International Journal of
INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING
ISSN:2147-6799 www.ijisae.org Original Research Paper

Towards an Open BPM-Enabled Smart City Platform

Mohamed Mustapha Benlahreche[1], Abdeldjalil Benelmaddjat[2], Iskander Zouaghi*[1], Abderrahmane Maaradji[3]

Submitted: 10/09/2022 **Accepted:** 20/12/2022

Abstract: Smart city platforms use information and communication technologies to improve the quality of urban services and reduce its cost. This paper presents a smart city platform that puts BPM (business process management) as a first-class artifact of the smart city's information system. BPM enables the coordination and planning of services involving various public service stakeholders and private service operators and suppliers (water and energy). This platform integrates BPM and IoT capabilities into one information system leading to better management of permit processing and urban services. A use case is provided as part of an automation of a public road permit approval process involving IoT sensors and traffic prediction.

Keywords: *BPM, Business process management, Smart city, IoT*

1. Introduction

Smart city is an urban area that uses different types of electronic data collection sensors to supply information which is used to manage assets and resources efficiently. This infrastructure is used to improve the quality of life of the city residents. A smart city can use data collected by the sensors to manage traffic, reduce crime, and improve city services.

Information and communication technologies have shaped the concept of a smart city. Being at the heart of the city's information system, these technologies help improve the quality of urban services or reduce its costs by smartly leveraging infrastructure (transport, energy, communication, etc.) at the different hierarchical levels (building, district, city). Particularly, it integrates Internet of Things (IoT) technologies for data sensing and measuring.

BPM, or business process management, is a system of organizational and technical methods used to manage and improve business processes. It is a holistic approach that includes people, technology, and data. As a practice discipline, BPM allows to represent and model activities, resources, and processes in an organization to understand, plan, and measure the organization's operational performance. We strongly believe that the BPM discipline's tools and methods would help smart cities to accelerate their digital transformation through an optimized and automated process.

This paper proposes an open platform as an integrated information system where the smart city's stakeholders can communicate and collaborate seamlessly through modeled and automated business processes. This platform aims to coordinate public/private service operators' and energy/water suppliers' daily operations and allows the optimization of tasks and processes. We believe that such a platform would enable effective decision-making by ensuring that all key decision-makers in the system receive consistent and comprehensive information.

The proposed platform is based on the Sentilo smart city framework extended with both BPM and IoT capabilities. It allows for data integration and real-time automated processes. As a use case, we proposed, implemented, then tested a roadwork permit process involving different public/private service operators. Through this use case, we demonstrated that not only would such a platform improve operational performance and business responsiveness, but it also would contribute to better decision-making through process visibility. It can identify problems in real-time and predict possible bottlenecks, helping cities to respond to emerging opportunities and threats. A smart city platform augmented with BPM will connect the physical reality and urban managers' processes, contributing to the establishment of a city's digital twin.

Based on such an innovative platform, smart cities would benefit from a plethora of off-the-shelf tools and methods proposed by the BPM community. For instance, process mining and prediction tools would help constantly evolve and adapt processes according to the needs of the smart city's citizens. On the other hand, data generated from these processes and sensors deployed throughout the city would provide the BPM community with new challenges and real-life datasets.

The rest of this paper is organized as follows: section II gives an overview of related work, section III presents the architecture of our solution and its components, section IV provides a discussion about a roadwork permit process to showcase the usability of our platform before conclusion.

2. Related work

The smart city concept has been addressed in the literature from different perspectives. Yin et al. [1] proposed an extensive literature review of the smart city concept by its definition and application domains., Second, the article goes on to identify various dimensions of smart cities, including economic, social,

[1] National Polytechnic School, Algiers, ALGERIA
ORCID ID : 0000-0002-4577-2966
[2] Université Laval, Quebec City, CANADA
[3] ECE Engineering School, Paris, FRANCE
ORCID ID : 0000-0002-7969-2825
** Corresponding Author Email: iskander.zouaghi@g.enp.edu.dz*

environmental, and infrastructure. The article also provides performance indicators for smart cities and outlines various frameworks for developing and managing smart cities. For instance, a deep-learning-based data mining was performed in [11] on data obtained from different types of sources for smart city management and an approach was proposed to ensure that this data can be analyzed.
Santana et al. [2] provides an extensive literature review of the state of the art in software platforms for Smart Cities. The authors analyzed 23 projects concerning the most used enabling technologies, as well as functional and non-functional requirements, classifying them into four categories: Cyber-Physical Systems, Internet of Things, Big Data, and Cloud Computing. Based on these results, the authors derived a reference architecture to guide the development of next-generation software platforms for Smart Cities. The authors enumerated the most frequently cited open research challenges and discussed future opportunities. For instance, in [3] authors proposed an efficient architecture of different applications of smart cities using Internet of Things (IOT), Fuzzy Logic. Furthermore, an integrated intelligent smart city services framework has been proposed which can forecast different activities based on Quantum Deep Learning concept.
To the best or our knowledge, few studies have been conducted on the integration of BPM technologies in smart city information systems. Authors in [4] sought to understand the similarities and differences between Business Process Change challenges in Smart City Development and Enterprise Systems Integration. The study developed a comparison framework which will assist city authorities in designing their smart city development roadmap and prioritizing business process change challenges. This framework is based on best practices from the enterprise system integration context, in order to develop solutions for changing city processes.
Numerous studies addressed separately the integration of IoT systems with smart cities, and IoT systems with BPM. [5] reports on the results of a systematic literature review with the aim of developing a map on modelling notations for IoT-aware business processes. It includes 48 research works from the main computer science digital libraries. The authors present a description of the systematic literature review protocol they applied, then they report a list of available notations, discussing their main characteristics. A focus has been devoted to modelling tools and application scenarios. Finally, the authors provide a discussion on the capability of the identified modelling notations to represent requirements of scenarios enriched by IoT adequately.
Authors in [6] explores the smart city concept and proposes a strategy development model for the implementation of IoT systems in a smart city context. The authors argue that the emerging Internet of Things (IoT) model is foundational to the development of smart cities, and that integrated cloud-oriented architecture of networks, software, sensors, human interfaces, and data analytics are essential for value creation. The paper will also explore how IoT smart-connected products and the services they provision will become essential for the future development of smart cities.
A proof-of-concept implementation involving a smart city IoT sensors and BPM system was proposed in [7]. This paper proposes a blockchain-based solution for the insurance industry in smart cities (BIS). The data collected by the sensors is stored in cloud or local storage and is shared with insurance company on demand to find the liable party that in turn increases the privacy of the users. BIS enables the users to prove and share the history of their insurances with other users or insurances. The implementation results proved that BIS significantly reduces delay involved in insurance industry as compared with conventional insurance methods. Although this implementation is the closest work to ours, we intend to tackle scalability and real-time performance issues rather security matters.

3. Platform architecture

The main objective of the proposed platform is to leverage the data collected by the smart city's information system to automate BPM operations, and then to allow the city's resource optimization to have improved decision-making [8]. To build such a platform, we relied on City OS[1] (City Operating System) and the smart city platform developed by the city of Barcelona[2], as the central component that coordinates the different parts. This architecture decision was made based on benchmarked smart city platforms.
As depicted in Fig.1, we used Sentilo as the IoT middleware component. All deployed sensors and actuators are connected to Sentilo, then the collected data is stored in a shared data lake repository (big data cluster). Alongside these two components, we integrated the Camunda workflow engine (an open-source BPMS) that was deployed on a separate cluster, named Workflow cluster. All these components were deployed on an Openstack cloud environment to scale up the allocated resources in case of heavy network/computing/storage load. All these components are accessible through REST API (for instance traffic web-services), and our web application for users (Sentilo map, process modeler). This architecture offers process modeling, implementation, and deployment using IoT capabilities. It was designed to be robust, flexible, and easily scalable for the integration of even more partners (companies intervening on the road, such as telecom or water supply) and applications using its capabilities.

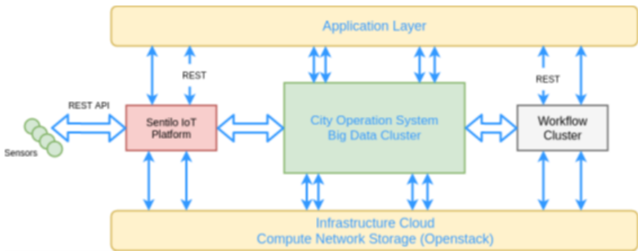

Figure 1. Our platform's architecture overview..

3.1. Workflow cluster

The Workflow cluster contains the process engine for which we used the Camunda Platform. It is an open-source workflow platform that provides tools for creating workflow models, operating deployed models in production, and allowing users to execute workflow tasks assigned to them.
The workflow engine will run our processes modeled with the BPMN2.0 standard. This engine allows the execution of not only BPMN process but also DMN and CMMN models. Execution data is stored as event logs in a dedicated database.

3.2. A Web service-oriented architecture

The Workflow Cluster was implemented as an Openstack cluster

[1]https://medium.com/intelligent-cities/city-os-the-city-operating-system-b8888e579b64

[2]https://github.com/AjuntamentdeBarcelona/CityOS_AjBCN, https://ajuntament.barcelona.cat/imi/en/projects/city-os

composed of 3 virtual machines:

- The first virtual machine hosts the Workflow Engine (BPMS).
- The second virtual machine is used for logging the event data in a relational database (MySQL).
- The last virtual machine is used as an endpoint for the different APIs, traffic web-services, and for displaying content on the Sentilo map.

The three virtual machines are connected to the same Private network and the entire cluster is connected to an internal network in the cloud which is accessible online. All activities in this process are external tasks (web services). All services follow the "RESTful" architecture.

In addition to the Sentilo service, the following services were implemented and provided via the online REST architecture:

- Time suggestion service: it provides the date and time where the road work will have the least impact on road traffic (detailed in section 3.4).
- Public maintenance geolocation service: This displays markers on the geographical map of Sentilo to represent all maintenance tasks with details such as the date and time of the task, the status of the task, etc... as shown in Figure 3.
- Traffic Incident API: it provides traffic incident information (e.g. roadblocks).

3.3. Sentilo

Sentilo is an IoT middleware platform developed for the Barcelona Smart City project. It is based on Pub/Sub systems using (i) an in-memory database (Redis) to ensures the high availability of the platform, (ii) a service-oriented architecture that makes the platform modular, and (iii) an OpenTSDB database (a time series database on Hadoop) to ensure the scalability of the solution. All these three components are deployed within an Openstack cloud environment.

In addition, Sentilo offers a programming interface, so that other applications can access the data generated by the sensors and interact with the platform, which is used to connect with our BPM solution (Workflow cluster).

3.4. Time suggestion service

The purpose of this service is to suggest the time when the roadwork will have the least impact on road traffic. To find the optimal time, we used the predictions based on traffic data collected by deployed sensors. The data is retrieved in the form of a table for each road (for instance Table 1). The table represents a prediction log: for each hour we have the intensity (number of vehicles per hour), the average speed (in Km/h) and the classification of the vehicles (the percentage of light vehicles in relation to the total).

In our case, the information of interest is the number of cars passing each hour because our goal is to minimize the impact of the intervention on traffic. Consequently, we aim at the time window where the intensity traffic is the lowest. Our mathematical model is represented as follows:

- k: represents the estimated duration of the intervention in hours, it is an integer between 1 and 24.
- i : is the index of the start time of the roadwork, and it is our decision variable.
- Q_j : represents the vector of density [# vehicle] during hour j.
- X: the cumulated vector of densities (Q)

$$X_i = \sum_{j=0}^{i} Q_j$$
$$F/O: \min(X_{i+k-1} - X_i)$$
$$i \geq 0, \quad i+k \geq 23, \ \forall i \in N \qquad (1)$$

To solve this equation, we opted for a direct resolution method which calculates all possible sums then compares them to return the solution of the problem which is $n*$.

Table 1. Example of road traffic prediction

Date and Hrs	*Traffic density*	*% Light vehicle*	*Velocity (km/h)*
01/02/2018 01:00	190	20	91
01/02/2018 02:00	187	10	93
01/02/2018 03:00	194	10	96
01/02/2018 04:00	160	20	109
01/02/2018 05:00	181	30	114
01/02/2018 06:00	586	73	114
01/02/2018 07:00	1055	81	113
01/02/2018 08:00	1330	80	112
01/02/2018 09:00	1219	77	114
01/02/2018 10:00	860	69	110
01/02/2018 11:00	696	64	108
01/02/2018 12:00	717	64	110
01/02/2018 13:00	738	64	109
01/02/2018 14:00	982	69	112
01/02/2018 15:00	865	67	111
01/02/2018 16:00	925	64	111
01/02/2018 17:00	897	59	109
01/02/2018 18:00	910	57	108
01/02/2018 19:00	884	54	107
01/02/2018 20:00	790	56	106
01/02/2018 21:00	662	55	107
01/02/2018 22:00	556	59	109
01/02/2018 23:00	386	57	106

This service will communicate with the BPM engine to retrieve the data related to the processed process instance; this communication is done respecting a REST architecture. First the service sends an HTTP request with the Post method to the link of the machine which contains the process execution engine which is Camunda, the link:

```
http://192.168.33.5:8080/engine-rest/external-task/fetchAndLock
```

associated with a packet in JSON format with the required data:

```
{ "workerId": "bestHour",
  "maxTasks": 1,
  "topics":
    [{ "topicName": "suggererDateHeur",
       "lockDuration": 10000,
       "variables":
          ["date_reqst", "longitude", "latitude",
          "dure_reqst"]
    }]
}
```

The expected response is a JSON packet that contains the requested variables:

- *date-reqst*: the date of the intervention.
- *dure-reqst*: the estimated duration of the work
- *longitud* and *latitude*: geographical coordinates to locate the works

After processing these variables and calculating the optimal timeframe (time window of the intervention), another HTTP request is sent to complete the task and add other variables. The *startTime* and *endTime* variables will be injected into the process instance.

```
http://192.168.33.5:8080/engine-rest/external-task/<Id>/complete
```

associated with a packet in JSON format with the required data:

```
{  "workerId": bestHour,
  "variables":
   {"startTime":
      { "value": "2018-06-15T01:00"},
    "endTime":
      {"value":"2018-06-15T04:00"}
   }
}
```

This service has allowed us to solve a major problem in the city which is the disruption of traffic caused by the works, by using the prediction of the state of traffic to decide of the optimal start-time of the roadwork for which the permit is being requested.

4. Roadwork permit process use case

Suppose a client of a water supply company lodges a request with the water supply (new installation, leak repair, etc.). This request might require accessing the underground pipes. In this case, the water company would need to get several permits (excavation, road closure...) and go through the city's extensive bureaucracy, not to mention if there are any other company's pipes or cables there, they would also have to approve of the water company excavating in their area. The city and all involved public/private service providers need to put forward a solution without leaving several residents without running water for a few days at a minimum.

In summary, based on the described scenario, the roadwork permit process is as follows. A customer lodges a request with her utility company (water, electricity, …). If the request requires public roadwork, then the maintenance department of the utility company must apply for authorization to intervene on roads at the city's public works department (roadwork permit). The city's public works department determines the public service stakeholders (utility companies and involved departments), then schedules a meeting to plan the roadwork intervention. After this meeting, the city's public works department notifies the utility company whether the roadwork permit is approved or not. Up to this stage, the process was relatively complex (Fig.2 represents a streamlined version of this process).

Our proposed platform was designed by putting the public work authorization process at its center to solve this problem and using sensors and traffic data, as well as a map of all pipes, cables, and tunnels in a city. This was done to not only make the permit approval process straightforward and quick, but to also monitor the actual roadwork through a roadwork management application.

To showcase some of the features available in the proposed platform, we modeled and then implemented this roadwork permit process. The process was first streamlined by automating a few tasks such as scheduling meetings (cf. Fig.2), online task forms (cf. Fig.3), and information systems connectors.

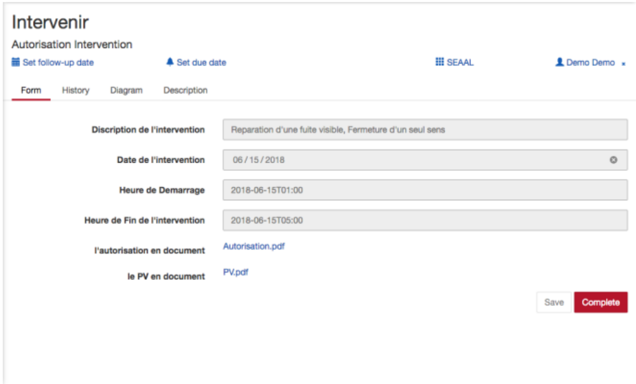

Figure 3. Screenshot of the task "Issue the committee meeting report".

A virtual roadwork status sensor is added to the Sentilo platform to send the status of the request (request pending, work authorized, or work completed). Another sensor of type startTime and endTime is added to display the start and end time of the work. Fig.4 depicts our Sentilo Web page showing a map with current workroad incidents' details.

Finally, our roadwork management system uses real-time sensors' data to keep track of the ongoing road works and compare them to the predefined plan. This information is also shared through a web service to be used by traffic monitoring services. Typically, this service collects data from available sensors in order to predict the road traffic density. The more data is collected, the more accurate the prediction would be.

In order to assess the robustness of our platform, the roadwork permit process was modeled and deployed in the workflow cluster, and sensors were deployed and connected to Sentilo (cf. Full report at [9]). This real-world test confirmed our predicted reliability of our proposed platform, which will make getting any city's public

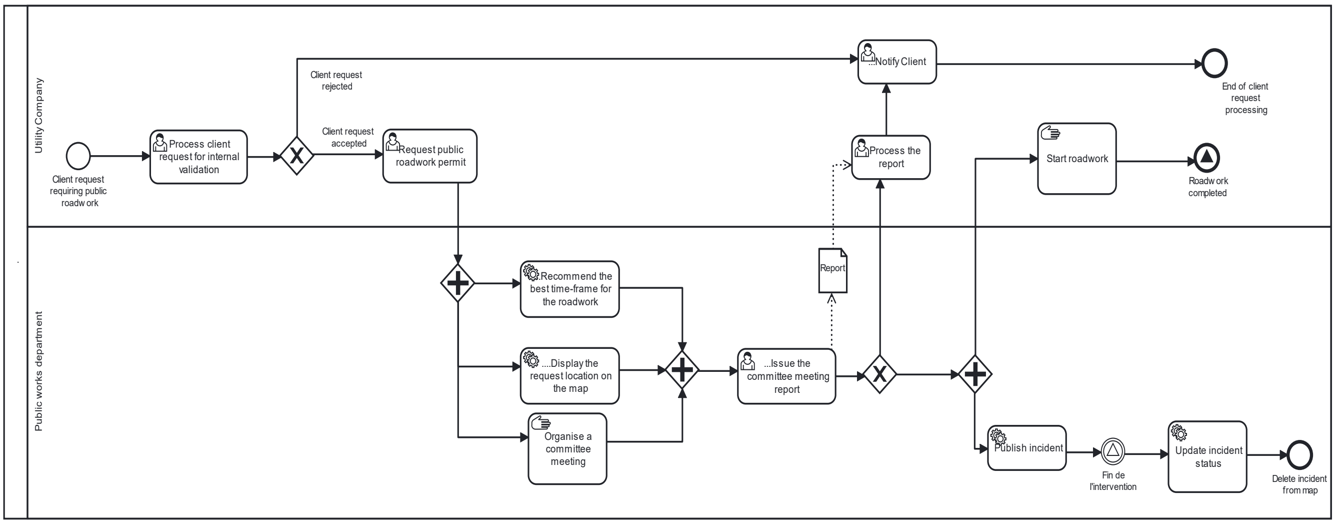

Figure 2. Screenshot of the task "Issue the committee meeting report".

works permit easy and increase the quality of life of the residents of the city.

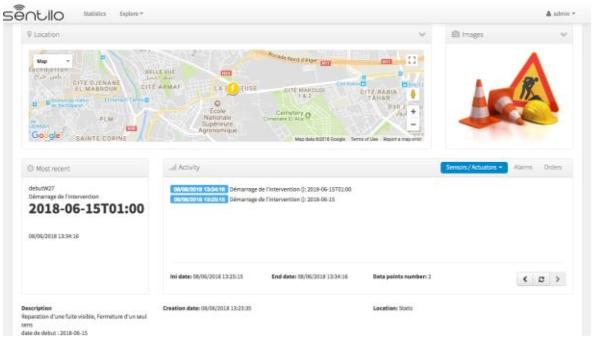

Figure 4. Screenshot of Sentilo Web page with road work tracking information.

5. Conclusion

The move towards smart cities has meant leveraging new information and data management solutions to optimize operations and deliver important services to citizens. These solutions are evolving rapidly with successive technologies which make incremental and open smart city solutions more important.

In this paper, we proposed a design of a smart city solution, namely the operating system of the smart city. It has three main cloud-based components: workflow engine, databases, and API endpoint. For reach component, we identified then deployed the relevant open-source technology such as Camunda (workflow engine) and Sentilo (IoT middleware). We developed a case study based on a roadwork permit process where we first modeled and improved the process model. We then implemented this process on our platform and added new web services that would stramline the process. Real-life tests were successfully conducted as a proof-concept.

References

[1] C. Yin, Z. Xiong, H. Chen, J. Wang, D. Cooper, B. David, "A literature survey on smart cities," Science China Information Sciences, vol. 58, no. 10, pp. 1–18, 2015.

[2] E. F. Z. Santana, A. P. Chaves, M. A. Gerosa, F. Kon, D. S. Milojicic, "Software platforms for smart cities: Concepts, requirements, challenges, and a unified reference architecture," ACM Computing Surveys (Csur), vol. 50, no. 6, pp. 1–37, 2017.

[3] K . Mukherjee, RK. Mandal, "A Theme of Smart Cities Based on IOT, Fuzzy Logic and Quantum-Deep Learning Technique". International Journal of Intelligent Systems and Applications in Engineering. 2020.

[4] V. Javidroozi, H. Shah, G. Feldman, "Urban computing and smart cities: Towards changing city processes by applying enterprise systems integration practices," IEEE Access, vol. 7, pp. 108023–108034, 2019.

[5] I. Compagnucci, F. Corradini, F. Fornari, A. Polini, B. Re, F. Tiezzi, "Modelling notations for iot-aware business processes: a systematic literature review," in International Conference on Business Process Management, 2020, pp. 108–121, Springer.

[6] R. R. Harmon, E. G. Castro-Leon, S. Bhide, "Smart cities and the internet of things," in 2015 Portland International Conference on Management of Engineering and Technology (PICMET), 2015, pp. 485–494, IEEE.

[7] M. Sharifinejad, A. Dorri, J. Rezazadeh, "Bis-a blockchain-based solution for the insurance industry in smart cities," arXiv preprint arXiv:2001.05273, 2020.

[8] A. Luque-Ayala, S. Marvin, Urban operating systems: Producing the computational city. MIT Press, 2020.

[9] M. M. Benlahreche, A. Benelmaddjat, "Coordination des travaux des concessionnaires de service public par l'implémentation du bpm à travers une plateforme de smart city : cas intégrant SEAAL-DTP-SDA dans la wilaya d'Alger," Master Thesis, École Nationale Polytechnique, Algeria, supervised by Iskander Zouaghi, 2018.

[10] J. Y. Fernández-Rodríguez, J. A. Álvarez-García, J. A. Fisteus, M. R. Luaces, V. C. Magaña, "Benchmarking real-time vehicle data streaming models for a smart city," Information Systems, vol. 72, pp. 62–76, 2017.

[11] Y. Santur, E. Karaköse, M. Karaköse, E. Akın. "Deep learning based artificial manager for smart city." In 5th International Conference on Advanced Technology & Sciences, pp. 197-201. 2017.

[12] G. Pan, G. Qi, W. Zhang, S. Li, Z. Wu, L. T. Yang, "Trace analysis and mining for smart cities: issues, methods, and applications," IEEE Communications Magazine, vol. 51, no. 6, pp. 120–126, 2013.

[13] D. Kyriazis, T. Varvarigou, D. White, A. Rossi, J. Cooper, "Sustainable smart city iot applications: Heat and electricity management & eco-conscious cruise control for public transportation," in 2013 IEEE 14th International Symposium on", A World of Wireless, Mobile and Multimedia Networks"(WoWMoM), 2013, pp. 1–5, IEEE.

[14] R. Borchard, R. Zeiss, J. Recker, "Digitalization of waste management: Insights from german private and public waste management firms," Waste Management & Research, vol. 40, no. 6, pp. 775– 792, 2022.

[15] T. Anagnostopoulos, A. Zaslavsky, K. Kolomvatsos, A. Medvedev, P. Amirian, J. Morley, S. Hadjieftymiades, "Challenges and opportunities of waste management in iot-enabled smart cities: a survey," IEEE Transactions on Sustainable Computing, vol. 2, no. 3, pp. 275–289, 2017.

[16] B. Anthony Jnr, "Managing digital transformation of smart cities through enterprise architecture– a review and research agenda," Enterprise Information Systems, vol. 15, no. 3, pp. 299–331, 2021.

[17] C. Perera, Y. Qin, J. C. Estrella, S. Reiff-Marganiec, A. V. Vasilakos, "Fog computing for sustainable smart cities: A survey," ACM Computing Surveys (CSUR), vol. 50, no. 3, pp. 1–43, 2017.

[18] K. Wang, J. Chen, Z. Zheng, "Insigma's technological innovation ecosystem for implementing the strategy of green smart city," in Proceedings of PICMET'14 Conference: Portland International Center for Management of Engineering and Technology; Infrastructure and Service Integration, 2014, pp. 892–899, IEEE.

[19] S. Zhu, D. Li, H. Feng, T. Gu, K. Hewage, R. Sadiq, "Smart city and resilient city: Differences and connections," Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery, vol. 10, no. 6, p. e1388, 2020.

[20] G. Hailemariam, J. v. Brocke, "What is sustainability in business process management? a theoretical framework and its application in the public sector of ethiopia," in International Conference on Business Process Management, 2010, pp. 489–500, Springer.

[21] A. Cleven, R. Winter, F. Wortmann, "Process performance management as a basic concept for sustainable business process management– empirical investigation and research agenda," in International Conference on Business Process Management, 2010, pp. 479–488, Springer.

[22] A. H. Sodhro, S. Pirbhulal, Z. Luo, V. H. C. De Albuquerque, "Towards an optimal resource management for iot based green and sustainable smart cities," Journal of Cleaner Production, vol. 220, pp. 1167–1179, 2019.

[23] P. Loos, W. Nebel, J. Marx Gómez, H. Hasan, R. T. Watson, J. Vom Brocke, S. Seidel, J. Recker, "Green it: a matter of business and information systems engineering?," Business & Information Systems Engineering, vol. 3, no. 4, pp. 245–252, 2011.