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# Enterprise Architecture Tools Assessment for Smart Cities Governance using Fuzzy Logic Techniques

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**Abstract:** This paper considers the "smart cities" phenomena as the digital transformation alternative for city governance similar to the digital transformation of enterprises. Therefore, in this paper, we propose to use the Enterprise Architecture (EA) methodology and relevant information systems by considering the city as a large organization. Suggested assessment procedure of government-specific EA tools uses customer experience ratings processed with fuzzy logic techniques.

**Keywords:** Smart City, Enterprise Architecture, Information System, Fuzzy Logic.

## Introduction

**Smart Cities.** Smart cities are sophisticated systems that leverage Information and Communications Technology (ICT) services to improve the quality of life for citizens. Dealing with the complexity of ICT services is one of the current difficulties in smart cities [1].

Sustainable city planning, management, and governance, as well as maximizing economic potential and avoiding environmental damage, will be important problems for governments in the twenty-first century. As a result, transforming traditional cities into smart cities is becoming an increasingly significant requirement [2].

Because of the importance of smart cities to various stakeholders, as well as the benefits and challenges associated with their implementation, the concept has piqued the interest of researchers in a variety of genre studies, including Internet of Things (IoT), Information Systems (IS), and more mainstream computer science and engineering disciplines. This is demonstrated by the growing body of research published in academic journals, publications, and conference proceedings [3].

The number of "smart city" publications over the last five years according to the Google Scholar platform is demonstrated in Fig. 1 below.

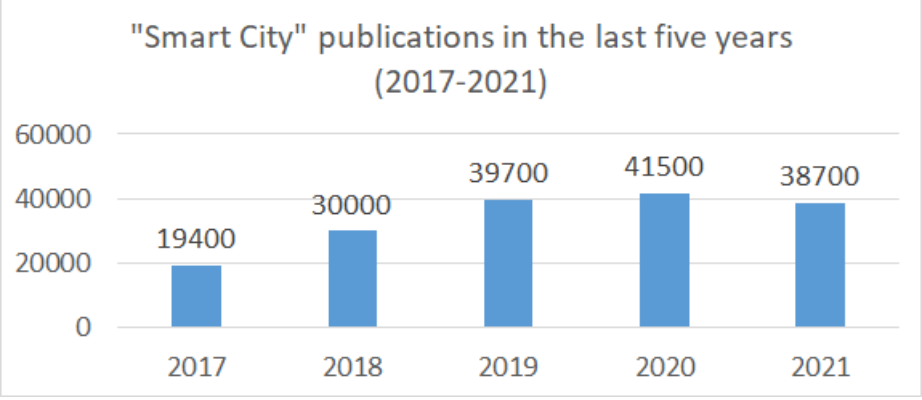


**Fig. 1.** The number of "smart city" publications over the last five years.

According to Fig. 1 above, the interest of scientific researchers in the "smart city" domain has grown significantly between 2017 and 2021 from 19,4K to 38,7K published papers respectively. The number of

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published papers in 2021 is insignificantly lower than in 2020, however, some publications have not been indexed by Google Scholar yet at the moment of this paper prepared (February 2022). By the moment of publications analysis, Google Scholar already indexed 7190 papers devoted to the "smart city" domain.

With the advent of smart gadgets and their subsequent improvements, the concept of connecting common things over existing networks has gained popularity. The growth of traditional networks that connect billions of connected objects resulted in the IoT. Smart cities have risen to the fore in recent decades as a result of increasing urbanization around the world. Using ICT to perform city operations has made cities more efficient in a variety of ways [4].

**Enterprise Architecture.** The EA method has become a popular domain for business and Information Technology (IT) system management due to its ability to model the intricacies of the actual world practically and to assist users in planning, designing, documenting, and communicating IT and business-related challenges. Because of the decision-making assistance it provides, EA is a perfect technique for sustainable smart cities, and it is rapidly being used in smart city initiatives. This strategy enables the sharing and reuse of functional components, as well as the standardization of infrastructure and technologies. By integrating and harmonizing data linkages, EA can improve the quality and performance of city processes as well as the overall productivity of a city [5].

Enterprise architecture can include many perspectives, such as data, application, business, value, governance, security, and so on, in a single architectural diagram. Authors of [6] contend that a smart city can be treated as an interconnected network of organizations that collaborate in the same manner that departments of a company do [6].

ArchiMate is an Open Group standard that describes an enterprise architecture modeling language. ArchiMate was created to model an EA within and across business and IT domains. ArchiMate (see Fig. 2 below) uses a tiered view of an organization depicted in the ArchiMate Framework [7], in which the essential elements of an enterprise are classified along two dimensions (layers and aspects). Furthermore, ArchiMate follows a service-oriented approach, in which each layer delivers services to the levels above it. ArchiMate is primarily concerned with defining a modeling standard for enterprise architecture [8].

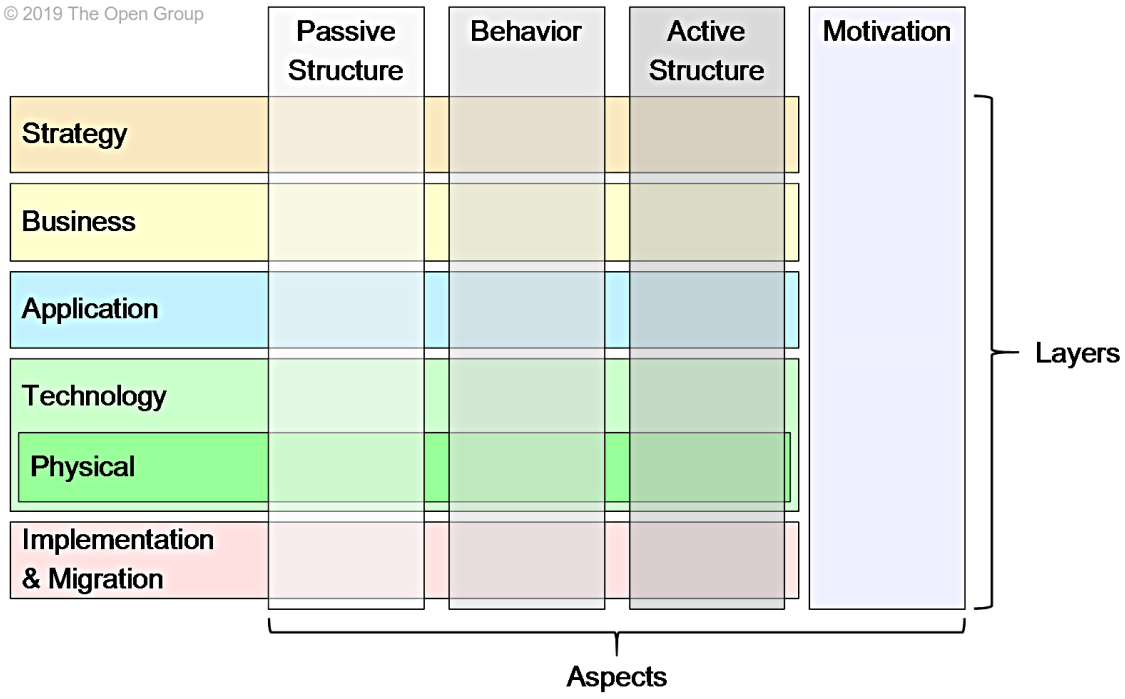


**Fig. 2.** ArchiMate 3.0 Framework [7].

**Information Systems.** Organizations can use EA methods to analyze both the need for and the impact of change. They capture the interdependence and interrelationships inside and between an ecosystem of

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partners, operating models, capacities, people, processes, information, applications, and technology. They provide a centralized repository for capturing data and metadata about the artifacts that a company is concerned with, as well as their associated life cycles. Models depict the links between these artifacts and are viewed as assets that serve to characterize and shape the enterprise's future. EA tools aid in the decision-making process for both IT and the broader company. When models are linked with operational performance data, they can aid in the improvement of business outcomes as well as the design and ongoing development of digital platforms [9].

Considering the variety of EA management IS, it is relevant to suggest an approach to EA tools assessment for smart cities governance as large organizations. EA is intimately related to a variety of tools, including frameworks, methods, techniques, and modeling notations designed to assist architects in planning companies and their information systems. One set of tools, in particular, is declared to be vital to the EA discipline, continuously pushed as worldwide EA standards, and widely taught in various EA courses, yet in truth, these tools are mostly, if not entirely, useless for all practical purposes. At the same time, another collection of tools represents the actual corpus of proven EA best practices that operate in businesses, but these tools are rarely addressed and lack sensible explanations from which beginner architects and students can learn [10]. Therefore, the proposed assessment procedure should use customer reviews and ratings rather than quarterly or annual analytical reports provided by EA-promoting organizations.

## Materials

According to the Gartner Peer Insights [9] resource that accumulates customer reviews (see Fig. 3), the following EA management tools are the best solutions for government institutions:

- *Abacus* by Avolution.
- *LeanIX Enterprise Architecture Management* by LeanIX.
- *HoriZZon* by BiZZdesign.
- *Alfabet Enterprise Architecture Management* by Software AG.
- *The Essential Project* by Enterprise Architecture Solutions.
- *iServer365* by Orbus Software.

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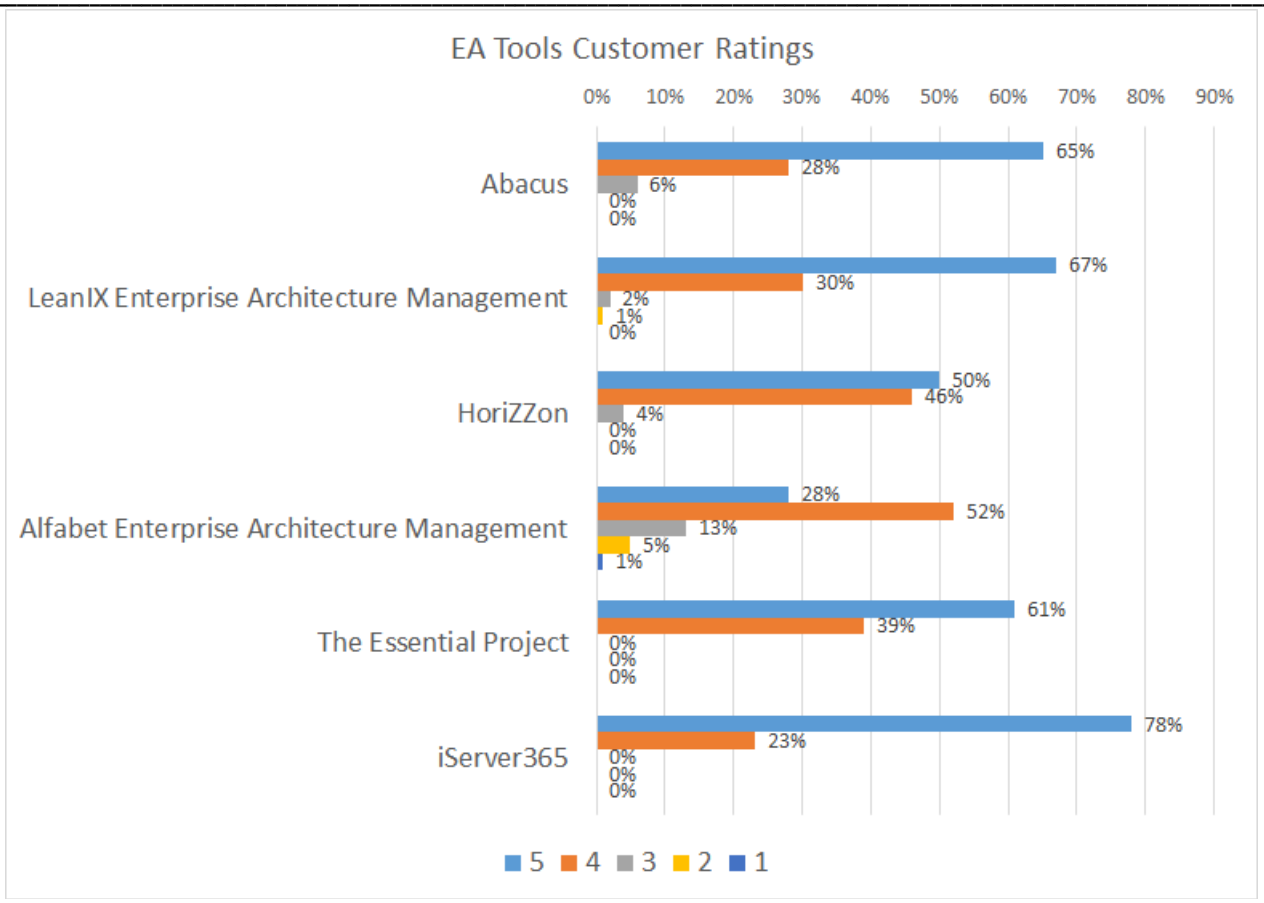


**Fig. 3.** EA Tools Customer Ratings [9].

Fuzzy logic allows us to reason in terms of approximations rather than exactness. Fuzzy logic is widely employed in a wide range of applications, including control systems, robotics, medical science, and expert systems. Most of these applications can be thought of as systems having numerical input and numerical output; nevertheless, these systems work with fuzzy values inside [11].

Using the customer ratings of EA management tools (see Fig. 3) [9], we can formulate the following membership function to characterize fuzzy sets that describe EA tools:

$$\mu_i(x) = \frac{r_i(x)}{\max\limits_{i=\overline{1,n}} r_i(x)}, i = \overline{1,n}, \tag{1}$$

where:

- $x \in X = \{5,4,3,2,1\}$ is the rating given to the $i$-th EA tool, $i = \overline{1,n}$;
- $r_i(x)$ is the percentage of customers who gave a rating $x$ to the $i$-th EA tool, $i = \overline{1,n}$;
- $n$ is the total number of assessed EA tools.

Using the suggested membership functions (1), we can formulate the following fuzzy sets that correspond to the assessed EA management tools:

- Abacus:

$$F_1 = \{(x_1|1), (x_2|0.43), (x_3|0.09), (x_4|0), (x_5|0)\}; \tag{2}$$

- LeanIX Enterprise Architecture Management:

$$F_2 = \{(x_1|1), (x_2|0.45), (x_3|0.03), (x_4|0.01), (x_5|0)\}; \tag{3}$$

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- HoriZZon:

$$F_3 = \{(x_1|1), (x_2|0.92), (x_3|0.08), (x_4|0), (x_5|0)\}; \quad (4)$$

- Alfabet Enterprise Architecture Management:

$$F_4 = \{(x_1|0.54), (x_2|1), (x_3|0.25), (x_4|0.1), (x_5|0.02)\}; \quad (5)$$

- The Essential Project:

$$F_5 = \{(x_1|1), (x_2|0.64), (x_3|0), (x_4|0), (x_5|0)\}; \quad (6)$$

- iServer365:

$$F_6 = \{(x_1|1), (x_2|0.29), (x_3|0), (x_4|0), (x_5|0)\}. \quad (7)$$

Therefore, we need to rank the EA tools using their fuzzy sets obtained after applying the membership function (1). We can sort the EA tools by customer ratings after defuzzification of fuzzy sets (2) – (7).

Defuzzification is the final step in a fuzzy system that turns the fuzzy output set to a crisp value. Maxima methods, distribution methods, area methods, parameter-based (extended methods), specialized techniques, and other approaches are the broad categories of defuzzification methods. The Center of Gravity (COG) technique is a fundamental universal distribution defuzzification method that computes the area's center of gravity under the membership function. This technology is widely utilized in fuzzy controllers and is quite popular. The COG approach has been shown to produce efficient and accurate outcomes. Its biggest disadvantage is that it takes too long to compute the center of gravity [11].

The defuzzification using the COG method is described mathematically as:

$$COG\big(\mu_i(x)\big) = \frac{\int_{x_1}^{x_n} x\mu_i(x)dx}{\int_{x_1}^{x_n} \mu_i(x)dx}, i = \overline{1,n}. \quad (8)$$

In the case of a discrete universal set, the COG formula looks as [11]:

$$COG\big(\mu_i(x)\big) = \frac{\sum_{x\in X} x\mu_i(x)}{\sum_{x\in X} \mu_i(x)}, i = \overline{1,n}. \quad (9)$$

Using the COG defuzzification method (8) – (9), we can obtain crisp values of the EA tool customer ratings and suggest the best option for smart city governance based on the EA methodology and principles.

## Results And Discussion

Fig. 4 demonstrates assessment results of governance EA tools [9] obtained using the COG defuzzification method compared to the Gartner Peer Insights customer ratings.

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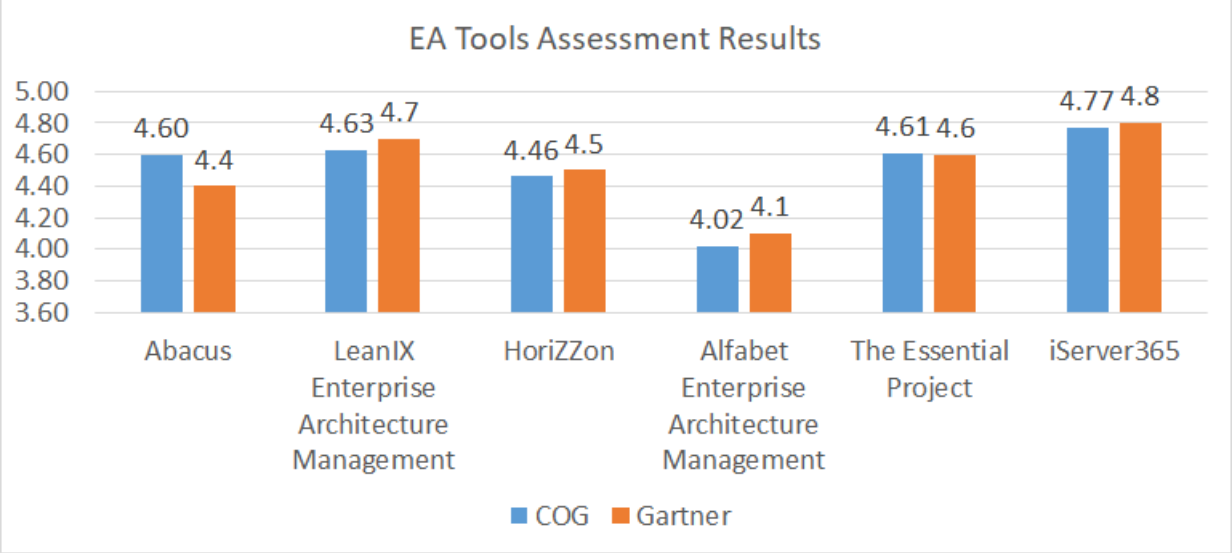


**Fig. 4.** Governance EA tools assessment results.

Table 2 demonstrates a comparison of COG and Gartner Peer Insights (GPI) ratings.

**Table 1.** The comparison of COG and Gartner Peer Insights ratings.

| **Governance EA Tools** | **COG Crisp Values** | **Gartner Peer Insights [9]** | **Deviation** |
|---|---|---|---|
| Abacus | 4.6 | 4.4 | 4.26% |
| LeanIX Enterprise Architecture Management | 4.63 | 4.7 | 1.51% |
| HoriZZon | 4.46 | 4.5 | 0.9% |
| Alfabet Enterprise Architecture Management | 4.02 | 4.1 | 1.98% |
| The Essential Project | 4.61 | 4.6 | 0.22% |
| iServer365 | 4.77 | 4.8 | 0.58% |

Obtained results (see Table 1) demonstrate a significant deviation of COG-based crisp value from the GPI customer rating for the “Abacus” (4.26%) EA tool.

“Alfabet Enterprise Architecture Management” (1.98%), “LeanIX Enterprise Architecture Management” (1.51%), and “HoriZZon” (0.9%) demonstrate intermediate deviation of the COG assessment results from the GPI customer ratings (see Table 1).

The COG assessment results (see Table 1) obtained for the remaining EA tools “iServer365” (0.58%) and “The Essential Project” (0.22%) demonstrate a minimum deviation from the GPI customer ratings.

According to the assessment results (see Table 1), the “iServer365” is the leading governance EA tool with the highest assessment values based on the COG defuzzification method (4.77) and GPI customer rating (4.8). Its other two competitors are “The Essential Project” and “LeanIX Enterprise Architecture Management” (see Fig. 5). They have similar COG and GPI assessment results with the relatively insignificant deviation of 0.22% and 1.51% respectively (see Fig. 5).

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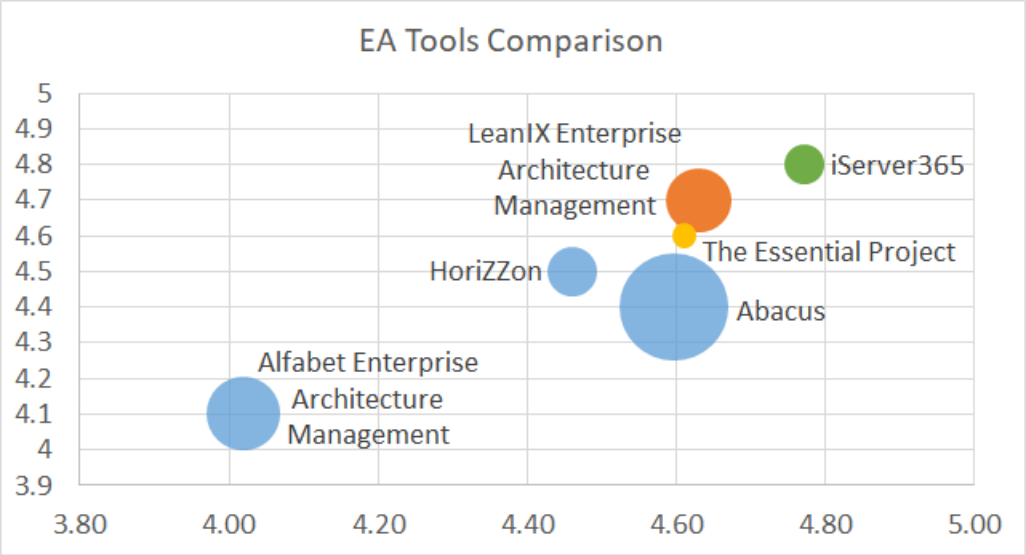


**Fig. 5.** The comparison of EA tools.

Therefore, we may recommend the "iServer365" EA management tool for EA-driven smart city management system implementation. Fig. 6 below demonstrates the ArchiMate diagram for the migration and implementation [12] of the EA-driven smart cities.

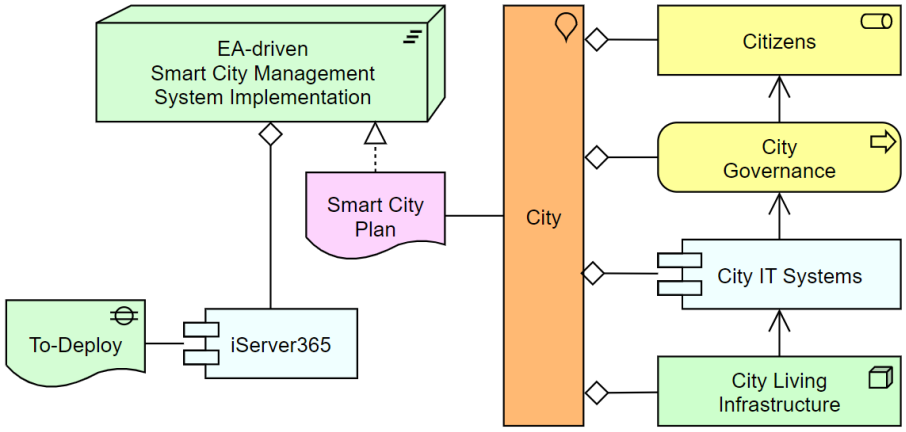


**Fig. 6.** The implementation and migration model for EA-driven smart cities.

It is expected that the deployment of EA tools for smart cities governance will improve the quality of life for citizens because of sustainable city planning and management.

## Conclusion

In this paper, we proposed an approach to the assessment of EA tools that can be used for smart cities governance. The proposed approach assumes that EA can be used for smart city planning and management through digital transformation aimed at improvement of citizens' quality of life. The proposed approach uses Gartner Peer Insights customer reviews of the top-rated EA tools suitable for the government domain. Assessment of governance EA tools using fuzzy logic techniques that utilize rating distribution of considered tools demonstrated industry leaders and possible ArchiMate implementation and migration model for EA-driven smart cities.

Future research may include Business Intelligence [13] and IoT integration with the smart city EA model. Previously proposed techniques of the EA model construction based on business process models [14] and intelligent analytical dashboard design [15] can be used as well.

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