# Improving Digitization of Urban Mobility Services with Enterprise Architecture

**Anthony Bokolo, Sobah Abbas Petersen, and Markus Helfert**

**Abstract** Cities are actively deploying modern digital technologies to foster digitalization due to the emergence of data-driven innovations. Through modern digital technologies, municipalities aim to enhance services performance. Despite prior studies that focused on digital transformation in smart cities, there have been few studies aimed at managing service transformation and complexities needed to support cities in getting smarter. Also, as the deployment of information technology (IT) continues to grow within urban environment, there has been little research conducted that develops data-driven approach for digital services within urban environment. Additionally, cities are exploring methods of providing seamless mobility services based on collaboration among several enterprises and stakeholders in urban environment while achieving seamless data-driven services. Therefore, this study explores the adoption of Enterprise Architecture (EA) for digital transformations to achieve seamless urban mobility services. Qualitative data was collected using case study by interview from an organization that employs distributed ledger technology (DLT) to deploy digital services in smart cities. Findings from the interview sessions were modelled in ArchiMate language to illustrate the application of digital payment solution via DLT toward digitization of urban mobility services. The findings reveal that EA supports digital transformation of cities and manages data integration and alignment. Besides, findings from this study propose an EA approach to support urban planners and developers in understanding the actions required to implement digital transformation of their city services in becoming smarter.

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## 1 Introduction

Digitization is the conversion of analog information to a digital format into zeros and ones such that computers can retain, process, and transmit such information. Digitization also refers to the transformation of analog to digital tasks [1]. Practically, it is the integration of information technology (IT) to existing tasks, and more specifically it is the enabler or development of IT. Hence, digitization entails the process of changing analog information into digital information [1]. Digitalization is a prevalent topic for both practitioners and researchers mostly seen as a driver toward the modernization of public sectors such as in smart healthcare, smart cities, etc. [2]. Digitization provides an instrument for the development of innovative business models and services [3]. In urban context, information system modelling approaches such as enterprise architecture (EA) are being adopted as a practice to support detailed description, design, and analysis of the enterprise's information and communications technology (ICT) and business structures enterprise [4].

Accordingly, EA is an artifact which comprises of models, principles, and methods employed to design and deploy institutional structures, information systems alignment, and business processes of an enterprise [5]. One of the goals of EA is to improve the management of complex information systems deployed in enterprise. Extant literature maintains that EA enhances an enterprise's IT capabilities and is seen as an important approach that enhances organizational agility [6]. EA enables the actualization of integrated solutions with the city from isolated silos system creating seamless service deployment. Hence, EA is considered as an important approach for successful digitalization of urban services [2]. EA is an established governance planning tool employed to help institutions manage constant change to align organizational resources toward a mutual goal [7]. Accordingly, EA is often adopted in organizations to manage the complexity of enterprise's structures in facilitating the integration of IT and business strategy with stakeholders' requirements [8].

Practically, enterprises holistically adopt EA to enable interoperability, support resource sharing across organizations, and decrease incurred cost of business and IT operations by specifying duplications and opportunities for reuse of IT and business services, thus enabling actualization of seamless services and development of shared data stream [4]. Presently, EA is adopted in organization based on enterprise architecture framework (EAF) which is usually developed based on prior EAF such as Zachman framework, The Open Group Architecture Framework (TOGAF), The Department of Defense Architecture Framework (DoDAF), etc. Such EAFs provide models to describe the process of planning and designing EA languages for representing of organizational, human, and infrastructural aspects across different EA perspectives such as business, application, data, and technologies [4]. Therefore, to contribute to existing body of knowledge, this study poses the following research question:

- How to achieve seamless urban mobility services in smart cities toward digitization?

To provide answer to this research question, this study presents an enterprise architecture framework that captures the technical and human resources required for digital transformations of electric mobility to achieve seamless urban mobility services. We draw on qualitative data collected during a case study via semi-structured interviews. Findings from the interview was received as feedback and was modelled in ArchiMate to show how the organization implements a digital payment solution via DLT toward digitization of urban mobility services. Additionally, findings from the analyzed data are used for modelling of seamless urban mobility services which help enterprises providing services to citizens in smart city digitalize their service. Besides, findings from this study suggest that EA can be utilized for analysis, design, and plan execution, aiding in transition from an as-is state to a to-be state of cities. EA manages information systems alignment with business interests. This alignment process is an important component that supports the success and continued digitalization of cities services. This study is structured as follows: Sect. 2 presents the literature review. Next, the methodology is presented in Sect. 3. In Sect. 4, the findings from the case study are presented. Section 5 presents the discussion and implications of the study. Finally, the conclusion is presented in Sect. 6.

## 2 Literature Review

This section discusses the overview of enterprise architecture, background of smart cities, and prior studies that employed EA in urban/smart city context.

### *2.1 Overview of Enterprise Architecture*

Architectures or computer architecture as a term has been in use in IT domain since the early 1960s, where it denotes the basics underlying the design of computer operating systems and hardware [5]. According to the definition provided by an IEEE working group, architecture is defined as the fundamental organization of a system in relation to the deployed components, their relationships to each other, and the deployed environment, as well as the principles controlling its design and evolution [9]. Likewise, the definition from The Open Group defined an architecture as a detailed plan of a system formal or a description guide of a system component implementation [9]. In information systems domain architectures are typically described in terms of architectural models such as an ICT architecture, service-oriented architecture, enterprise architecture, etc. [10, 11].

This study is more concerned with enterprise architecture which provides a holistic aggregated view of the business to ICT alignment within an enterprise encompassing its organizational structure, IT infrastructure, software and data, strategic aspects, as well as business processes [12]. EA is the description of a high-level representation of an organization's IT systems and business processes and their interrelationships and the degree to which these systems and processes are shared by diverse parts of the organization. EA mainly aims to define the anticipated future state of the enterprise's IT systems and business processes and provide a roadmap for realizing this target from the present state [13]. EA supports enterprise operations, reflecting standardization and integration requirements of the organization [14]. Thus, providing a strategic top-down and holistic view of an enterprise to enable decision-making for business executives, business managers, IT architects, software engineers, and IT technicians to coherently integrate, coordinate, and conduct enterprise activities seamlessly [15].

### *2.2 Background of Smart Cities*

The course of urbanization has importantly improved modern economy and enhanced human capability to transform society and achieve increase in standard of living [16]. However, the progression of urban development around the world also brings new issues, such as pollution, depletion of natural resources, etc. [8]. To resolve these issues, the idea of "Smart City" was coined to denote the process by which a city can make appropriate changes to reduce those issues [17]. The progression of smart cities started in the 1990s when the phrase was proposed to highlight urban development toward globalization, technology, and innovation [18]. In 2009, discussion on smart cities received more attention when IBM cultivated and published their report on corporate initiative of Smarter Planet, which then received wide acceptance from enterprises, governments, universities, and other partners around the world [19].

Ever since, smart city has developed as a term for pervasive implementation of ICT deployed to enhance various areas of urban surrounding [20]. Besides, a smart city can be referred to as a complex ecosystem embodied by the intensive use of technologies to make cities more sustainable and attractive [21]. Additionally, a smart city is a city in which ICT provides technological, business, and social support to address city challenges and enhance attractiveness of citizens' experiences [22]. In such cities, private and public services are deployed in an affordable, integrated, and sustainable way [23]. ICT can support city's vision of becoming smart by providing a unified and integrated system that manages huge volumes of data to improve city services [24].

### *2.3 Prior Studies on EA Adoption in Smart City/Urban Context*

Due to the potential of EA in managing IT and business component, it has been employed in a smart city/urban context. A few studies have employed EA in their research; among these studies, Gobin-Rahimbux et al. [25] carried out a review on existing ICT architectures for smart governance in a local council. The study is elicited toward the overall transformation of a city to achieve smart city initiatives. Jindal et al. [26] developed an ICT architecture to facilitate supplementary services in future energy distribution networks. The authors further implemented a dashboard based on the architecture to support communication and to allow management of the grid. Jnr et al. [11] presented a big data-based multi-tier architecture to enhance electric mobility as a service in smart cities. The authors focused to achieve interoperability and foster the sharing of data among deployed infrastructures needed for electric mobility services.

Additionally, Anthony et al. [27] presented an architecture based on an EAF for management of big data generated to promote energy prosumption service in smart community districts. Based on a multi-case study, the authors offered help for cities to design their energy platforms. The presented architecture can be employed as a guide to help cities in making decisions toward energy services and energy prosumption development. Similarly, Anthony and Petersen [28] presented an architecture to support electric mobility as a service in smart cities. The authors employed Application Programming Interfaces (APIs) to enhance interoperability of mobility-associated data. Tanaka et al. [29] designed a proposal toward an ICT governance framework with a focus on EA aimed at achieving a smart city. A case study was employed in the educational sector to illustrate the view in ArchiMate language. After which, a questionnaire was used to collect data to assess the maturity level of the city.

Strobbe et al. [30] presented an ICT architecture to manage demand response in a residential area. The architecture is designed to support sharing of energy metering data and providing flexibility information to citizens and demand response balancing of renewable energy within the distribution grids. Janssen [31] provided a sociopolitical approach and adopted EA as a tool to advance e-government, create rationality, and enhance interoperability. Their study aimed at reducing the gap between complex policies in enterprises and less-complex adoption of information systems. Scheibmayer and Deindl [32] designed an ICT architecture to aid business processes achieve Internet of Energy in smart city. Thus, a smart architecture was developed as a decentralized method to connect diverse stakeholders involved in the energy sector toward supporting flexible and open communication.

Furthermore, Toh et al. [33] presented an ICT and business architecture based on EA for a logistics city. EA was adopted in the study to facilitate the development of a collaborative business model to improve productivity based on social, environmental, and economic factors. Evidence from the reviewed ten studies suggest that EA is adopted to facilitate different services in smart cities. However, there are fewer studies that investigated how EA can be employed to achieve seamless urban mobility services in smart cities toward digitization. Thus, this current study aims to address these shortcomings.

# 3 Methodology

## *3.1 Designed Enterprise Architecture Framework*

To achieve seamless urban mobility services in smart cities toward digitization, EA is employed. Grounded on prior studies [11, 27], an EA framework was presented as seen in Fig. 1.

The EA framework comprises of different layers. Each of which are discussed below.

**Context**
This layer necessitates requirements that relate to stakeholders' wants, concerns, and associated key performance indicators (KPIs) that improve quality of life [22]. This layer comprises of the set of goals, constraints, principles, and main requirement related to smart city initiatives. The context layer also captures the interests of city stakeholders and citizens [11].

**Service**
This layer is responsible for presenting the city's action plans, resources, and capabilities [8]. It consists of high-level processes provided by the enterprises collaborating to provide new functionalities to citizens [34]. This layer also provides interfaces which deliver services to citizens. Thus, the service layer aims to effectively implement specified outputs and competently realizing specified key performance goals within the city such as digitalization of urban services [11].

**Business**
The business layer is responsible for listing all enterprises involved in providing functions and processes to deliver digital services to stakeholders [35]. Business layer involves activities that provide and deliver digital urban services [34]. Thus,

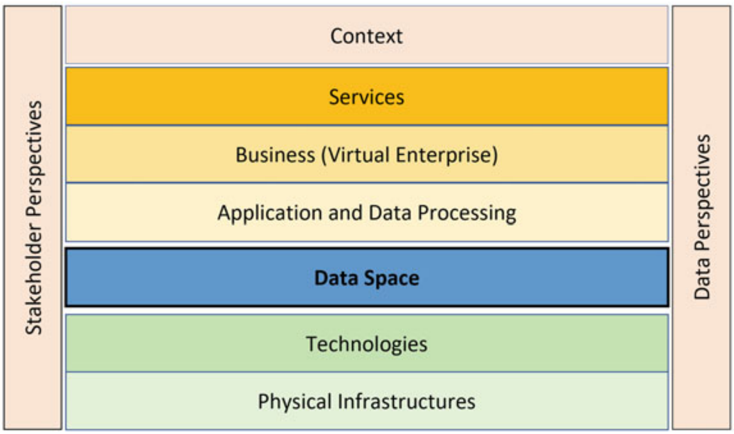


**Fig. 1** Presented architecture adapted from [8]

this layer involves virtual enterprises that cooperate toward providing digital services to citizens to support in making urban services smarter [11].

**Application and Data Processing**
The application and data processing layer encompasses all systems deployed to provide digital services to stakeholders [36]. This layer collects data from the data space layer in providing digital services [11]. Moreover, this layer processes and transforms data into useful information to provide digital services and insights [34]. Hence, this layer provides applications that expose digital services to support the actualization of a smart city operations [8].

**Data Space**
This layer specifies which data are being utilized by the enterprises in providing digital services within the city [22]. The data space layer consists real-time data, online data, historical data, and third-party data form external sources [35]. Moreover, data space layer comprises of non-relational and relational databases that support city operations. The data space layer provides access to data sources through APIs [11].

**Technologies**
The technological layer comprises all the technologies deployed across the city such as ubiquitous computing, big data, processing, cloud computing, service-oriented architecture, etc. The technology layer provides the required software and hardware infrastructures needed to provide digital services in smart cities [34]. This layer consists of infrastructures needed to collect, process, handle, and store urban data.

**Physical Infrastructures**
This layer comprises of physical assets within the city that generates data [34]. Physical infrastructures layer produces real-time data generated from physical sources that is transferred to the technology layer [22]. This layer comprises of physical infrastructures such as sensors, metering devices, IoT devices, and sensing device deployed within the city that generates data [11].

Figure 1 also comprises of the data perspectives and stakeholders' perspectives. Stakeholders' perspective includes policies and regulations, data ownership and access, and privacy and trust, whereas data perspective comprises of data standards, data interoperability, risk assessment, security, and data governance.

## *3.2 Research Approach*

A qualitative research approach was employed for this study similar to a prior study by Gregor et al. [37]. This method allowed data to be triangulated across multiple secondary sources such as from interview, observation, and document review of publicly available archival documents [38, 39]. Documents that provided information on the technology specification and requirements for implementing urban mobility services were provided by the organization discussed in Sect. 4.1, and

**Table 1** Overview of participants

| Current position and years of experience | Education | Current role and responsibilities |
|---|---|---|
| Junior Project Manager with >5 years' experience | M.Sc. | • Focuses on digital technology and its benefits within IoT and industry 4.0 to design testbeds for future full-scale deployment<br>• Works on formal parts of project management for communication, reporting, documenting, etc. |
| Head of Infrastructure Development with >3 years' experience | PhD | • Focuses on research and development in IoT and data in enterprise and smart cities<br>• Contributes in achieving trust infrastructure for creation of novel data sharing ecosystem<br>• Experienced in managing stakeholder initiatives to address real-world challenges |
| Senior Technical Analyst with >3 years' experience | M.Sc. | • Experience knowledge in mobility within cities<br>• Focuses in creation, prototyping, and deployment of digital services |
| Business Development Director with >5 years' experience | M.Sc. | • Involved in development of digital ecosystem toward achieving synergies among multi-stakeholders<br>• Focuses on smart energy, electric mobility, and sustainability |

qualitative data was collected from four participants (see Table 1), during an online interview conducted on the 26th of November 2019, on how the organization implements micropayment to support electric mobility services in smart cities.

In the second online interview, data was also collected concerning the technical specifications and requirements for DLT payment module to be integrated to foster urban mobility services. The use case was modelled in the presented EA framework (see Fig. 2). The model was sent to participants (see Table 1) in the organizations, and feedback was provided on September 3, 2020. The feedback provided helped refine the modelled in providing a final use case illustrated in Fig. 2.

### *3.3 Overview of Modelling Language*

A modelling language comprises of notation, syntax, and semantics that provide the required modelling needed to design a model within an EA framework [40]. Modelling language provides graphical modelling languages that facilitate communication among stakeholders [11]. One of such modeling tools employed in the literature is ArchiMate tool which introduces a language for describing EA. ArchiMate is a modelling language developed based on Unified Modelling Language (UML) class diagram but tailored and modified to a limited set of modelling parameters for simplicity of use and learning [40]. Besides, ArchiMate provides a standard set of

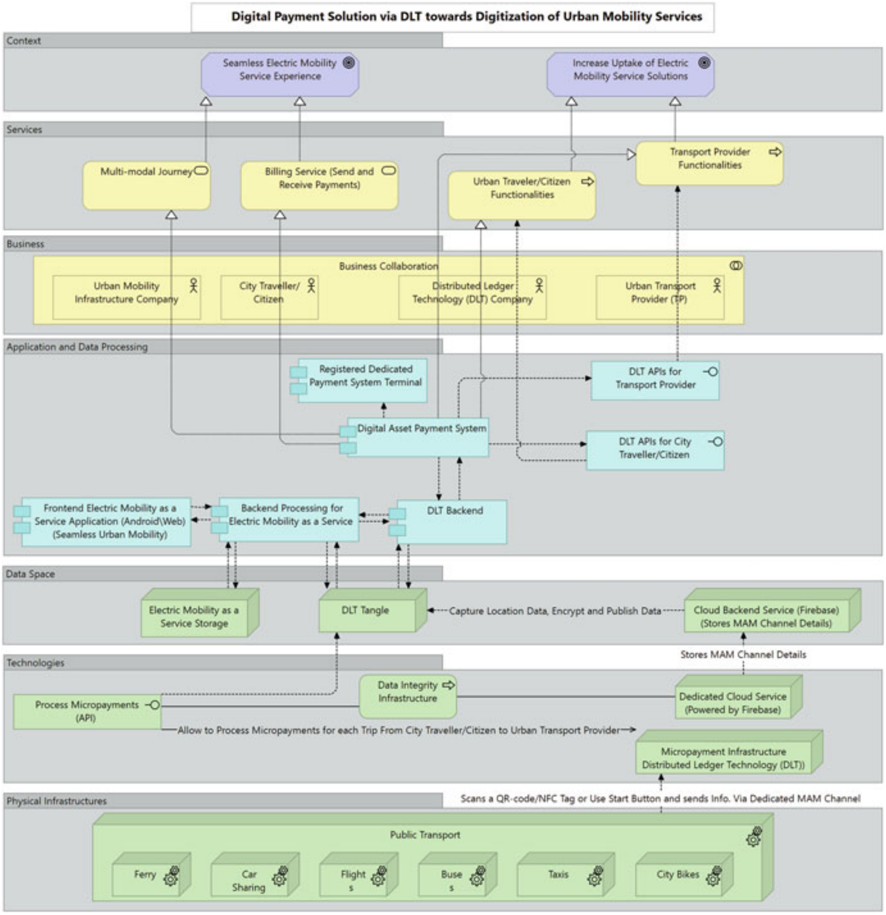


**Fig. 2** Meta-modeling of the digital payment for digitization of urban mobility services

objects and relationships with their associated icons for illustration of architecture descriptions [29].

Thus, ArchiMate can be utilized to model EA in an intelligible way while adapting the content for different stakeholders. However, ArchiMate language does not support automatic reasoning as it comprises of basic concepts, objects, and relationships that are suitable mainly for enterprise architecture modelling purposes [40]. ArchiMate is mostly used for modelling EA as it aligns with the TOGAF framework, and it also provides concepts for designing use case model that fits to TOGAF architecture (business, application, and technology) layers. In this study, qualitative data was collected, and ArchiMate was the language utilized to capture the content for urban mobility services modelled as a use case to elicit requirements needed for achieving digitization of urban mobility services based on the feedback provided by the participants. The designed use cases as seen in Fig. 2 reflect the current and potential future functionalities related to an innovative digital asset payment system to support urban mobility services in smart cities.

# 4 Findings

## *4.1 Background of Case Study*

In this study, an organization based in Germany that provides open data toward achieving a smarter community provided data on how EA support cities to enhance digitization of urban mobility services. The organization aims to show the potential of distributed ledger technology (DLT) as the backbone of transparent and open smart city infrastructures to support innovative business models and digital services. Also, the organization is working toward the actualization of smarter cities using and sharing data in a way that provides insights and is useful to all stakeholders in a city. Presently, the organization is opening up and providing access to urban data silos offering visibility and improving citizens' quality of life.

In improving digital services in smart cities, the organization is using DLT to enable permissionless open data innovations. The organization supports the municipality by providing data generation and access to urban data to citizens, visitors, and businesses. It can provide a common digital platform for enterprises within a city to interact with all stakeholders in infrastructure, mobility, energy, etc., providing a mutual standardized open secure platform for data sharing. Additionally, the organization provides incentives capabilities offered by its feeless, real-time token, developed with microtransactions and IoT. Table 1 depicts the participants involved in providing qualitative data related to improving digitization of urban mobility services in smart city.

Table 1 depicts that data collected from four participants as recommended by [8, 41] where the researchers recommended that data should be collected from more than three participants in a single case study. During the interview session, data was collected from an organization that provides distributed ledger technology in smart cities as previously stated. The data was provided as comments and during three semi-structured interviews and follow-up discussions which lasted for up to 2 h in duration. The interview questions were based on the usefulness of the presented enterprise architecture framework as shown in Fig. 1. The feedback from the interview was later modelled in ArchiMate modelling tool.

## 4.2 Modeling of Use Case for Digitalization of Urban Mobility Services

Findings from the interview session are modelled in ArchiMate as seen in Fig. 2 as a use case for the innovative digital asset payment system implemented to support digital payment via DLT toward improving digitization of urban mobility services.

Figure 2 depicts the modelled use case in ArchiMate for a seamless electric mobility service supported by a digital asset payment system modelled in the presented enterprise architecture framework (see Fig. 1). The digital asset payment system was implemented by the organization discussed in Sect. 4.1 as a proof of concept to enable citizens to reserve and make payment for several journeys provided by different mobility providers seamlessly in one step. Findings also indicate that the digital asset payment system is deployed with infrastructure to support users that utilize electric mobility services application to directly reserve and pay for urban mobility services with DLT micropayment's native digital asset.

As seen in Fig. 2, the physical infrastructures comprise of all urban mobility options that can be employed by citizens for transportation within the city. The technologies layer comprises of real-time data that is transmitted from public transports to DLT micropayment infrastructure via dedicated Masked Authenticated Messaging (MAM) channel. The MAM is a layered data communication protocol which aids to encrypted data stream DLT infrastructure. Besides, in the layers, the data integrity infrastructure aids citizens to book and record travel data on the DLT Tangle. Using Application Programming Interfaces (API), DLT offers audit trail to enforce integrity of payments distributed to urban transport provided within smart city. Considering the data space, all related urban data both historical and real time are retained in this layer in relational and non-relational database. Next, the application and data processing layer captures all systems that seamlessly connect to provide urban mobility services. This layer also comprises of API that provides data.

The business layer comprises of stakeholders and enterprises that collaborate to provide and utilize digital payment for the urban mobility services provided to citizens. As seen in Fig. 2, the business layer comprises of urban transport provider who is the organization that provides mobility services to citizens and city travelers. The urban transport provider receives payment for the journey performed by the citizens and city travelers, the urban mobility infrastructure company provides urban mobility data, and DLT company processes the payment. The service layer comprises of digital services provided by the digital asset payment solution to support urban mobility services as seen in Fig. 2. These digital services are provided to the city traveler/citizen and transport provider within the city. The context layer comprises of the main goal of urban mobility to be achieved in the city which is the seamless electric mobility service experience and increase uptake of electric mobility service solutions as a sustainable transportation means.

# 5 Discussion and Implications

## *5.1 Discussion*

EA provides an outline of the as-is state of the city and facilitates digital transformation to a to-be state for the city by reducing the gap between IT deployed and business strategies employed within the city. In urban environment, EA includes use case models developed to help manage the continuous development transformation, implementation, and migration plan to a future state of the city being a smart city. Therefore, EA provides the rules, blueprint, and standards required with planning the transition of urban services to a digitalization state. This study builds upon earlier work of Anthony et al. [27] and Jnr et al. [11] who presented an EA framework to support cities in becoming smarter. Accordingly, findings from this research show the adoption of enterprise architecture for digital transformations to achieve seamless urban mobility services. EA supports urban strategy by guiding the digitization processes of enterprises that provide digital services within cities. EA improves enterprise capabilities and links isolated systems and data sources to achieve seamless services toward digitalizing urban core services.

EA plays a vital role in ensuring that IT can deliver value in aligning business strategies of enterprises in smart cities [42]. As stated by Kluge et al. [43], EA comprises of a methods, models, and principles that are used in the development of institutional structure, information systems, infrastructure, and business processes. Findings reveal that EA supports digitalization of cities mobility services toward managing data integration and alignment to provide electric mobility services similar to prior studies [11]. Besides, findings from this study suggest that EA supports developers and urban planners in understanding the actions required toward digitalization of their city services in becoming smarter. Additionally, findings from this study are analogous with results from the literature [3] which suggested that EA provides a critical role in deploying the vision of digitalization. EA captures the business processes and IT infrastructure and entails how to align business and IT components in relation to the strategies and objectives of cities. Thus, EA aligns IT and business processes toward management of urban process.

## *5.2 Implications of the Study*

Findings from this study have several contributions to digitalization research and practice. Theoretical findings from this study show how EA can contribute to the digitalization toward enhancing city's agility. The presented enterprise architecture framework (see Fig. 1) assists cities in anticipating and assessing the business and technological infrastructures required for successful EA adoption for digitalization of urban mobility services. This study extends research on the emerging literature on

EA by providing an empirically validated understanding of the role of EA anchoring as a critical constituent for digitalization of cities grounded on qualitative data.

Besides, this study provides a comprehensively designed and verified EA framework that helps cities alike to rigorously deploy digital payment via DLT toward digitization of urban mobility services. This research contributes to practice by taking a broader view of the usefulness of EA, illustrating how EA-based capabilities across urban environment can be attained. Thus, this research provides insights into the potential benefits of EA in making cities smarter.

## 6 Conclusion

This current research extended previous EA studies by presenting an approach that supports the seamless mobility services based on collaboration among several enterprises and stakeholders in urban environment while achieving seamless data-driven services. An enterprise architecture framework was presented that can be employed by cities to support the digitalization of urban mobility services. Furthermore, qualitative research approach was employed for this study, and data was collected using semi-structured interview from four participants during an online interview and archival documents provided on how the interview participant's organization implements micropayment for the electric mobility services in smart cities. The collected data was modelled in ArchiMate language as a use case illustrated (see Fig. 2). Although this study provides several contributions, there are a few limitations that need to be addressed. First, data was collected from only one organization.

Second, only qualitative data was employed in this study; no quantitative data was used in this study. Third, the data perspectives and stakeholders' perspectives in the present EA framework were not modelled or captured in the modelled use case. Last, in this study, only a use case related to digital payment via DLT toward digitization of urban mobility services was modelled. Future works will consider collecting data from more than two organizations in Norway where EA is adopted for digitalization services. Moreover, survey questionnaires will be used to collect data from practitioners that employ EA for digitalization of cities. Further work will consider the data perspectives and stakeholders' perspectives in modelling of use cases. Finally, more use case related to energy prosumption, community engagement, decision support tool, and monitoring and evaluation of smart city services will be modeled as use cases in ArchiMate.

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