quality of application service):* The relationship between an application service that meets a quality of application service.
Stakeholders	City authorities, citizens, service providers, service developers.
Design Rationale	A stakeholder should be able to identify the expected qualities of application services (e.g., response time, throughput, availability, security) when designing or managing a Smart City.
Supporting Sources	Aleksic et al. (2019); Engdaw (2019); Jureta et al. (2009); Kyriazopoulou (2015); Sá et al. (2016); Santana et al. (2017); Schulte et al. (2017); Weber and Podnar Žarko (2019)

Table 5.11 Concept Definition - City Actor.

Design Principles	DP1, DP2, DP3, DP4, DP5, DP6
Design Requirement	DR6. It is required to provide dedicated concepts to represent the decision-making process.
Concept	*City Actor*
Relationships	• *plays (city actor, city role):* The relationship between a city actor who plays a city role.
Stakeholders	City authorities, citizens, service providers, service developers.
Design Rationale	A stakeholder should be able to identify and represent different actors of the city (e.g., citizen, city authority, service provider, retailer) who directly interact with city services and make informed decisions.
Supporting Sources	Barns (2018); Carli et al. (2016); Harrison and Sayogo (2014); Janssens et al. (2016); Kitchin (2014); Mannaro et al. (2017); Matheus et al. (2018); Sarikaya et al. (2018)

Table 5.12 Concept Definition - City Role.

Design Principles	DP1, DP2, DP3, DP4, DP5, DP6
Design Requirement	DR6. It is required to provide dedicated concepts to represent the decision-making process.
Concept	*City Role*
Relationships	• *participates (city role, decision):* The relationship between a city role who participates in a decision. • *is responsible (city role, indicator):* The relationship between a city role that is responsible for a city indicator. • *belongs to (city role, domain):* The relationship between a city role that belongs to a domain. • *uses (city role, city service):* The relationship between a city role that uses a city service. • *uses (city role, dashboard):* The relationship between a city role that uses a dashboard.
Stakeholders	City authorities, citizens, service providers.
Design Rationale	A stakeholder should be able to identify and represent the roles or responsibilities that city actors play in the city and the decisions within which they are involved.
Supporting Sources	Barns (2018); Carli et al. (2016); Harrison and Sayogo (2014); Janssens et al. (2016); Kitchin (2014); Mannaro et al. (2017); Matheus et al. (2018); Sarikaya et al. (2018)

Table 5.13 Concept Definition - Decision.

Design Principles	DP1, DP2, DP3, DP4, DP5, DP6
Design Requirement	DR6. It is required to provide dedicated concepts to represent the decision-making process.
Concept	*Decision*
Relationships	• *requires information (decision, data):* The relationship between a decision that requires specific information represented in a particular data set.
Stakeholders	City authorities, citizens, service providers.
Design Rationale	A stakeholder should be able to identify the decisions made with the information from the city at different levels (e.g., strategic, operational) when designing or managing a Smart City.
Supporting Sources	Barns (2018); Carli et al. (2016); Harrison and Sayogo (2014); Janssens et al. (2016); Kitchin (2014); Mannaro et al. (2017); Matheus et al. (2018); Sarikaya et al. (2018)

Table 5.14 Concept Definition - Dashboard.

Design Principles	DP1, DP2, DP3, DP4, DP5, DP6
Design Requirement	DR6. It is required to provide dedicated concepts to represent the decision-making process.
Concept	*Dashboard*
Relationships	• *assists (dashboard, decision):* The relationship between a dashboard that assists a decision in the city. • *visualises (dashboard, indicator):* The relationship between a dashboard that visualises an indicator. • *belongs to (dashboard, domain):* The relationship between a dashboard that belongs to a domain.
Stakeholders	City authorities, citizens, service providers, service developers.
Design Rationale	A stakeholder should be able to identify graphic dashboards that visualise and presents important information on cities, citizens, institutions and their interactions.
Supporting Sources	Barns (2018); Carli et al. (2016); Harrison and Sayogo (2014); Janssens et al. (2016); Kitchin (2014); Mannaro et al. (2017); Matheus et al. (2018); Sarikaya et al. (2018)

The next section presents how the defined concepts and their relationships are instantiated to explicitly represent the alignment between the service and information layers in Smart City architectures.

5.3 Phase II: Design

This section presents the design of the ArchiSmartCity metamodel to explicitly model the alignment between the service and information layers in Smart City architectures. It includes the definition of the abstract syntax and concrete syntax to instantiate the concepts and relationships defined in section 5.2.

5.3.1 Abstract Syntax

The abstract syntax of the ArchiSmartCity metamodel is specified by using simplified UML class diagrams (Wu, 2016). The metamodel is presented in a modular structure to facilitate the understanding of the abstract syntax. We use an Enterprise Architecture (EA) top-down approach to present the concepts, starting with the strategy or vision concepts, and ending up at the implementation concepts. These concepts and the relationships between them are represented within the service and information layers to explicitly model their alignment as follows.

Figure 5.3 depicts the concepts of the metamodel that express **Smart City strategy management**; and illustrates the design requirements that the concepts meet: DR1, DR2, and DR3 (see section 5.2). Particularly, this research follows the Business Motivation Model (BMM) of the Object Management Group (2015) to define these concepts. The BMM provides a guide and notations for defining goals, refining them into objectives, and then defining the indicators (metrics) to measure the performance. The main concepts are outlined as follows:

- **Domain:** This class represents a key field of urban development in Smart Cities such as health, environment, education, safety, and mobility. This class has attributes to define general information on the domain, such as: name, description, and objective. One domain **consists of** one or more sub-domains. For example, the energy domain consists of the smart grid sub-domain and the public lighting sub-domain.

- **Goal:** This class represents the expected results to be achieved for a Smart City. It is a decomposition of the Smart City vision. This concept has attributes to define general information on the goal, such as: name and description. One goal **belongs to** one or more domains.

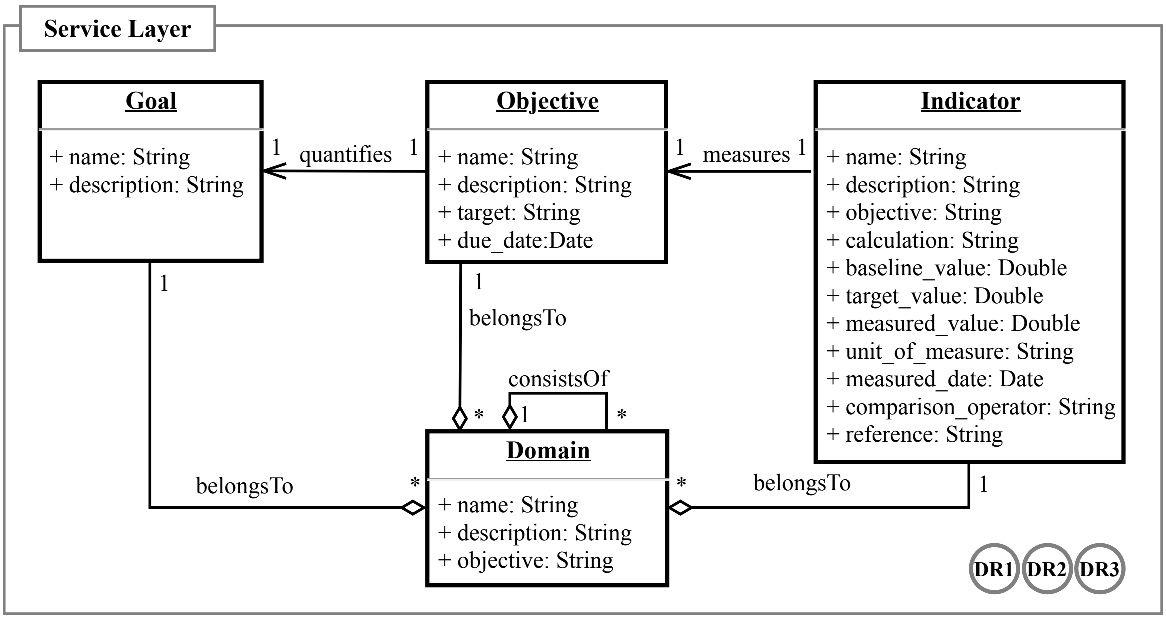


Fig. 5.3 Abstract Syntax. Smart City Strategy Management.

- **Objective:** This class represents a milestone for a Smart City that is used to demonstrate progress towards a city goal. This concept has attributes to define general information on the objective, such as: name, description, target, and due_date. One objective **quantifies** one city goal and **belongs to** one or more domains.

- **Indicator:** This class represents a quantitative, qualitative or descriptive measure required to demonstrate performance in the delivery of city services and quality of life. This concept has attributes to define general information on the indicator, such as: name, description, objective, calculation, baseline_value, target_value, measured_value, unit_of_measure, measured_date, comparison_operator, and reference (e.g., the documentation and information source of each indicator). One indicator **measures** one city objective and **belongs to** one or more domains.

Figure 5.4 depicts the concepts of the metamodel that express **Smart City services and Quality of Life (QoL)**; and illustrates the design requirements that the concepts meet: DR1, DR3, and DR4 (see section 5.2). This allows city managers to assess the efficacy of the performance management of the city services and quality of life over time. The main concepts are outlined as follows:

- **City Service:** This class represents a service offered to the citizens by the city government and private institutions. This concept has attributes to define general information

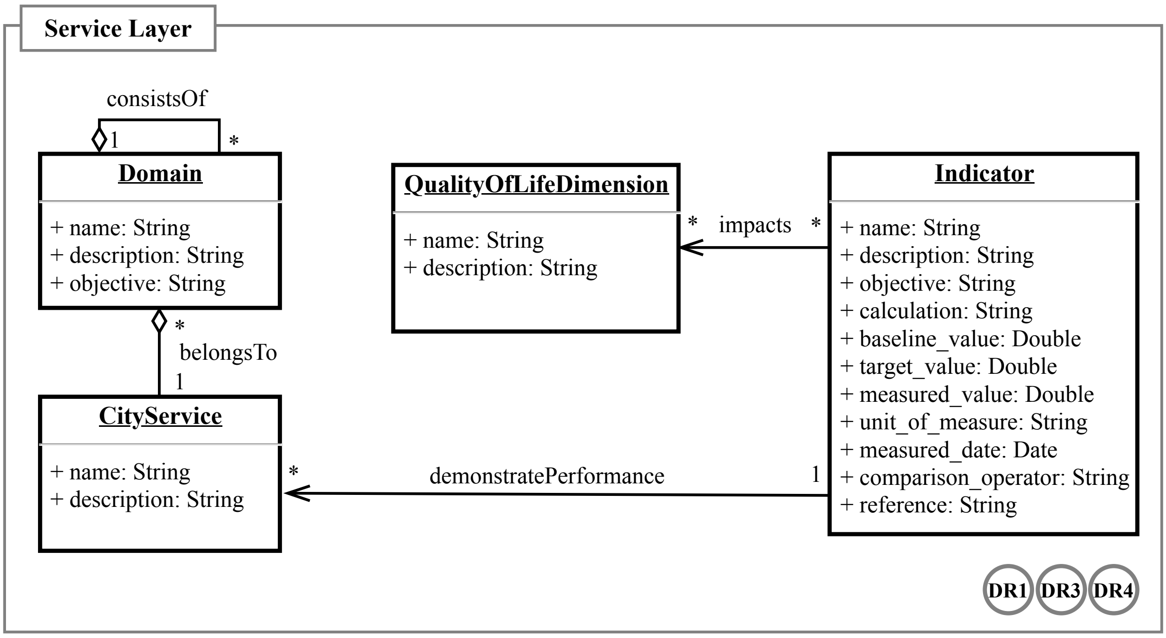


Fig. 5.4 Abstract Syntax. Smart City Services and QoL.

on the city service, such as: name and description. One city service **belongs to** one or more domains. For instance, the bike-sharing city service belongs to the mobility domain. One indicator **demonstrates performance** of one or more city services.

- **Quality of Life Dimension:** This class represents the qualitative aspects of individuals that are impacted by the services available in cities. The dimensions of the quality of life include, for example, health, education, environmental quality, personal security, civic engagement, housing conditions, and work-life balance. This class has attributes to define general information on the quality of life dimension, such as: name and description. One indicator **impacts** one or more quality of life dimensions. For example, the traffic noise indicator impacts the quality of life dimension: housing conditions.

Figure 5.5 depicts the concepts of the metamodel that express **City Services Automation**; and illustrates the design requirements that the concepts meet: DR1, DR4, and DR5 (see section 5.2). The main concepts are outlined as follows:

- **Application Service:** This class represents a software service provided for one or more application components. An application service is exposed through well-defined interfaces (e.g., web services). This concept has attributes to define general information on the application service, such as: name and description. One application service

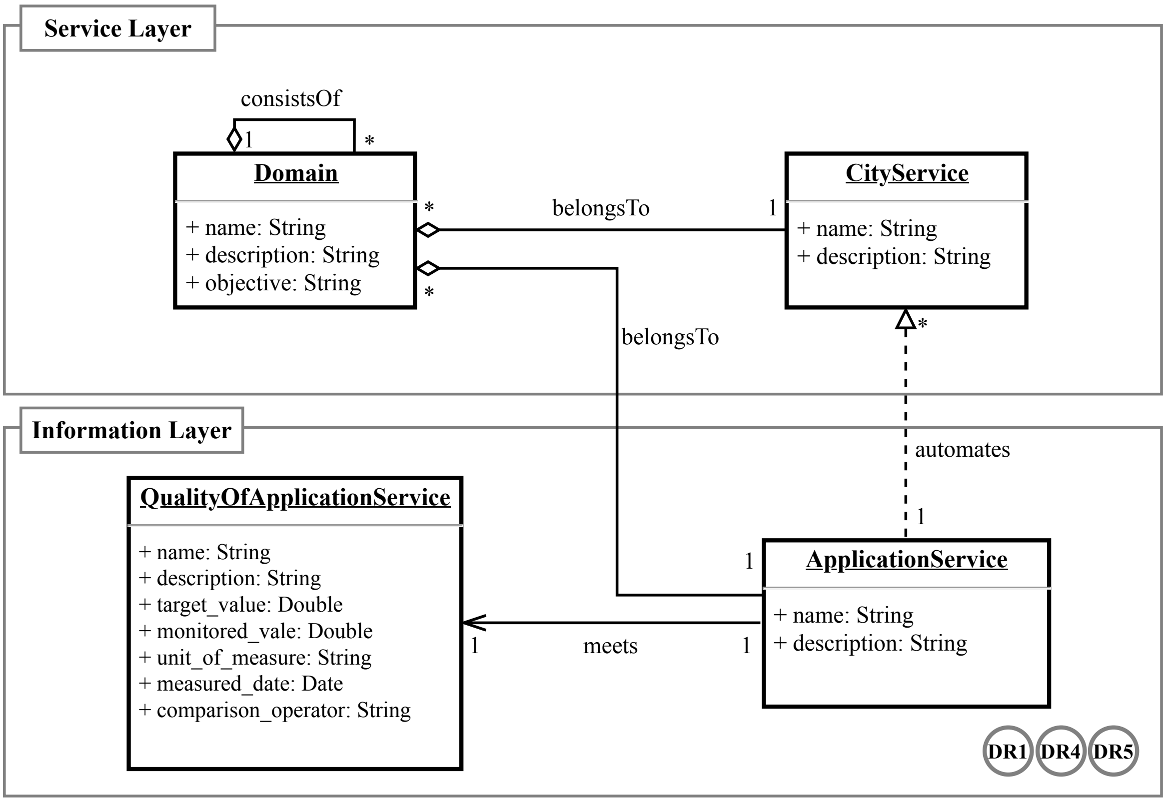


Fig. 5.5 Abstract Syntax. City Service Automation.

automates one or more city services and **belongs to** one or more domains. For instance, the application service that provides information on the air-pollution levels supports the contamination control city service.

- **Quality of Application Service:** This class represents a quality support or performance characteristics of an application service. This concept has attributes to define information on the quality of application service, such as: name, description, target_value, monitored_vale, unit_of_measure, measured_date, and comparison_operator. One application service **meets** one quality of application service. For example, the application service that provides information on the actual time of bus service arrival meets the accuracy of real-time information.

Figure 5.6 depicts the concepts of the metamodel that express **Service Management and Integration**; and illustrates the design requirements that the concepts meet: DR1 and DR4 (see section 5.2). The main concepts are outlined as follows:

- **Web Service:** This class represents a software service used to communicate between two applications or systems on a network. This concept has attributes to define general

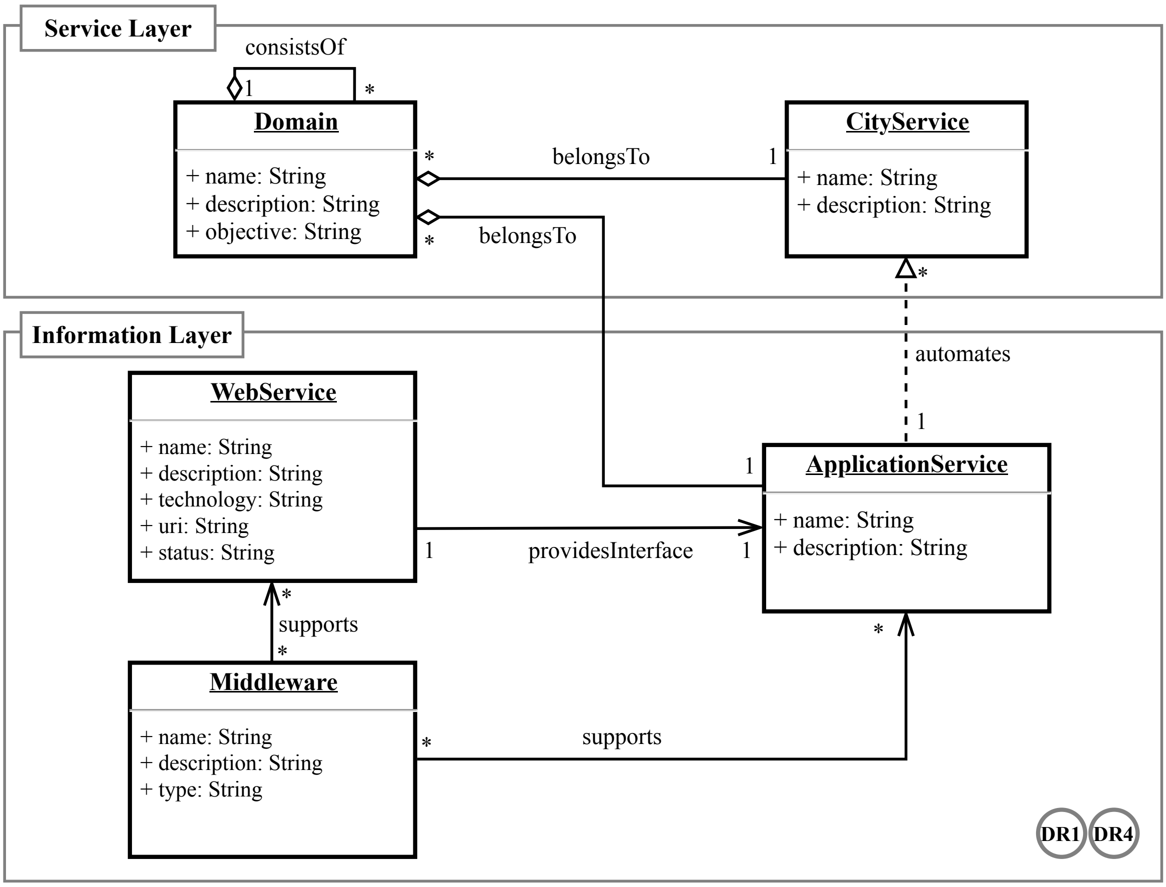


Fig. 5.6 Abstract Syntax. Service Management and Integration.

information on the web service, such as: name, description, technology (e.g., REST, SOAP, GraphQL), URI (Uniform Resource Identifier), and status. One web service **provides an interface** to one application service.

- **Middleware:** This class represents a software that offers common services for applications and facilitates the development of applications by integrating heterogeneous services in Smart Cities. This concept has attributes to define general information on the middleware, such as: name, description, and type (e.g., service-oriented, database-oriented, application-specific). One middleware **supports** one or more web services and one or more application services.

Figure 5.7 depicts the concepts of the metamodel that express **Decision Support**; and illustrates the design requirements that the concepts meet: DR4 and DR6 (see section 5.2). The main concepts are outlined as follows:

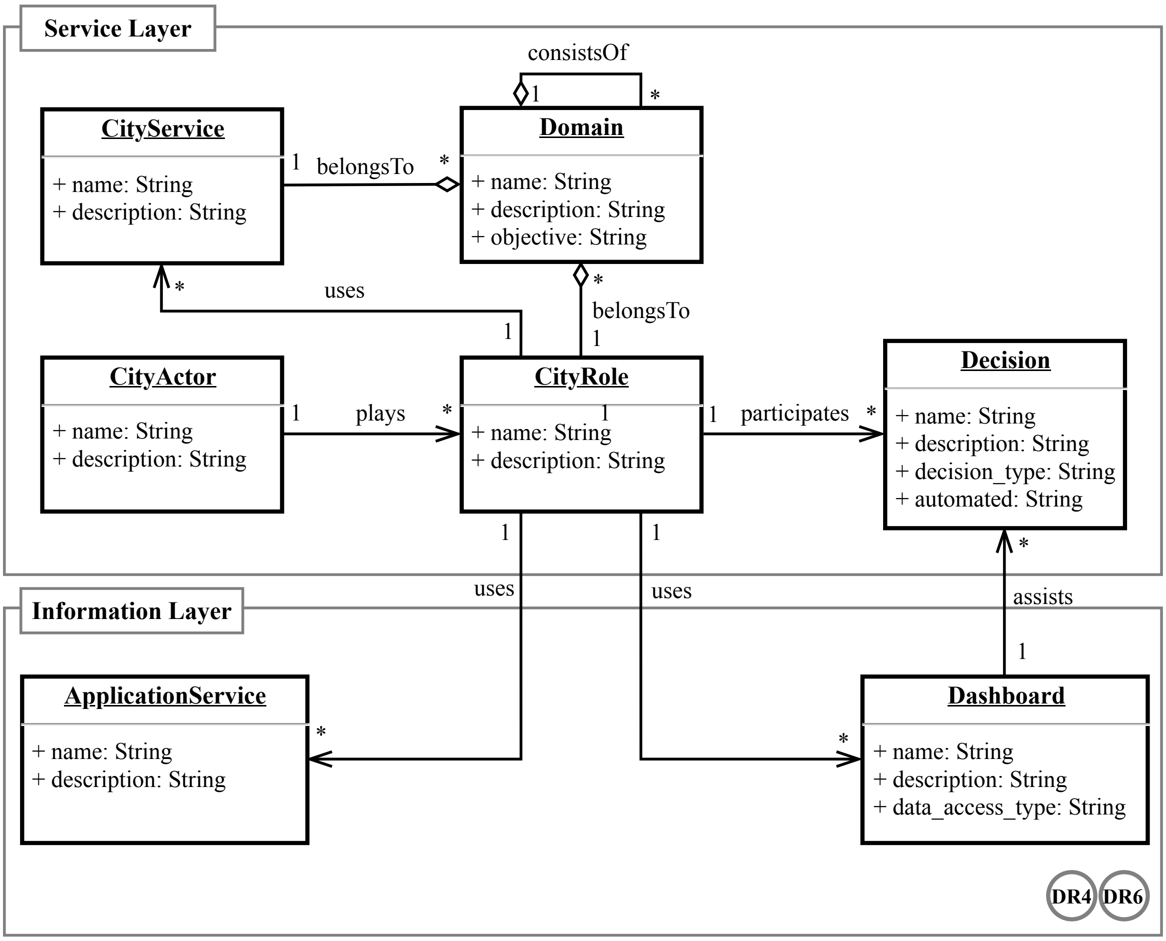


Fig. 5.7 Abstract Syntax. City Actors and Decision Support.

- **City Actor:** This class represents a person, group or organization (e.g., city authorities, citizens, communities, retailers) that interact with city services and their related application services. This concept has attributes to define general information about the city actor, such as: name and description. One city actor **plays** one or more city roles. For instance, a city authority plays the role of a Smart City project manager.
- **City Role:** This class represents the responsibility assigned to a city actor in a particular action or event in a Smart City. This class has attributes to define general information on the city role, such as: name and description. One city role **participates** in one or more decisions and **belongs to** one or more domains. For example, the city role "Bus Operator" participates in the decision "modify the schedule of buses" due to traffic accidents, operational disruptions, or technical problems. One city role **uses** one or more city services, application services, and dashboards.

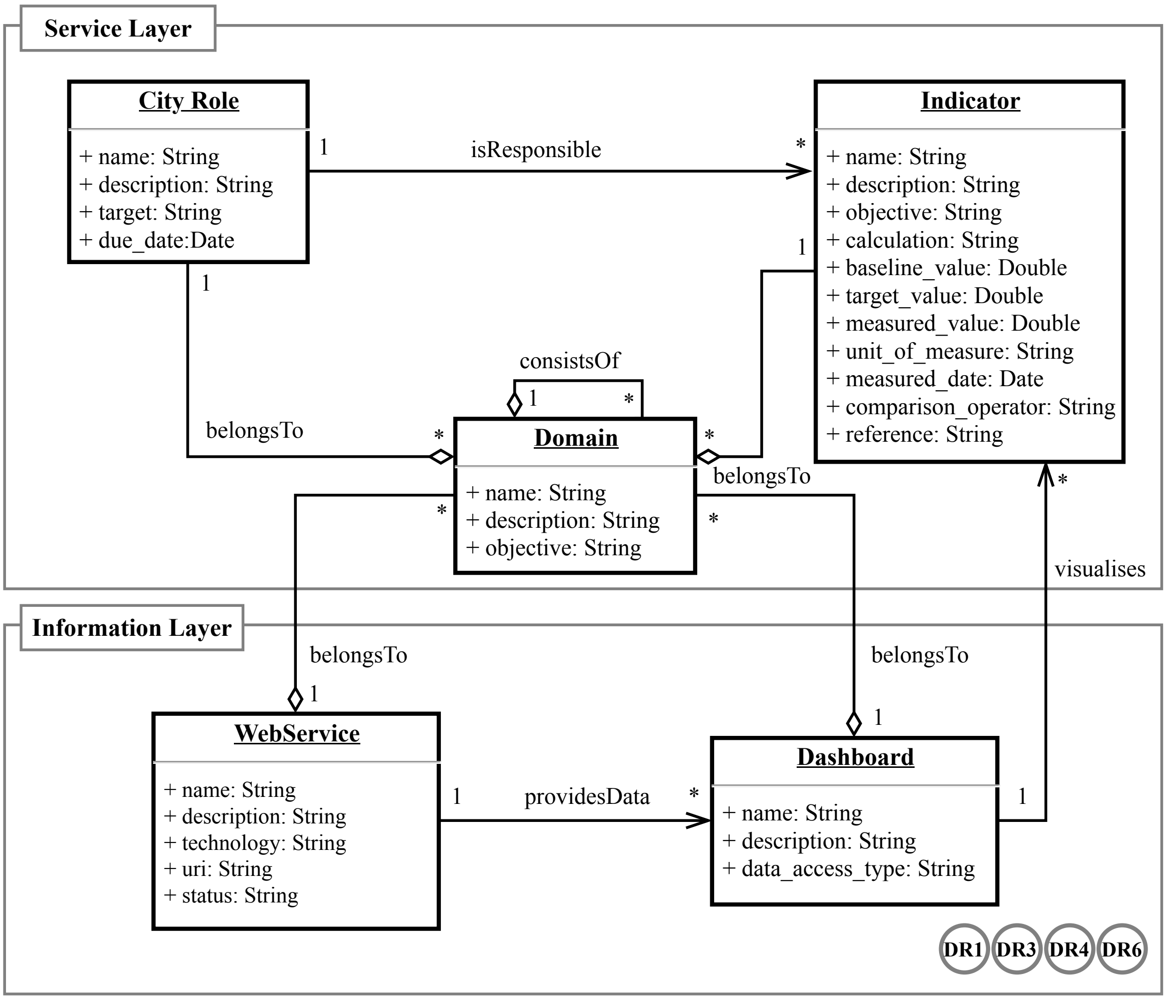


Fig. 5.8 Abstract Syntax. Smart City Performance and Visualisation.

- **Decision:** This class represents an option or action based on the data collected to support the decision-making process in Smart Cities. This concept has attributes to define general information on the decision, such as: name, description, decision_type (e.g., strategic planning, city operation), and automated.

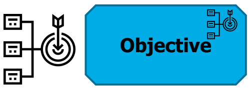
- **Dashboard:** This class represents an interactive application interface that provides city managers, businesses, and citizens with a view of the urban condition. This concept has attributes to define general information on the dashboard, such as: name, description, and data_access_type (e.g., public data, private data). One dashboard **assists** one or more decisions.

Figure 5.8 depicts the concepts of the metamodel that express **Smart City Performance and Visualisation**; and illustrates the design requirements that the concepts meet: DR1, DR3, DR4, and DR6 (see section 5.2). The concepts represented include city role, indicator, domain, web service, and dashboard. In particular, dashboards allow the visualisation of information through graphs and indicators, providing a better understanding of what is happening in the cities (Barns, 2018; Sarikaya et al., 2018). One dashboard **visualises** one or more indicators. One city role **is responsible** for one or more indicators. One web service **provides data** to one or more dashboards. Finally, the city role, indicator, domain, web service, and dashboard concepts **belong to** one or more domains.

5.3.2 Concrete Syntax

The concrete syntax of the ArchiSmartCity metamodel includes the graphical notation and description (semantics) of the concepts, see Table 5.15. Notation refers to the graphical representation of syntactic concepts while semantics specify the meaning of them (Bork et al., 2020). The graphical notation for the metamodel brings it closer to the Smart Cities domain experts. This can support intuitive usage and increase familiarity among domain experts and architects. The meanings of the graphical symbols are defined by mapping them to the concepts they represent (Moody, 2009). We used the existing notation elements available (e.g., goal, objective, web services) and created new ones (e.g., domain) that were validated during the evaluation of this research in Chapter 7.

Table 5.15 Description of the concepts and their graphical notation

Concept	Graphical notation	Description (Semantics)
Domain		A key field of urban development in Smart Cities such as smart economy, mobility, environment, etc.
Goal		A statement on the desired state for the city as a common outcome for its stakeholders.
Objective		A milestone for a Smart City used to demonstrate progress towards a city goal.
Indicator		A quantitative, qualitative or descriptive measure required to demonstrate performance in the delivery of city services and quality of life.
Quality of Life Dimension		A dimension that represents qualitative aspects of individuals that are impacted by the services available in cities.
City Service		A service offered to the citizens by the city government or private institutions, e.g., transport service.
City Actor		A person, group or organisation that interacts with the services offered in the city, such as city authorities, citizens.
City Role		A role to which a city actor can be assigned, e.g., head of the Smart City strategy, GIS manager.
Decision		An option or action based on the data collected to support the decision-making process.
Application Service		A software service which provides useful information through a software application to the end-users.
Quality of Application Service		A quality support or performance characteristics of an application service.
Web Service		A software service interface that allows communication between two software programs in a network.
Dashboard		An interactive application interface that provides city managers, businesses, and citizens with a view of the urban condition.
Middleware		A software that supports the management and interoperability of heterogeneous applications and services.

5.4 Phase III: Formalise

The formalisation phase ensures that the outcome of the design phase has no ambiguity, either with the purpose of sharing specification within a community or in preparation for a metamodel platform implementation (Götzinger et al., 2016). Figure 5.9 presents the full ArchiSmartCity metamodel by using the UML notation. ArchiSmartCity explicitly models the concepts and their relationships to address the alignment between the service and information layers in Smart City architectures.

The Service Layer describes the closest level of a city service (e.g., air-quality service, transport service, health service, etc.) to the stakeholders. This layer encompasses the set of concepts: *Domain, Goal, Objective, Indicator, Quality of Life Dimension, City Service, City Actor, City Role, and Decision*, to meet different requirements of Smart Cities. The concept *Domain* groups other concepts that share one or more common characteristics relevant to Smart Cities, both in the service layer and in the information layer. This concept can also consist of other domains (i.e., sub-domains). For example, the transport and mobility domains can consist of sub-domains such as city logistics, info-mobility, and people mobility. The *Goal* concept explicitly represents the expected results to be reached. The *Objective* concept decomposes city goals in more specific milestones. The *Indicator* links city objectives to key city performance indicators. The *Quality of Life Dimension* concept represents the quality of life as a key element for the development of Smart Cities. This concept is associated with the *Indicator* concept that measures the performance of city services and quality of life over time. The *City Service* concept represents a central concept of Smart Cities and belongs to one or more domains, allowing the representation of a collection of services linked to a logical grouping of functionality. The *City Actor* concept represents the entities that interact with the city services, such as people, organisations, and public/private institutions. The *City Role* concept expresses a role that a city actor plays in the city and the *Decision* concept represents a decision in which a city role participates.

The Information Layer describes the information systems and data that automate city services. This layer comprises the set of concepts: *Dashboard, Application Service, Quality of Application Service, Web Service, and Middleware* to fulfill the requirements of various Smart Cities. The *Web Service* concept provides an interface to application services and feeds data to dashboards. The *Quality of Application Service* concept describes the performance characteristics of application services (e.g., security, availability, throughput). This concept can be related to a group of other qualities, for example, the quality aspect of security can be grouped with the quality aspect of confidentiality. The *Dashboard* concept represents a graphical user interface to visualise information on relevant aspects of the city. This concept is related to other concepts in the information layer, such as web services. The *Middleware*

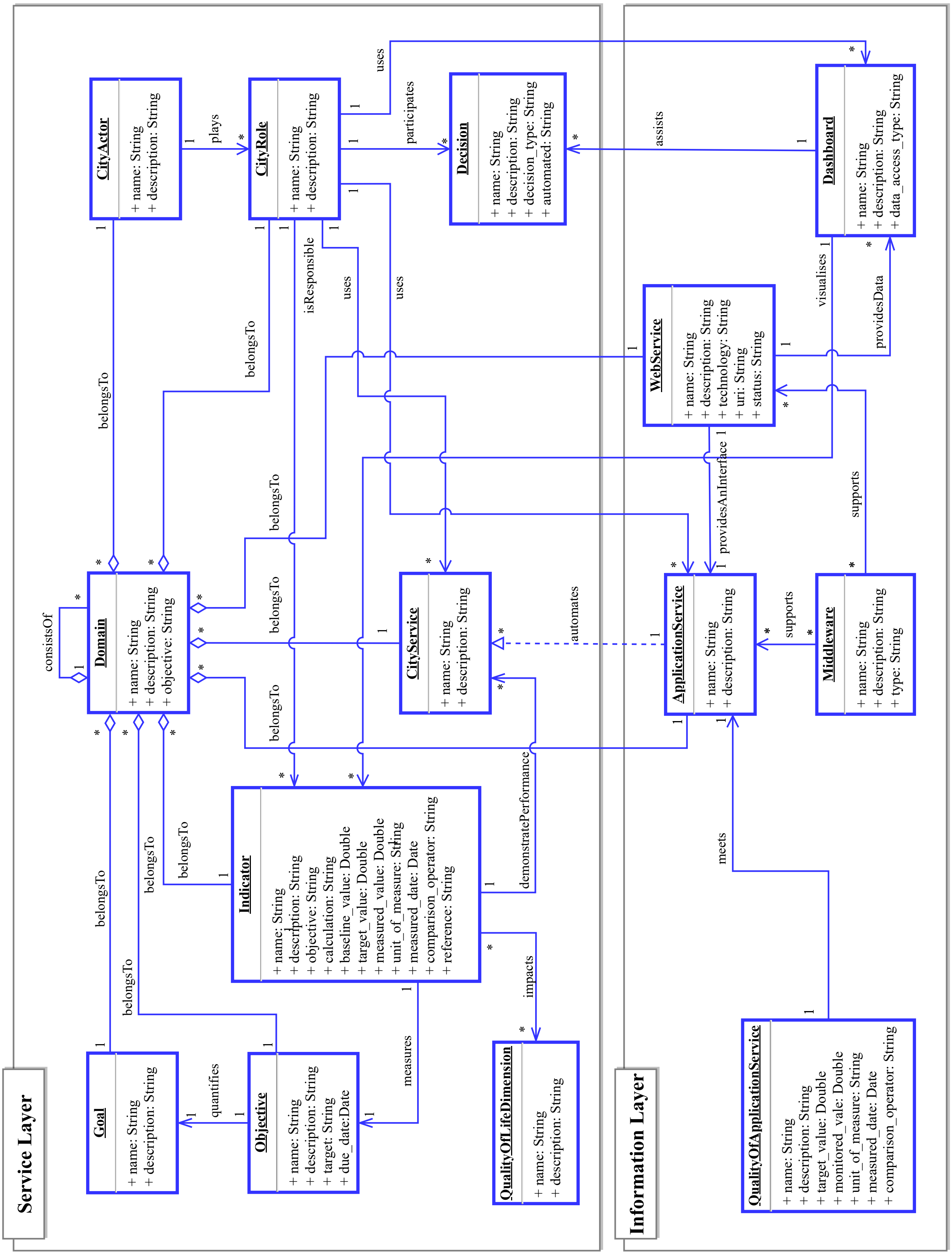


Fig. 5.9 ArchiSmartCity Metamodel.

concept represents a software component that manages multiple services by using service-oriented and middleware technologies. A middleware supports both application services and web services.

The Alignment of the Service and Information Layers is modelled by connecting them through three main kinds of relationships: *Aggregation, Association, and Realisation*. The **Semantics** of these relationships are outlined as follows.

- **Aggregation relationship:** Represents that a concept combines one or more other concepts. For example, the relationship between a *Domain* concept and an *Application Service* concept: one application service belongs to one or more domains. This helps to link a domain to any concept from the information layer that needs to be grouped and integrated to achieve city goals and objectives.
- **Association relationship:** Represents that a concept provides its functionality to another concept. For example, the relationship between the *City Role* concept and the *Application Service* concept: one city role uses one or more city services and one or more application services. This helps to understand the dependencies between city services and the underlying information systems.
- **Realisation relationship:** Represents that a concept is fundamental for the creation, achievement, or operation of a more abstract concept. For example, the relationship between a *Application Service* concept and a *City Service* concept. One application service automates one or more city services. This helps to identify the impact of information systems on city services.

5.5 Metamodel Summary

This chapter introduces ArchiSmartCity and its design to address the alignment between the service and information layers in Smart City architectures. Concepts and relationships are defined based on a set of design principles and design requirements from the literature in order to meet the requirements of various Smart Cities. These concepts are instantiated through the ArchiSmartCity metamodel that describes this alignment to support Smart City strategies.

ArchiSmartCity formalises this alignment in a metamodel that includes service and information concepts. It realises the vertical alignment of services within a specific domain and the horizontal alignment that enables the cross-domain integration of services. ArchiSmartCity uses the Business Motivation Model (BMM) of the Object Management Group (2015) to

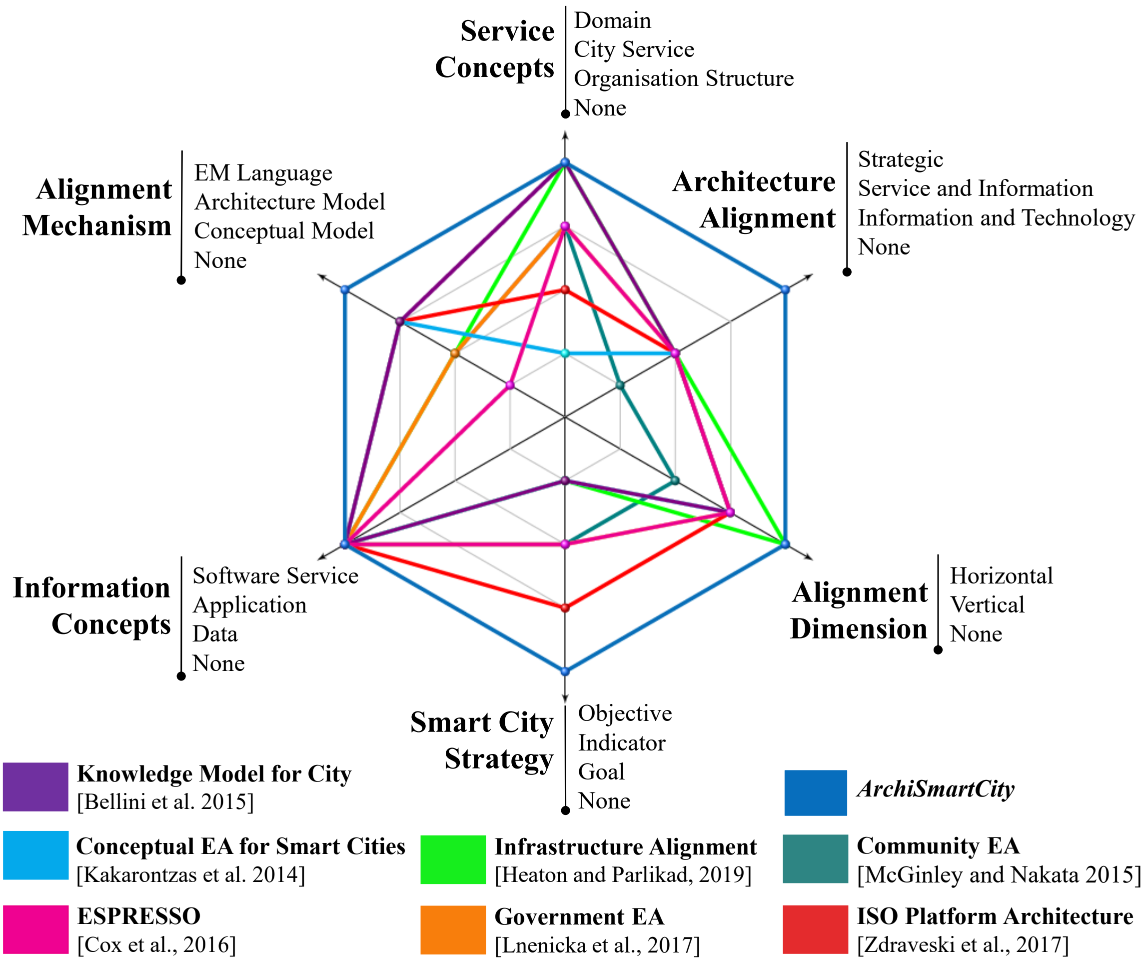


Fig. 5.10 The features of ArchiSmartCity compared to the closest approaches.

define the ways in which a city service and its information systems contribute to the achievement of Smart City vision and strategy. It expresses Smart City performance measurement through city indicators to document and demonstrate the smartness and progress of Smart Cities, based on Smart City standards such as the ISO37120 (2018). ArchiSmartCity captures the concept of service and its relevant types (e.g., city service, application service, web service) to support the service orientation of Smart Cities. It has dedicated concepts to express the quality of services which are fundamental to specify the quality expectations surrounding the city services and the quality of supporting application services. ArchiSmartCity captures the decision-making support to drive better decision-making through the use of data for all structured entities within the organisation which involves city actors (e.g., government, business, and residents) and their roles.

ArchiSmartCity enables the link between service concepts and information concepts along with their alignment with Smart city goals and objectives. It defines a common language (abstract and concrete syntax) for stakeholders in the Smart Cities domain. Figure 5.10 compares ArchiSmartCity features with the closest approaches from the literature. ArchiSmartCity contributions close the gap across the current approaches with regard to the alignment between the service and information layers in Smart City architectures.

This study presents an analysis of EM languages, focusing on the different EM languages (including ArchiMate) for Smart Cities as presented in Section 2.4.2 and discussed in Section 2.4.3. Consequently, ArchiMate is not individually represented in Fig 5.10, but it is considered within the group: *EM Language* in *Alignment Mechanism*. ArchiMate is used in this thesis to model different scenarios of Smart Cities because this language allows the creation of EA models with cross-layer dependencies to addresses the strategic alignment (Jonkers et al., 2004), which is crucial in this study. However, we found that ArchiMate needs to be extended to meet the needs of the Smart Cities domain. Therefore, the ArchiSmartCity concepts and relationships will be used to extend the ArchiMate language in the next section. The rest of this thesis presents the implementation, evaluation, and limitations of ArchiSmartCity.

Chapter 6

ArchiSmartCity Implementation

Chapter 5 describes the design of ArchiSmartCity and the design decisions to address the alignment between the service and information layers in Smart City architectures. This chapter details the implementation of ArchiSmartCity as an extension of the ArchiMate language. Section 6.1.1 presents an overview of the ArchiMate language and its structure. Section 6.1.2 introduces the ArchiSmartCity modelling extension. Section 6.1.3 details the context, functional, and deployment models of the architecture that describes the ArchiSmartCity implementation. Finally, Section 6.2 summarises this chapter.

6.1 Phase IV: Develop

Design Science research requires the construction and development of the artefact based on design specifications (Hevner et al., 2004). The development of the artefact should be a search process that draws from existing theories and knowledge to build a solution to a defined problem (Peffers et al., 2007). This chapter focuses on the development phase to implement ArchiSmartCity in the form of an extension of the ArchiMate language. Figure 6.1 illustrates the phases and tasks that this thesis follows to define the concepts and build the metamodel. This process follows the Agile Modelling Method Engineering (AMME) approach (Visic et al., 2015). The development phase includes a mapping approach to link the ArchiSmartCity concepts defined in section 5.2 to the ArchiMate concepts. Additionally, it describes the ArchiSmartCity modelling extension and implementation using the Eclipse Modelling Framework (EMF).

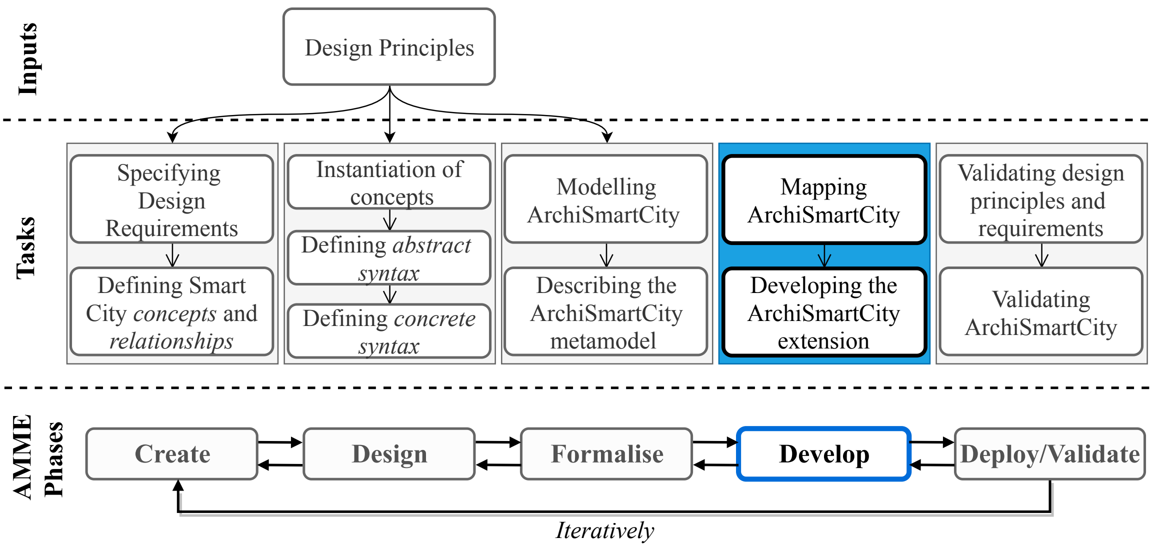


Fig. 6.1 ArchiSmartCity Metamodel Design and Construction Method. Development Phase.

6.1.1 ArchiMate Language Overview

Exemplary EM Languages include, among others (de Kinderen and Kaczmarek-Heß, 2018; Lara et al., 2019), the Architecture of Integrated Information Systems (ARIS) (Scheer, 2000), Multi-Perspective Enterprise Modeling (MEMO) (Frank, 2014), and ArchiMate (The Open Group, 2017). They were analysed in this thesis due to their abilities to represent and describe EAs and IS architectures. Table 6.1 summarises the main characteristics of these languages, which are relevant to the research problem domain.

Table 6.1 Comparison between EM Languages - Overview

Features	**Principal Orientation**			**Alignment Support**		**IS Support**
EM Language	**Service**	**Process**	**Organisation**	**Strategies**	**BITA**	**Information**
ARIS (Scheer, 2000)		✓				✓
MEMO (Frank, 2014)			✓	✓	✓	✓
ArchiMate (The Open Group, 2017)	✓			✓	✓	✓

For the *Principal Orientation* feature, ARIS focuses on business process, MEMO is mainly focused on the overall organisation and its structure, and ArchiMate adopts a service-oriented model in which each layer provides services to the upper layers (Lankhorst, 2004). This service-oriented approach supports current trends such as the service orientation of Smart Cities. For the *Alignment Support* feature, ARIS does not include strategic aspects, whereas MEMO and ArchiMate include strategic and motivation concepts such as goal, course of action, driver, value, etc. At the same time, ARIS does not address the business and IT alignment (BITA), while MEMO and ArchiMate support the alignment by providing the

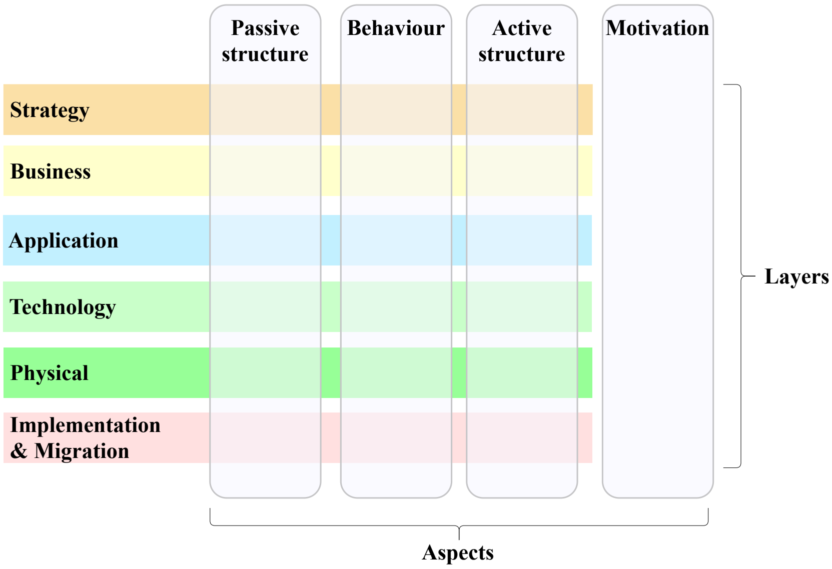


Fig. 6.2 ArchiMate 3.0.1 Framework (The Open Group, 2017)

dependencies among architecture layers. For the *Information Support* feature, the analysed languages provide concepts to support data and applications among different architecture layers. For instance, ArchiMate includes the application and technology layers which provide the information support characteristics to realise service concepts. Therefore, these three main characteristics make ArchiMate a suitable EM language to be used as a base language to address the alignment between services and information in Smart City architectures.

Additionally, ArchiMate is a widely accepted standard of the Open Group that describes an Enterprise Architecture Modelling Language (EAML) (The Open Group, 2018). ArchiMate is a graphical language for describing, analysing, and communicating Enterprise Architecture (EA) models, which is extensively used in the industry. This language conforms to the ISO/IEC/IEEE 42010 (2011) standard, which provides a model for architecture description. One of the major advantages of ArchiMate is that it provides notations for relationships between concepts among different layers, addressing strategic alignment (Bhattacharya, 2017; Desfray and Raymond, 2014; Rurua et al., 2019). Figure 6.2 depicts the ArchiMate Framework that is categorised along two dimensions: *layers* and *aspects*, which are described as follows.

- **Layers:** ArchiMate contains a number of layers to describe architectures. The ArchiMate language defines the concepts and relationships from various layers: business, application, technology, strategy, physical, and implementation & migration.

  - *The business layer* describes the structure and interaction between the business strategy, organisation, functions, business processes, and information needs.
  - *The application layer* supports the business layer through application services and their interactions.
  - *The technology layer* offers technology and infrastructure services needed to run the applications.
  - *The strategy layer* depicts strategic concepts to model strategic direction and choices.
  - *The physical layer* comprises the concepts for modeling physical facilities and equipment, distribution networks, and materials.
  - *The implementation & migration layer* adds concepts to support the implementation and migration of architectures.

- **Aspects:** ArchiMate concepts are classified based on layer-independent aspects related to the concerns of different stakeholders: active structure concepts, behaviour concepts, and passive structure concepts.

  - *Active structure concepts* are concepts that can perform behaviour, for example, the business actors, application components, nodes, and interfaces that expose this behaviour to the environment.
  - *Behaviour concepts* represent units of activities performed by one or more active structure elements and are considered the dynamic aspects of any EA model, such as business process and business services that are exposed to the environment.
  - *Passive structure concepts* represent objects that are the subject of behaviour, such as information or data objects.
  - *The motivation aspect* includes motivational concepts to model the motivation or reasons behind the architecture of an organisation.

6.1.2 ArchiSmartCity Modelling Extension

Two mechanisms can be followed to extend a metamodel (Atkinson et al., 2015): (1) the enhancement of the metamodel with additional concepts from the same domain as the original concepts, (2) the augmentation of the metamodel with new concepts from a different domain than the original concepts. This research follows the second mechanism and extends the ArchiMate metamodel with the concepts from the Smart Cities domain by adding the proposed ArchiSmartCity concepts.

Table 6.2 Mapping Concepts

<table>
<tr><th colspan="2">ArchiSmartCity</th><th rowspan="2">Expressed by</th><th colspan="2">ArchiMate</th></tr>
<tr><th>Layer</th><th>Concept</th><th>Concept</th><th>Layer</th></tr>
<tr><td rowspan="9">Service</td><td>Domain</td><td>(+)</td><td>New Notation</td><td></td></tr>
<tr><td>Goal</td><td>(☑)</td><td>Goal</td><td>Motivation</td></tr>
<tr><td>Objective</td><td>(+)</td><td>New Notation</td><td></td></tr>
<tr><td>Indicator</td><td>(+)</td><td>New Notation</td><td></td></tr>
<tr><td>Quality of Life Dimension</td><td>(+)</td><td>New Notation</td><td></td></tr>
<tr><td>City Service</td><td>(+)</td><td>New Notation</td><td></td></tr>
<tr><td>City Actor</td><td>(+)</td><td>New Notation</td><td></td></tr>
<tr><td>City Role</td><td>(+)</td><td>New Notation</td><td></td></tr>
<tr><td>Decision</td><td>(+)</td><td>New Notation</td><td></td></tr>
<tr><td rowspan="5">Information</td><td>Dashboard</td><td>(+)</td><td>New Notation</td><td></td></tr>
<tr><td>Application Service</td><td>(☑)</td><td>Application Service</td><td>Application</td></tr>
<tr><td>Quality of Application Service</td><td>(+)</td><td>New Notation</td><td></td></tr>
<tr><td>Web Service</td><td>(+)</td><td>New Notation</td><td></td></tr>
<tr><td>Middleware</td><td>(+)</td><td>New Notation</td><td></td></tr>
<tr><th colspan="2">ArchiSmartCity Relationships</th><th>Expressed by</th><th colspan="2">ArchiMate Relationships</th></tr>
<tr><td colspan="2">Belongs to</td><td>(+)</td><td colspan="2">New Relationship (Belonging)</td></tr>
<tr><td colspan="2">Quantifies</td><td>(+)</td><td colspan="2">New Relationship (Quantify)</td></tr>
<tr><td colspan="2">Measures</td><td>(+)</td><td colspan="2">New Relationship (Measure)</td></tr>
<tr><td colspan="2">Demonstrates performance</td><td>(+)</td><td colspan="2">New Relationship (Performance)</td></tr>
<tr><td colspan="2">Impacts</td><td>(+)</td><td colspan="2">New Relationship (Impact)</td></tr>
<tr><td colspan="2">Automates</td><td>(+)</td><td colspan="2">New Relationship (Automate)</td></tr>
<tr><td colspan="2">Provides interface</td><td>(+)</td><td colspan="2">New Relationship (Interface)</td></tr>
<tr><td colspan="2">Meets</td><td>(+)</td><td colspan="2">New Relationship (Meet)</td></tr>
<tr><td colspan="2">Provides data</td><td>(☑)</td><td colspan="2">New Relationship (Provide data)</td></tr>
<tr><td colspan="2">Requires information</td><td>(☑)</td><td colspan="2">New Relationship (Require information)</td></tr>
<tr><td colspan="2">Plays</td><td>(☑)</td><td colspan="2">New Relationship (Play)</td></tr>
<tr><td colspan="2">Participates</td><td>(☑)</td><td colspan="2">New Relationship (Participate)</td></tr>
<tr><td colspan="2">Is responsible</td><td>(☑)</td><td colspan="2">New Relationship (Is responsible)</td></tr>
<tr><td colspan="2">Supports</td><td>(☑)</td><td colspan="2">New Relationship (Support)</td></tr>
<tr><td colspan="2">Uses</td><td>(☑)</td><td colspan="2">New Relationship (Use)</td></tr>
<tr><td colspan="2">Assists</td><td>(☑)</td><td colspan="2">New Relationship (Assist)</td></tr>
<tr><td colspan="2">Visualises</td><td>(☑)</td><td colspan="2">New Relationship (Visualise)</td></tr>
</table>

Legend: (+) - new concept; (☑) - ArchiMate concept

The foundation of the metamodel is ArchiMate 3.0.1., which allows us to model the ArchiSmartCity concepts and relate them to the existing business, application, technology, and motivation concepts.

Mapping Concepts

It is necessary to map ArchiSmartCity concepts in the ArchiMate metamodel before starting to develop the extension. The design decisions for the mapping were made based on the analysis of available documentation for the ArchiMate language and its customization mechanisms (The Open Group, 2017). Table 6.2 summarises the mapping of ArchiSmartCity to the ArchiMate concepts and relationships. The *Goal* concept that represents a city goal is expressed by the Goal concept of ArchiMate (motivation layer) due to their syntax and semantics being closely related. The *Application Service* concept that represents a software service in ArchiSmartCity is expressed by the Application Service concept of ArchiMate (application layer) because of the similarity. Many relationships of ArchiSmartCity are mapped to the existing ArchiMate relationships. The rest of the ArchiSmartCity concepts are augmented with the new notations defined in Chapter 5. The new relationships created are required to specify the semantics of the Smart City domain, including the *Belonging, Quantify, Measure, Performance, Impact, Automate, Interface, and Meet* relationships. Several of these concepts specialise those concepts from existing motivation, business, application, and technology concepts as is presented in the next section.

ArchiSmartCity Metamodel Extension

Figure 6.3 depicts the ArchiSmartCity metamodel extension using the syntax of the ArchiMate language. ArchiSmartCity concepts are structured within the service and information layers and inherit the relationships from existing ArchiMate concepts. The service layer presents the main ArchiMate concepts including the business concepts (yellow concepts), motivation concepts (purple concepts), and composite concepts (e.g., location). The information layer presents the principal Archimate concepts of the application layer (light blue concepts). Both the service and information layers include the ArchiSmartCity concepts (dark blue concepts), which have the initials ASC (corresponding to ArchiSmartCity) located in the left corner of the figure. Only the most important ArchiMate concepts and the relationships between them are represented to clearly present the metamodel extension. Appendix D presents the ArchiSmartCity metamodel extension by using the UML notation. The main components are described as follows.

- **The Service Layer:** This layer represents the concepts: *Domain, Goal, Objective, Indicator, Quality of Life Dimension, Quality of City Service, and Decision*. The *Domain* concept is a specialisation of the Grouping concept. This enables the *Domain* concept to group other concepts (e.g., City Services, Stakeholders, Location, Application Services, Web Services, etc.) that share one or more characteristics relevant

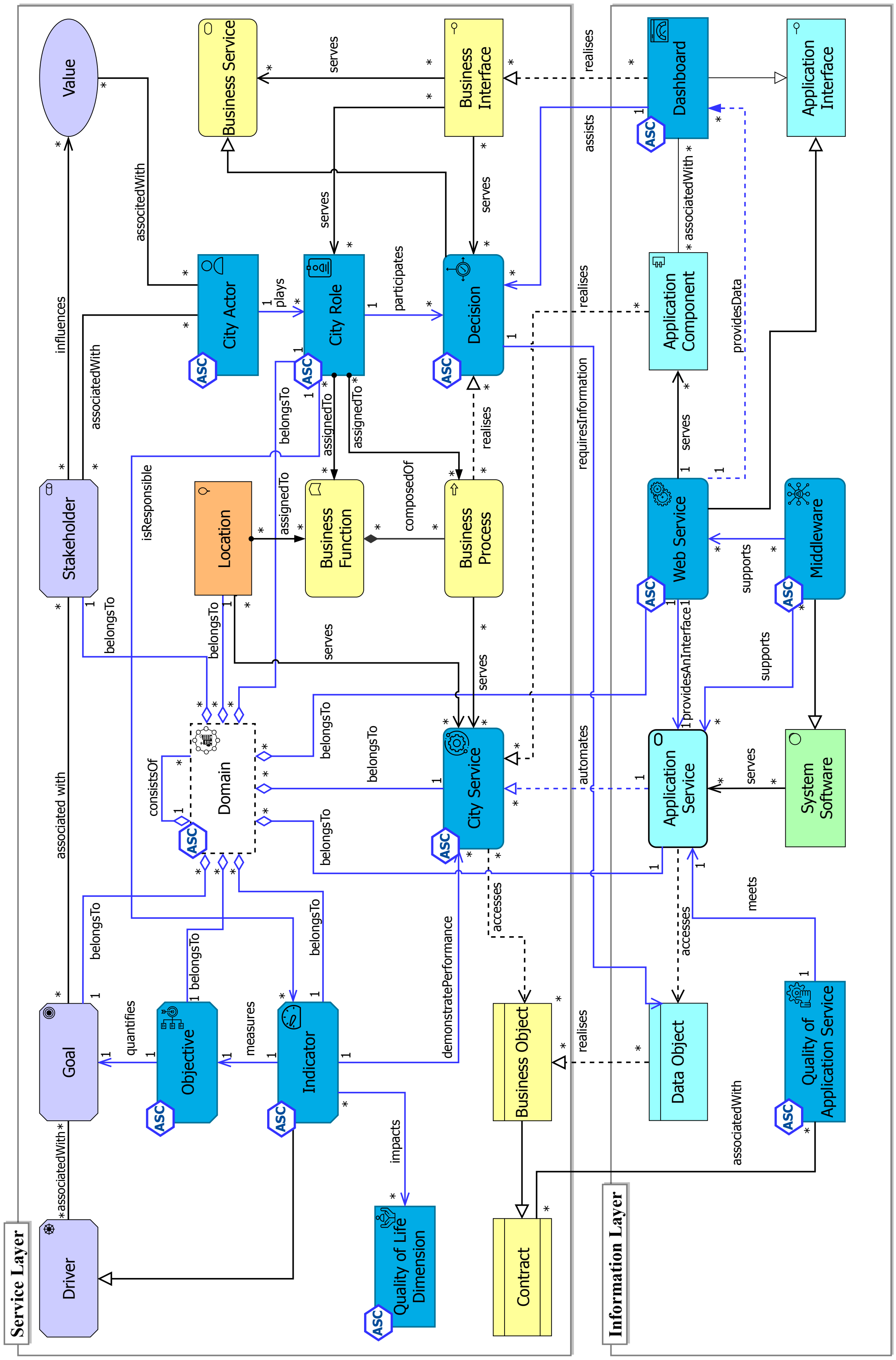


Fig. 6.3 ArchiSmartCity Metamodel Extension.

to Smart Cities. The *Goal* concept from ArchiMate is used to express a city goal and represent expected results to be reached. The *Objective and Indicator* concepts specialise concepts from the motivation layer of ArchiMate. The *Objective* concept is a specialisation of the Goal concept, while the *Indicator* concept is a specialisation of the Driver concept. The *Quality of Life Dimension* concept is modelled as a new concept and is associated with the *Indicator* concept. The *City Service* concept is a specialisation of the *Business Service* concept to model any service offered to the citizens as part of Smart City initiatives. The *City Actor* concept is a specialisation of the Business Actor concept and is associated with the Stakeholder concept to represent a link with Smart City stakeholders who are interested in the effects of the architecture. The *City Role* concept is a specialisation of the Business Role concept to distinguish Smart City roles from the existing roles of city authorities. The *Decision* concept is a specialisation of the Business Service concept to model decisions made with the information collected from the cities.

- **The Information Layer:** This layer represents the concepts: *Application Service, Web Service, Quality of Application Service, Dashboard, and Middleware*. The *Application Service* concept from ArchiMate is used to express an application service (i.e., software service) from the Smart Cities domain. The *Web Service* concept is a specialisation of the Application Interface concept to allow the communication between application components. The *Quality of Application Service* concept is modelled as a new concept and can be related to a group of other qualities. The *Dashboard* concept is a specialisation of the Application Interface concept. This concept is related to other concepts in the information layer, for example, the application component, application function, and web services. The *Middleware* concept is a specialisation of the System Software concept to support the interoperability of multiple applications and services in the Smart Cities domain.

- **The Alignment of the Service and Information Layers:** The alignment addresses how to apply information technology in an appropriate and timely way according to business strategies, goals, and needs (Luftman, 2004). For instance, organisations support their business services on business processes, which are supported by technology solutions to assist the materialisation of business strategies and objectives (Cañas et al., 2015). This thesis focuses specifically on modelling the alignment between city services and information systems in order to support the Smart City strategies and the needs of citizens. ArchiMate contributes to support the strategic alignment through a model-based approach (Lankhorst et al., 2009; Lankhorst, 2004). We extend the

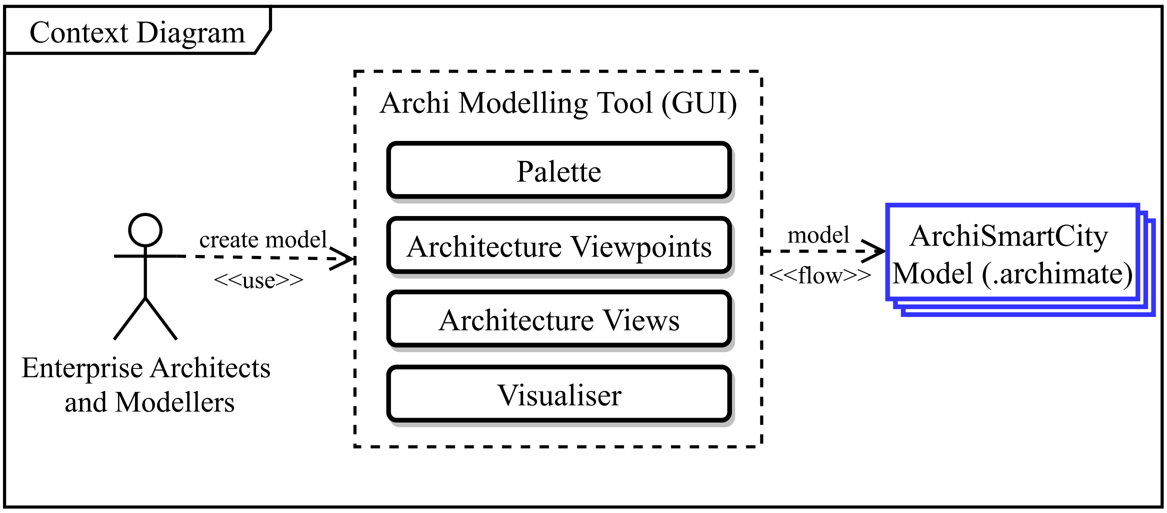


Fig. 6.4 ArchiSmartCity EMF - Context Diagram.

ArchiMate language to model the alignment between the service and information layers of Smart City architectures. This alignment is modelled by connecting service concepts and information systems concepts through different kinds of relationships, such as: *Quantify* (e.g., an objective quantifies a goal), *Belonging* (e.g., an application service belongs to a domain), *Assist* (e.g., a dashboard assists a decision), and *Automation* (e.g., an application service automates a city service). Such ArchiSmartCity relationships are implemented as specialisations of the ArchiMate relationships.

6.1.3 ArchiSmartCity EMF Implementation

We implement ArchiSmartCity using the Archi Modelling Tool[1]. Archi is an open source software solution that relies on the model and diagram management technology of the Eclipse Modelling Framework (EMF). The EMF is a Java framework and code generation facility for building tools and other applications based on a structured model (Budinsky et al., 2004). The EMF is one implementation of The Meta-Object Facility (MOF) architecture. Archi provides an open source reference implementation of ArchiMate, and is currently being used as one of the tools to generate exchange ArchiMate models in an Extensible Markup Language (XML). The source code of ArchiSmartCity for practitioners and developers is available on a public GitHub repository[2]. Figure 6.4 illustrates the context of the ArchiSmartCity implementation that uses the Archi Modelling Tool and is described as follows.

[1] The Archi Modelling Tool - https://www.archimatetool.com/
[2] ArchiSmartCity - https://github.com/vivikaing/ArchiSmartCity

- **Enterprise Architects and Modellers:** End-users who create Enterprise Architecture (EA) models. The Archi tool helps Enterprise Architects and modellers to describe, analyse, and visualise the relationships among different architecture models in an unambiguous way.

- **Archi Modelling Tool (GUI):** Archi is a tool implemented using the EMF. Its graphical user interface (GUI) allows modellers to describe and visualise EAs.

- **Palette:** The palette contains the graphical notations of concepts and relationships that can be added to an architecture view.

- **Architecture Viewpoints:** The architecture viewpoints present a set of concepts and relationships focusing on particular aspects and concerns of the stakeholders. Archi displays different architecture viewpoints, such as the goal realisation viewpoint.

- **Architecture Views:** The architecture views present the concepts and relationships used in a diagram. Archi displays the views in a model tree window.

- **Visualiser:** The visualiser displays a selected concept and all of its relationships with other concepts in a graphical way.

- **ArchiSmartCity Model (.archimate):** Archi normally generates models in the *.archimate file extension as single plain text XML format files. These types of files can be used to visualise and analyse EA models and the strategic alignment by both Smart City stakeholders and other tools and applications.

Functional Viewpoint

Figure 6.5 illustrates, at a general level, the components of the ArchiSmartCity developed and added using the EMF. The main components are described as follows.

- **Archimatetool.model Plug-in:** This component implements the EMF to produce and edit a set of Java classes for a structured model, such as ArchiMate and ArchiSmartCity models.

- **Archimate.ecore:** This component implements the core EMF framework and includes a metamodel (Ecore) for describing models.

- **ArchiSmartCity EClass:** This component represents an ArchiSmartCity modelled class that has a name and attributes. This class is added to the archimate.ecore and inherits from existing ArchiMate concepts.

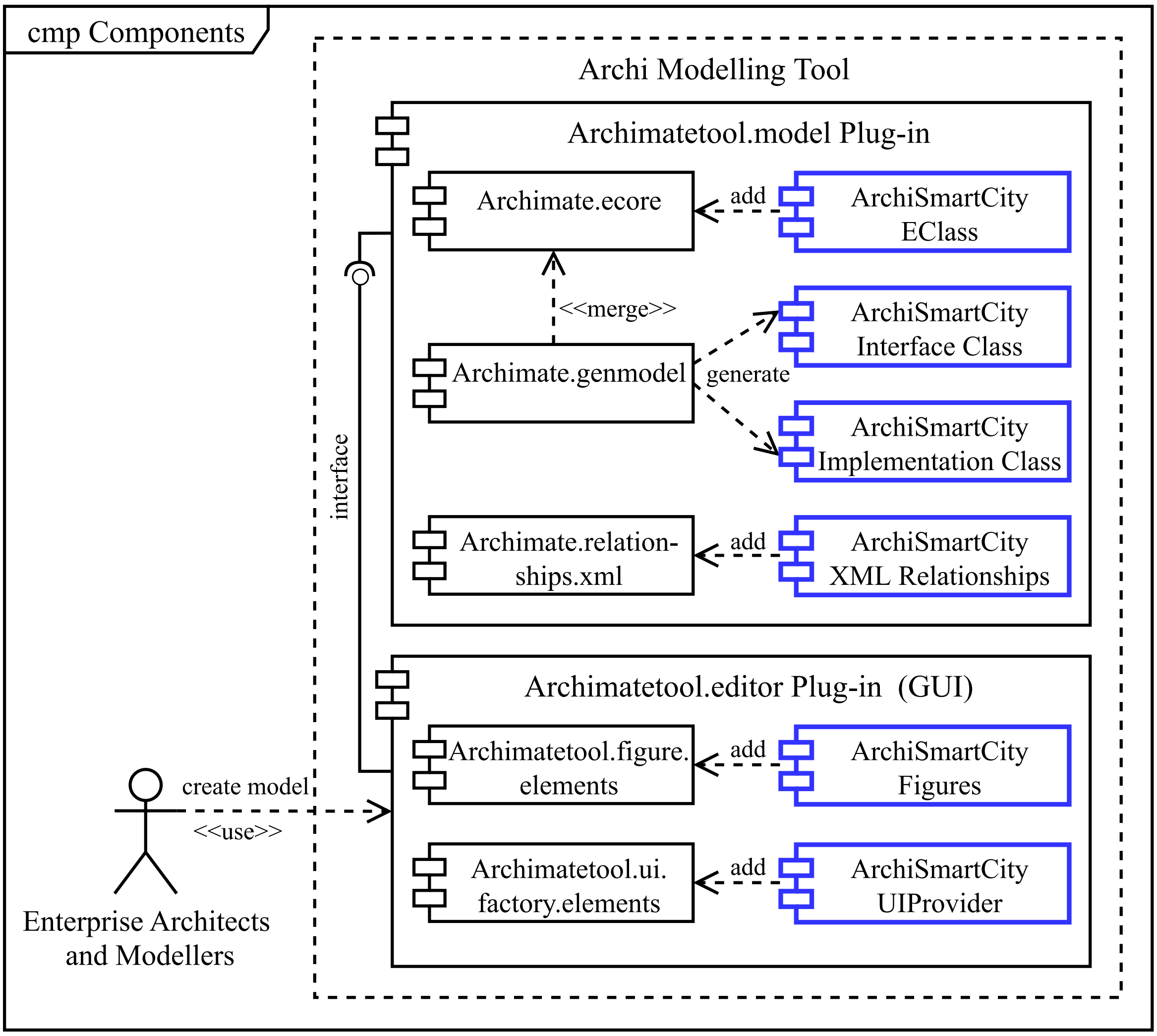


Fig. 6.5 ArchiSmartCity EMF - Components Diagram.

- **Archimate.genmodel:** This component implements the EMF code generator that is capable of producing the java code needed to build a complete editor for models.
- **ArchiSmartCity Interface Class:** This component represents an interface java class that represents the client interface to ArchiSmartCity models. This class is generated by the archimate.genmodel.
- **ArchiSmartCity Implementation Class:** This component represents an implementation java class that contains corresponding implementation classes of ArchiSmartCity models. This class is generated by the archimate.genmodel.
- **Archimate.relationships.xml:** This component represents the relationships between the ArchiMate concepts (i.e., source and target concepts) declared in XML format.

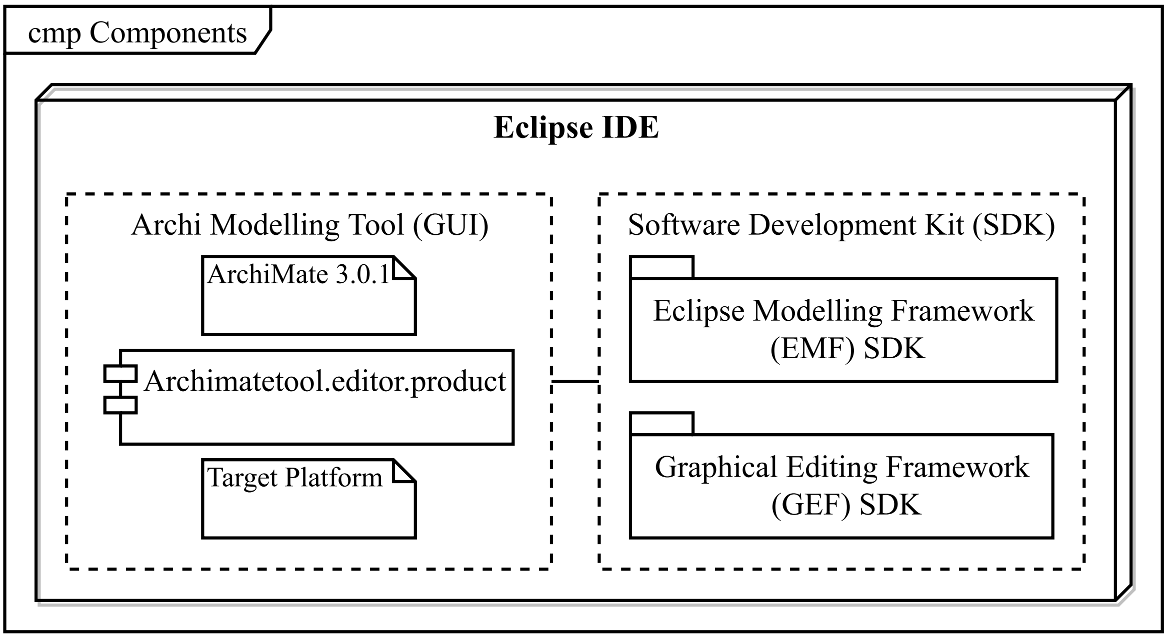


Fig. 6.6 ArchiSmartCity EMF - Deployment and Development Diagram.

The XML files define the key letters to identify each relationship name and the set of relationship rules.

- **ArchiSmartCity XML Relationships:** This component represents ArchiSmartCity relationships by using XML elements that are added as a new set of relationship names and rules.
- **Archimatetool.editor Plug-in (GUI):** This component provides the code for the model that directly interacts with the end-users.
- **Archimatetool.figure.elements:** This component provides the code for drawing a figure that represents an ArchiMate concept.
- **ArchiSmartCity Figures:** This component provides the code for drawing a figure (i.e., graphical notation and color) that describes an ArchiSmartCity concept. Each new class is added to the archimatetool.figure.elements component.
- **Archimatetool.ui.factory.elements:** This component provides the code for the user interface of a model.
- **ArchiSmartCity UIProvider:** This component provides the code for the user interface of an ArchiSmartCity model. Each new class is added to the archimatetool.ui.factory.elements component.

Deployment Viewpoint

ArchiSmartCity was developed on top of Archi and the EMF using the Eclipse IDE. Figure 6.6 illustrates the technologies used to configure the environment and deploy ArchiSmartCity. The main components are described as follows.

- **Archimatetool.editor.product:** This component contains the target platform to run or debug the Archi tool that provides the features of ArchiMate 3.0.1. It defines what plug-ins to include and exclude in the configuration.
- **Eclipse Modelling Framework (EMF) SDK:** This package provides a code generation facility for building ArchiSmartCity. The core of EMF contains the modeling framework and the infrastructure for code generation and manipulation of EMF models.
- **Graphical Editing Framework (GEF) SDK:** This package is used to define the graphical editor and visual interface for ArchiSmartCity. The editor created with GEF includes, among others, the following components: the diagram editor and its palette; figures which graphically represent the underlying ArchiSmartCity concepts; the EditParts which match figures and their respective ArchiSmartCity concepts.

Appendix E presents the screenshots of ArchiSmartCity implemented using the Archi Modelling Tool.

6.2 Implementation Summary

This chapter presents the implementation details of ArchiSmartCity in the form of an ArchiMate extension. We initially outlined the development phase of ArchiSmartCity by adopting a modelling method engineering approach. We mapped the ArchiSmartCity concepts into the ArchiMate metamodel before starting to develop the ArchiSmartCity modelling extension. The extension is then detailed by a diagram that illustrates the ArchiSmartCity concepts and how to relate them to the existing business, application, technology, and motivation concepts. The architecture of the ArchiSmartCity modelling extension and its components rely on architecture viewpoints (e.g., context, functional, and deployment models) to detail the implementation using the Eclipse Modelling Framework (EMF). The ArchiSmartCity is built in an iterative manner by using the feedback of Smart City domain experts during the validation and evaluation of the artefact, which will be provided in Chapter 7.

Chapter 7

Demonstration and Evaluation

Previous chapters introduced ArchiSmartCity design and implementation details. This chapter demonstrates and evaluates ArchiSmartCity, by presenting how it supports a suitable alignment between the service and information layers in Smart City architectures in order to answer RQ.3. This chapter is organised as follows: Section 7.1 outlines the phases to demonstrate and evaluate ArchiSmartCity. Section 7.2 demonstrates the use and application of ArchiSmartCity. This consists of two parts; the demonstration in the real-world by conducting multiple case studies and the demonstration and artificially evaluation of ArchiSmartCity by developing a computer-based solution for semantic alignment analysis. Section 7.3 presents the evaluation criteria and the evaluation results of ArchiSmartCity. It includes the assessment within the case studies and the validation of ArchiSmartCity by Smart City domain experts in order to corroborate our proposal. Triangulation is used in this research as a method to increase the reliability and validity of research findings. Finally, Section 7.4 summarises this chapter.

7.1 Demonstration and Evaluation Overview

A detailed outline of how we applied Design Science Research Methodology (DSRM) to this study is presented in Section 3.6 and depicted in Figure 3.1. This section presents the overview of the demonstration and evaluation phase of this thesis. The demonstration phase involves the demonstration in the real-world by conducting multiple case studies. The purpose and contributions of each case study during the different phases of DSRM are described as follows.

Limerick Case Study

The Limerick case study was conducted during both phases: *problem identification and motivation* and *demonstration and evaluation* of DSRM. The purpose and contributions of this case study during each phase are described as follows.

- ArchiMate models were designed and evaluated by asking the primary stakeholders (e.g., Smart City domain experts and data manager) for feedback on the designed artefacts. This helps to understand the current limitations of TOGAF and its ArchiMate language in practice and the need for the ArchiSmartCity concepts. Table 7.1 summarises the main findings of this evaluation. This practical application was conducted during the *problem identification and motivation* phase of DSRM (See Section 3.6.1).

- Design principles, design requirements, and the ArchiSmartCity concepts and relationships were evaluated (i.e., ex ante evaluation) by asking the primary stakeholders for feedback on their relevance for this domain. Section 7.2.3 presents a cross-case analysis that details the main results. Besides, data gathered during this case study was used in the validation of the semantic alignment analysis in Section 7.2.4. This demonstrates the practical relevance of our research proposal (e.g., design principles, design requirements, and the ArchiSmartCity concepts and relationships) during the *demonstration and evaluation* phase of DSRM (See Section 3.6.3).

Netanya Case Study

The Netanya case study was conducted during the *demonstration and evaluation* phase (see Section 3.6.3) of the applied DSRM. The purpose and contributions of this case study during this phase are described as follows.

- Design principles, design requirements, and the ArchiSmartCity concepts and relationships were assessed (i.e., ex ante evaluation) by asking the primary stakeholders (e.g., Smart City domain experts) for feedback on their relevance for this domain. Table 7.2 and Section 7.2.3 present the main findings of this evaluation. This helps to validate the design of the ArchiSmartCity metamodel.

- Data gathered during this case study was used in the validation of the semantic alignment analysis in Section 7.2.4. Additionally, The ArchiSmartCity metamodel was evaluated (i.e., ex post evaluation) by asking the primary stakeholders for feedback on the utility and quality of the designed artefacts. Section 7.3 details the main findings of this evaluation. This demonstrates the practical relevance and high-quality of our proposed ArchiSmartCity metamodel.

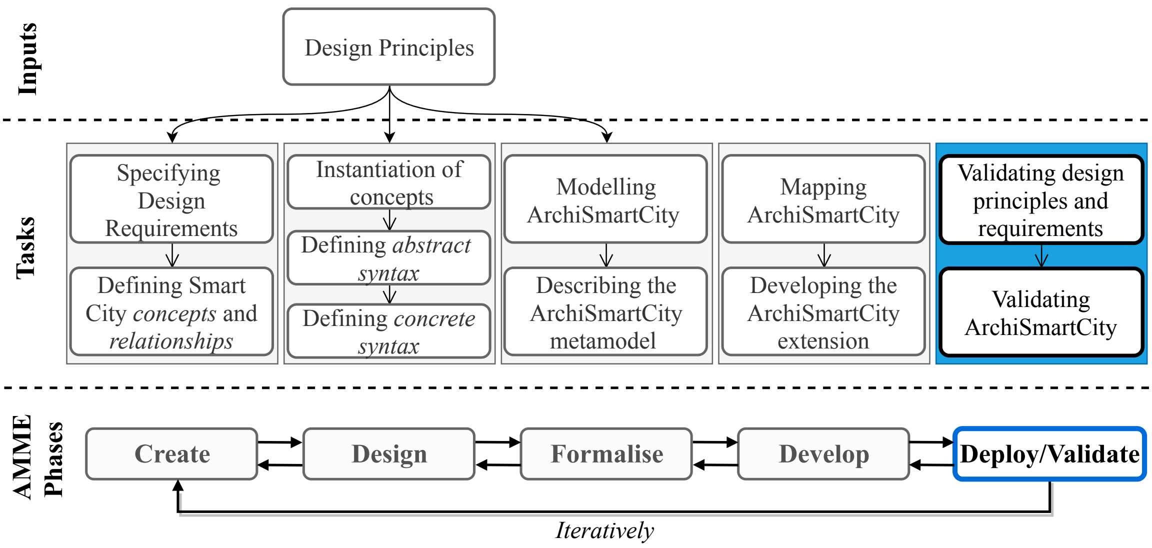


Fig. 7.1 ArchiSmartCity Metamodel Design and Construction Method. Validation Phase.

The demonstration phase also includes the demonstration and artificially evaluation of ArchiSmartCity by developing a computer-based solution for semantic alignment analysis. The evaluation involves the validation of ArchiSmartCity by Smart City domain experts in order to corroborate our proposal as presented bellow.

7.1.1 Phase V: Deployment and Validation

The evaluation involves observing and measuring how well the artefact supports the solution to the problem. It is necessary to decide whether to iterate back to the design phase and improve the effectiveness of the artefact or to move to communication (Hevner and Chatterjee, 2010a; Peffers et al., 2007). This chapter focuses on the evaluation and validation phase of ArchiSmartCity. Figure 7.1 illustrates the phases and tasks that this thesis follows to evaluate the metamodel. This process utilises the Agile Modelling Method Engineering (AMME) (Visic et al., 2015). The deployment and validation phases involve the stakeholders who evaluate the metamodel and the results are then fed back into the next iteration. We conduct multiple case studies to evaluate and demonstrate the applicability of ArchiSmartCity in the real world. We evaluate the metamodel with Smart City domain experts. The next sections present the demonstration and evaluation of the final artefact.

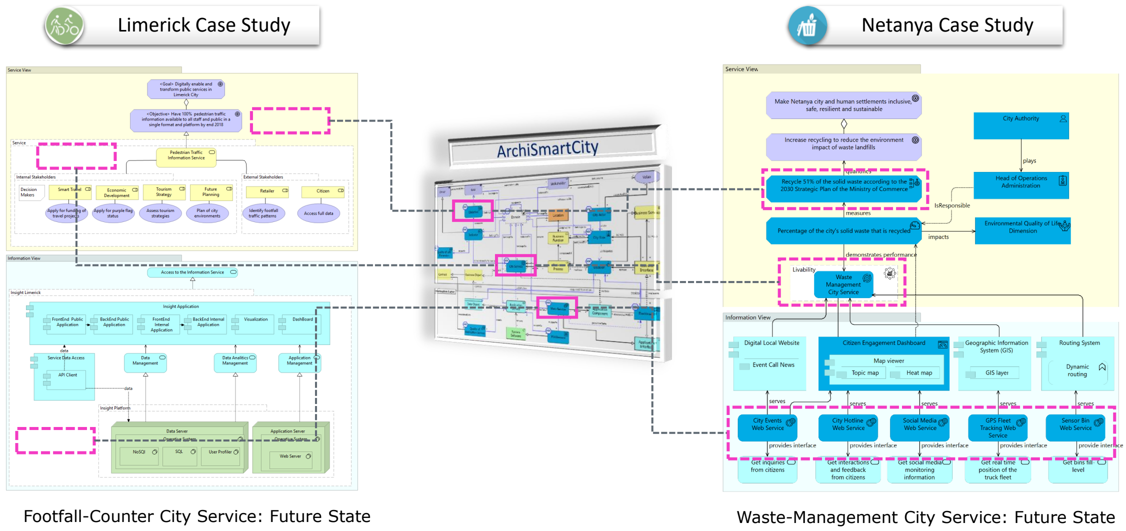


Fig. 7.2 Replication Logic Across Case Studies in this Thesis.

7.2 Demonstration

This study demonstrates the use and application of the artefact in the real-world by conducting multiple case studies. The demonstration consists of an iterative process by observing and measuring how well the artefact supports the solution to the problem within the case studies. The case studies were conducted in Limerick City and County Council in Ireland, and Netanya Municipality in Israel. Data collected from the case studies were used to demonstrate the ArchiSmartCity metamodel using semantic alignment analysis.

The *Limerick Case Study* focuses on the design of an EA solution for a footfall-counter city service, including the improvement of smart travel initiatives for cycling and walking in the city. The *Netanya Case Study* focuses on the design of an EA solution for a waste-management city service, including the improvement of the recycling and dynamic adaptation of routes during the garbage collection activity. Figure 7.3 illustrates the replication logic used across the cases to replicate the findings, following (Runeson and Höst, 2009; Yin, 2014). In the *Limerick Case Study*, we identified the concepts needed to support the alignment by modelling the city service using ArchiMate. This helps us to evaluate the designed artefats with the practitioners, understand the limitations of the ArchiMate language, and identified the ArchiSmartCity concepts and relationships needed in this field. The identified ArchiSmartCity concepts and relationships from the *Limerick Case Study* were used to frame and desing the solution in the *Netanya Case Study* by instantiating our developed ArchiSmartCity metamodel. Each case study is detailed in the next sections.

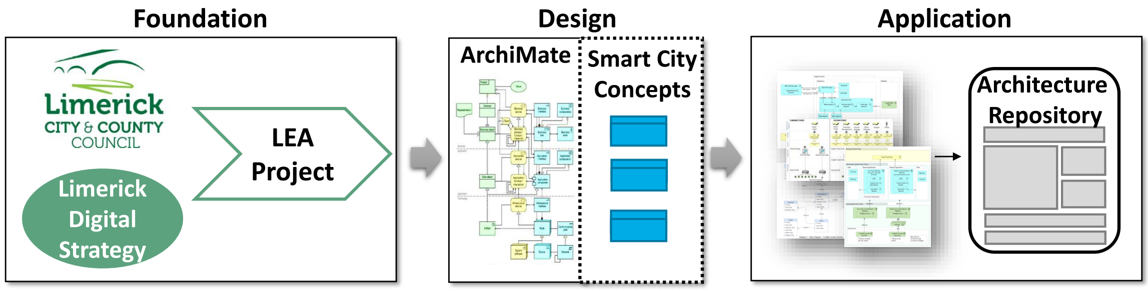


Fig. 7.3 Limerick Enterprise Architecture Project.

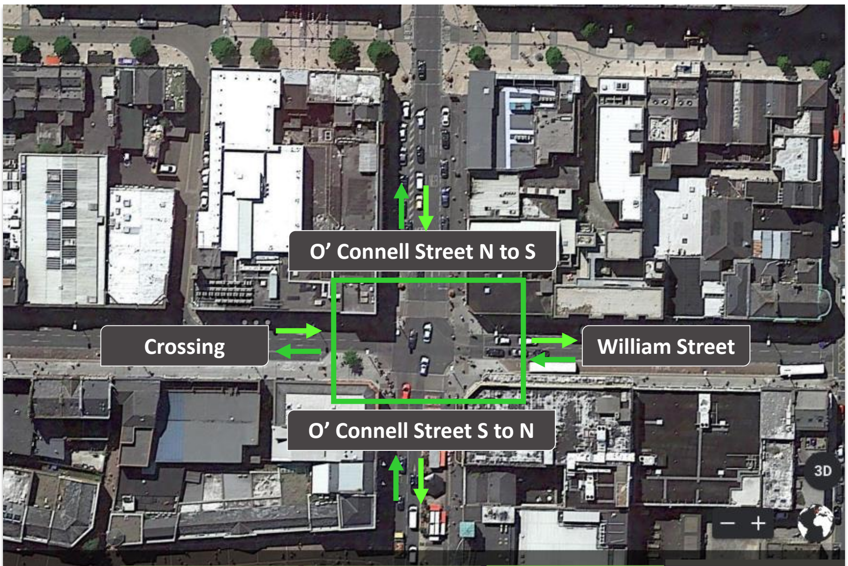
7.2.1 Limerick Case Study

Limerick Smart City Overview

Limerick is a city in the County of Limerick, Ireland. It is situated in the Mid-West Region of Ireland with a population of approximately 94,192 residents, making it the third-largest city in Ireland. The city of Limerick covers a total area of 59.2 km2 (22.9 sq mi). This area brings the population density to 1,591 residents per square kilometer (4,120 residents per square mile). Limerick has held the title of European Lighthouse Smart City. It has a digital strategy (Limerick City and County Council, 2017) that defines a road map of initiatives to create better services and accelerate sustainable, social and economic growth. Limerick digital strategy aims to support the digital transformation and innovation of public services aligned to the needs of the citizens by using digital technologies. This strategy defines a set of six Smart Limerick domains needed to describe and improve public services from various perspectives, including (1) Economy & Innovation, (2) Community & Citizenship, (3) Culture & Entertainment, (4) Movement & Transport, (5) Urban Places & Spaces and, (6) Environmental Practices.

Limerick Enterprise Architecture

Limerick Enterprise Architecture (LEA) is the adoption of Enterprise Architecture (EA) best practices to provide a set of EA guidelines for any local government-related project in Limerick. We developed the LEA project that focuses on different Case Studies to illustrate how EA can be applied to add value to the services of Limerick City and County Council. Figure 7.3 illustrates the foundation, design, and application of the LEA project. The *Foundation* comprises the Limerick digital strategy which presents the Smart City goals, principles, and initiatives such as the footfall-counter city service. The *Design* involves the modelling of architecture diagrams by using the ArchiMate language following the TOGAF Architecture Development Method (ADM). The *Application* includes the creation of the



Entries	**Crossing** 1,887	**O'Connell N to S** 1,983	**O'Connell S to N** 2,641	**William St. to OC** 1,664
Exits	**Crossing** 1,972	**O'Connell N to S** 1,454	**O'Connell S to N** 2,094	**William St. to OC** 1,517

Fig. 7.4 Limerick Footfall Counter City Service.

Architecture Repository of Limerick City and County Council which holds information concerning the EA models. With this project, we developed the foundations for “Insight Limerick” – the portal for information sharing, open data, data visualisation, and analytics to gain insights leading to value-added services. The use of TOGAF and its modelling language ArchiMate during the project allows us to identify and validate the concepts of Smart Cities that support the alignment between the service and information layers in Smart City architectures.

Footfall Counter City Service

A footfall counter service is selected for this case study because measuring footfall is one of the major indicators of urban and rural activity and the success of initiatives and events. This city service belongs to the Movement & Transport domain of Limerick City. It provides information about the number of people in various places of interest in Limerick City and its rural areas. The main stakeholders of this service belong to the smart travel department of the city council. They use this information to make informed decisions related to the planning of the city environments and the improvement of smart travel initiatives (e.g., cycling and walking). Limerick City was awarded the Purple Flag, an international accreditation for towns and city centres in the evening and at night-time, as a result of the practical application of this data. Purple Flag areas report a steady rise in footfall within the evening and night-time economy. Limerick City implemented a pilot solution for the footfall-counter service. Figure 7.4 depicts a map of Limerick City centre where a footfall counter is installed at the main intersection between O'Connell Street and William Street. There are Exits and Entries on each side of the counting zone. North, in this case, is at the top of the image. For example, O'Connell St N to S entries are people entering the zone from North towards South. However, the collected data is only available from the cloud platforms of the service providers with limited access and formats. This causes data and application silos due to the lack of access to the collected data by the main stakeholders of the service.

As part of the future state of the service, Limerick City needed to deploy new footfall counters and cycling counters that gather pedestrian mobility data in the city. The main stakeholders of the future city solution are internal stakeholders working in different departments of the city council, including the smart travel department, tourism strategy department, forward planning department, and the economic development department. Furthermore, this city service involves external stakeholders outside the city council such as retailers and citizens. Historical and real-time information of footfall-counters for pedestrians and cyclists must be available in an integrated environment. The baseline and the target architecture of this footfall-counter service are modelled and described in this case study.

Data Collection and Data Analysis

A major strength of case study data collection is the opportunity to use different sources of evidence (Yin, 2014). We collected the data for the case study using a direct method and independent analysis (Runeson and Höst, 2009). This study is based on two principal data sources, namely meetings and secondary data. First, a total of 18 meetings were held as evidence of the current and future state of the footfall-counter service in Limerick City and County Council, between April 2017 to October 2018. The people involved played various roles in the LEA project implementation from the start to the end of the project. The meetings ranged from 45 minutes to 90 minutes and the questions were developed in line with the purpose and scope of each stage of the service design. These meetings were documented and stored in a repository for data analysis. Among the participants of the meetings are: the head of digital strategy, the data manager, and the senior managers of the city council departments involved in the Smart City initiative. The first meeting was conducted with the head of the digital strategy and the data manager. They expressed the main objectives of the LEA project and the relevance of applying EA to deliver services that meet the needs of citizens. This meeting facilitated having an overview of the LEA project and its activities during the time-line.

After the first meeting, the footfall-counter service was selected, according to the criteria and priorities of the city council. The data manager supported the selection of key stakeholders of this service inside of the council. These stakeholders were also identified to understand the need for the information collected from the service and the value of applying EA. Secondary data refers to data sources such as internal documents (e.g., Limerick digital strategy), reports, and deliverables published in an internal document repository in the council. Service providers were contacted at one stage of the project. They provided information (e.g., technology advice, service solutions brochures, and quotations), which was also included as part of the secondary data. The identification of the meetings was made manually, using a unique text identifier with the corresponding date. We began the analysis process by coding the concepts found in the literature in parallel to the case study regarding the three main findings of this research: (1) codes related to the design principles; (2) codes related to the design requirements; and (3) codes related to the concepts and relationships to support the alignment. We follow an inductive and iterative process of reading and reviewing in detail the different data sources to assign the information analysis units to the identified coding concepts (Hancock and Algozzine, 2017).

The design strategy was to organise the case study according to the different phases of the TOGAF ADM (The Open Group, 2018) based on the data collected. In particular, the architecture vision and the design phases of the TOGAF ADM were selected to illustrate the evolution of a baseline to a target architecture of the footfall-counter service. The design phases of the TOGAF ADM include the business architecture, information systems architecture, and technology architecture which provide the basis for further implementation of the service. The architecture design of the footfall-counter service comprises documenting the architecture by using the ArchiMate Language. The models are created and validated in an iterative manner by asking the primary stakeholders for feedback on the designed models.

Limerick Enterprise Architecture Models

Limerick City decided to develop an EA based on the specifications: TOGAF 9.2 (The Open Group, 2018) and ArchiMate 3.0.1 (The Open Group, 2017). The application of a modelling technique through constructions of architecture models helps to represent a holistic and multi-dimensional view of the footfall-counter city service. The artefacts and their purpose of use are presented for each phase of TOGAF ADM (e.g., Requirements Management and Phases A, B, C and D). Each iteration of the TOGAF ADM facilitates the addition of resources to the Architecture Repository of the project. The main architectural artefacts are described and modelled as follows.

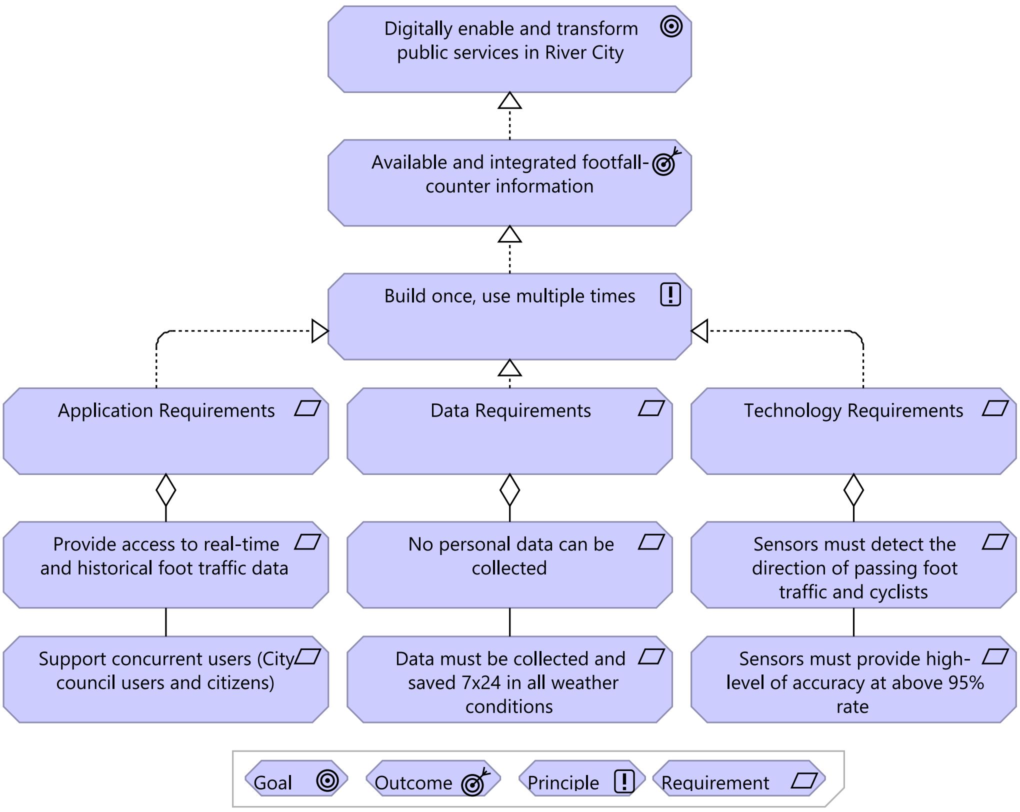


Fig. 7.5 Limerick Case Study. Motivation and Requirements View.

- **Requirements Management:** This phase defines a process for identifying, storing, and assigning the footfall-counters requirements to the business, application, and technology phases. A requirements catalog summarises all the gathered requirements from different stakeholders. We developed a procurement guideline based on the identified requirements in order to conduct an appropriate procurement process. Such a guideline is used to invite service providers to a bidding request for the supply of new traffic counters for pedestrians and cyclists. Figure 7.5 illustrates the motivation and requirements view in Limerick City. It presents how the goal: "Digitally enable and transform public services in Limerick City" is realised by the outcome: "available and integrated footfall-counter information". This outcome is defined according to the Limerick digital strategy principle: "Build once, use multiple times". This principle defines that in the implementation of smart initiatives, "duplication will be avoided in order to avoid inefficient use of resources, silo approaches and missed opportunities to improve current capabilities". This principle is realised by identified requirements at the application, data, and technology levels.

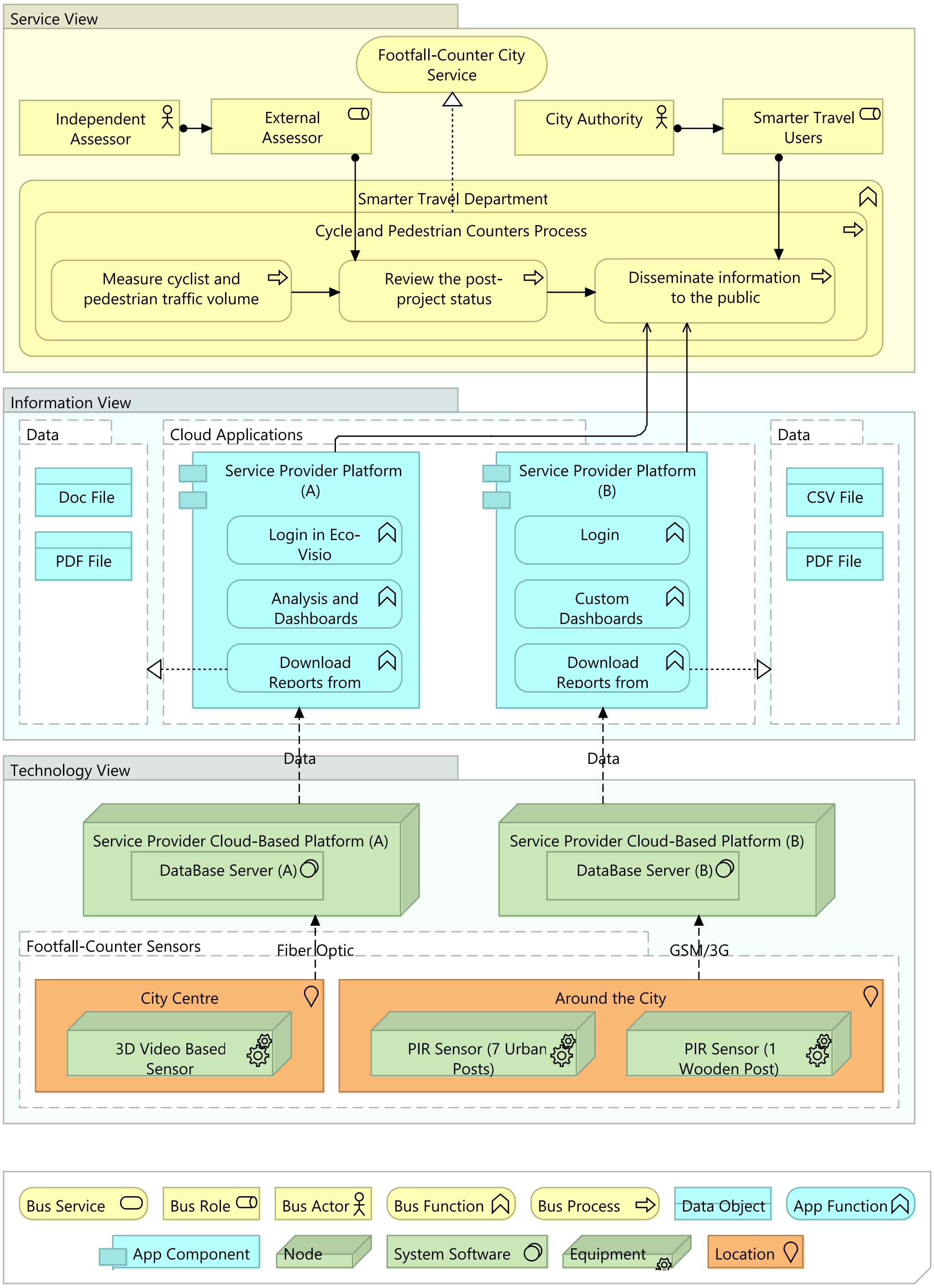


Fig. 7.6 Limerick Case Study. Solution Concept Diagram (Baseline Architecture).

- **Phase A - Architecture Vision:** This phase develops a high-level description architecture that will be delivered as a result of the future solution for the footfall-counter city service. A baseline solution architecture is presented to understand the current

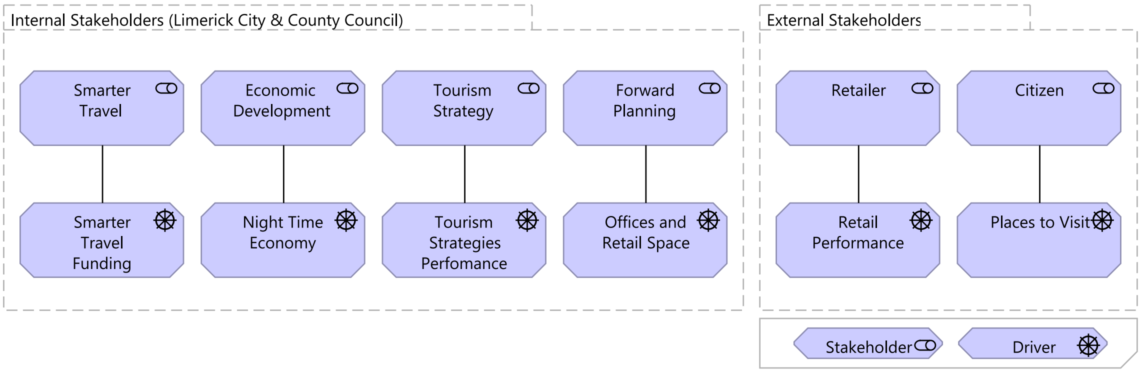


Fig. 7.7 Limerick Case Study. Stakeholders Map View.

issues of the pilot solution. The main stakeholders and their concerns are identified in this phase. Moreover, a target solution architecture is specified to respond to new requirements and address current issues.

- **Solution Concept Diagram (Baseline Architecture):** A solution concept diagram illustrates concisely the major components of the architecture. Figure 7.6 depicts the solution concept diagram of the baseline architecture represented through the service, information, and technology views. The service view presents the footfall-counter city service and its end-users. The information view presents the software platforms provided by two different service vendors. Both software platforms allow users to authenticate in the system, configure the dashboards, and download the data in different formats (e.g., doc, pdf, and csv). The technology view presents the hardware and software infrastructure to sense pedestrian and cyclist data from different city locations. In total, there are nine (9) sensors deployed in the city, one (1) in Limerick City centre and eight (8) around the city. These sensors use 3D video-based and passive infrared (PIR) technologies. This architecture model shows how each user downloads information from diverse sources with different data formats. Information is not adequately shared but rather remains stored independently within each system, resulting in data and application silos. This causes stakeholders not to perceive the real value of the footfall-counter city service.
- **Stakeholders Map View (Target Architecture):** Limerick City aims to provide the footfall-counter service to a wide range of users in the city. Figure 7.7 shows the stakeholders map organised in two groups: internal stakeholders and external stakeholders. Internal stakeholders belong to different departments within the city council (e.g., smart travel, economic development, tourism strategy, and

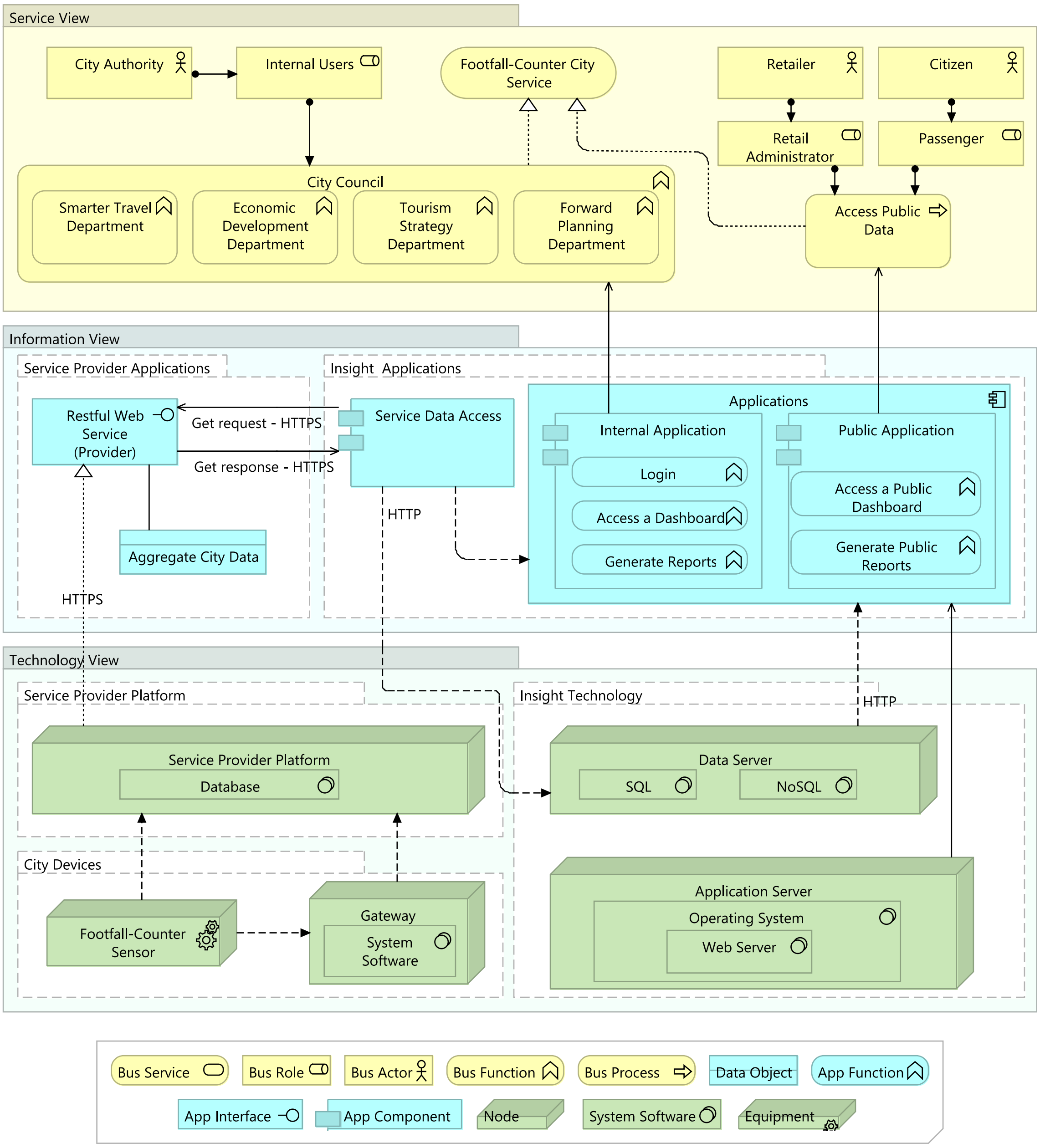


Fig. 7.8 Limerick Case Study. Solution Concept Diagram (Target Architecture).

forward planning). External stakeholders refer to stakeholders outside of the city council (e.g., retailers and citizens). The concerns of those stakeholders are modelled as drivers. For example, "Smarter Travel" stakeholders should identify the number of people who use bicycles to justify and request funding for smart travel projects.

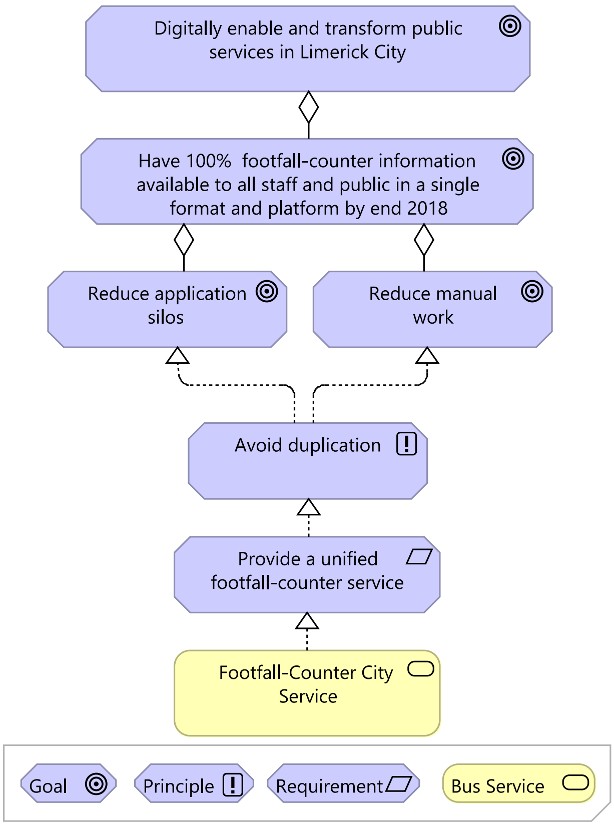


Fig. 7.9 Limerick Case Study. Goal Realisation View.

– **Solution Concept Diagram (Target Architecture):** Figure 7.8 presents a structured overview of the target architecture, using a layered solution concept diagram. One of the main objectives of the target architecture is to avoid data and application silos while providing accurate real-time and historical information. The target architecture entails models and concepts that are specified in the service, information, and technology views. The service view presents the main actors (e.g., city authorities, retailers and citizens) and their roles, and the departments within the city council that will use the footfall-counter service. The information view presents the application programming interfaces offered by the service providers in order to access data collected by the footfall-counter sensors. Insight Applications (i.e., applications deployed in the city council) comprise the service clients and software applications (e.g., internal and public applications) to retrieve and visualise the collected data. Restful Web Services encapsulate the data provided by service vendors. The technology view presents the hardware

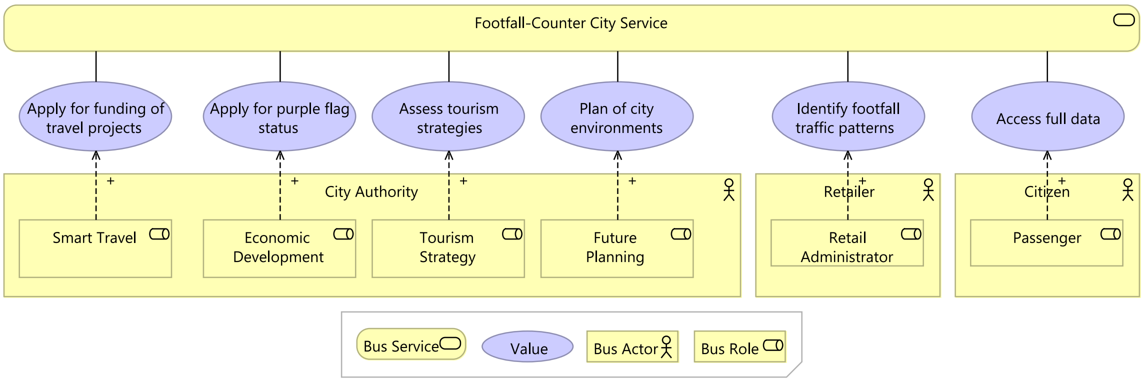


Fig. 7.10 Limerick Case Study. Value Stream View.

and software infrastructure to gather pedestrian and cyclist data. Data can be transmitted directly from the sensor to a provider database or to a gateway.

- **Phase B - Business Architecture:** The Business Architecture Phase aims to develop a target business architecture to describe how to achieve the business goals and respond to the strategic drivers that support the Architecture Vision. Business catalogs, matrices, and models were developed to demonstrate the applicability of TOGAF ADM within the LEA project. Architecture views are modeled to support the target architecture of the footfall-counter city service. The main architecture artefacts are outlined as follows.

  – **Goal Realisation View:** Figure 7.9 illustrates the goal realisation view of the footfall-counter city service represented by a business service. This model describe how the city service contributes to the achievement of the city vision and strategy. This helps Limerick City to understand how services contribute to similar aspects of city performance. This architecture model refines the high-level goals of the Limerick digital strategy into more tangible goals and the refinement of these tangible goals into the principles and requirements to realise the goals.

  – **Value Stream View:** Figure 7.10 represents the value stream view to show how the footfall-counter service creates the value that is exchanged with the main stakeholders (e.g., city authorities, retailers and citizens). Limerick City uses the value stream to analyse the delivery of value within the scope of the project. This helps to better support the development of new solutions in later phases, focusing on all the city stakeholders and the value generated for them.

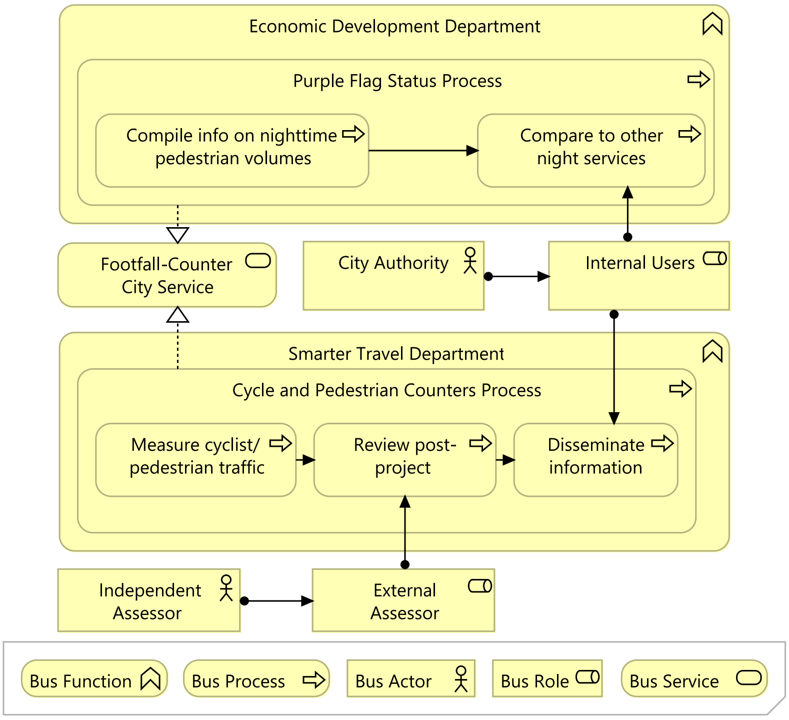


Fig. 7.11 Limerick Case Study. Business Process View.

– **Business Process View:** Figure 7.11 shows a business process view, identifying the "Economic Development Department" and "Smarter Travel Department" inside of the city council represented by business functions and their key activities. The business process describes the flow of the structured activities which provides the city service in a specific sequence. Limerick City uses the business processes model to provide any city authority with insight into the business functions (i.e., city council departments), their processes, and shared city services.

- **Phase C - Information Systems Architecture:** The Information Systems Architecture Phase enables the architecture vision and target business architecture to address the stakeholder concerns. Phase C comprises the combination of both data and application architectures. Matrices (e.g., Data Entity - Business Function matrix), and diagrams (e.g,. Class diagram, Application Communication diagram, System Use Case diagram, Entity Relationship diagram) were develop to demonstrate the applicability of TOGAF ADM within the LEA project. The following architecture models are presented to address the major challenges in Limerick City regarding data and application integration.

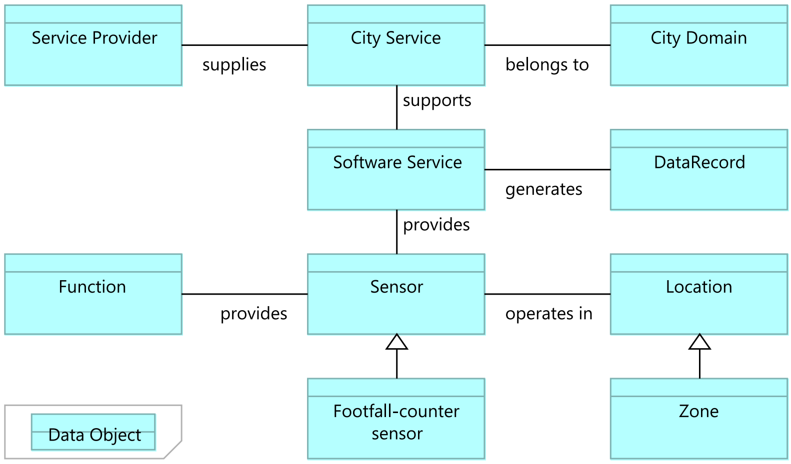


Fig. 7.12 Limerick Case Study. Data Objects View.

- **Data Objects View:** Figure 7.12 illustrates a data objects view to represent the relationships between data objects involved in the footfall-counter city service. For example, the "Sensor" data object is linked to the "Location" data entity through the relationship "operates in". This architecture model helps to derive and define service application components, services data exchange, and repository data schemas.
- **Application Communication View:** Figure 7.13 depicts application components and interfaces between Web Services offered by service providers and the application components deployed in the city council. The purpose of the model is to show the architecture models in relation to communication between applications. Restful Web Services expose the API from the application in a secure and uniform manner to the calling client. APIs enable interaction between data, applications, and devices and are associated with HTTP clients to support data integration in Limerick City.

• **Phase D - Technology Architecture:** This phase enables the architecture vision, business architecture, and information systems architecture to be delivered through technology components and technology services. Matrices (e.g., Application/Technology matrix) and diagrams (e.g., Environments and Locations diagram) were developed to demonstrate the applicability of TOGAF ADM within the LEA project. The following architecture model is designed to support the collection of pedestrian and cyclist information and analyse the implications on the technology components and services.

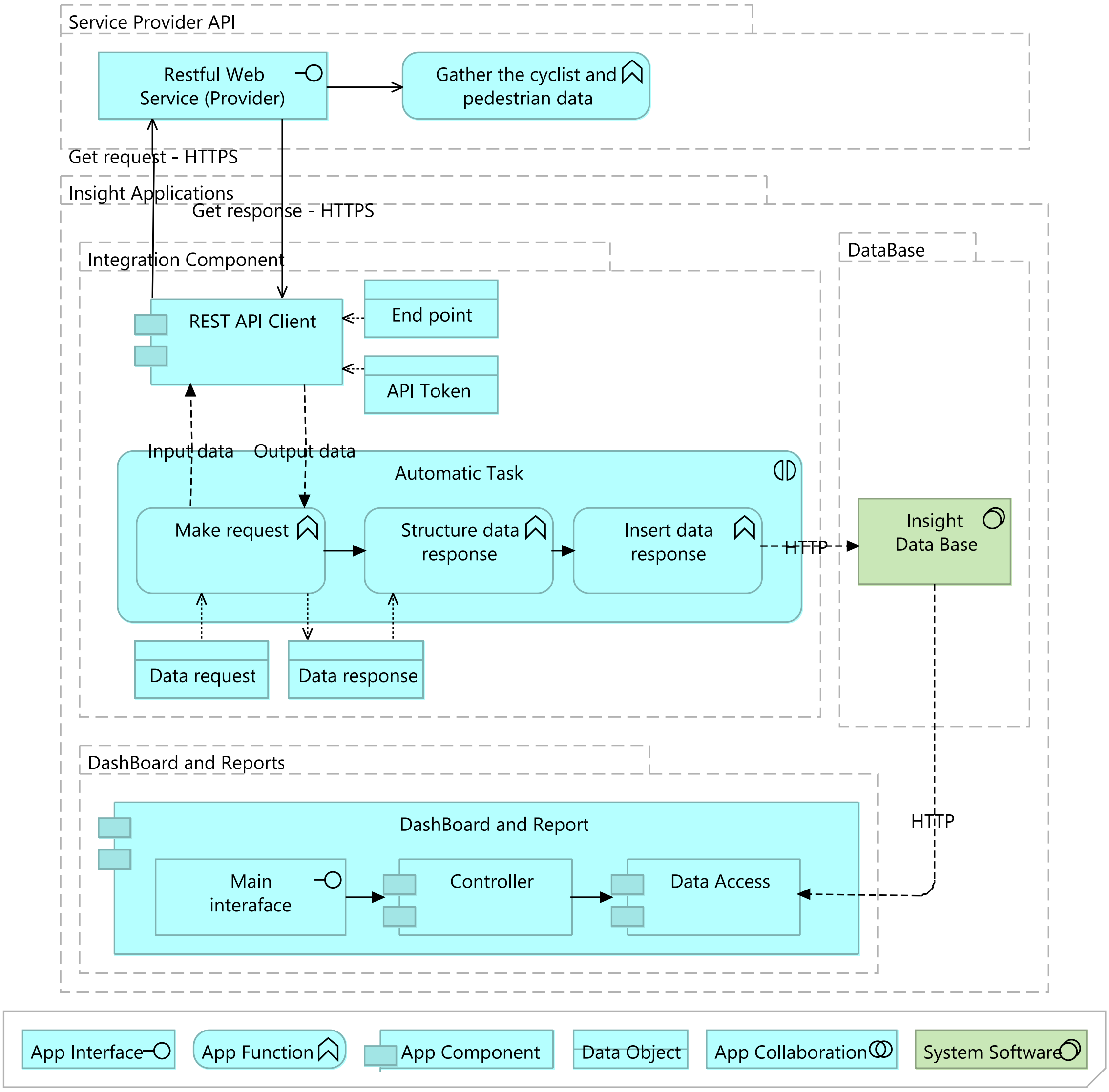


Fig. 7.13 Limerick Case Study. Application Communication View.

– **Environments and Locations View:** Figure 7.14 illustrates the environments and locations view. It shows the physical devices (e.g., footfall-counters) and technologies (e.g., 3D video-based technology) used in each location. The purpose of this model is to represent in which locations of the city the sensors will be deployed. The technology of the sensors in each location is selected according to the physical characteristic of the place, i.e., sensors must be non-intrusive, suitable for the urban location, and must not be influenced by weather conditions. The collected information will be stored in a centralised data base in the city council.

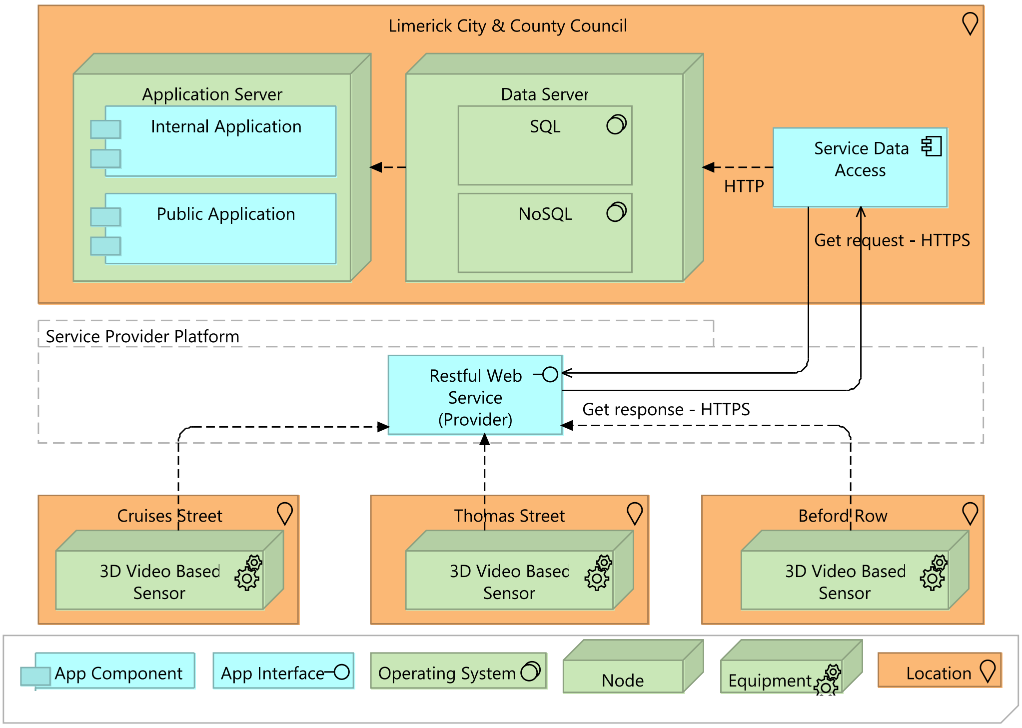


Fig. 7.14 Limerick Case Study. Environments and Locations View.

Conclusion

We conducted the Limerick case study to explore the concepts that would support a suitable alignment between the service and information layers in Smart City architectures. This helped us to validate our findings in parallel to the literature review. This case study also presents the problems and issues of managing and modelling such alignment in a real-world city.

The application of a modelling technique through the constructions of architecture models helps us to represent a holistic and multi-dimensional view of the footfall-counter city service. Each iteration of the TOGAF ADM facilitates the identification of the concepts of the Smart City architectures, focusing mainly on the service and information layers. Table 7.1 presents a comparison between the concepts of ArchiSmartCity (see Chapter 5), TOFAF ADM, and its representation in the ArchiMate Models of this case study. Each row cell in the column "LCS" filled with a ✓indicates the need for the concept in the Limerick Case Study. Each row cell in the column "TOGAF ADM Concept" is filled in with either the TOGAF concept or an ✗, indicating the existence/non-existence of a similar concept in TOGAF. Each row cell in the column "ArchiMate Models" is filled in with either the ArchiMate concept or an ✗,

Table 7.1 Limerick Case Study (LCS)

ArchiSmartCity Concept		LCS	TOGAF ADM Concept		ArchiMate Models
Service	Domain	✓	Business	✗	✗
	Goal	✓		Goal	Goal
	Objective	✓		Objective	Goal
	Indicator	✓		Measure	✗
	Quality of Life Dimension	✓		✗	✗
	City Service	✓		✗	Business Service
	City Actor	✓		Actor	Business Actor
	City Role	✓		Role	Business Role
	Decision	✓		✗	✗
Information	Dashboard	✓	IS	✗	Application Component
	Application Service	✓		IS Service	Application Service
	Quality of Application Service	✓		✗	✗
	Web Service	✓		✗	Application Interface
	Middleware			✗	✗
ArchiSmartCity Relationships		✓		✗	✗

Legend: ✓- Required in the Case Study ; ✗- No Defined

indicating the presence/no presence of the ArchiMate concept to create the models during the service design.

TOGAF defines a business architecture to describe how to achieve business goals and respond to the strategic drivers (The Open Group, 2018). In Limerick City, the digital strategy contains the main motivations, goals, objectives, principles, indicators, and initiatives to become a Smart City. Smart City authorities in Limerick recognises that it is necessary to establish a link between its digital strategy and our proposed Enterprise Architecture (EA). TOGAF assists in the establishment of this relationship, however, particular concepts of Smart Cities need to be defined in the architecture. For example, the footfall-counter service belongs to the "Movement and Transport" domain, but neither TOGAF nor ArchiMate provides concepts to represent it. All city services and solutions in Limerick must be related to the domains to identify and integrate systems and to enhance decision-making processes from different domains. The modelling of city goals, for instance, provides qualitative input on what constitutes high performance for this city service in alignment with the Limerick digital strategy, but not quantitative input associated with objectives and indicators. Although TOGAF proposes different elements at the business architecture (e.g., goals, objective, and measure), it does not explicitly determine the connection of such business concepts with application concepts and there are no architectural artefacts in the TOGAF ADM Phases able to represent it. In addition to this, ArchiMate lacks expressiveness to represent these objectives and indicators. On the other hand, the Business Architecture of TOGAF focuses on business motivations and operations, but Smart Cities have a service orientation, mainly centered on city services and the needs of citizens. TOGAF and ArchiMate focus on the specification and representation of business motivations and operations. Smart cities have a service orientation and are focused on city services and needs of citizens. There are no specific concepts to represent city services in TOGAF and ArchiMate.

This case study shows that traditional EA layers (e.g., business, information systems, and technology) are suitable for structuring an EA for Smart Cities but not optimal for this purpose. More refinement layers are required, e.g., by identifying city services which operate differently. Citizen needs should be considered as one of the central aspects when refining architecture layers, as the point of view of citizens is crucial for Smart Cities (Pereira et al., 2018). Our observations during the design suggest that there is a need for ArchiSmartCity concepts (e.g., objective, indicator, quality of life dimension, web service, dashboard, etc.) in order to express the strategic alignment between city services and the underlying information systems in the Smart Cities domain.

This case study also presents the problems and issues of managing the alignment in Limerick City. In the public sector, it is possible to have duplicated efforts, objectives, and implementation options of the same initiatives (Tammel, 2017). In this case study, we observe how software applications that support a city service were duplicated, increasing the cost to manage the applications and the difficulty of using several platforms. This case study demonstrates that the alignment of services and information is necessary since an early stage of design to avoid significant duplication of costs and effort, incompatible systems that generate information silos and that limit the ability of city council functional departments to collaborate in service provision. Limerick City developed a dashboard for making footfall data available on the Insight Limerick website based on the Architecture Repository created and the advice provided during the LEA project.

7.2.2 Netanya Case Study

Netanya Smart City Overview

Netanya is an innovative Israeli Smart City of about 250 thousand people (8th largest city in Israel) covering a total area of 35,000 square kilometers. Netanya is situated along the Israeli shore and has approximately 70,000 housing units and 1.2 million square meters built in industrial and business parks. The Smart City project is a paramount aspect of the policy of Netanya, as part of the desired development. In this sense, Netanya is required to progress in many areas, such as strategy, organisational culture, intraorganisational processes,

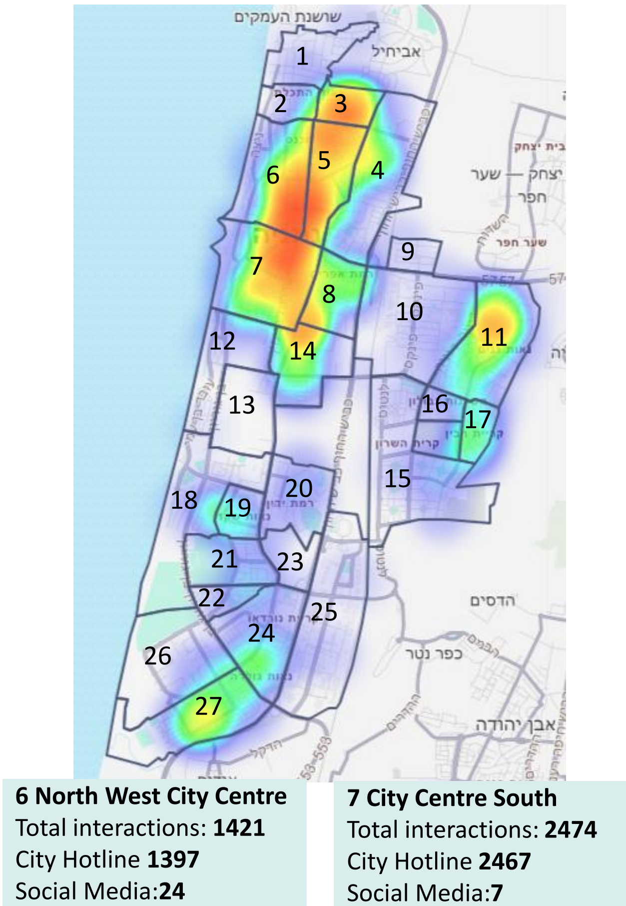


Fig. 7.15 Netanya Citizens Interactions per Neighbourhood. Waste Management City Service.

information systems, technologies, and services, particularly digital services for its residents. Netanya has set a goal of being a resident-centric city, by analysing the needs of the residents and investing in different platforms to improve their quality of life, while making the maximum use of ICT to improve the management, operation, and control of a variety of systems and services. Netanya has, among others, the following Smart City Initiatives: experimenting SKYTran, Car2Go, Netanya 3D city model, traffic lights control, natural hazards predictions, and citizen participation based on Artificial Intelligence (AI).

Waste Management City Service

We explored a waste management service in Netanya because the efficient management of waste has a significant impact on the environment thus on the health of citizens and their quality of life (Pérez González and Díaz Díaz, 2015). Waste management involves not only the collection of the waste in the field but also the recycling, transport and disposal to the appropriate locations (Anagnostopoulos et al., 2017). Netanya serves 27 neighbourhoods and collects 134,342.05 tons of solid waste produced per year in the city. On a daily basis, the municipality of Netanya uses 25 trucks with a capacity of 4 tons per truck. In accordance with the national waste management regulations, Netanya municipality recycles 17.61 percent of municipal waste produced in the city (e.g., organic, paper, plastic and glass) that corresponds to 23,653.7 tons of waste per year. The recycling target in the Strategic Plan 2030 of the Ministry of the Interior is 51 percent of waste recycled.

Netanya municipality tracks the resident feedback in real-time and over time to understand the needs of residents and the impact of different city initiatives. A dashboard aggregates different data sources from external and internal channels such as social media and the city hotline. The system runs a sentiment analysis algorithm to determine if the data reflects positive, negative, or neutral feedback on several city services. Figure 7.15 presents a series of interactions on the waste management service that help Netanya city to visualise localised problems by neighborhood. Most of the interactions from residents (e.g., city hotline and social media) are in the city centre (e.g., neighbourhoods 6,7), where there is also a negative feedback related to the garbage collection (red color).

Netanya city managers plan the future state of the service by digitising certain activities that impact garbage collection in order to solve this problem and improve the service: (1) in the recycling of the garbage from the production source during the recycling activity, (2) in the dynamic adaptation of routes that affect the collection of waste. For this purpose, we model waste management as a city service on top of information systems in the city. Specifically, we instantiate *ArchiSmartCity* by designing a solution for the waste management service, focusing on the alignment of city services and information systems. All the resulting models are validated by asking the primary stakeholders for feedback during the design process.

Data Collection and Data Analysis

The case study was selected because of the importance of the link between waste management services and information systems to enable city authorities and a wide range of stakeholders to develop environmentally urban planning systems (Cheela and Dubey, 2019). The data of the case study is collected by using a direct method and independent analysis (Runeson and Höst, 2009). This study is based on two principal data sources, namely interviews and secondary data. First, we conducted semi-structured interviews with various stakeholders, including the Smart City and digital domain manager, GIS manager, and waste management process owner in Netanya municipality. A total of 8 interviews were conducted as evidence of the current and future state of the waste management service in Netanya municipality, between April 2019 to December 2019. The interviews ranged from 60 minutes to 120 minutes and the questions were developed in line with the purpose and scope of each stage of the service design. These interviews were transcribed and stored in a repository for data analysis.

Secondary data refers to data sources such as internal documents (e.g., organisation structure and city dashboard reports) and the official municipality website, which are also used to acquire more information on the waste management service. This information was checked for relevance and accuracy with the local waste management process expert in Netanya municipality. We followed an inductive and iterative process of reading and examining the transcriptions and the secondary data to assign the information analysis units to the coding concepts (Hancock and Algozzine, 2017): (1) codes related to the design principles; (2) codes related to the design requirements; and (3) codes related to the concepts and relationships to support the alignment. We instantiate the ArchiSmartCity metamodel to design architecture models specific to the case study based on the analysed data. The models are created and validated in an iterative manner by asking the primary stakeholders for feedback on the designed models.

Modelling - Instantiation of ArchiSmartCity

We develop the architecture models of Netanya to represent a holistic and multi-dimensional view of the waste management city service. We design architecture models conforming to the *ArchiSmartCity* metamodel for this case study. We organise the models according to the Enterprise Architecture (EA) realisation levels from top to bottom, starting from the service layer followed by the information systems implementation details. A top-down approach to design EAs assumes a comprehensive scope and strictly follows a formal process that is influenced by strategic goals and requirements (Langenberg and Wegmann, 2004; Peristeras and Tarabanis, 2000). The *ArchiSmartCity* models created for the case study are outlined as follows.

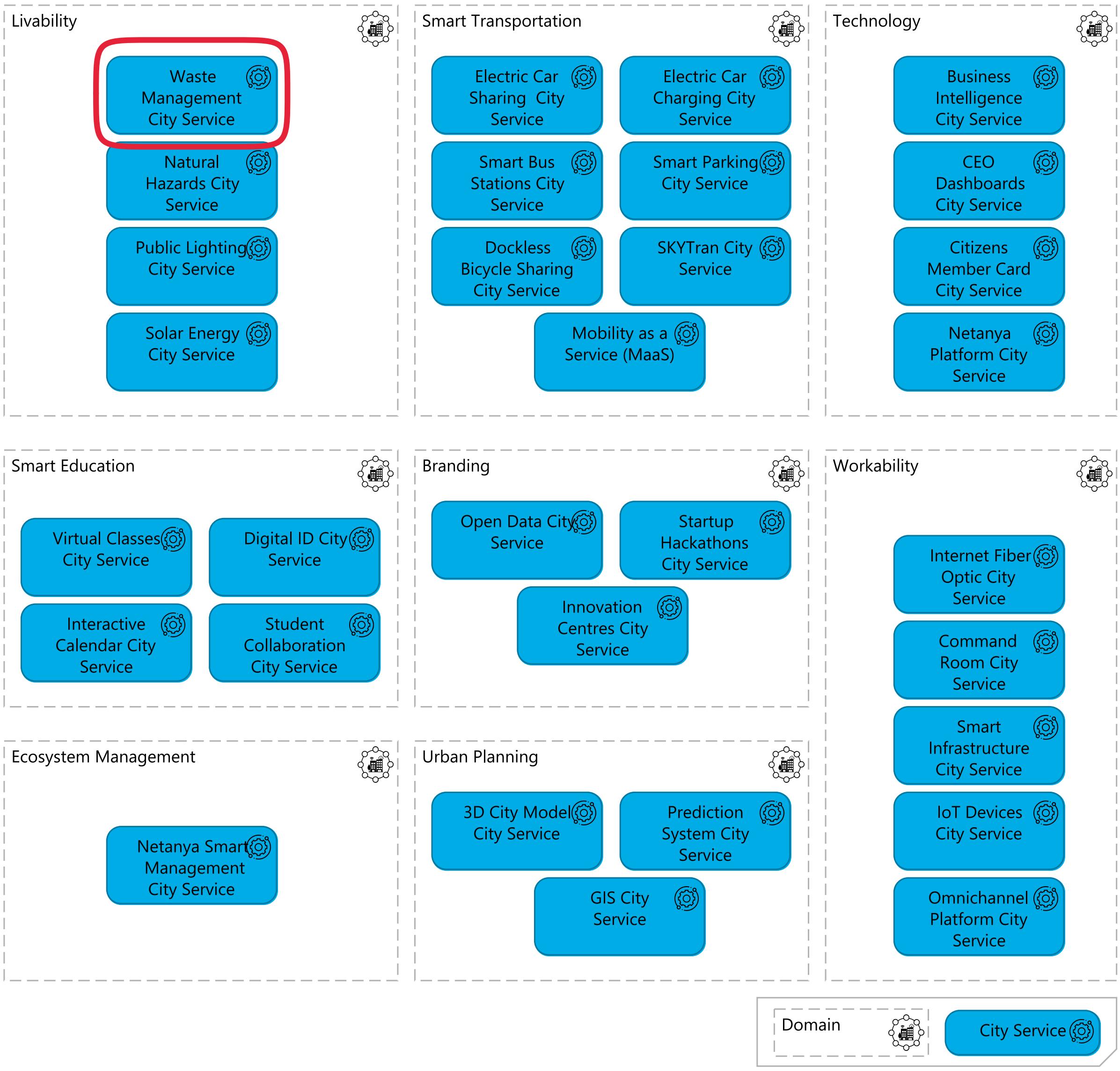


Fig. 7.16 Netanya Case Study. City Service Portfolio View.

- **City Service Portfolio View:** Figure 7.16 illustrates an *ArchiSmartCity* view to represent the city service portfolio of Netanya Municipality. It allows Smart City managers and architects to create an overview of the domains and related city services. This view is used as a heat map to identify areas of current work, associated issues, and future development. The "Waste Management City Service" that belongs to the "Livability" domain is highlighted as an area of current work. This view is also used to identify the relationships across city services from the same or different domains.

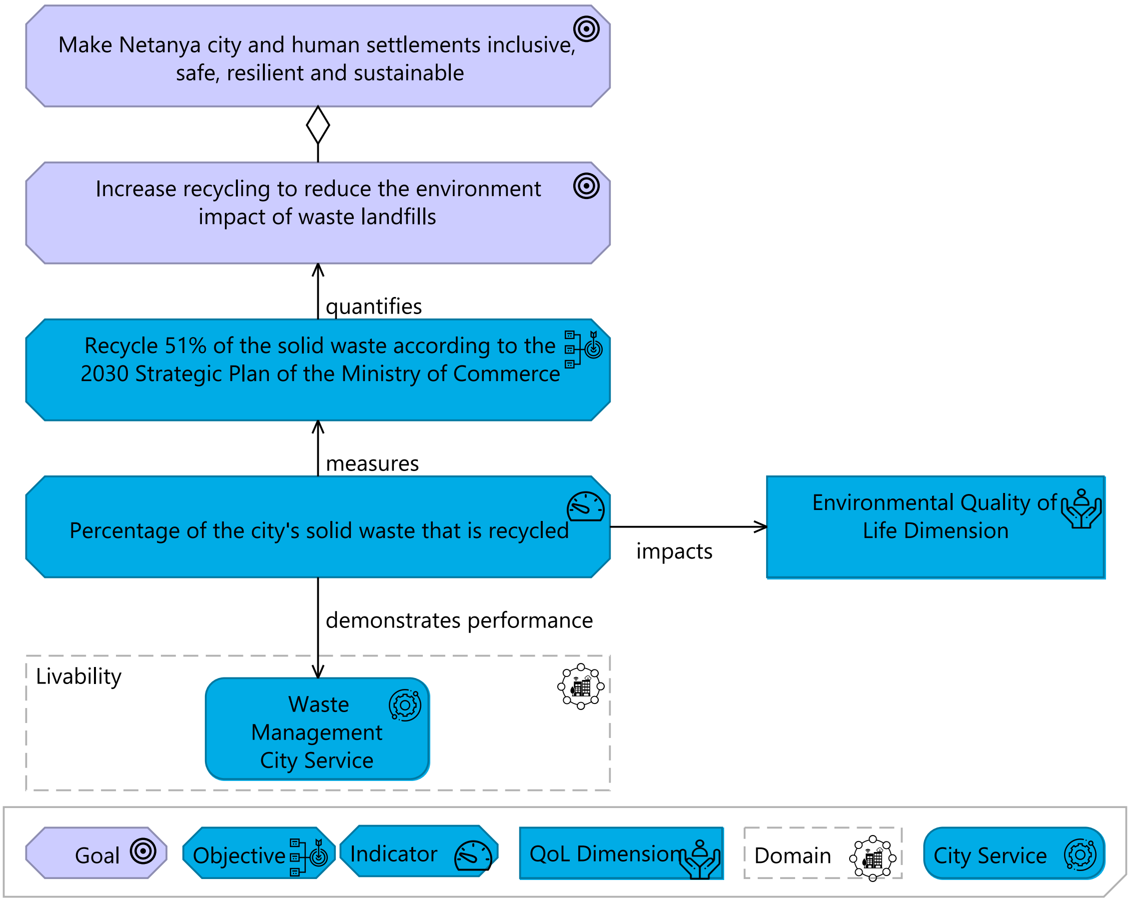


Fig. 7.17 Netanya Case Study. Smart City Strategy and Performance View.

- **Smart City Strategy and Performance View:** Figure 7.17 illustrates an *ArchiSmartCity* view to describe the Smart City strategy and performance view of Netanya. It shows the decomposition of city goals towards the measurement of Smart City performance in terms of city services and quality of life. The goal: "Make Netanya city and human settlements inclusive, safe, resilient and sustainable" results from the successive decomposition of the goal: "Increase recycling to reduce the environmental impact of waste landfills". The objective: "Recycle 51% of the solid waste according to the 2030 Strategic Plan of the Ministry of Commerce" is used to quantify both goals. In addition, the indicator: "Percentage of the city's solid waste that is recycled" measures the objective and impacts the quality of life: "Environmental Quality". This indicator demonstrates the performance of the "Waste Management City Service" that belongs to the "Livability" domain.

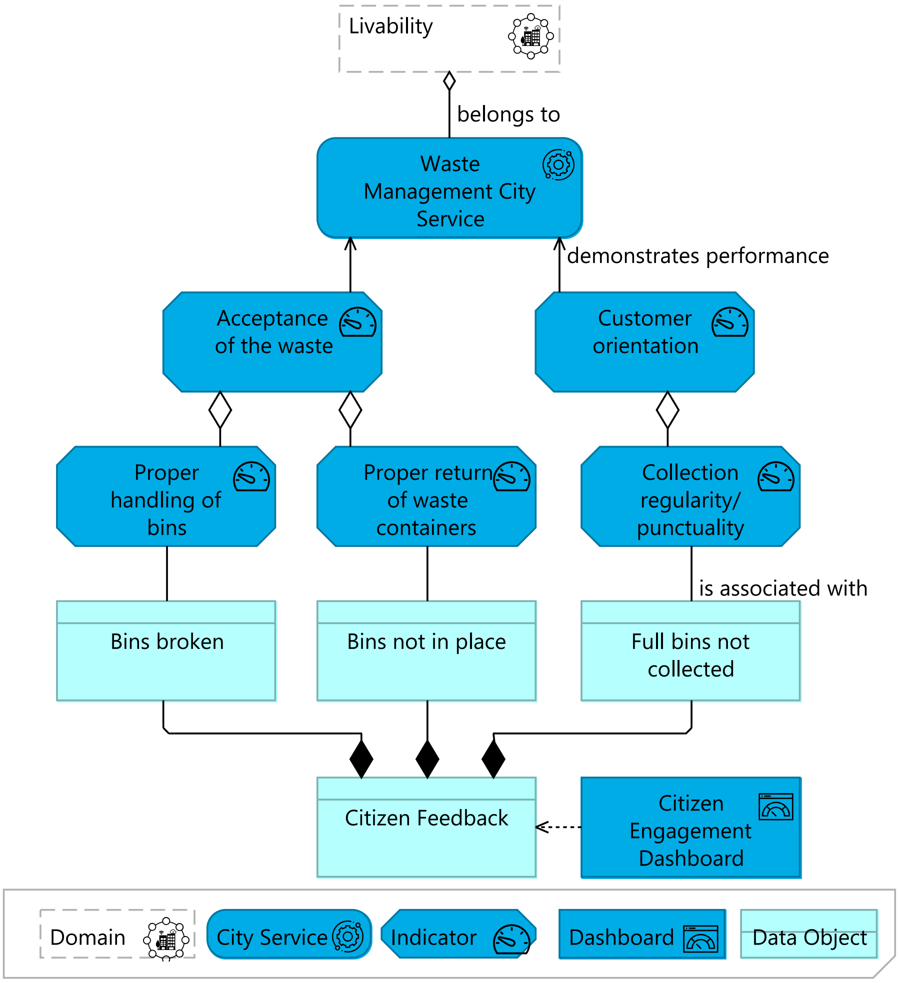


Fig. 7.18 Netanya Case Study. Quality of City Services View.

- **Quality of City Services View:** Figure 7.18 illustrates an *ArchiSmartCity* view to model the quality of city services in Netanya. This view presents how different qualities of city services are captured from the feedback of citizens. "The Waste Management City Service" from the "Livability" domain is associated with two qualities of service: "Acceptance of the waste" and "Customer orientation". The Acceptance of the waste aggregates two more specific qualities such as "Proper handling of bins" and "Proper return of waste containers after collection". The customer orientation aggregates an additional quality: "Collection regularity/punctuality". These qualities of service are assessed based on the information presented in the "Citizen Engagement Dashboard". This dashboard displays information on "Citizen Feedback", in terms of "Bins broken", "Bins not in place", and "Full bins not collected".

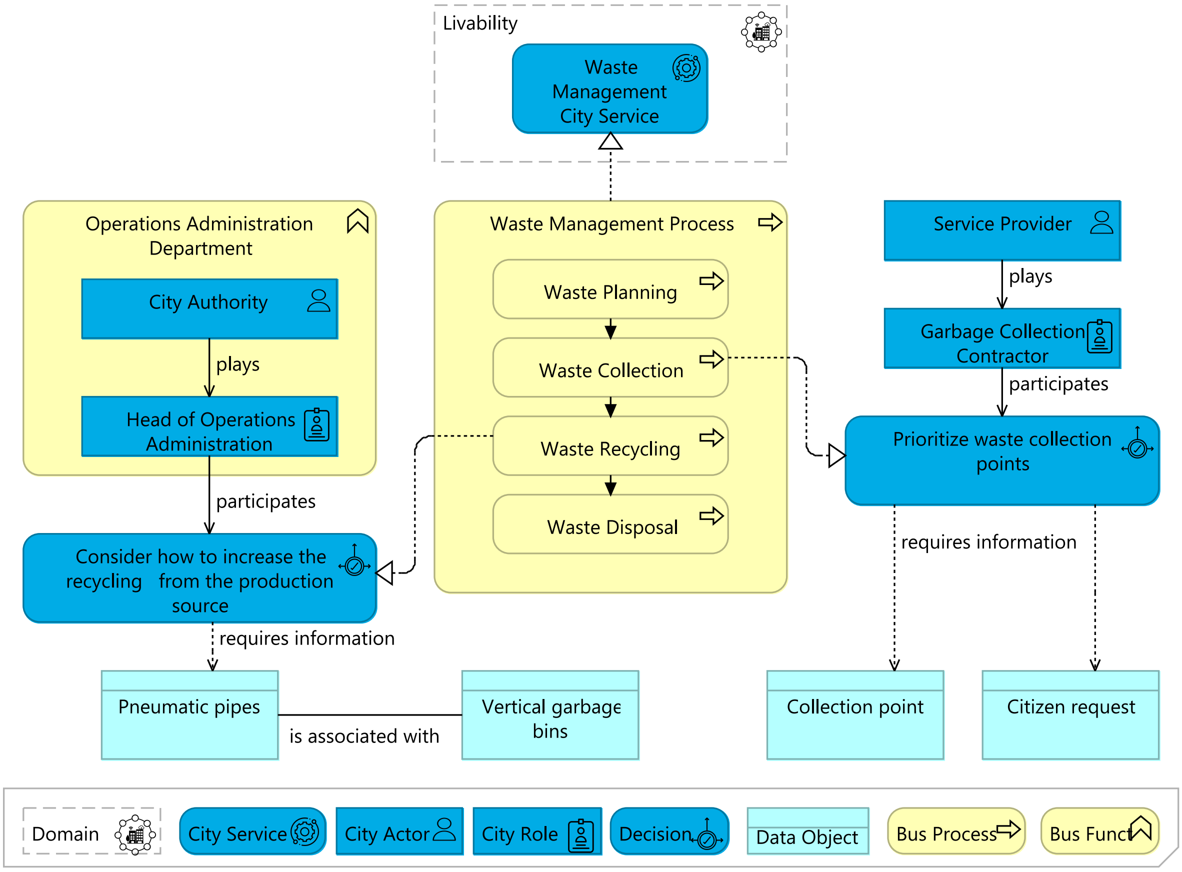


Fig. 7.19 Netanya Case Study. Decision Making Process View.

- **Decision Making Process View:** Figure 7.19 illustrates an *ArchiSmartCity* view to represent the decision making process in Netanya. This process involves different city actors who make decisions regarding the Waste Management City Service. The "Head of Operations Administration" is a "City Authority" in the "Operations Administration Department" in Netanya. She makes the decision: "Consider how to increase recycling from the production source". This decision supports the realisation of the "Waste Recycling" activity of the "Waste Management Process". At the same time, the "Garbage Collection Contractor", as a "Service provider", makes the decision: "Prioritize waste collection points to support the Waste Collection". Both city actors need more concrete data to make such decisions. The city authority requires information regarding "Pneumatic pipes" associated with "Vertical garbage bins" which will be installed in the city. The contractor requires information about "Collection point" and "Citizen request" to respond to new garbage collection events in the city.

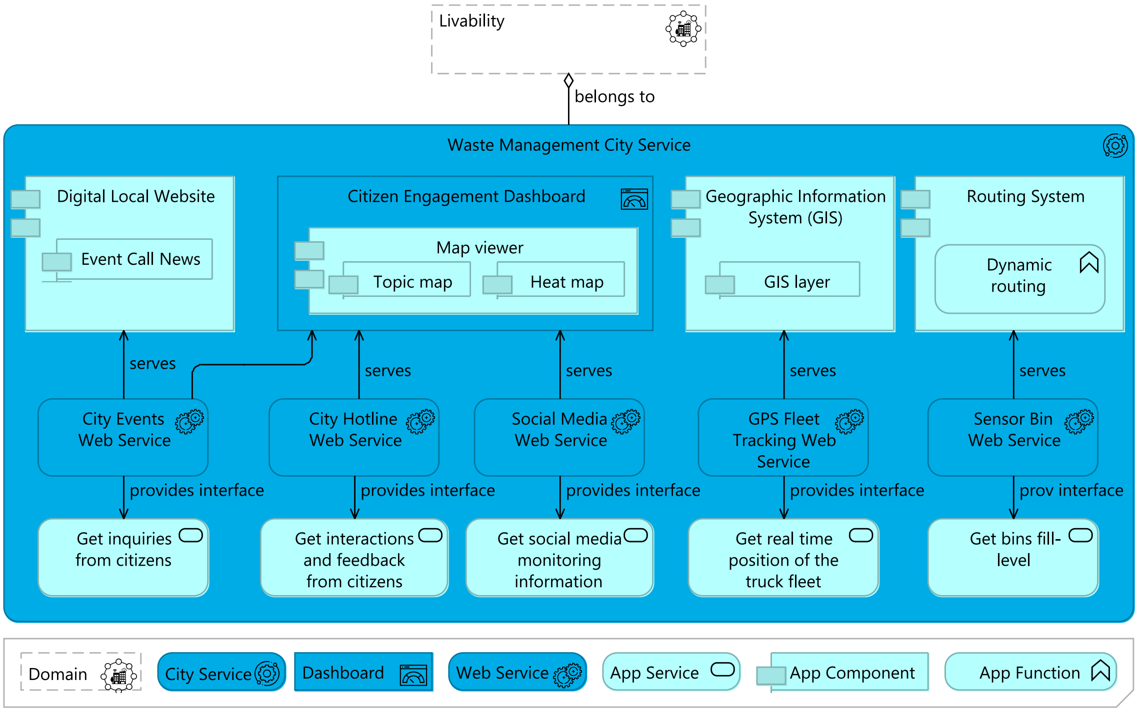


Fig. 7.20 Netanya Case Study. City Service Automation View.

- **City Service Automation View:** Figure 7.20 illustrates an *ArchiSmartCity* view to represent the automation of the "Waste Management City Service" in Netanya. This service from the Livability domain is automated by different application systems including the "Digital Local Website", the "Citizen Engagement Dashboard", the "Geographic Information System (GIS)", and the "Routing System". Each application is composed by other application components, and application functions. These applications get data from various application services through different web services. The "City Events Web Service" provides an interface for the application service "Get inquiries from citizens". The "City Hotline Web Service" provides an interface for the application service "Get interactions and feedback from citizens". The "Social Media Web Service" provides an interface for the application service "Get social media monitoring information". The "GPS Fleet Tracking Web Service" provides an interface for the application service "Get real time position of the truck fleet". The "City Hotline Web Service" provides an interface for the application service "Get interactions and feedback from citizens". The "Sensor Bin Web Service" provides an interface for the application service " Get bins fill-level".

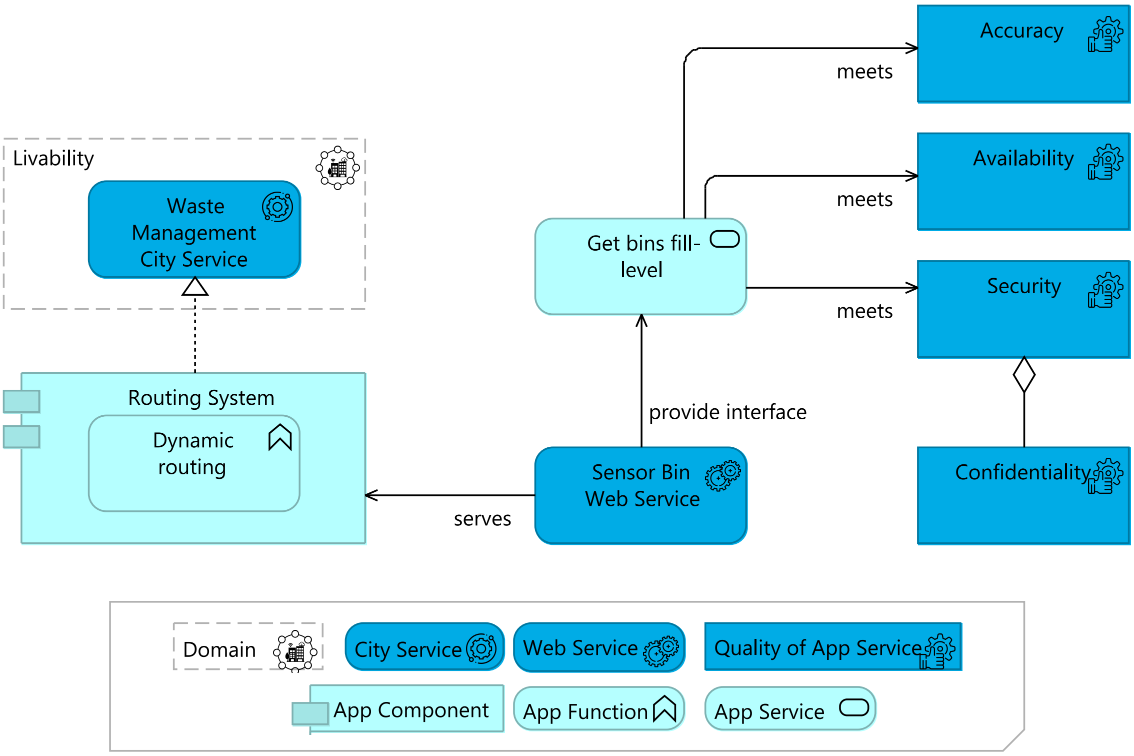


Fig. 7.21 Netanya Case Study. Quality of Application Services View.

- **Quality of Application Services View:** Figure 7.21 illustrates an *ArchiSmartCity* view to describe different qualities of application services. The "Routing System" realises the "Waste Management City Service" from the "Livability" domain. This system offers a functionality to supports the dynamic routing for the garbage collection. This functionality is based on the data retrieved by the "Sensor Bin Web Service". This Web Service provides an interface for the application service: "Get bins fill-level" that meets a number of quality characteristics, including "Accuracy", "Availability", and "Security". The "Confidentiality" quality is aggregated by the "Security" quality to ensure that the application service is protected from unauthorized access. For instance, 100% of the requests to the service must use access tokens. These tokens are used for token-based authentication to allow any application to access an application service.
- **City Actors Management View:** Figure 7.22 illustrates an *ArchiSmartCity* view to model the city actors who manage the public services in Netanya Municipality. This view shows those responsible for the indicators of city services from multiple domains such as "Livability" and "Smart Transportation". These indicators and are integrated into the "Citizen Engagement Dashboard". The city role "Transportation Manager"

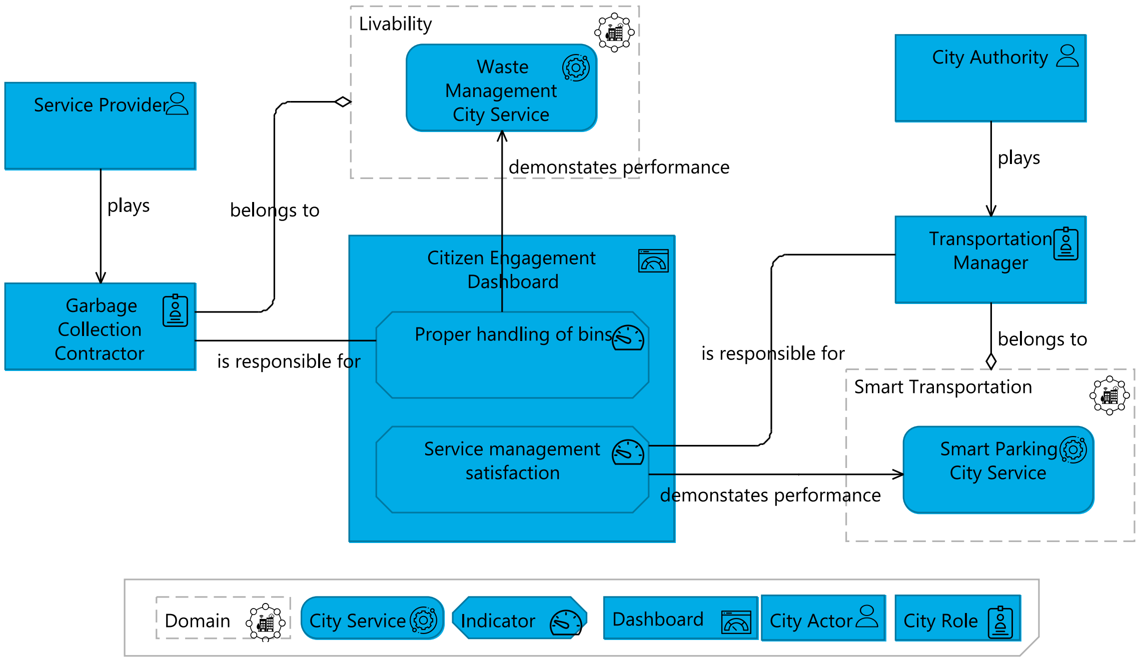


Fig. 7.22 Netanya Case Study. Multi-Domain Application View.

is responsible for the indicator "Service management satisfaction" and the city role "Garbage Collection Contractor" is responsible for the indicator "Proper handling of bins". In particular, the municipal waste is collected by or on behalf of the municipality. The dashboard only refers to the waste flows managed under the responsibility of the local administration including waste.

Conclusion

The case study in Netanya municipality was conducted to demonstrate the applicability of the concepts that support a suitable alignment between the service and information layers in Smart City architectures. This helped us to replicate and validate our findings in a different city context by designing a solution for a waste management city service. The application of a modelling technique follows the EA realisation levels from top to bottom, starting from the service layer followed by the information systems implementation details.

Table 7.2 presents a comparison between the concepts of ArchiSmartCity (see Chapter 5) and their application in Netanya. Each row cell in the column "NCS" filled with a ✓indicates the need for the concept in the netanya Case Study. Each row cell in the column "ArchiSmartCity Models" is filled in with the ArchiSmartCity concept used in the models during the design of the proposed waste management city service solution.

Table 7.2 Netanya Case Study (NCS)

ArchiSmartCity Concept		NCS	ArchiSmartCity Models	
Service	Domain	✓	**Service**	Domain
	Goal	✓		Goal
	Objective	✓		Objective
	Indicator	✓		Indicator
	Quality of Life Dimension	✓		Quality of Life Dimension
	City Service	✓		City Service
	City Actor	✓		City Actor
	City Role	✓		City Role
	Decision	✓		Decision
Information	Dashboard	✓	**Information**	Dashboard
	Application Service	✓		Application Service
	Quality of Application Service	✓		Quality of Application Service
	Web Service	✓		Web Service
	Middleware			
ArchiSmartCity Relationships		✓		ArchiSmartCity Relationships

Legend: ✓- Required in the Case Study

Netanya municipality follows a resident-centric approach to respond to its residents and visitors. This city uses a centralised system to analyse the citizens feedback on city services from different domains (e.g., environment, mobility, security, health). This helps us to corroborate that beyond focusing on technological aspects, cities and municipalities should focus on supporting a continuous alignment to meet the needs of citizens. The application of ArchiSmartCity in Netanya shows that these concepts are relevant to support the alignment of city services and the underlying information systems with the main city goals and objectives. Netanya city managers use these models to communicate the solution design to the main stakeholders of the waste management service (e.g., the head of operations administration, the garbage collection contractor, the GIS manager). The case study helps city managers to plan the transformation of the city service before developing new application platforms and solutions or hiring new service providers. This supports Netanya transparency on city data and the reliability of Smart City initiatives which must be measured against Israeli government indicators, for example: "Recycle 51% of the solid waste according to the 2030 Strategic Plan of the Ministry of Commerce". According to the feedback of the Smart City and Digital Domain Manager of Netanya municipality, the proposed ArchiSmartCity concepts provide a structured approach to the design and transformation of public city services.

Table 7.3 Cross Case Analysis - Data Sources.

Case Study	Data Source
Limerick City	• Main Data – Meetings • Secondary Data – Limerick Digital Strategy – Internal documents (e.g., departments and functions) – Software service platforms (e.g., real-time data, dashboards, reports) – Third-party service providers (e.g., technology advice, service solutions brochures, and quotations)
Netanya Municipality	• Main Data – Semi-structured interviews • Secondary Data – Internal documents (e.g., organisation structure, waste management service reports based on citizens feedback) – Netanya future state of waste management service – Official municipality website

7.2.3 Cross Case Analysis

Conducting multiple case studies allows us to apply a cross-case analysis to examine themes, similarities, and differences across cases (Yin, 2014). In this research, data is collected emphasising the alignment between the services and information layers in Smart City architectures. The design process of each case study comprised the modelling of public city services to support this alignment. The units of analysis are Limerick City and Netanya Municipality. We collected data for the case studies using a direct method and independent analysis (Runeson and Höst, 2009). Table 7.3 presents the data sources involved (i.e., main and secondary data) within the multiple case studies. We use data source triangulation to compare and contrast the findings across the data sources for each case study (Runeson and Höst, 2009). We examine all the results of this research across cases, including the proposed design principles (see Chapter 4), design requirements, and the ArchiSmartCity metamodel (see Chapters 5). They were evaluated by asking the primary stakeholders (e.g., Smart City domain experts and data managers) for feedback on their relevance and applicability in the

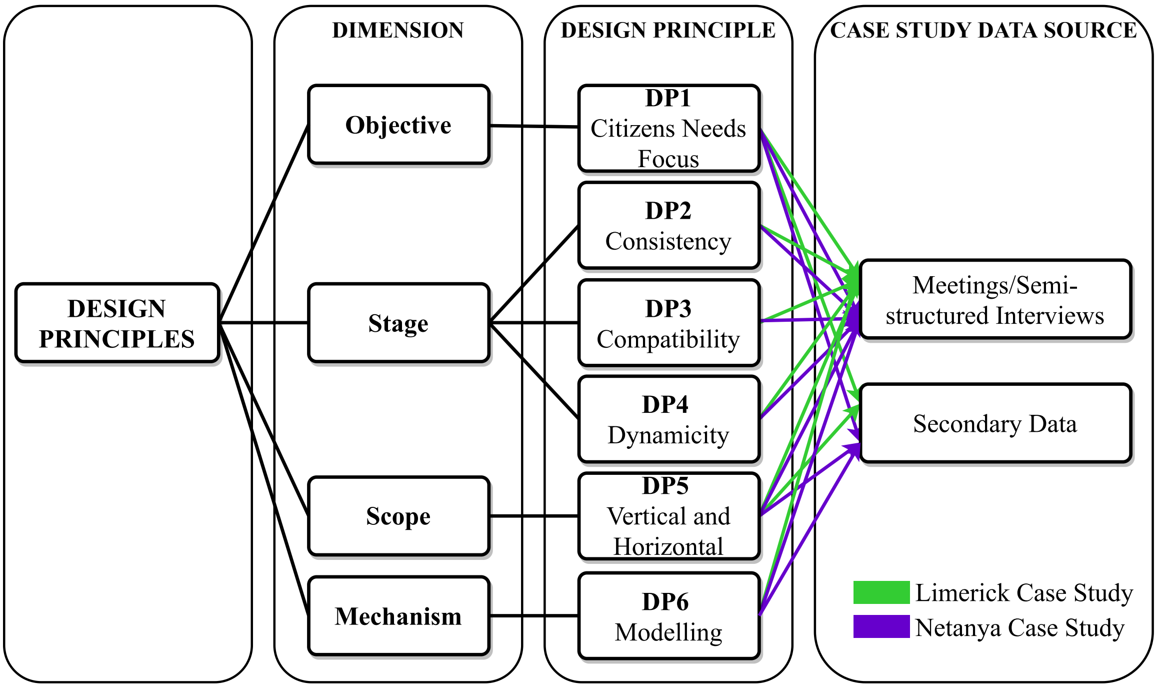


Fig. 7.23 Cross Case Analysis. Design Principles.

architecture models design. Secondary data was also used to compare the main findings. The cross case analysis is outlined as follows.

- **Cross Case Analysis - Design Principles:** Figure 7.23 presents the set of design principles and data sources used to contrast the main findings across case studies. These design principles were defined to support the alignment between the service and information layers in Smart City architectures. They were grouped along four dimensions: Objective, Usage, Scope, and Mechanism. For instance, the first design principle, *DP1 - Citizens Needs Focus: Support the alignment of the service and information layers in order to meet the needs of citizens*, was also validated against the Limerick digital strategy and Netanya master plan. The Limerick digital strategy defines: "While support for customers is paramount any initiatives will put the citizen's interest first. Any designs must start with the citizen needs as far as it is practical". The master plan of Netanya Municipality establishes: "Netanya has been working to transform into a Smart City through a master plan and by creating a well-defined strategic thinking methodology. Analysis of citizens' needs and investment of substantial resources in the technological development are required to improve the quality of their lives which first and foremost puts the citizens at the center".

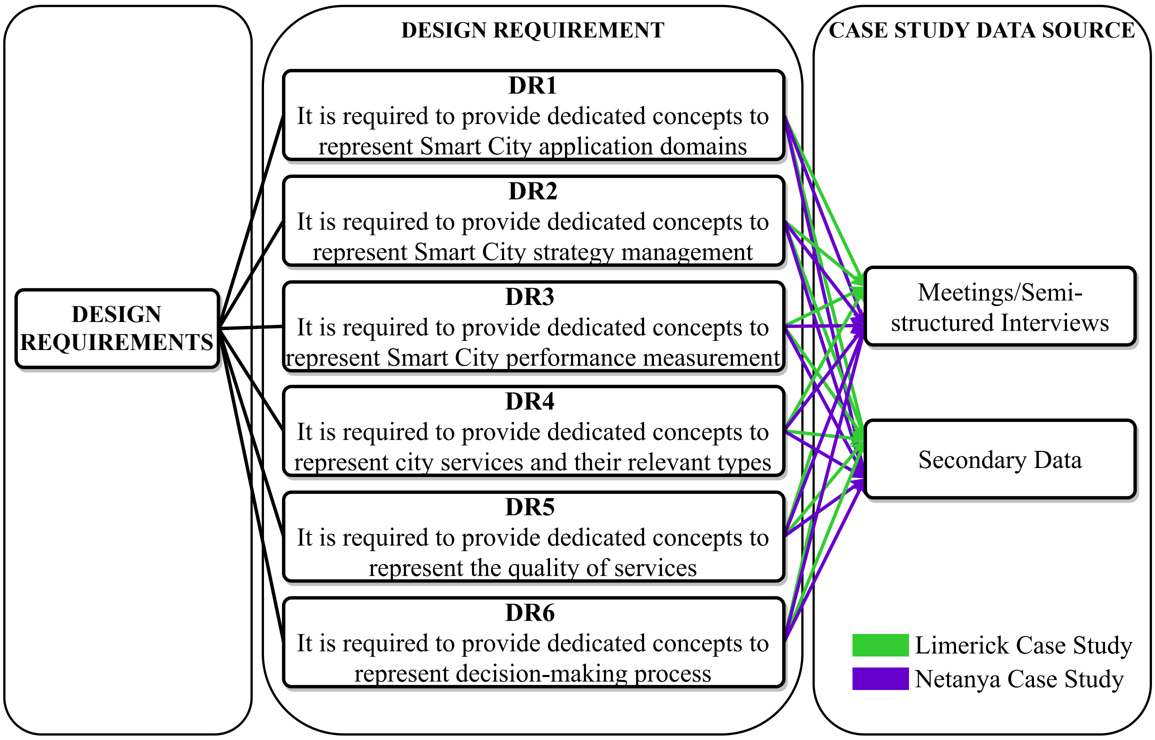


Fig. 7.24 Cross Case Analysis. Design Requirements.

- **Cross Case Analysis - Design Requirements:** Figure 7.24 presents the set of design requirements and the data sources used to compare the main findings across case studies. These design requirements were defined to support the alignment between the service and information layers in Smart City architectures. For example, the design requirement, *DR6 - It is required to provide dedicated concepts to represent decision-making process*, was validated by the main stakeholders in the case study. The identification of the city actors who can use the footfall-counter data to make different decisions was key during the case study. The data manager of Limerick City states: "The identification of the decisions helps us to understand the value of the data regarding the footfall-counter services to the different stakeholders and processes of different city council departments (e.g., Smarter Travel, Tourism Strategy, Future Planning, Economic Development)". Decision-making support is a key activity in Netanya municipality. The Smart City domain manager from the Netanya municipality states: "All the head of the departments receive the information, obviously the CEO, and specific head of units for whom the reports are related to, so for example, if the main subject of the report is about garbage management, I will send to all the people who handle the garbage". We modelled all the decisions and information needed to support the waste management city service.

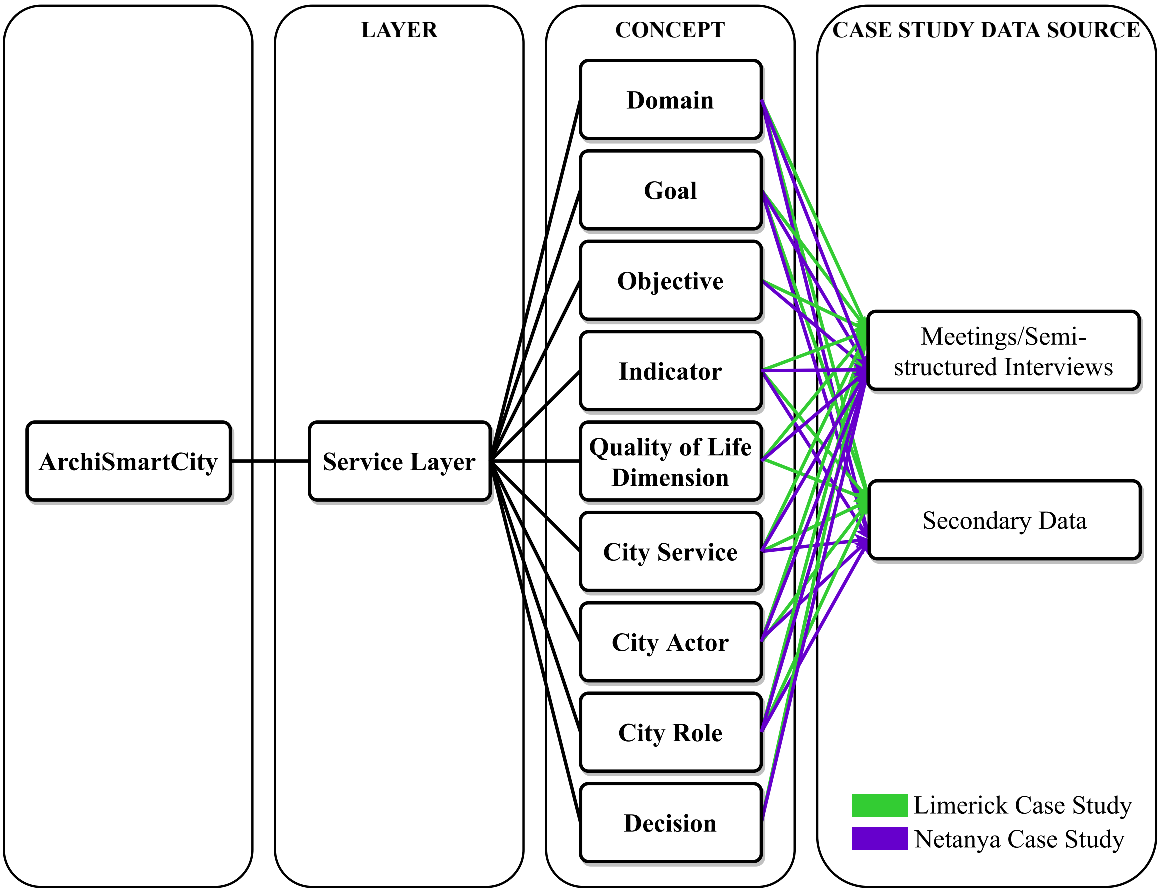


Fig. 7.25 Cross Case Analysis. ArchiSmartCity Service Concepts.

- **Cross Case Analysis - ArchiSmartCity:** Figure 7.25 presents the set of ArchiSmartCity service concepts and data sources used to compare the main findings across case studies. In both cases, these cities have a high-level definition of *city goals*. This made difficult to establish the communication among different strategic stakeholders and operational stakeholders. We refined the city goals in terms of their objectives and connected them with the relevant indicators. For example, in Limerick City, the objectives were connected to indicators that support the digital strategy, such as: "Number of services integrated in a singular operations center leveraging real-time data" and "Percentage of commuters by walking or cycling". Whereas in Netanya Municipality, the objectives were connected to indicators that support the waste management indicators, such as: "Percentage of total waste recycled per year", "Percentage of organic waste recycled per year", and "Percentage of paper, plastic, and glass recycled per year". These indicators impact the quality of life of their citizens in terms of the “Mobility” “Preservation and improvement of environment”, “Responsible resource use” and “Wellbeing” aspects of city life as defined in ISO37120 (2018).

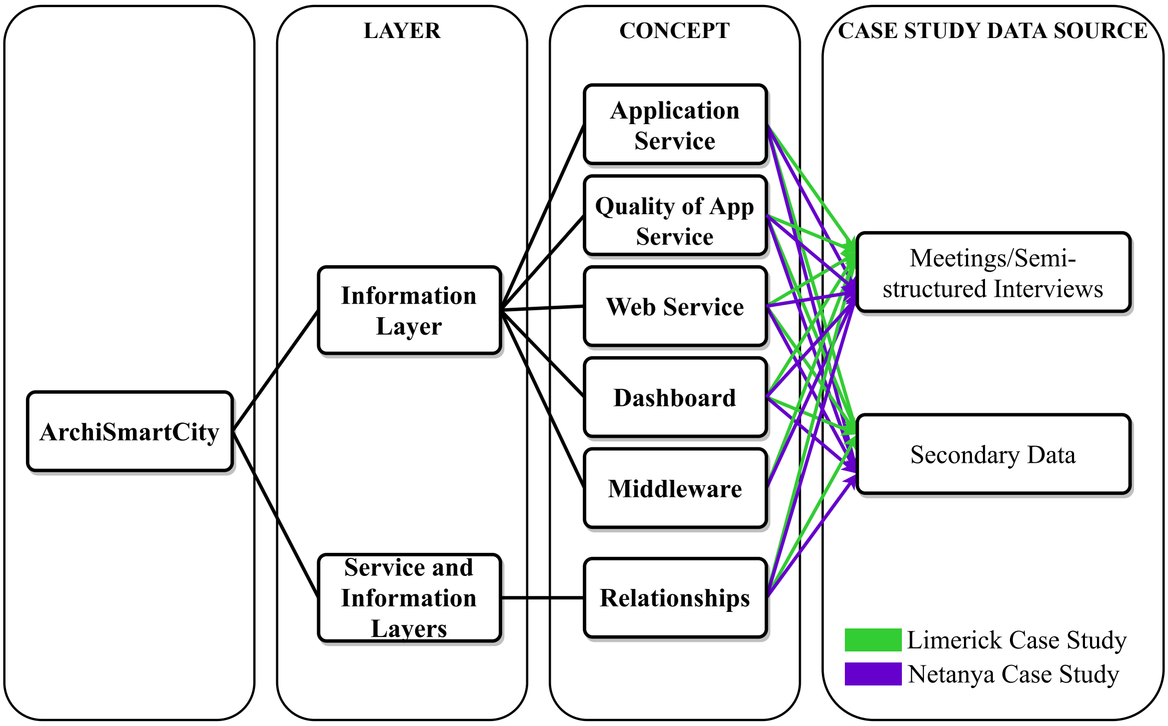


Fig. 7.26 Cross Case Analysis. ArchiSmartCity Information Concepts and Relationships.

Figure 7.26 presents the set of ArchiSmartCity information concepts, relationships, and data sources used to contrast the main findings across case studies. For instance, the data collected from city services is stored in a centralised database in Limerick, with little understanding on how to manage and share the data among multiple Smart City stakeholders. The service providers of footfall counters in Limerick mainly offer web services for data integration (Restful Web Services) using a service-oriented approach. Netanya follows a decentralised architecture where data is consumed directly from the web services offered by service providers. The Smart City domain manager from the Netanya municipality states: "Everything related to IoT comes to my eyes, and to the CEO. So, we have the cyber issue and the IoT issue. When I speak about the IoT, I refer to web services, to take the data, and then to implement it". Moreover, both Limerick and Netanya understand the importance of having middleware. However, because they do not have a high number of services, this concept was not used to design their city service solutions. Finally, the proposed relationships between the service and information layers to represent the alignment through a model-based approach were identified in the Limerick case study and refined in the Netanya case study in an iterative fashion. It allowed the connection of the public services design with the Smart City strategy and vision to deliver services that meet the needs of citizens.

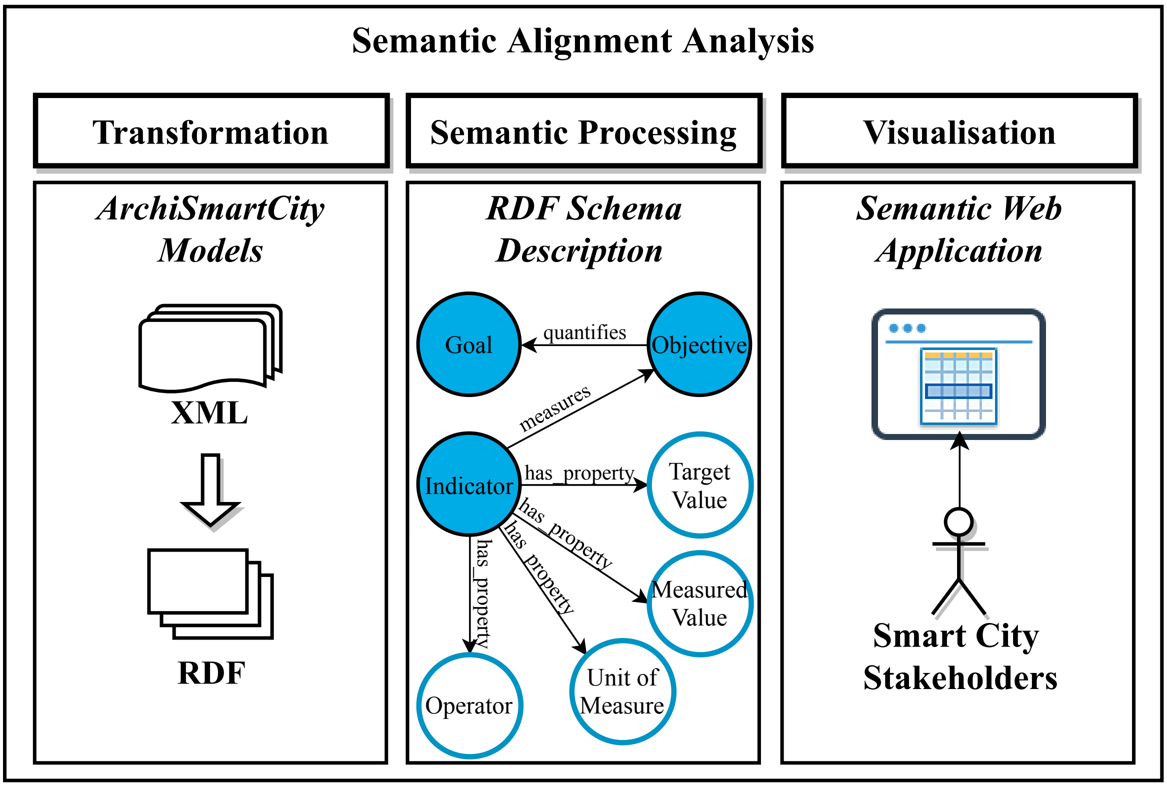


Fig. 7.27 Semantic Alignment Analysis Solution.

7.2.4 Semantic Alignment Analysis

This research demonstrates and artificially evaluates ArchiSmartCity by developing a computer-based solution for semantic alignment analysis. The artificial evaluation is used to examine and analyse the alignment between the service and information layers in Smart City architectures to support Smart City strategies by using semantic analysis. This analysis uses a top-down Enterprise Architecture (EA) approach starting with city goals and objectives, and ending up in city services implementation details. This is critical for city managers who need alignment information to support the operation and management of public city services (Cañas et al., 2015; Őri, 2017a). The source code of this solution for practitioners and developers is available on a public GitHub repository[1]. Figure 6.2 depicts its main components as described as follows.

- **Transformation:** This component implements the transformation of ArchiSmartCity models generated in XML format into the Resource Description Framework (RDF). The unit of knowledge (statement) in RDF is a single triplet consisting of a subject, a predicate, and an object which is both machine-actionable and human-

[1] Semantic Alignment Analysis - https://github.com/vivikaing/SemanticAlignmentAnalisisWeb

readable (Suchánek and Slifka, 2019). This component imports and reads the ArchiSmartCity models in XML and then transform them into RDF models by using the java framework Apache Jena[2]. The Jena API allows the manipulation of the RDF models and the interpretation of RDF specifications.

- **Semantic Processing:** This component examines the knowledge of the models created and analyses the alignment between city services and their underlying information systems. This software component reads the RDF models and extracts the identifier and name of each ArchiSmartCity concept and enriches them with semantic information, including its relationships and properties information. It improves the description of each ArchiSmartCity concept, enhancing it with a set of additional information (e.g., city services quality information) that can be extracted from an ArchiSmartCity model.
- **Visualisation:** This component presents the information on the RDF models in a web application interface that can be used by Smart City stakeholders (e.g., city authorities, service providers). End users can query the models starting from city goals, city objectives, or city services. The system then displays the identified alignment between the Smart City strategies, city services, and their information systems according to the ArchiSmartCity metamodel definition. Furthermore, this alignment is analysed by comparing the current and target values of the city services qualities to present a detailed level of alignment.

Semantic Alignment Analysis Cases

The validation of the semantic alignment analysis was performed with the data of city services from both Limerick City and Netanya Municipality. It demonstrates the applicability of the semantics of ArchiSmartCity to examine the alignment in real world-cases.

Figure 7.28 illustrates the RDF graph model of Limerick City. This model expresses the information related to the "Air Quality City Service" and "Footfall Counter City Service". The RDF graph represents the ArchiSmartCity RDF classes, including Smart City strategies (e.g., city goal and objective), city services (e.g., domain, city service, indicator, quality of life dimension), and information systems (e.g., application service, quality of application service, and web service). ArchiSmartCity RDF properties are expressed in the graph to enrich the model with the semantics of indicators (e.g., target value, measured value, unit of measure, and comparison operator) and quality of application services (e.g., target value, monitored value, unit of measure, and comparison operator). The analysed alignment is represented by the relationships between ArchiSmartCity RDF Classes.

[2]Apache Jena - https://jena.apache.org/

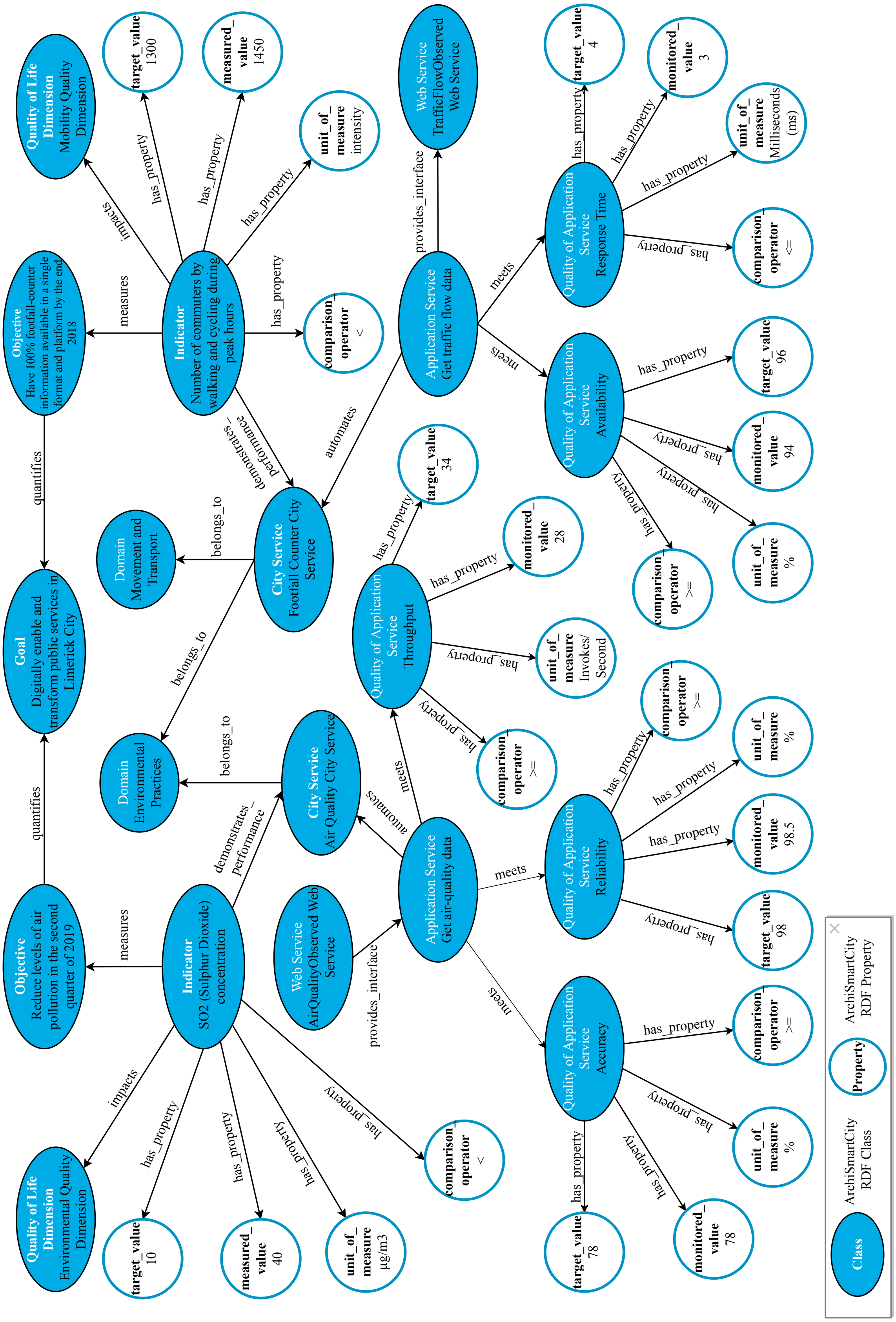


Fig. 7.28 Semantic Alignment Analysis. Limerick RDF Graph Data Model.

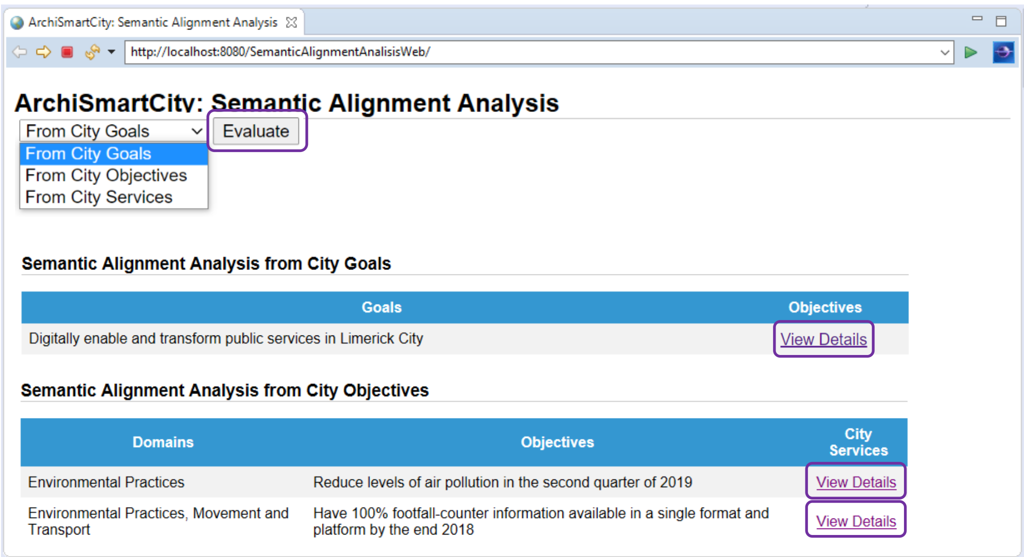


Fig. 7.29 Semantic Alignment Analysis. Limerick City Strategy.

Figure 7.29 presents the user interface of the web application for the semantic alignment analysis. The analysis begins with the city goal "Digitally enable and transform public services in Limerick City" that is quantified by two different objectives from the domains "Environmental Practices" and "Movement and Transport".

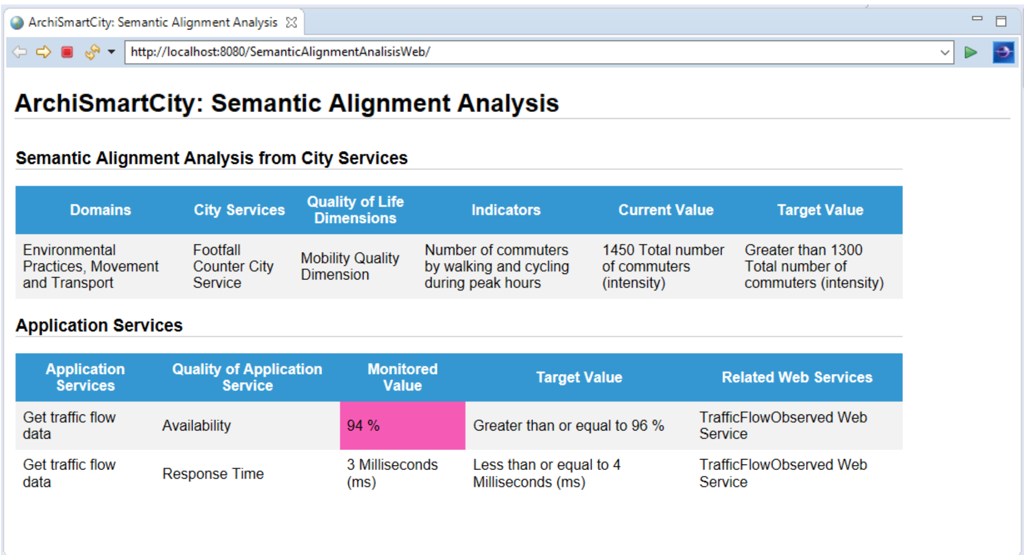


Fig. 7.30 Semantic Alignment Analysis. Footfall Counter City Service.

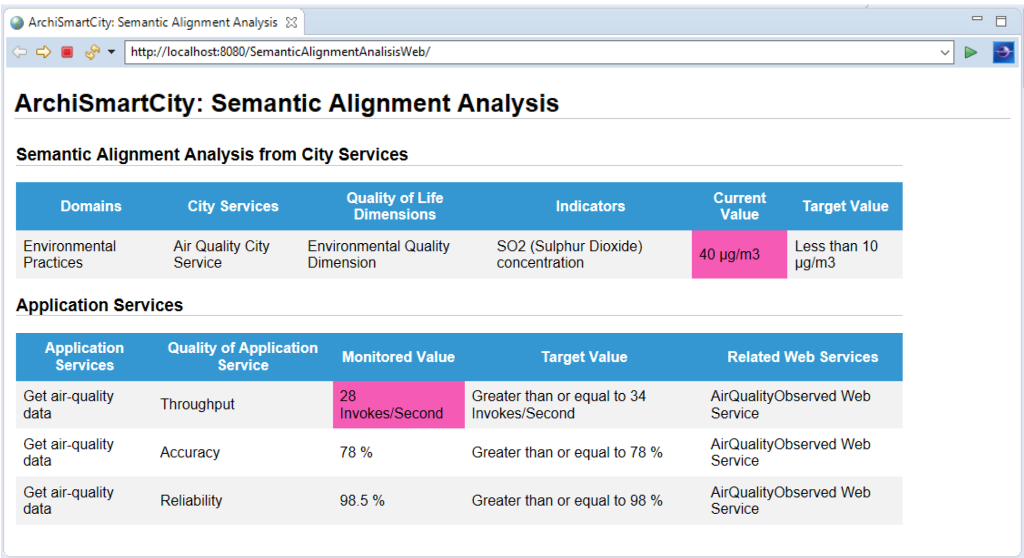


Fig. 7.31 Semantic Alignment Analysis. Air Quality City Service.

Figure 7.30 depicts the "Footfall Counter City Service" that realises the objective "Have 100% footfall-counter information available in a single format and platform by the end of 2018". The indicator "Number of commuters by walking and cycling during peak hours" is used to demonstrate the performance of this service. The measured value "1450 Total number of commuters (intensity)" is aligned with the target value "Greater than 1300". However, the monitored value for the "Availability" of the application service "Get traffic flow data" is less than the target value "96%". The system highlights this alignment issue related to the quality of the application service detected in the model during the semantic alignment analysis.

Figure 7.31 presents the "Air Quality City Service" that realises the objective "Reduce levels of air pollution in the second quarter of 2019". The indicator "SO2 (Sulphur Dioxide) concentration" is used to demonstrate the performance of this service. However, the measured value "40 µg/m3 (micrograms per cubic metre)" of SO2 is higher than the target value "10 µg/m3". At the same time, the monitored value "28 invokes/second" for the "Throughput" of the application service "Get air-quality data" is less than the target value "34 invokes/second". The system highlights these alignment issues related to the performance and quality of this city service detected in the model during the semantic alignment analysis.

Figure 7.32 illustrates the RDF graph model of Netanya Municipality. This model expresses the information related to the "Waste Management City Service". The RDF graph represents the ArchiSmartCity RDF classes, including Smart City strategies (e.g., city goal and objective), city services (e.g., domain, city service, indicator, quality of life dimension),

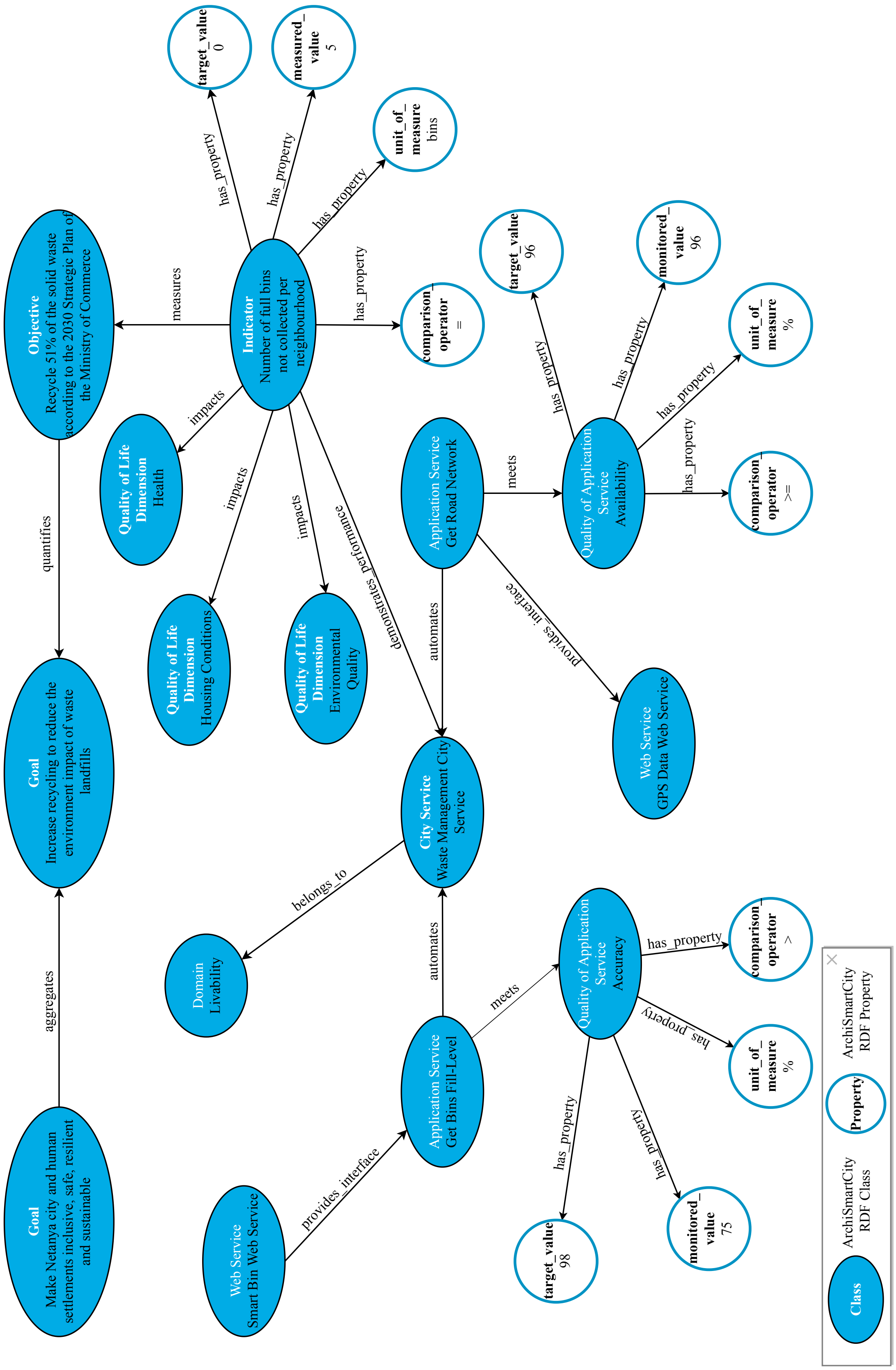


Fig. 7.32 Semantic Alignment Analysis. Netanya RDF Graph Data Model.

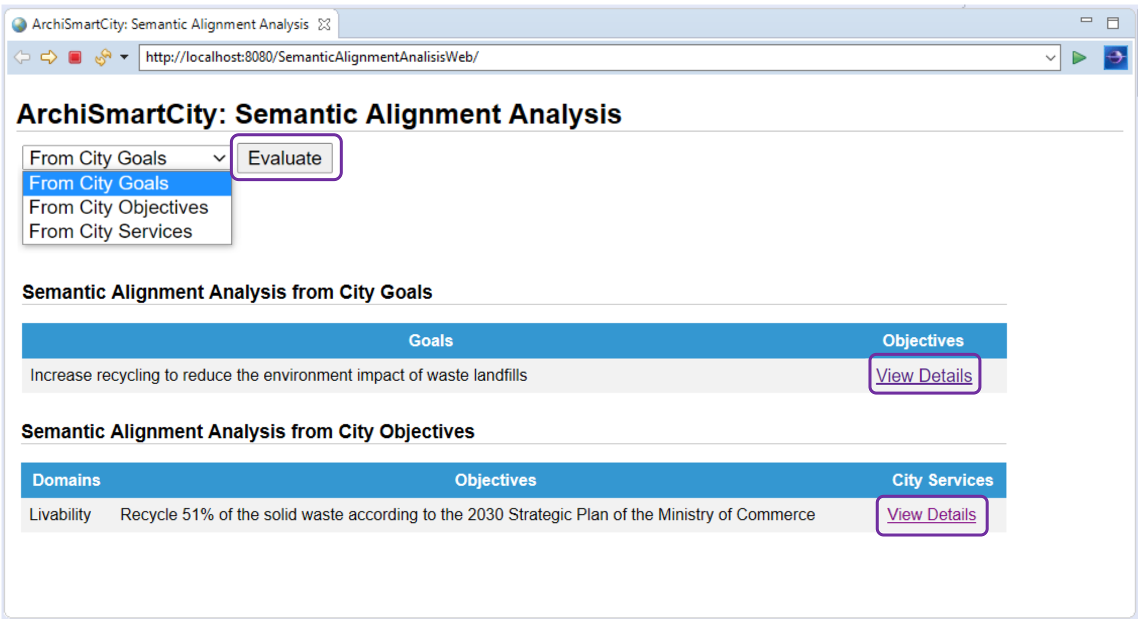


Fig. 7.33 Semantic Alignment Analysis. Netanya Municipality Strategy.

and information systems (e.g., application service, quality of application service, and web service). ArchiSmartCity RDF properties are expressed in the graph to enrich the model with the semantics of indicators (e.g., target value, measured value, unit of measure, and comparison operator) and quality of application services (e.g., target value, monitored value, unit of measure, and comparison operator). The analysed alignment is represented by the relationships between ArchiSmartCity RDF Classes.

Figure 7.33 presents the user interface of the web application for the semantic alignment analysis. The analysis begins with the city goal "Increase recycling to reduce the environment impact of waste landfills". This city goal is quantified by the objective "Recycle 51% of the solid waste according to the 2030 Strategic Plan of the Ministry of Commerce" that belongs to the domain "Livability".

Figure 7.34 presents the "Waste Management City Service" to realise the Netanya strategy. The indicator "Number of full bins not collected per neighbourhood" is used to demonstrate the performance of the city service. This indicator impacts the quality of life dimensions: "Health", "Housing Conditions", and "Environmental Quality". However, the measured value "5 bins" is higher than the target value "0 bins". At the same time, the monitored value "75%" for the "Accuracy" of the application service "Get Bins Fill-Level" is less than the target value "98%". The system highlights these alignment issues related to the performance and quality of this city service detected in the model during the semantic alignment analysis.

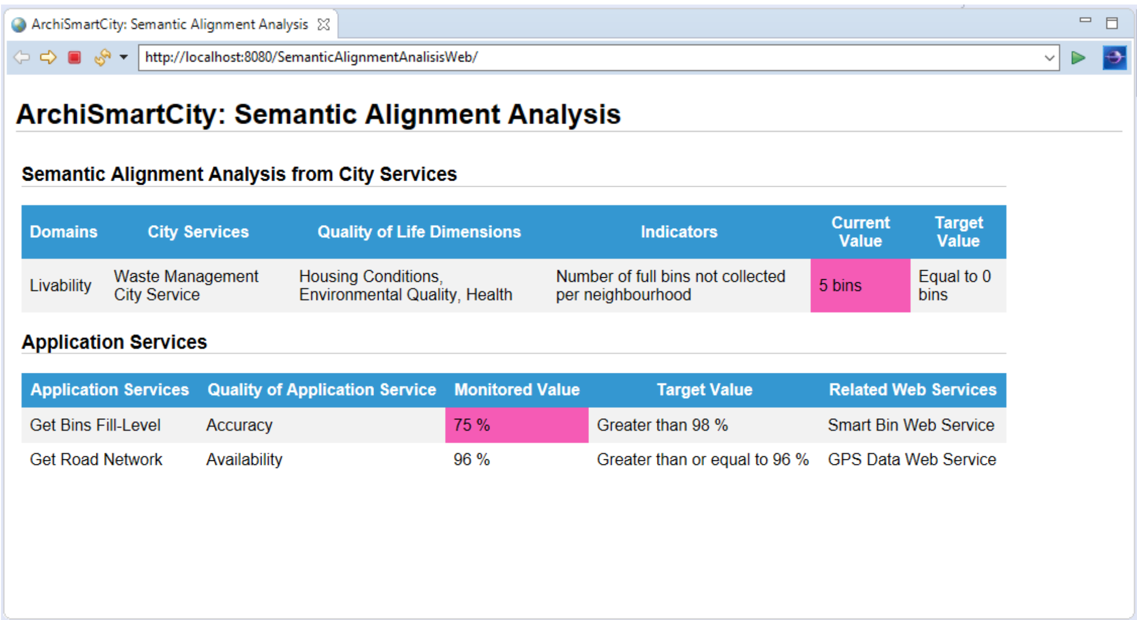


Fig. 7.34 Semantic Alignment Analysis. Waste Management City Service.

Finally, the semantic analysis can help cities and municipalities to examine the alignment between the service and information layers in Smart City architectures. City authorities and decision-makers can analyse how the quality of application services influences the performance of city services and the achievement of city goals and objectives. Additionally, city managers can use this semantic analysis to visualise and infer alignment issues from the knowledge of ArchiSmartCity models.

7.3 Evaluation

Previous sections demonstrate the applicability of ArchiSmartCity in real cases and artificially evaluate the artefact by developing a computer-based solution for semantic alignment analysis. This makes our theory actionable by providing a solution to examine the alignment between the service and information layers in Smart City architectures. We have collected evidence of the *utility* and *quality* through an initial assessment with two case studies, following (Helfert et al., 2012). This section presents the results of the evaluation which includes the ex-post evaluation of ArchiSmartCity within the case studies and the validation of our proposal by Smart City domain experts.

Many design science evaluation approaches focus on three core levels of quality: Syntactic Quality, Semantic Quality, and Pragmatic Quality (i.e., Perceived Usefulness) (Helfert et al.,

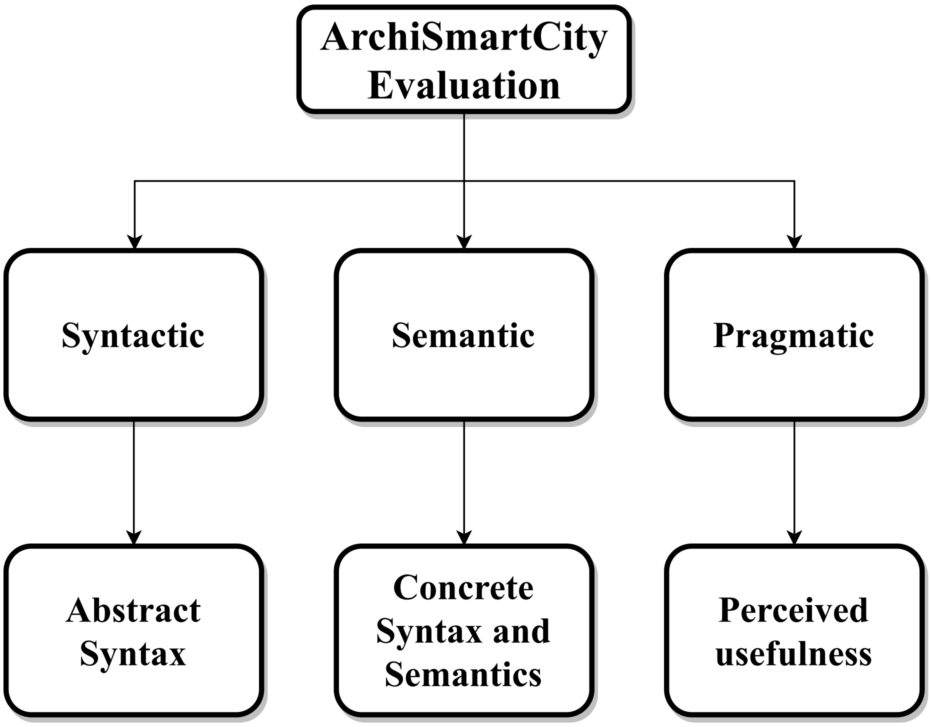


Fig. 7.35 ArchiSmart City Evaluation Dimensions.

2012; Janiesch et al., 2019; Lei, 2012; Maes and Poels, 2007; Mendling et al., 2007; Moody, 2002; Rittgen, 2010; Venkatesh and Davis, 2000). Figure 7.35 presents these levels of quality used as the main evaluation dimensions for this thesis. Syntactic and semantic qualities refer to quality standards and specifications, whereas the pragmatic quality is related to utility. According to (Lindland et al., 1994; Mendling et al., 2007), syntactic quality refers to model and modelling language (i.e., the model adheres to the modelling language rules); semantic quality to model, domain, and knowledge; and pragmatic quality involves the model and modeling and its ability to enable learning and action. This thesis uses the syntactic quality dimension to evaluate the abstract syntax of ArchiSmartCity, by considering the syntactic correctness of the metamodel. The semantic quality dimension is used to evaluate the concrete syntax (i.e., notations) and semantics of ArchiSmartCity by Smart Cities domain experts. The pragmatic quality dimension is used to evaluate the perceived usefulness (i.e., utility) of ArchiSmartCity. This involves the application of the ArchiSmartCity in case studies and its perceived usefulness by Smart Cities domain experts.

Table 7.4 Evaluation Criteria in this Thesis.

Evaluation Dimension	What to Evaluate	Quality Criteria	Technique	Supporting Source
Syntactic	Abstract Syntax: • ArchiSmartCity concepts • Relationships between concepts	• Syntactical correctness	Use a Tool: • Formally specify ArchiSmartCity metamodel based on MOF	Bork and Fill (2014); Cengarle et al. (2009); Helfert et al. (2012); Huber et al. (2019); Moody (2009); Rittgen (2010)
Semantic	Concrete Syntax: • Graphical representation of each syntactic element Semantics: • Meaning of each syntactic element	• Precise definitions and terminology • Easy to understand • Completeness	• Case Study Evaluation (Netanya Municipality) • Survey (Domain Experts Feedback)	Bork and Fill (2014); Cengarle et al. (2009); Helfert et al. (2012); Huber et al. (2019); Moody (2009); Rittgen (2010)
Pragmatic	Perceived Usefulness (Utility): • Usefulness of ArchiSmartCity in its application environment	• Relevance	• Case Study Evaluation (Netanya Municipality) • Survey (Domain Experts Feedback)	Bork and Fill (2014); Helfert et al. (2012); Janiesch et al. (2019); Moody (2009)

7.3.1 Evaluation Criteria

Ex-post evaluation with suitable criteria allows for the legitimisation of the final artefact (Cleven et al., 2009). Table 7.4 presents the evaluation criteria used in this thesis in the syntactic, semantic, and pragmatic dimensions.

Syntactic Quality of ArchiSmartCity

The syntactic quality of a metamodel refers to the extent to which it observes the rule of its underlying meta-modelling language (Rittgen, 2010). It involves the evaluation of the abstract syntax of the metamodel. The abstract syntax covers concepts and relationships from the target domain in terms of a metamodel (Bork et al., 2020; Huber et al., 2019). One quality characteristic is evaluated in the syntactic quality dimension as described as follows.

- **Syntactic Correctness:** The metamodel is correct from a syntactic point of view if all statements of the metamodel are according to the syntax and vocabulary of the meta-metamodel (meta^{2}model) (Bork and Fill, 2014; Cengarle et al., 2009). We formally specified ArchiSmartCity metamodel based on the Meta-Object Facility (MOF) standard for model-driven engineering during the design (Section 5.1) and implementation phases (Section 6.1.3). MOF is the meta^{2}model of ArchiSmartCity models, which means that ArchiSmartCity syntax does conform to the MOF metamodel.

Semantic Quality of ArchiSmartCity

The semantic quality dimension involves the evaluation of both concrete syntax and semantics. The concrete syntax defines graphical and textual notational elements that enable representing models as diagrams, while the semantics specify how to interpret the concepts and relationships included in the abstract syntax (Huber et al., 2019). The quality characteristics evaluated in the semantic quality dimension are outlined as follows.

- **Precise definitions and terminology:** The metamodel uses precise definitions and terminology to describe the syntactic elements they represent. These definitions and terms are described within the global lexicon of domain experts (Bork and Fill, 2014; Cengarle et al., 2009; Helfert et al., 2012; Moody, 2009). We evaluate this quality criteria by employing case studies and a semi-qualitative survey to get feedback from domain experts.

- **Easy to understand:** The metamodel has graphical representations to express natural associations with the syntactic elements they represent. These notations and semantics need to be easy to understand by the domain experts (Bork and Fill, 2014; Cengarle et al., 2009; Helfert et al., 2012; Moody, 2009). We evaluate this quality criteria by employing case studies and a semi-qualitative survey to get feedback from domain experts.

- **Completeness:** The metamodel representation contains all statements about the domain that are correct and relevant. Each concept has the necessary properties to describe and represent it (Bork and Fill, 2014; Cengarle et al., 2009; Helfert et al., 2012; Moody, 2009). We evaluate this quality criteria by employing case studies and a semi-qualitative survey to get feedback from domain experts.

Pragmatic Quality of ArchiSmartCity

The pragmatic quality dimension is at the most specific and personal level where stakeholders apply their meanings of communication to practical uses in this particular research context (Helfert et al., 2012; Janiesch et al., 2019). It helps to assess whether the output fits the purpose and meet the users subjective needs or utility of the artefact. One quality characteristic is evaluated in the pragmatic quality dimension as described as follows.

- **Relevance:** All the syntactic and semantic elements are relevant for the problem definition. The metamodel is relevant and important for the Smart Cities domain experts (Bork and Fill, 2014; Helfert et al., 2012; Moody, 2009). We evaluate this quality criteria by employing case studies and a semi-qualitative survey to get feedback from domain experts.

Table 7.5 Measurement Statements in this Thesis.

Quality Criteria	Description	Statement to be Measured
Precise definitions and terminology	Definitions and terms are described within the global lexicon.	• *Concepts Description:* The description is clear, concise and non-ambiguous to represent the defined concept within the Smart Cities domain. • *Concepts Relationships:* The defined relationships represent clearly the connection with the defined concept within the Smart Cities domain.
Easy to understand	The material is easy to understandable for information managers.	• *Graphical Notation:* The graphical notations are easy to understand by Smart Cities domain experts.
Completeness	The representation contains all statements about the domain that are correct and relevant.	• *Attributes:* The defined attributes represent necessary properties to describe the defined concept.
Relevance	All statements in the representation are relevant to the problem.	• *Concepts and Relationships:* All the concepts and relationships are relevant to represent the alignment between city services and information systems to support Smart City strategies.

Table 7.5 presents each quality criteria, its description, and the measurement statement used in this thesis during the semantic and pragmatic evaluation. The next section presents the results of the ArchiSmartCity evaluation based on the quality criteria defined.

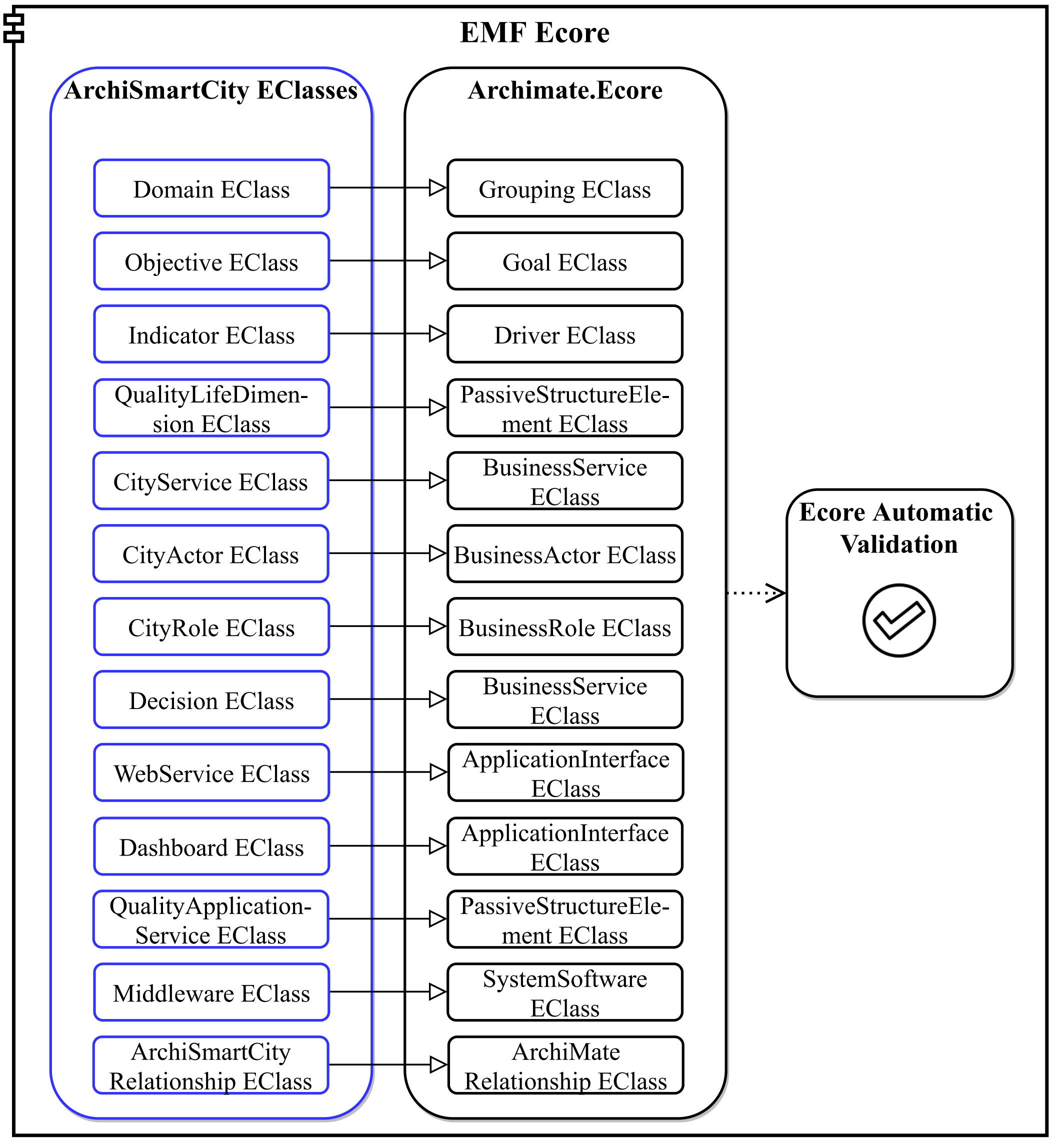


Fig. 7.36 EMF ArchiSmartCity Ecore.

7.3.2 ArchiSmartCity Evaluation Results

Syntactic Quality of ArchiSmartCity

- **Syntactic Correctness:** The syntactic correctness of ArchiSmartCity was evaluated using the Eclipse Modelling Framework (EMF). The EMF metamodel consists of two parts; the Ecore model and the Genmodel. An Ecore model contains a number of EClasses to represent the classes of a metamodel, while a Genmodel contains additional information for the metamodel code generation (Budinsky et al., 2004). The Ecore model is an implementation of the Meta-Object Facility (MOF), which

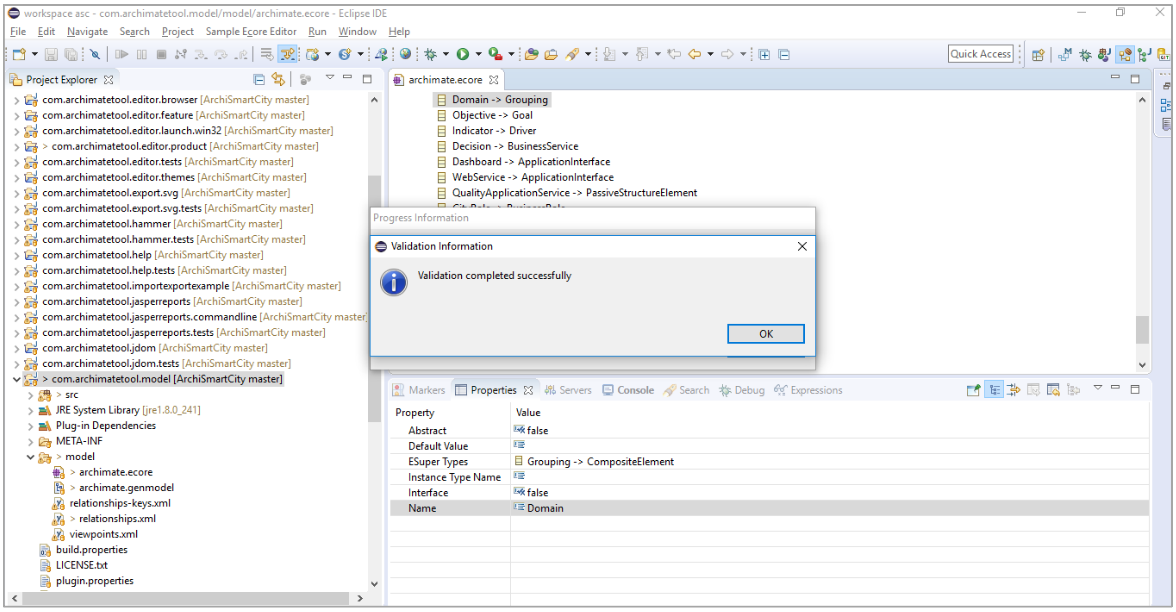


Fig. 7.37 Syntactic Evaluation. EMF ArchiSmartCity Ecore.

allowed us to formally specify and build the ArchiSmartCity metamodel based on MOF. Figure 7.36 illustrates the EMF Ecore, where each ArchiSmartCity EClass inherits from an existing ArchiMate EClass. The EMF enables the validation of the Ecore model by using the validation option on the Ecore editor. Figure 7.37 presents a screenshot of the validation of the ArchiSmartCity Ecore. The EMF did not show any syntactic error or inconsistencies and ArchiSmartCity syntax is conformant to the MOF metamodel.

Semantic and Pragmatic Quality of ArchiSmartCity

- **Interviews with Domain Experts**
  - **Relevance:** We evaluated the pragmatic quality (i.e., utility) of our proposal as a form of assessing whether the artefact fits the purpose and meet the users subjective needs (i.e., relevance) within the case studies. During the data collection, we asked the domain experts on the importance of the design principles and design requirements to align city services and their information systems with Smart City strategies. All the design principles and design requirements discussed during the meetings and semi-structure interviews were relevant to the stakeholders (Section 7.2.3).

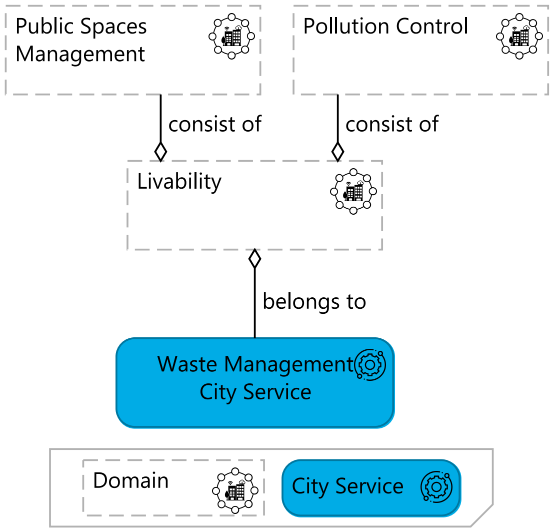


Fig. 7.38 Example Scenario (quality assessment).

We also held a meeting with the Smart City domain manager of Netanya to evaluate the resulting models for the waste management city service solution created by using ArchiSmartCity. First, we presented the models created in the case study (Section 7.2.2), according to the collected data and the feedback of stakeholders during the solution design. Second, a semi-structured interview was conducted to ask the opinion of the domain expert on the relevance of the concepts, their relationships, and their use in each model. The overall evaluation of the proposed concepts and solution was positive. The expert confirmed the relevance of the research problem and appreciated the development of ArchiSmartCity to support the alignment between city services and the underlying information systems. The expert also agreed with the notations and semantics of the metamodel. For example, the domain expert stated: "These concepts enable the management and oversight of a variety of systems and services". The domain expert also affirmed: "The different models, for example, the service catalog grouped by domains, is interesting for people from the municipality to see the current work areas, associated problems and future development of services to serve the needs of residents". More details of the interview can be found in Appendix F.

- **Semi-qualitative Survey**

A semi-quantitative survey is used to evaluate ArchiSmartCity with Smart City domain experts. We requested the judgment of a group of domain experts to evaluate primarily

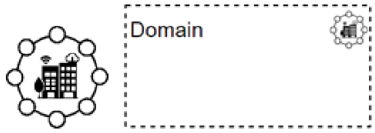
Graphical Notation	
Description	A domain is a key field of urban development in Smart Cities such as Smart Economy, Smart Transportation, Smart Education, Livability, etc.
Attributes	• *Attributes:* Name, Objective • *Sample:* Name: Livability Objective: This domain aims to help citizens and communities to preserve clean spaces that promote clean streets and water, sustain wildlife, and provide families with place to walk, play, and relax.
Relationships	• ***Rs1: A smart city service belongs to a domain*** o *Sample:* The waste management service belongs to the Livability domain • ***Rs2: A domain can consist of sub-domains*** o *Sample:* The Livability domain can consist of the sub-domains such as Public Spaces Management and Pollution Control

Fig. 7.39 Domain Concept (quality assessment).

the *quality* of our proposal. The participants involve the Smart City domain manager of Netanya municipality and five senior directors and managers of the Federation of Local Authorities in Israel (i.e., participants outside the case study). The roles of the participants within this Federation include the CEO, the Deputy CEO, the Director of Innovation, the Director of MuniExpo - Urban Innovation Fair, and the Director of Infrastructure and Urban Development. They were selected because of their expertise in the public sector and their work in the Smart Cities field that impact different aspects of daily life for all Israeli citizens (e.g., urban planning, education, transport, and more).

A meeting was held with the domain experts where they received a QR code to access a survey with seven modelled scenarios. Figure 7.38 shows an example of the modelled scenarios evaluated. Each scenario presents a description and questions related to the *quality* of the proposed concepts, including the *graphical notation, description of concepts, attributes, and relationships between concepts*. The evaluation of the

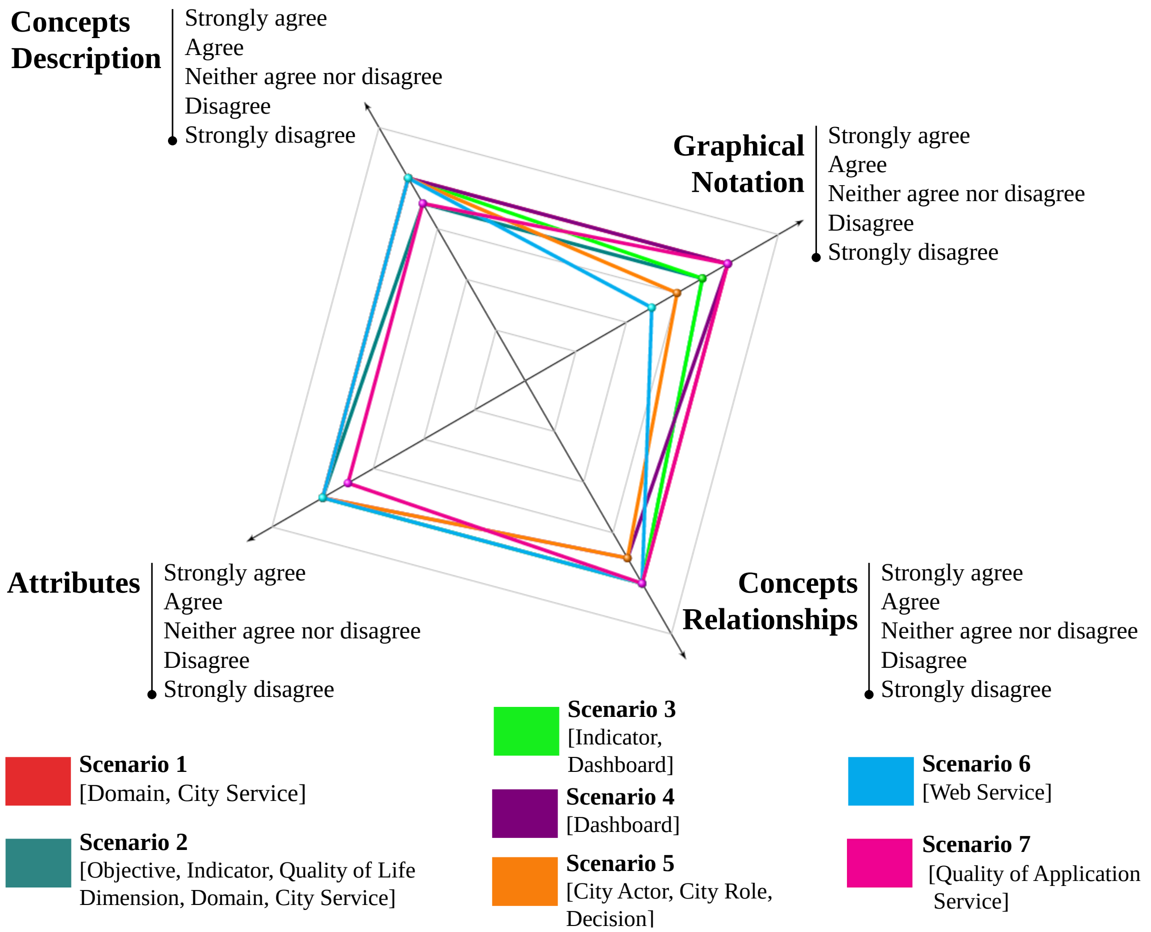


Fig. 7.40 Evaluation results (quality assessment).

ArchiSmartCity concepts and their relationships are crucial to corroborate our proposal on the alignment between the service and information layers in Smart City architectures. Figure 7.39 illustrates an example of the domain concept and its graphical notation, description, attributes, and relationships. The domain experts were requested to score from 1 to five following a Likert scale (1 = strongly disagree, 5 = strongly agree). The results of the survey about the *quality* of the artefact is presented in Figure 7.40 on a scale of one to five. The median of the graphical notation was 3.8. The description of the concepts was rated with a median of 4. The median of the relationships between the concepts was 4. In addition to this, the attributes of concepts was rated with a median of 4. Finally, the survey had space for additional opinions or comments to provide the respondents with the option to write an open opinion about the modelled scenarios and their relevance. The results show that participants found the proposed concepts and relationships relevant to the Smart Cities field. The overall feedback received on the quality of ArchiSmartCity from the domain experts was positive. Common practical suggestions were used to improve our proposal based on their feedback. Table 7.6 presents their practical suggestions and how we tackled this feedback. The results of the evaluation of the quality criteria with the domain experts are outlined as follows.

- **Precise definitions and terminology:** The domain experts reviewed all the presented scenarios and the definitions of the concepts and their relationships. They were of the opinion that these definitions were clear, concise, and non-ambiguous to represent the Smart Cities domain. They agree on the terminology used to represent both the service concepts and the information concepts. The service concepts are related to the strategy and management of city services, whereas, the information concepts refer to the implementation and automation of such services.
- **Easy to understand:** The domain experts examined the graphical notation of the proposed concepts and their visual representation in each scenario. The notations and semantics to express the concepts of the Smart Cities domain were easy to understand by the domain experts. They provided some practical suggestions to better express a few concepts (e.g., the quality of life dimension) which were adopted as a result. This helped us to improve the visual notation (i.e., graphical symbols) used to represent the concepts and to provide a common understanding of the concepts in the Smart Cities domain.
- **Completeness:** The domain experts confirmed that the ArchiSmartCity meta-model contains all statements about the Smart Cities domain that are correct and relevant for the problem. They were of the opinion that the concepts specify the necessary attributes or properties to represent the modelled concepts. The experts also found these attributes necessary to complement the definition (i.e., semantics) of the modelled concepts. The graphical interface of ArchiSmartCity allows the users to add user properties, or attributes, to a concept, model, or view.
- **Relevance:** The domain experts stressed the high relevance of the problem addressed. They confirmed that the proposed concepts and relationships can help them to support the alignment between the service and information layers in Smart City architectures. They recognize the value of the design and visualisation of the architecture models to communicate architecture decisions, allowing the consideration of various views and strategic aspects of Smart Cities. Table 7.7

Table 7.6 Detailed expert feedback - Concrete syntax and semantics

Topic	Transcription from the survey	Action Taken
Concepts	**A:** "Quality of City Service: Why the quality of city service is not an indicator?"	**A:** We defined the indicator concept to represent the quality of city services that measure performance management of such city services. We did not include a further specialisation for the quality of city services to avoid redundancy in the metamodel.
Attributes	**B:** "More specification is required for the attributes of the domain concept."	**B:** We agree and propose more attributes to describe the domain concept. We explained to the domain expert that additional attributes can be added during the design of the models using the ArchiSmartCity tool.
Attributes Example	**C:** "The description attribute of Environmental Quality: very partial, what about parks, green areas, water sewage, etc.?"	**C:** We shared our definition of the description attribute with the domain expert. We also clarified that the description is an open text field that can be completed according to Smart City domains defined in each municipality.
Graphical Notation	**D:** "The web services icon represents maintenance rather than web services."	**D:** We shared our understanding of web service icon representation with the domain expert. We clarified that the icon is widely used in service oriented architectures to represent web services.
	E: "The icon does not represent clearly the quality of life dimension. I would add an icon more related to the well-being of people."	**E:** We agree and updated the icon for the quality of life dimension concept based on this suggestion.
	F: "I like the flow for describing the models and the graphical notations to present the concepts."	**F:** We agree with the domain expert. We followed a EA top-down approach to present the concepts.

details the feedback of the domain experts on the relevance of our proposal. The statements listed in the table are transcriptions of the responses from the experts.

Table 7.7 Detailed expert feedback - Relevance

Topic	Transcription from the survey
Concepts and Relationships	**A:** "The concepts you suggest indeed give an instrument to simplify the discussion regarding a rather complicated field and might be used to build a common language."
	B: "The concepts proposed represent a wide contribution to Smart Cities and it is connected to the reality to support the municipalities."
	C: "These concepts are useful for us as managers and decision-makers because this is what we do every day. The flow of the models helps to understand the city services and solutions."
	D: "The definition of the goals in Smart Cities is generic, for example in the model, the first goal is too general (It can be suitable for security as well as a building). So, the definition of the objective concept is good to specify more the goals."
	E: "The connection of the services and information concepts with the goals, objectives and the smart city quality, provides a connection with the citizens needs."
City Service Example	**F:** "It is important that you chose a waste management city service because it is an example easy to understand and relevant for any city."

7.3.3 Validity and Reliability of this Research

This thesis considers different validity and reliability aspects to evaluate the quality of this research, which are outlined as follows.

Construct validity reflects what is investigated according to the research questions (Runeson and Höst, 2009; Teegavarapu and Summers, 2008). This research used multiple data sources (data triangulation) such as meetings, semi-structured interviews, digital strategy, city service platforms, etc., to provide evidence in accordance with (Runeson and Höst, 2009; Yin, 2009). Another method to improve construct validity is to create a case study report which may have different audiences, such as practitioners and researchers (Yin, 2009). We created reports for each case study conducted which were reviewed by key informants (e.g., Smart City domain managers) to tackle construct validity. A journal article of each case study was submitted to validate the main findings with peer reviewers in the scientific community.

Internal validity concerns the causal relations investigated during the case studies and the factors that influence the design process (Runeson and Höst, 2009; Yin, 2009). The threat to the internal validity of this research is addressed by spending sufficient time with each case study. In fact, during the first case study, we had long-term cooperation with the city council due to the execution of the Limerick Enterprise Architecture project.

This allowed us to understand real-world city services and related alignment issues as well as to model city service solutions on top of information systems aligned with Smart Cities strategies. Additional considered factors include architectural standards, Enterprise Architecture (EA) guidelines, and modelling techniques used for creating the ArchiSmartCity metamodel (Bézivin, 2004; ISO/IEC/IEEE 42010, 2011; The Open Group, 2018), and the feedback of case study participants on the models and the overall architecture design process. Besides, the ArchiSmartCity concepts and relationships were abstracted from the Smart Cities domain (literature review and practice) and designed to make these concepts language-independent.

External validity refers to the extent to which the findings can be generalised (Runeson and Höst, 2009). This research addresses the external validity by building the solution on established theories and techniques from the existing knowledge base on business and IT alignment and EA. We extracted the design principles and design requirements from the literature and defined them in a high-level abstraction description to meet the requirements of various Smart Cities. According to the literature, conducting multiple case studies helps to provide an analytical generalisation by replicating findings across cases (Yin, 2009). We conducted the case studies in Irish and Israeli cities in order to analyse the relevance of the findings and replicate the results in different contexts. We asked domain experts inside and outside of the case studies to judge our proposal. The interviews with the experts and the results of the semi-quantitative survey showed that ArchiSmartCity is especially important for them. The experts confirmed the relevance of ArchiSmartCity for modelling the alignment of city services and the underlying information systems in Smart Cities architectures. According to their feedback, ArchiSmartCity provides a solid foundation to model and manage the alignment with Smart City strategies and goals.

Reliability is concerned with the repeatability of research findings (Runeson and Höst, 2009; Yin, 2009). Repeatability of this research process is addressed by following standard guidelines, formulating a case study protocol, and following the same for multiple cases. This criterion is satisfied by developing a case study database and creating individual case study reports. This provides us with a clear process with respect to the storage of defined questionnaires and interview questions as well as to code collected data (e.g., expert feedback on resulting models) for the data analysis phase. Data triangulation is applied using a variety of data sources in each case study to validate the design principles, design requirements, and ArchiSmartCity concepts and relationships. It is used in this research as a method to increase the reliability and validity of research findings. In addition to this, the reliability of this research during the design phase was addressed by following a Model Driving Engineering (MDE) approach and an Agile Modelling Method Engineering with defined and clear steps as operational as possible for the definition and design of ArchiSmartCity in section 5.1. Design rationale was described for documenting design decisions made and the reasons why they were made in section 4.3 and section 5.2.2. This provides traceability and transparency in the design process and helps to justify the final design before its demonstration and evaluation.

7.4 Demonstration and Evaluation Summary

This chapter presented the demonstration and evaluation of *ArchiSmartCity*. The demonstration involved the application of *ArchiSmartCity* in multiple case studies and the development of a computer-based solution for semantic alignment analysis. The evaluation included the assessment of the utility of *ArchiSmartCity* in the case studies with Smart City domain experts. We furthermore used a semi-qualitative survey to evaluate the quality of *ArchiSmartCity*. It included the evaluation of the abstract syntax, concrete syntax and semantics, and perceived usefulness of the final artefact. The domain experts confirmed the relevance of the research problem and recognised the development of *ArchiSmartCity* to support the alignment of city services and the underlying information systems in this field. In Chapter 8 we will outline a review of our research, including a discussion of the contributions of our work along with some of its limitations and some possibilities for future research.

Chapter 8

Conclusion

This thesis investigates the alignment between the service and information layers in Smart City architectures. It identifies the limitations in current alignments between city services and information systems to support Smart City strategies and proposed *ArchiSmartCity*, a metamodel to explicitly express this alignment in the Smart Cities domain. *ArchiSmartCity* includes the definition of the syntax, semantics, and notations, to create a common language to help the communication and understanding of Smart City stakeholders. This thesis evaluates *ArchiSmartCity* using multiple research methods and techniques from both naturalistic (e.g., multiple case studies, interviews, surveys) and artificial approaches (e.g., computer-based solution). Results were presented according to the evaluation criteria selected for this thesis. The remainder of this chapter summarises the contributions and limitations of this thesis and examines future directions for this work.

8.1 Revisiting the Research Questions

Smart Cities have significant challenges for providing services aligned with Smart City visions and goals, thus improving the quality of life for the citizens. In particular, this research addresses the challenge related to the alignment of city services and information systems to support the strategic alignment in the Smart Cities context. The research questions defined to address these challenges are presented in section 1.6. In the following, this section revisits these RQs and presents their main results.

For RQ.1, Chapter 4 describes how this study derives and defines a set of design principles to support the alignment between the service and information layers in Smart City architectures.

- A set of six new design principles are proposed as explicit prescriptions on how to address this alignment in the Smart Cities domain. These design principles are grounded in the literature and validated with Smart City domain experts.
- The demonstration of these design principles is conducted through the instantiation and implementation of a metamodel for Smart Cities to make these principles actionable by supporting the alignment.

For RQ.2, Chapter 5 outlines how this research designs a novel metamodel to explicitly specify this alignment in Smart Cities architectures using the design principles resulting from RQ.1.

- Smart City concepts and their relationships are defined and structured into the *ArchiSmartCity* metamodel to explicitly represent the alignment between city services and the underlying information systems according to Smart City strategies.
- The specification of the *ArchiSmartCity* metamodel includes the definition of its syntax, semantics, and notations to create a common language to support this alignment in the Smart Cities domain.
- The *ArchiSmartCity* metamodel is implemented in the form of an extension of the ArchiMate modelling language. The approach followed for the development of such extension is presented in Chapter 6.

For RQ.3, Chapter 7 details how this research applies and evaluates the proposed concepts and relationships resulting from RQ.2.

- This study considers different validity and reliability aspects to evaluate the quality of this research.
- Results demonstrate the high-quality and practical relevance of the proposed concepts and relationships for cities and municipalities.
- These results were complemented with an artificial evaluation that shows the effective alignment in Smart City architectures that use the proposed concepts and relationships.

8.2 Thesis Contributions

This study addresses the research challenge of supporting alignment in the Smart Cities field. This section outlines the research contributions of this study as well as its implications for practitioners. We build on the findings of this research and their positioning within the existing literature.

8.2.1 Impact for Research

First, this study advances current research on the Smart Cities field, which has been mainly focused on the implementation of the information and technology aspects in these complex and dynamic urban environments. This research contributes to the current understanding of how city strategies should be aligned with Smart City implementations. This research provides a prescriptive view to guide a coherent architecture design to support the fulfillment of the Smart Cities vision. Such a prescriptive view ensures that Smart City implementations are built according to city goals which reflect the needs and expectations of citizens (e.g., residents, visitors, and businesses). Our case studies demonstrate the application of this prescriptive view by designing city service solutions in line with city master plans and digital strategies where the technology is only the enabler of these solutions. This is important to advance the concept of Smart Cities, as research has so far primarily focused on technical and engineering challenges with little attention to how to achieve desired outcomes (e.g., sustainability, economy, society, and governance) (Pérez González and Díaz Díaz, 2015; Ramaprasad et al., 2017; Yigitcanlar et al., 2018). Furthermore, the design-oriented approach adopted within this study and the richness of our findings in multiple real-world scenarios complements the existing quantitative dominant view on Smart Cities implementations in the current literature.

Second, this research allows us to understand the wider challenges in developing Enterprise Architecture (EA) in Smart Cities, which has been mostly guided by experience in the corporate and profit-oriented sector. This research builds an understanding of the different concepts and relationships from the Smart Cities domain that together provide a coherent and unambiguous EA description of this domain. Coherent architecture descriptions and understandable Smart City concepts allow city planners and architects to manage the complexity of these cities and support continuous alignment. In our case studies, we create integrated models covering integration and service quality issues that allow change impact analysis of the dependence of city services on information systems. The resulting models show that multiple configurations of the proposed concepts and relationships can be created for modelling different cities. These multiple configurations are conformant to our proposed

EA description for Smart Cities, fulfilling the requirements of diverse urban contexts. This research provides important results to enrich the academic conversation on the diversity of these cities, which is currently relying on qualitative results from social science (Echebarria et al., 2020; Lnenicka et al., 2017; Ramaprasad et al., 2017), with limited effort to capture a comprehensive understanding of how the components of these cities should be interconnected differently depending on the context. We envisage that this EA description will be leveraged as a reference for guiding a coherent architecture design and enabling more complete comparisons of Smart Cities.

Third, this research outlines what information is necessary for the alignment analysis and how to perform the analysis in the Smart City context. This enhances the understanding of the role of the alignment to support and manage transformation and change in dynamic urban contexts. We provide a computer-based solution to identify alignment issues between these elements using an Enterprise Architecture (EA) approach, starting with city goals and objectives and ending up in city services implementation details. We use the knowledge of the developed models in our case studies based on the critical elements identified, such as the quality perspectives of Smart Cities: quality of life dimensions, city service qualities, and application service qualities. This contributes to the Smart Cities field by understanding how these elements should work together in consonance and the impact on each other, rather than operate by the inherent characteristics of individual components. The automation of this analysis is particularly beneficial for these urban environments where architecture models are based on large heterogeneous datasets, making it challenging to find alignment problems. This tool will facilitate the analysis of the current and future state of these cities and help decision-makers and designers to know the impact of design decisions.

8.2.2 Impact for Practice

First, the results of this study show that our proposal can provide a comprehensive foundation to guide the design of Smart City services, considering the digital transformation challenges. In practice, it is very difficult to have an overall perspective on the architecture changes and to provide city authorities and architects managing the changes with the information they need. Cities and municipalities can manage the change by structuring and aligned service concepts (e.g., domains, city goals, city services, city actors, and other service concepts) with information concepts (e.g., application services, quality of application services, dashboards, web services, and other information concepts) in a coherent Enterprise Architecture (EA) description. Hence, we claim the proposed concepts and relationships to have a referential character, meaning that they together provide a guide for a coherent architecture design of the desired services, and assist the digitalisation and transformation of public services.

Second, our case studies lead us to understand that digital transformation in these cities is a significant strategic challenge. It is necessary to answer during the city service design, why these services exist or why they need to be changed. For instance, the proposed city goals and objectives concepts connected to implementation concepts are relevant to help city managers and architects to provide the motivations or reasons that guide the design. Moreover, these cities have many broad initiatives in different domains such as mobility, environment, sustainability, etc. They have implemented some of these initiatives, with different maturity levels and applications in such domains. However, most of these solutions focus on a specific domain, target a specific problem, and were developed to meet the requirements of a limited number of stakeholders, with disconnected applications that do not share relevant information. Since they do not interoperate, they lead to duplication of work and cost, incompatible solutions, and non-optimized resource use. City services need to be integrated within the same or different domains since the early stage of design to contribute to the achievement of common city goals, thus our research proposal can assist cities in this challenge.

Third, this study proposed an approach to extend ArchiMate for Smart Cities where domain-specific elements are required. Our observations suggest that this tool is valuable for practice as it enables Smart Cities managers and designers to use a common language close to the domain experts as a means for communication between them. This extension allows the modelling of various views and strategic aspects of city services and the modelling of simple and complex real-world scenarios of Smart Cities to support decision-making that affects the quality of life for the citizens. Additionally, we see in practice that there is a need for city data to be available to all stakeholders in order to added value to these data sources (Lnenicka et al., 2017). Early identification of city actors (e.g., city authorities, service providers, and citizens) and their requirements regarding the data for decision making contributes to the design of added-value services within the case studies. The case studies also show how our proposal help to improve the ability of city functional departments to collaborate in city service provision and add value to public services aligned to the needs of citizens.

8.3 Research Limitations

This thesis explores the alignment between the service and information layers in Smart City architectures by using a design-oriented research approach. This section outlines and discusses the limitations related to the research from a critical perspective.

Cross-Domain Solutions

This thesis defines domain-specific concepts (e.g., domain, city service) and relationships (e.g., belongs to) to link city services and information systems and realise the horizontal alignment in the Smart Cities field. According to the literature, the seamless flow of information among cross-domain services can help to realise the horizontal alignment of city systems and applications to support multiple stakeholders (Hefnawy et al., 2015). We apply and validate these concepts within our case studies. However, we did not have the opportunity to design cross-domain city service solutions. In Limerick City, we had access to some information on the air quality city service from the *environmental practices domain*, but the main focus of the case study was on the footfall-counter city service from the *movement and transport domain*. This did not allow us to create models that represent the interconnection between strategies and implementation solutions in multiple domains. At the Netanya Municipality, we conducted a case study to explore the waste management city service from the *livability domain* because this city service had more associated issues to be solved. Additionally, the proposed Enterprise Architecture (EA) description for Smart Cities was quite beneficial to represent the future state of the waste management city service within this complex urban context. Hence, future research is needed to design and evaluate cross-domain solutions in real cities that demonstrate the horizontal alignment among different domains.

Number of Services

This thesis demonstrates that services play a central role in Smart Cities. Service has changed thanks to digital transformation developments in these cities using information technology (IT) (Huber et al., 2019). We abstract the service concept and represent it at the city service and information systems levels. For instance, web services are a key technology to automate and support city services at the information level (Purohit and Kumar, 2019). The number of web services in a city can grow and need to be managed. This thesis addresses this requirement and proposes the *middleware* concept. A middleware supports the interoperability of diverse applications and services running on heterogeneous devices. We identified this concept from the literature and validated its relevance for practitioners within multiple case studies. Our case studies were conducted in cities with a small number of services, but the number of services in Smart Cities is expected to be large (i.e., large scale). More research (i.e., future research) is necessary to validate the proposed metamodel in these large scale cities where new concepts (e.g., middleware) of the metamodel can be identified.

8.4 Future Work

Future research directions are outlined focusing on the need for further research and identified issues in practice. They are described as follows.

- **Strategic and Operational Planning:** This research explores the modelling of Smart Cities and validates the findings in multiple case studies. The knowledge of the resulting models was used to analyse the alignment using available city data (e.g., city service reports). For instance, our alignment analysis tool highlights when there is a problem of alignment due to the indicators of city services are not reaching the established target levels. Using our proposal as a foundation, cities, and municipalities could enrich their architecture models with real-time urban data (e.g., city services performance, citizens feedback from social media and quality of life over time) and display the results in various dashboards. These dashboards can be shared with relevant stakeholders in the cities, including strategic decision-makers as well as operational stakeholders. Therefore, future research should continue investigating how to close the gap between strategic and operational planning tools in order to make decisions based on all relevant city data using integrative planning solutions.

- **Formal Specification:** Our proposal is implemented as an extension of ArchiMate to support the alignment in the Smart City domain. The ArchiMate modelling language uses graphical notations to represent Enterprise Architectures (EAs). The graphical notations are easy to understand and transferable between different standards. However, using graphical representation alone can be not enough to represent all the elements in a domain (e.g., rules and constraints). This is because not every rule can be captured by ArchiMate graphical notations. For example, consider the task of defining a rule for a Smart City metamodel that specifies a data management policy for data privacy. This would be helpful to increase the level of robustness in designing Smart City systems while adding the capabilities for verification of the quality of architecture models. Here, it would be very helpful to design a textual specification language to complement current ArchiMate graphical notations. In this way, users can go beyond its graphical representations and have the freedom of specifying rules to make Smart City models more formal and precise.

- **Procurement Process:** The procurement process of services in the public sector needs to be adjusted to respond to the growing transformation (Ylinen and Pekkola, 2019). End-users in Limerick City and the Netanya Municipality have domain knowledge of their field such as planning city environments, economic development, tourism strategies, waste management, etc. However, they have little understanding of the capabilities of IT and the improvements offered by new products that are constantly being released (e.g., cloud computing services, application programming interfaces, sensor technologies). Understanding the potential of technology is essential before drafting the final specifications of services. For example, we use the different Smart City models created during the case study in Limerick City to understand and specify the requirements of a request for tenders for the provision of pedestrian and cyclist traffic counters. Consequently, procurement plans and proposals should be prepared based on the requirements and needs of the stakeholders in collaboration with experts in the Smart City domain and Enterprise Architecture experts that can stand or bridge the interface between knowledge of the technology and its application in this problem domain. Hence, more research is necessary to understand the procurement process for technological adoption in this field, to ensure that city solutions developed conform to the specifications.

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Appendix A - Smart City Architectures Alignment

Literature Review Process

The goal of this literature review is to explore the alignment in Smart City architectures, focusing on Enterprise Architectures (EAs), IT architectures, Smart City Concepts, and Metamodels for Smart Cities as introduced in Chapter 2 and Chapter 3. This study follows the phases and the concept-centric approach proposed by (Corradini et al., 2018; Webster and Watson, 2002). Figure A1 illustrates the process for the article selection. The phases of the applied methodology are described in the following.

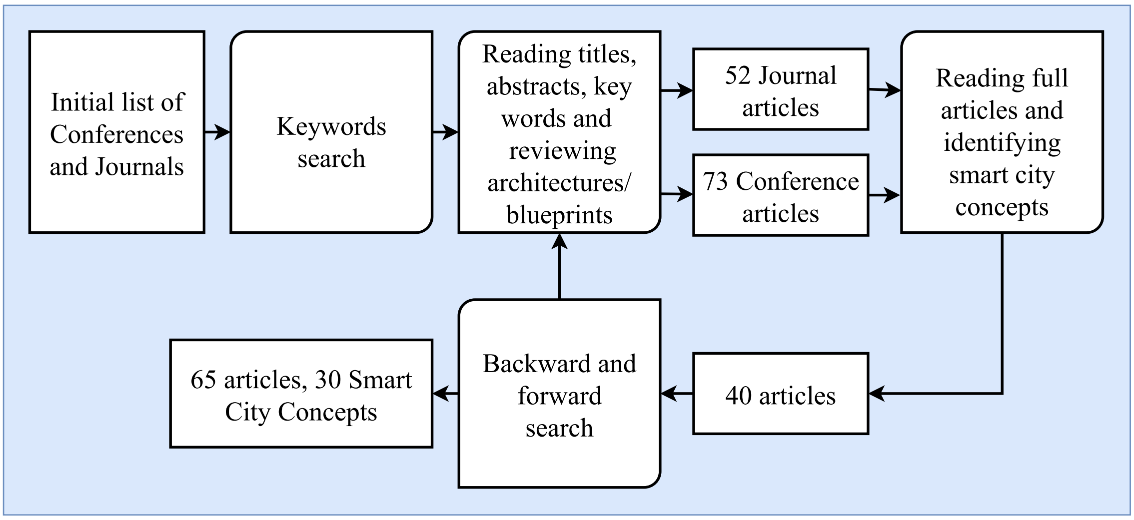

Fig. A1 Literature Review. Article Selection.

Search Strategy and Scholarly Sources

The search strategy follows a structured approach to determine the source material for the review. The preliminary selection of available material was carried out according to the problem investigated, using a variety of academic sources that are relevant and current. Particularly, the method suggests starting from an initial set of papers manually identified in order to select the set of relevant research papers to consider in the literature review. The initial set of papers was selected by retrieving all the titles of the papers published by a relevant set of scientific journals on topics regarding Smart Cities, Information Systems, and related topics. The following initial list of journals and conferences was considered:

- European Journal of Information Systems
- Information Systems Journal
- Information Systems Research
- International Journal of Information Management
- Journal of Association of Information Systems
- Journal of Information Systems and Technology Management
- Business and Information Systems Engineering Journal
- Cities Journal
- Government Information Quarterly Journal
- International Journal of Public Sector Management
- Journal of E-Government
- Journal of Urban Technology
- Local Government Studies Journal
- Smart Cities Journal
- Smart Cities, Green Technologies, and Intelligent Transport Systems
- International Journal of Conceptual Modeling
- IEEE Transactions on Services Computing
- Hawaii International Conference on System Science
- IEEE International Conference on Smart Computing
- International Conference on Advanced Information Systems Engineering

Key Words, Inclusion and Exclusion Criteria

The keywords used in the search process are specified in the following list: smart city enterprise architecture(s), smart city architecture(s), smart city IT architecture(s), smart city business architecture(s), smart city information architecture(s), smart city information technology architecture(s), digital city architecture(s) smart city metamodel(s), smart city enterprise modelling language(s), smart city enterprise architecture modelling language(s). The keywords are derived based on an initial search, especially considering the overview and content of the articles. The keywords are searched in the title, abstract, and keywords terms. The publication date is considered as a further criteria to shape the initial collection of papers. In particular, the selected articles were published between 2006 and 2020 which is probably the most recent period with a complete set of research for digital (as an initial stage of Smart Cities) and Smart Cities. The papers included in the selection are relevant articles that focus on the architecture layers (e.g. service, information, and technology) of EA for Smart Cities. The articles are excluded if they do not present any architecture description or architecture model (i.e., architecture blueprint) to describe the main architecture layers and the proposed concepts. Successively, additional relevant papers are identified proceeding backward by reviewing the citations of the identified articles and proceeding forward by reviewing the citations of the identified articles. In total, 52 journals and 73 conference papers were collected and reviewed entirely.

Structuring the Review

The logical approach developed to grouping and presenting the findings of the literature review is as follows. First, we explore Enterprise Architectures (EAs) for Smart Cities. These EAs are classified into frameworks, reference architectures, and architecture layers based on the results. Second, we explore IT Architectures for Smart Cities. These IT architectures are grouped into digital architectures, IS architectures, and technology architectures. Third, Smart Cities concepts are extracted from the EA and IT architectures reviewed and classified into service concepts, information concepts, and technology concepts. Finally, Metamodels for Smart Cities are reviewed and classified into abstract syntax and Enterprise Modelling languages.

Identifying Smart City Concepts

The Smart City Concepts and the relationships between them are the main unit of analysis in this review. They are derived from the entire review of EAs and IT architectures for Smart

Cities. For this purpose, first, each article is reviewed in order to extract the architecture layers. These layers are classified according to their similarity in terms of service, information and technology layers. Once the layers are identified and classified, each layer is reviewed in detail and the concepts and the relationships between them are extracted. The sources for the extraction are the description of the architecture layers and the blueprint(s) of the architectures in each paper. The identified concepts (30) and their relationships are defined and compiled in a concept matrix as each article is read, see Table 2.1.

Appendix B - Design Principles

Design Principles - Literature Review Process

This section describes the steps followed to derive the design principles from relevant literature. The search strategy follows a structured approach for literature reviews in order to determine the source material for the review (Corradini et al., 2018; Webster and Watson, 2002) as introduced in Chapter 2 and Chapter 3. This review focuses on high-quality journals and papers related to design principles for addressing the alignment in the Smart City domain as defined in Section 4.2. Figure A2 illustrates the process for the article selection. The phases of the applied methodology are described in the following.

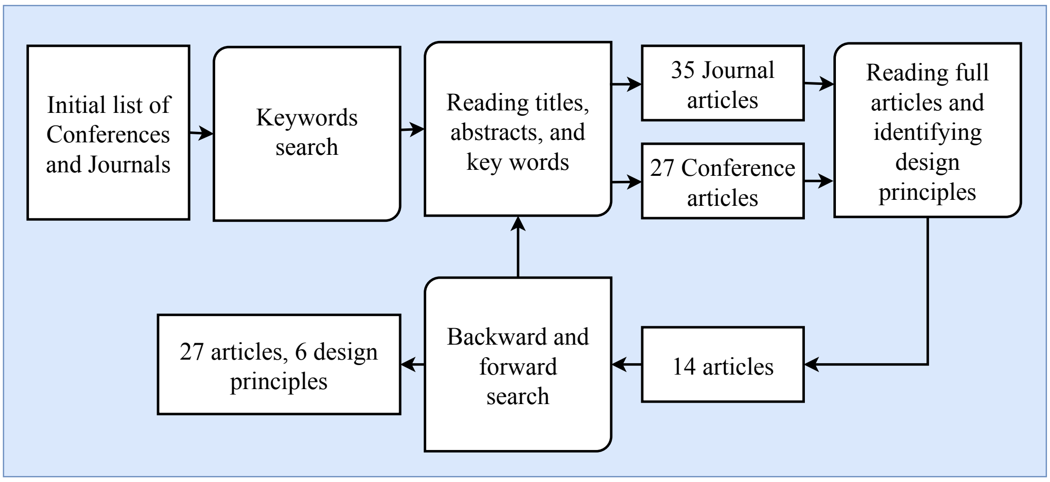

Fig. A2 Design Principles. Article Selection.

The initial set of papers is selected by retrieving all the titles of the papers published by a relevant set of scientific journals and conferences on topics regarding Information Systems, Enterprise Architecture, Smart Cities, and related topics. The following initial list of journals and conferences is considered:

- European Journal of Information Systems

- Information Systems Journal
- Information Systems Research
- International Journal of Information Management
- Journal of Association of Information Systems
- Journal of Information Systems and Technology Management
- Business and Information Systems Engineering Journal
- Organization Science Journal
- Cities Journal
- Government Information Quarterly Journal
- International Journal of Public Sector Management
- Journal of E-Government
- Journal of Urban Technology
- Local Government Studies Journal
- Smart Cities Journal
- Smart Cities, Green Technologies, and Intelligent Transport Systems
- International Journal of Conceptual Modeling
- IEEE Transactions on Services Computing
- Hawaii International Conference on System Science
- IEEE International Conference on Smart Computing
- International Conference on Advanced Information Systems Engineering

The keywords used in the search process are specified in the following list: smart city alignment, enterprise architecture alignment, alignment principle(s), and alignment design. The keywords are derived based on an initial search, especially considering the overview and content of the articles. The keywords are searched in the title, abstract, and keywords terms. A total of thirty-five journal articles and twenty-seven conference articles were identified. These papers are then selected and reviewed entirely. Next, the first set of design principles was identified by reflecting on the existing knowledge for alignment in Enterprise Architecture and design knowledge acquired from working on modelling public services. The papers included in the selection are relevant articles that focus on the alignment principles, architecture alignment, and the alignment of city services and information systems in Smart Cities. The articles are excluded if they do not present any design principle related (fourteen articles selected). Successively, additional relevant papers are identified proceeding backward by reviewing the citations of the identified articles and proceeding forward by reviewing the citations of the identified articles. Next, the identified articles were analysed by following a logical approach to grouping the design principles in dimensions that represent the key design principles uncovered. These criteria resulted in the four dimensions and six design principles.

Appendix C - Design Requirements

Design Requirements - Literature Review Process

The goal of this literature review is to identify the design requirements of Smart Cities. This study follows the phases and the concept-centric approach proposed by (Corradini et al., 2018; Webster and Watson, 2002) as introduced in Chapter 2 and Chapter 3. This review focuses on the main characteristics for modelling the alignment between city services and information systems to support Smart City strategies as defined in Section 5.2.1. Figure A3 illustrates the process for the article selection. The phases of the applied methodology are described in the following.

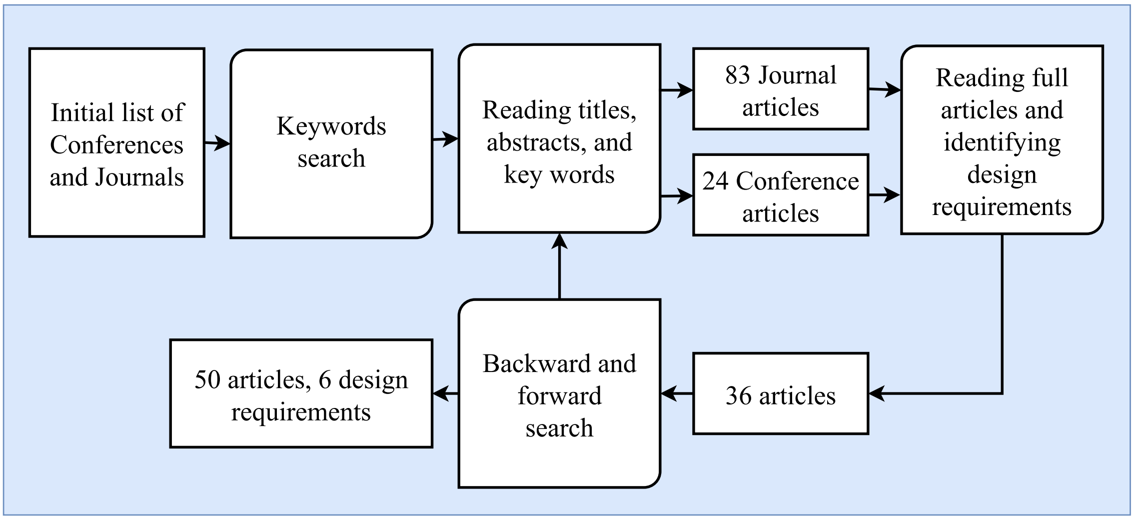

Fig. A3 Design Requirements. Article Selection.

Search Strategy and Scholarly Sources

The search strategy follows a structured approach to determine the source material for the review. The preliminary selection of available material was carried out according to the problem investigated, using a variety of academic sources that are relevant and current.

Particularly, the method suggests starting from an initial set of papers manually identified in order to select the set of relevant research papers to consider in the literature review. The initial set of papers was selected by retrieving all the titles of the papers published by a relevant set of scientific journals on topics regarding Smart Cities, Information Systems, and related topics. The following initial list of journals and conferences was considered:

- European Journal of Information Systems
- Information Systems Journal
- Information Systems Research
- International Journal of Information Management
- Journal of Association of Information Systems
- Journal of Information Systems and Technology Management
- Business and Information Systems Engineering Journal
- Cities Journal
- Government Information Quarterly Journal
- International Journal of Public Sector Management
- Journal of E-Government
- Journal of Urban Technology
- Local Government Studies Journal
- Smart Cities Journal
- Smart Cities, Green Technologies, and Intelligent Transport Systems
- International Journal of Conceptual Modeling
- IEEE Transactions on Services Computing
- Hawaii International Conference on System Science
- IEEE International Conference on Smart Computing
- International Conference on Advanced Information Systems Engineering

Key Words, Inclusion and Exclusion Criteria

The keywords used in the search process are specified in the following list: smart city service(s), smart city information system(s), smart city alignment, smart city model(s), smart city business architecture, smart city information architecture. The keywords are derived based on an initial search, especially considering the overview and content of the articles. The keywords are searched in the title, abstract, and keywords terms. The publication date is considered as a further criteria to shape the initial collection of papers. In particular, the selected articles were published between 2007 and 2020 which is probably the most recent period with a complete set of research for Smart Cities (83 journal papers and 24 conferences papers collected). These papers are then selected and reviewed entirely. The papers included in the selection are relevant articles that focus on city services and information systems management. The articles are excluded if they do not present any requirements related to city services or application services in Smart Cities (36 journal papers selected). Successively, additional relevant papers are identified proceeding backward by reviewing the citations of the identified articles and proceeding forward by reviewing the citations of the identified articles. In total, 50 articles were selected, including journal papers, conference papers, and international standards for Smart Cities.

Identifying the Design Requirements

The design requirements are derived from the entire review of the selected articles. For this purpose, first, each article is reviewed in order to extract the requirements to align and manage city services and information systems the Smart Cities domain. These requirements are classified according to their similarity in terms of Smart Cities application domains, strategy and performance, services and quality of services, and decision-making support, which are essential to Enterprise Architecture Management. These design requirements were iteratively refined and aggregated during the review. Finally, six design requirements are defined, compiled, and described according to the aforementioned classification.

Appendix D - ArchiSmartCity Metamodel Extension

ArchiSmartCity Metamodel Extension - UML Notation

Figure A4 depicts the ArchiSmartCity metamodel as an extension of the ArchiMate language by using a simplified UML class diagram. ArchiSmartCity concepts are structured within the service and information layers and inherit the relationships from existing ArchiMate concepts.

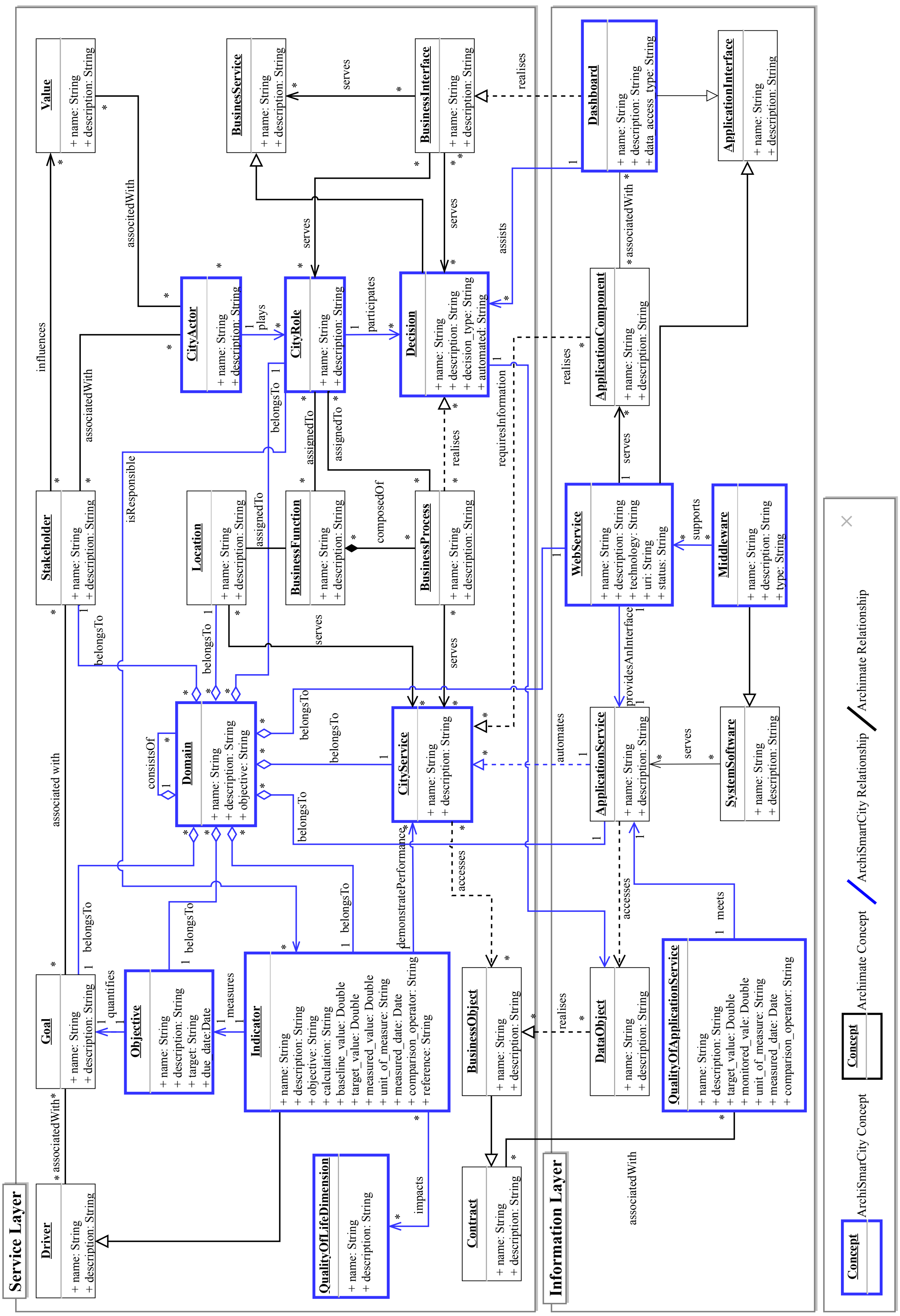

Fig. A4 ArchiSmartCity Metamodel Extension. UML Notation.

Appendix E - ArchiSmartCity EMF Implementation

This appendix presents a number of screenshots of the developed ArchiSmartCity metamodel. ArchiSmartCity is implemented using the Archi Modelling Tool that relies on the Eclipse Modelling Framework (EMF).

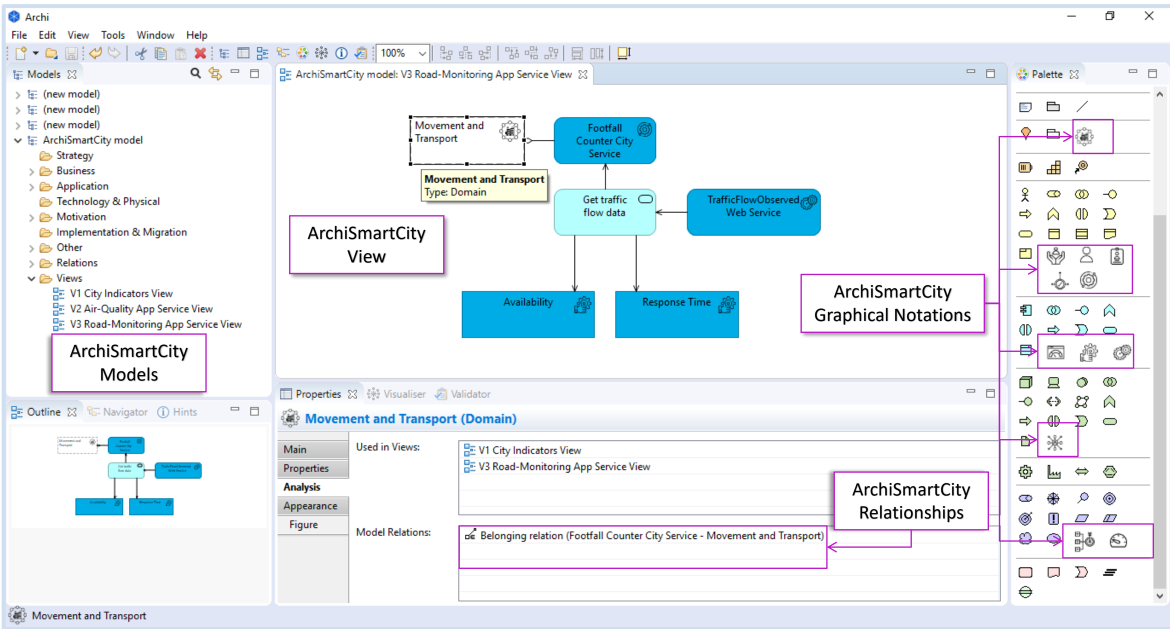

Fig. A5 ArchiSmartCity EMF Implementation in the Archi Tool. Screenshot.

Figure A5 depicts the ArchiSmartCity elements added into the Archi tool, including the ArchiSmartCity concepts, relationships, and graphical notations. The palette contains the graphical elements and relationships extended that can be used in the views. All these new elements allow the end-users to create ArchiSmartCity views and models which conform to the ArchiSmartCity metamodel. The figure shows a list of ArchiSmartCity views, including the City Indicators View, Air-Quality App Service View, and Road-Monitoring App Service

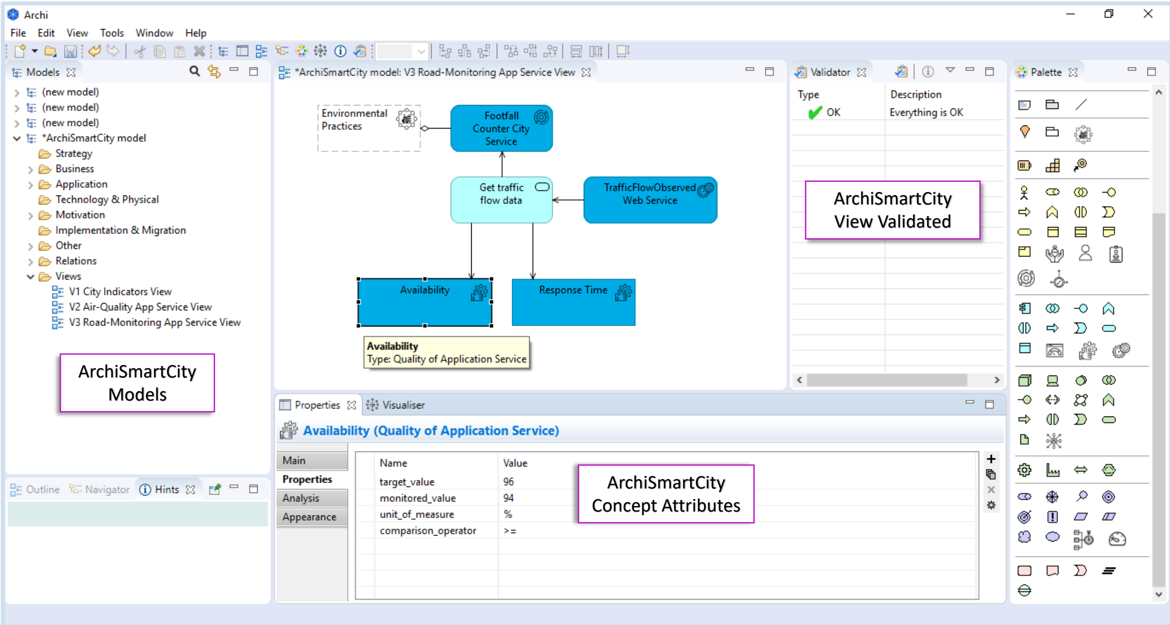

Fig. A6 ArchiSmartCity Models Validation and Concepts Attributes. Screenshot.

View. The Movement and Transport domain is selected in the view, which allows the tool to visualise all its existing ArchiSmartCity relationships within the model for analysis purposes.

Figure A6 depicts a screenshot of the ArhiSmartCity models and views. The figure presents that the ArchiSmartCity views created are validated successfully in the Archi tool by using its validator component. This demonstrates that the ArchiSmartCity EMF implementation enables the creation of ArchiSmartCity models that do conform to the ArchiSmartCity metamodel. Moreover, the Availability concept is selected in the model to show how the tool enables the representation of its properties, including the target_value, monitored_value, unit_of_measure, and comparison_operator. End-users can add the necessary ArchiSmartCity attributes as concepts properties to enrich the knowledge within the models.

Figure A7 depicts a screenshot of the ArhiSmartCity concepts and relationships. The figure illustrates how all the ArchiSmartCity relationships of the Footfall-Counter City Service are represented in the Archi tool by using its visualiser component. This shows that the ArchiSmartCity EMF implementation enables the visualisation of all existing relationships of a concept among all the views of an ArchiSmartCity model. This is relevant for end-users when managing and designing complex scenarios of Smart Cities. In this example, the visualiser component displays the Footfall-Counter City Service and its relationships to the Movement and Transport domain of the Road Monitoring App View as well as to the Environment Practices domain represented in the Cities Indicator View. The Footfall-Counter City Service has also relationships with the indicator: Number of commuters by walking and

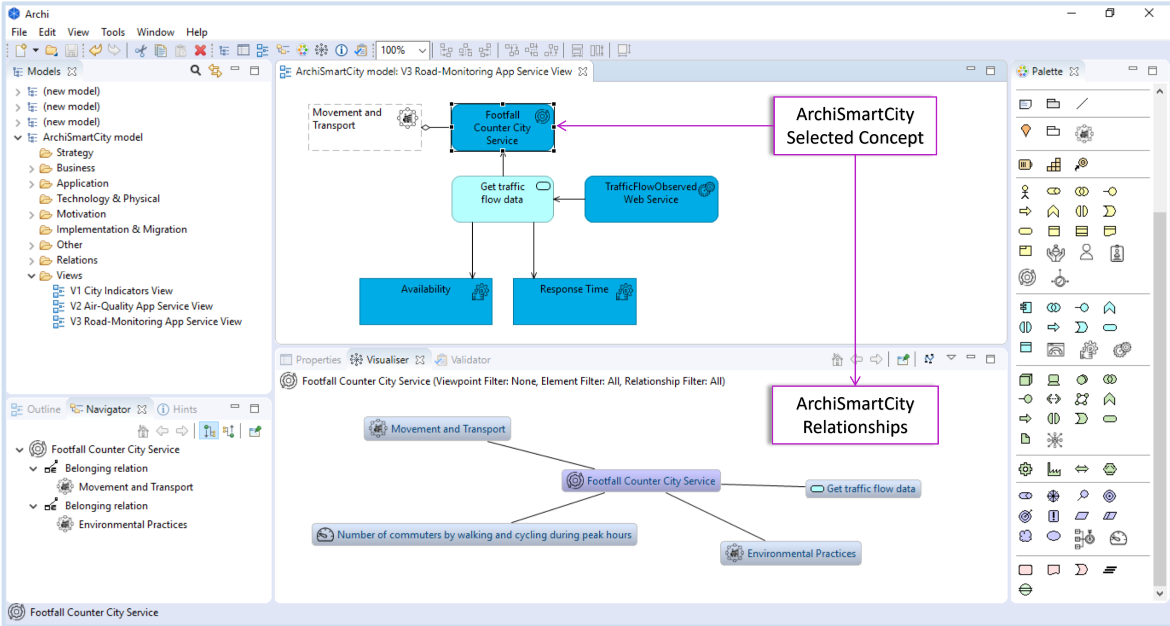

Fig. A7 ArchiSmartCity Concepts and Relationships. Screenshot

cycling during peak hours, from the Cities Indicator View, and with the application service: Get traffic flow data from the Road Monitoring App View. Therefore, the ArchiSmartCity modelled concepts are mapped to facilitate concept traceability and perform alignment analysis.

Appendix F - ArchiSmartCity Evaluation

ArchiSmartCity Evaluation - Detailed Feedback from The Smart City Domain Expert Interview

A semi-structured interview was conducted to ask the opinion of the Smart City domain manager of Netanya municipality on the relevance of the key concepts and their use in each model. The overall evaluation of the proposed concepts and solution was positive. Table A1 includes the feedback from the expert interview and how we tackled this feedback. The statements listed in the table are transcriptions of the voice of the domain expert.

Table A1 Detailed expert feedback - Interview

Key concept	Transcription from the interview	Action Taken
Domain	**A:** "The definition of the domains is very important for Netanya. We defined these domains for Netanya: Livability, Smart Transportation, Technology, Urban Planning, Branding, Ecosystem Management, Workability, and Smart Education. But also, it is important to see who is responsible in the municipality for these domains. Let's say, for the Smart Transportation domain, we need to know who is responsible for the sub-domains: Mobility as a Service, Electric Car Sharing Service, Smart Parking, an so on."	**A:** "Based on this feedback, we added a relationship between City Stakeholders and domains to identify in the metamodel the responsible of these domains in the municipalities."

(Continues)

Key concept	Transcription from the interview	Action Taken
Goal	**A:** “Of course, the definition of the city goals concept is important. We aim to make Netanya city as the smart city quality and connecting and putting the city on the centre, via analysing citizens needs and invest in the technology channels to improve their life quality. It is very important to have trust and good satisfaction of citizens."	**A:** “We confirm the relevance of the definition of the goal concept. We also realize that city goal are defined at a high level."
Objective	**A:** “The objective is important for the Smart City domain Manager. We have a plan, in fact, we have many consultants for this: Smart City consultants, Smart City SMS consultants, guidelines, another consultant. So, we have many documents, but for us, the definition of specific objectives is also important for mapping the goals."	**A:** “We confirm the relevance of the definition of the objective concept."
Indicator	**A:** “Regarding the indicator concept, for example, we measure the number of calls from neighborhoods about the garbage collection. The indicator is around 20 calls from the call center per day, this is a kind of standard, but if we have more than 20, if we have 200, it indicates that we have a problem. And Netanya is doing it great. For example, here in the report from the dashboard, we see that this month we have a problem in this area because the complaints are higher than the indicator, and we have to deal with it."	**A:** “We confirm the relevance of the concept and the need from the city managers to monitor city services."

(Continues)

Key concept	Transcription from the interview	Action Taken
Quality of Life Dimension	**A:** "About the quality of life dimension, this is very important for us. This is part of our mission: Make Netanya city as the smart city quality and connecting and putting the city on the centre, via analysing citizens needs and invest in the technology channels to improve their life quality."	**A:** "We confirm the relevance of the quality of life dimension concept."
City Service	**A:** "City services are very important for Netanya, services centered on residents. We plan to create services to answer people. This idea was not easy for me, we are working very hard each day. It is very important to have trust and good satisfaction of citizens. City services, for example, should improve some neighborhoods that have social and economic problems. About the concept in the models, in the first model for the domains, you need to correct some names of city services for Netanya. I will send you an image with the correct names."	**A:** "We update the first scenario with the list of domains, subdomains and services sent by the Smart City domain manager from Netanya. It was updated for the next evaluation with the Federation of Local Authorities in Israel."
Application Service	**A:** "About application services, this is an important concept for Netanya. We need to take most of the services as possible as you can to the technology structure and use it via the internet and mobile in every place."	**A:** "We confirm the relevance of the definition of the application service concept."

(Continues)

Key concept	Transcription from the interview	Action Taken
Web Service	**A:** “The web service concept is very important for Netanya. We plan the improvement of services by proactive information from the municipality and gather the data using web services. Something smart that we do, in the contract with service providers, we put an obligation that they must have a web service to connect to the commander control service that we are building, and by that, we can make a whole agent and they are connected between, let’s say camera o where the track is if there is any traffic jam when collecting the garbage. So, for the first time, we can see how the garbage trucks are making all the traffic."	**A:** “We confirm the relevance of the definition of the web service concept."
Quality of Application Service	**A:** “This is an important concept for us. Security is a good example of the quality of application services in Netanya and in all Israel. All the application services should comply with our security standards. But, in the model about these qualities, it is not clear the connections you make. It should be more clear."	**A:** “We confirm the relevance of the definition of this concept. We also update the metamodel and the scenario to better represent the relationships between application services and the qualities they meet."

(Continues)

Key concept	Transcription from the interview	Action Taken
City Stake-holder	**A:** “City stakeholders are important for Netanya, for example, residens, the heads of the departments and obviously the CEO. They analyse the data collected from the city. After they trust the information that I give them, after we passed the trust issue, they ask for more specific information, for example, separate information of the call center and the social media, where exactly this and that."	**A:** “We confirm the relevance of the definition of the city stakeholder concept and their need of city information."
Decision	**A:** “This is the Netanya idea, to improve decisions. We use the collected information from the citizens in an accurate time, we have a lot of knowledge for making decisions. This (a dashboard) is for the people of the municipality and you can know in an accurate time, to be very agile regarding the decision that you are going to make. So, useful and accurate information is core for decisions."	**A:** “We confirm the relevance of the decision concept supported by applications such as dashboards."

(Continues)

Key concept	Transcription from the interview	Action Taken
Dashboard	**A:** “This concept is very important as the dashboards are needed by city employees and also for citizens. Making a revolution of the relationship between citizen and the city and some other authorities that work in the municipalities by supplying real-time data during electronic and digital for all the information that the citizen needs. To this kind of service, they need interaction with the city employees. From my opinion the monitoring and dashboards, are even, open here, you see this is Netanya (dashboards) and this is the subject, transportation, community, culture, welfare, economic, security, sport, construction, education."	**A:** “We confirm the relevance of the concept and the need from the city managers and citizens to use dashboards."