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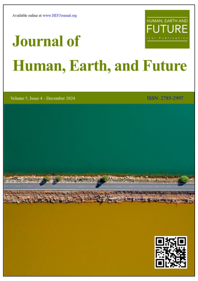

Evaluating Enterprise Architecture Frameworks for Digital Transformation in Agriculture

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Abstract

This study aims to identify the most suitable Enterprise Architecture (EA) framework for driving digital transformation within Malaysia's agricultural sector. The objective is to evaluate and compare four leading EA frameworks—the Zachman Framework (ZFEA), the Department of Defense Architecture Framework (DoDAF), the Federal Enterprise Architecture Framework (FEAF), and The Open Group Architecture Framework (TOGAF)—using eight key criteria: adaptability, scalability, ease of implementation, support for modern technologies, cost-effectiveness, compliance, traceability, and risk management. A systematic comparative analysis assessed these frameworks' effectiveness in addressing the agricultural sector's specific needs. The findings indicate that TOGAF is the most appropriate framework due to its high adaptability, scalability, and robust support for modern technologies, making it ideal for the sector's requirements. In contrast, ZFEA, though versatile, faces significant challenges in practical implementation and scalability. DoDAF's defense-centric focus limits its applicability in agriculture, and while FEAF is adaptable, it lacks strong support for modern technological integration. This study provides novel insights and practical recommendations for policymakers and practitioners to select the most effective EA framework, thereby supporting Malaysia's agricultural sector's digital transformation and modernization.

Keywords: Agriculture; Enterprise Architecture Framework; Comparative study; Modern Technology; Digital Transformation.

1. Introduction

Agriculture is critical to a country's overall development, and Malaysia's economy heavily relies on its agricultural industry [1, 2]. This sector significantly contributes to the national Gross Domestic Product (GDP) by providing food and raw materials and supporting economic growth and stability. Additionally, agriculture enhances job opportunities, increases food production, supports rural development, and improves livelihoods. To ensure robust and sustainable growth, the Malaysian government has implemented several policies to stabilize production and increase efficiency [3].

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Despite its importance, Malaysia's agricultural sector faces numerous challenges, including shrinking arable land, environmental degradation due to extensive use of fertilizers and pesticides, and concerns about food security. The potential for mechanization and the integration of advanced technologies remains underutilized. Although new agricultural techniques have been introduced to improve efficiency and productivity, high production costs and low profitability continue to constrain income growth for farmers and reduce the agricultural labor force. There is a clear need for standardized practices in managing complex agricultural systems, and integrating rigorous engineering methods can address this. Moreover, incorporating modern information technology into agricultural enterprises is essential for enhancing operational efficiency, reducing costs, and meeting growing consumer demands for safe and nutritious agricultural products.

The Malaysian government has recognized these challenges and focused its agricultural strategy on income generation and food security. This strategy includes elevating Malaysia to developed nation status by boosting productivity, ensuring food security, supporting smallholders, fishermen, and farmers, and strengthening the supply chain to comply with international market requirements [3]. However, these efforts must address structural challenges such as crop disease prevention, low productivity, slow adoption of new technologies, limited traceability, and low levels of automation in cultivation processes [4].

Food safety has become a major concern for Malaysian consumers, particularly agricultural products such as grains, meat, vegetables, and seafood. Recent food safety scandals have eroded consumer confidence, prompting the government to introduce stringent regulations to enhance food safety and strengthen quality standards [5, 6]. Introducing these food safety standards is essential as they encourage the adoption of new technologies and best practices within the food industry. As scientific knowledge and technological advancements evolve, these standards serve as catalysts for innovation, supporting developing and utilizing advanced technologies, improving testing methods, and enhancing traceability systems. This continuous improvement in food safety practices benefits both businesses and consumers by ensuring higher food quality and safety standards.

Digital transformation is crucial for addressing the challenges related to food security and agricultural policy [7]. This transformation requires a deep understanding of technology and its implications for the sector. The theoretical foundation of this research is grounded in the application of Enterprise Architecture (EA) frameworks, which offer a structured methodology for aligning IT infrastructure with business objectives, thereby supporting digital transformation, IT development, and modernization efforts [8].

The study examines EA frameworks such as the Zachman Framework (ZFEA), The Open Group Architecture Framework (TOGAF), the Federal Enterprise Architecture Framework (FEAF), and the Department of Defense Architecture Framework (DoDAF), which provide systematic methods for managing complexity, optimizing resources, and improving decision-making within organizations. These frameworks were chosen based on their established methodologies and their potential applicability, as discussed by Kotusev [9] and Sessions & DeVadoss [10]. Traditionally used in large organizations and government projects, these frameworks have shown promise in addressing specific needs and enhancing operational efficiency. However, despite their potential, the application of EA frameworks is still in its early stages within the agricultural sector. It remains underexplored in the context of Malaysian agriculture, creating a significant gap in the literature.

This study seeks to address this gap by conducting a comparative analysis of the ZFEA Framework, TOGAF, FEAF, and DoDAF to evaluate their effectiveness in agriculture. The research will focus on adapting these frameworks to meet the unique requirements of Malaysian agriculture, with particular emphasis on digital transformation. Through this analysis, the paper aims to identify best practices and provide recommendations for the broader application of EA in agriculture.

2. Literature Review

In recent years, the agricultural sector has faced significant challenges related to food safety, sustainability, and technological advancement. Addressing these issues requires a comprehensive and structured approach to managing information and processes, where EA plays a crucial role. EA frameworks offer systematic methods for aligning IT infrastructure with business objectives, thereby enhancing decision-making, optimizing resources, and improving adaptability in a rapidly evolving environment. By applying EA in agriculture, stakeholders can ensure robust food safety systems, enhance traceability, and utilize predictive analytics to respond swiftly to potential outbreaks.

EA is primarily utilized in large organizations and major projects, such as enterprise planning and government development [11, 12]. The purpose of EA is to use architectural principles akin to construction to reduce the complexity of developing information systems (ISs). EA provides a comprehensive view of the organization, enabling better decision-making, resource optimization, and adaptation to changes in the business environment. The principles of EA, which include standardization, alignment, and integration, are important for planning, aligning, controlling [11, 13], and managing the diverse and often fragmented components of modern agricultural enterprises, making these frameworks particularly suitable for this sector.

Furthermore, a holistic and unified view of diverse architectural perspectives in agriculture is essential. This comprehensive approach ensures alignment and optimization across all aspects of the agricultural enterprise, enhancing decision-making and resource utilization. However, many agricultural enterprises face challenges due to isolated systems that lack synergy, resulting in redundant applications and insufficient informatization benefits. Addressing the Research Gap: A well-planned and integrated system is necessary to justify the costs and enhance efficiency fully. The application of EA in agriculture, particularly in regions like Malaysia, remains underexplored due to a lack of awareness and expertise in applying these frameworks within the agricultural context and the prevailing traditional farming practices. This study aims to fill this gap by demonstrating how EA can be adapted to enhance agricultural operations and outcomes.

EA planning comprises two primary approaches: Architecture Framework and Architecture Implementation methodology [14]. These approaches support EA implementation by providing project planning, modeling artifacts, guiding implementation, supporting management, and sustaining operations. Integration of Emerging Technologies: While the EA framework focuses on collecting and modeling information about the organization's business and IT, the implementation approach develops appropriate ISs, and IT infrastructure based on these models [15]. This structured approach is increasingly vital for integrating emerging technologies such as IoT and AI, which have the potential to revolutionize agriculture by improving data-driven decision-making and operational efficiency. By aligning these technologies within an EA framework, agricultural enterprises can better leverage these advancements to achieve precision farming, enhanced resource management, and improved sustainability.

2.1. The Four EA Frameworks Used in This Comparison are Briefly Described Below

Several EA frameworks have been developed to address the needs of different sectors. This section reviews the four major EA frameworks—the ZFEA, DoDAF, FEAF, and TOGAF Architecture Framework.

The Zachman Framework (ZFEA): Introduced by John Zachman, the ZFEA Framework employs a Perspective Approach [10], examining EA from various viewpoints such as business, information, technology, and application perspectives. This framework uses roles such as planner, owner, designer, builder, subcontractor, and enterprise to define and organize different perspectives. It aids in understanding how various components of the enterprise interact and contribute to overall goals. The framework addresses six fundamental questions: what, how, where, who, when, and why, providing a comprehensive view of the organization [16]

Department of Defense Architecture Framework (DoDAF): Designed for the US Department of Defense, DoDAF provides a structured approach to developing and using architecture to support the DoD's mission and goals. It follows a systematic approach with viewpoints and models to capture defense systems' architecture comprehensively. This method ensures that all aspects are addressed logically and orderly, involving predefined steps, models, and tools. The development process includes six stages: context definition, scope, requirements, perspectives, development, and implementation [9]. This framework suits large systems with complex integration and interoperability challenges [17].

Federal Enterprise Architecture Framework (FEAF): Specifically designed for use in the US federal government, FEAF employs a standardized approach [10] to EA across all federal agencies. It uses established standards and best practices to ensure consistency and interoperability within the EA. FEAF helps achieve uniformity across different systems and processes, reducing complexity and improving integration. Established in 1999, FEAF outlines organizational goals and visions in a documented fashion [18]. It comprises six parts, each with a reference model: Strategy, Business, Data, Application, Infrastructure, and Security. These models build FEAF's mission to coordinate and encourage federal information exchange across the government [19].

The Open Group Architectural Framework (TOGAF): TOGAF seeks to thoroughly cover all aspects of EA, ensuring a comprehensive approach to the organization. It provides a holistic enterprise view, addressing all relevant dimensions, including strategy, processes, information, applications, and technology. TOGAF encompasses business process modeling, data architecture, application integration, and IT infrastructure planning. Developed in 1995, TOGAF offers a comprehensive approach to designing, planning, building, maintaining, and using EA. Its Architecture Development Method (ADM) outlines a procedure for creating EA, including stages like Preliminary, Architecture Vision, Business Architecture, Information Systems Architecture, Technology Architecture, Opportunities & Solutions, Migration Planning, Implementation, Governance, and Change Management [19].

2.2. Case Study

This case study compares four EA frameworks, separated by their use field. Figure 1 presents the analysis and findings of different EA frameworks based on Nyale et al. [20]. When comparing the four EA frameworks in use cases, ZFEA, DoDAF, FEAF, and TOGAF, each has strengths and weaknesses across various criteria.

Approach: TOGAF and the ZFEA stand out in their comprehensive and perspective-based approaches. TOGAF covers all aspects of EA thoroughly, making it highly versatile, while the ZFEA's detailed perspective approach [21] aids in understanding interactions within the enterprise. DoDAF's structured approach is well-suited for large, complex systems, and FEAF's standardized approach [10] ensures consistency across federal agencies, though it may lack the flexibility of the others.

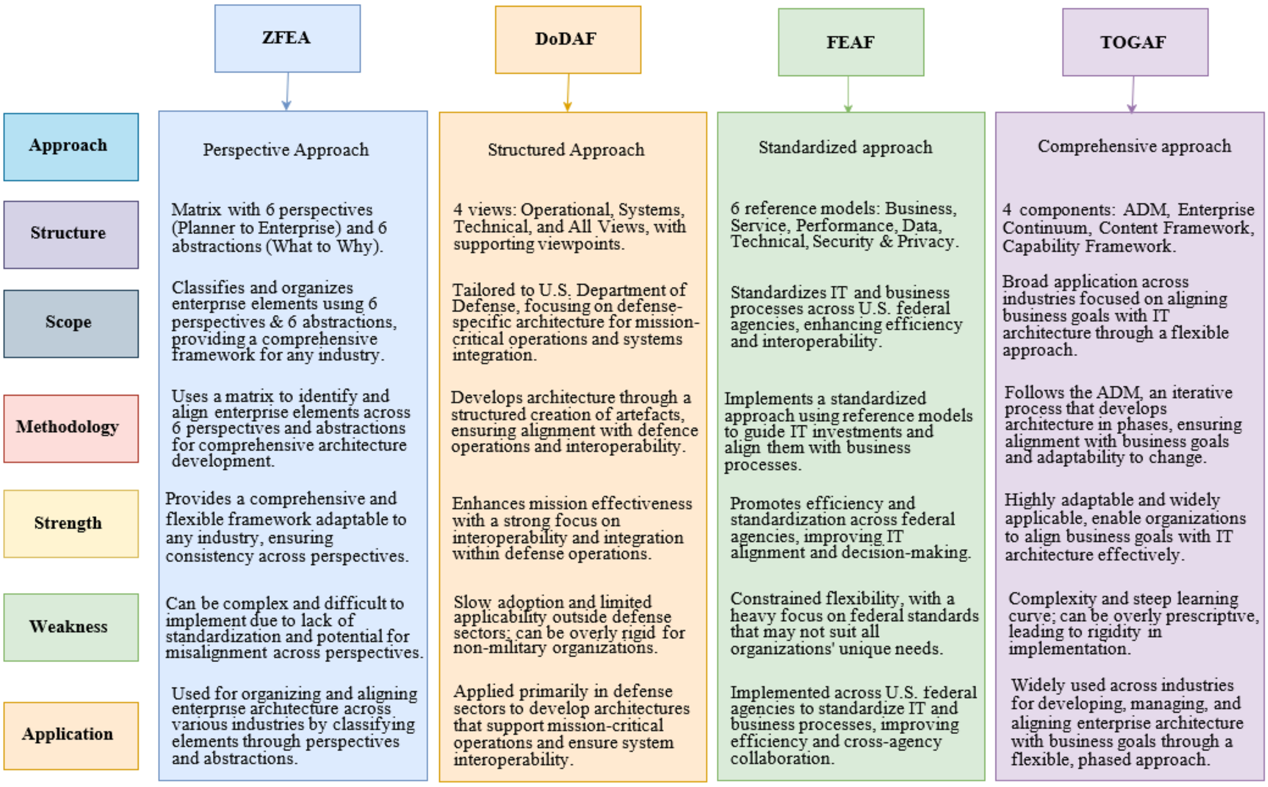

Figure 1. Analysis and findings of different EA frameworks

Structure: TOGAF excels with its four main components, offering a detailed and thorough structure that is highly versatile. FEAF's reference models ensure interoperability and cover essential areas, making it a strong contender. The ZFEA, with its six perspectives and abstractions, is highly structured but can become complex. DoDAF, while solid with its four main parts, may be seen as less adaptable.

Scope: TOGAF, again, leads with its comprehensive scope, which is suitable for various types of organizations. The ZFEA offers a detailed classification and organization of EA, providing significant insight. FEAF focuses on federal government strategies and policies, which can be limiting outside this context. At the same time, DoDAF's scope is specifically tailored to the Department of Defense, making it less applicable to other sectors.

Methodology: TOGAF's Architecture Development Method (ADM) is the most detailed and comprehensive, covering all phases of EA development. The ZFEA's matrix approach is thorough but can be complex to implement. FEAF's use of reference models effectively supports strategic goals but can be rigid. DoDAF's systematic methodology can be too rigid and slow to adapt.

Strength: TOGAF offers high effectiveness, flexibility, and efficiency while minimizing potential business consequences. The ZFEA is also effective and efficient with a clear structure. FEAF improves IT investments but can limit decision-making. DoDAF enhances mission accomplishment and information sharing but suffers from slow adoption.

Weakness: FEAF's constrained decision-making is a manageable issue. Extensive support and resources offset TOGAF's steep learning curve and adoption challenges. The ZFEA's lack of standardization can lead to significant complications. DoDAF's slow adoption critically hampers its implementation.

Application: TOGAF provides a standardized approach suitable for developing, managing, and maintaining EA across various sectors. The ZFEA offers a comprehensive view and helps in organizing EA. FEAF effectively creates a common language for federal agencies but is limited to the public sector. DoDAF is highly specific to the defense sector, limiting its broader applicability.

2.3. EA Frameworks in Agriculture

In Malaysia, the adoption of modern information technology in agriculture is still limited. Many farmers lack direct access to essential agricultural information, which hinders productivity and innovation. The government aims to modernize and transform agriculture into a high-income sector by increasing productivity, ensuring food security, supporting smallholders, fishermen, and farmers, and strengthening the supply chain to meet international market requirements [3]. The strategic use of EA frameworks is important in this transformation, as they align IT infrastructure with agricultural business objectives, facilitating the integration of advanced technologies and enhancing the overall efficacy of agricultural practices.

Implementing modern information technology involves numerous stakeholders, including farmers, suppliers, customers, industry, and government [21]. The deployment process requires a strategic approach encompassing the organization's vision and mission, data requirements, information and knowledge management, technological infrastructure, application needs, and human resources. EA frameworks are instrumental in orchestrating these elements to ensure that technologies such as scientifically precise and automated farming techniques are seamlessly integrated and effectively support the sector's strategic goals. Such technologies are expected to yield significant benefits, including increased productivity, risk mitigation, profit optimization, effectiveness, and sustainability [22]. By enabling organizations to align their business goals with IT systems, EA frameworks significantly enhance operational efficiency and effectiveness [8].

An effective EA framework is essential to leverage these technological advancements fully. Such a framework enables food traceability, enhances predictive analytics, responds more quickly to outbreaks, addresses new business models, reduces food contamination, and fosters the development of a food safety culture [23]. Table 1 summarizes the EA frameworks and their applications in agriculture and food safety.

Table 1. Specific adaptations for the agriculture industry

No.	Reference	Definition	EAF
1	Sari & Hindarto (2023) [24]	Implementing EA is a crucial step in enhancing the agriculture sector (food industry).	TOGAF
2	Afif et al. (2022) [25]	Using the ZFEA method to design and develop an integrated information system to support Cafe Warung'e Dony's business needs and processes.	ZFEA
3	Rachmaniah et al. (2022) [26]	Utilizing an EA framework ZFEA method to manage the chili agrosystem's	ZFEA
4	Camatti et al. (2020) [27]	Construct IoT application architectures and integrate them with the TOGAF framework.	TOGAF
5	Delima et al. (2016) [28]	The IAIS is designed for implementation, with the system blueprint developed using the TOGAF framework	TOGAF
6	Delima et al. (2017) [29]	Developed a blueprint using TOGAF, with a particular focus on the business architecture.	TOGAF
7	Rubhasy & Hasibuan (2012) [30]	Developed the Indonesian E-Agriculture Strategic Framework (IESF) using the TOGAF Enterprise Architecture approach.	TOGAF

Table 1 highlights the application of various EA frameworks in agriculture and food safety. Sari & Hindarto [24] discuss the significant role of TOGAF in improving the food industry through cyber-security EA. Afif et al. [25] and Rachmaniah et al. [26] demonstrate the use of the ZFEA for designing integrated information systems and managing smart enterprise systems in the chili agrosystem, respectively, emphasizing its suitability for small organizations despite its lack of a robust development methodology. Camatti et al. [27] explore the use of TOGAF for constructing IoT application architectures, while Delima et al. [28] showcase its effectiveness in designing the Indonesian Integrated Agriculture Information System (IAIS).

Delima et al. [29] discussed the significant role and design of the business architecture of the Integrated Agriculture Information System (IAIS) using TOGAF, and Rubhasy & Hasibuan [30] explore the use of ICT in agriculture and design the Indonesian E-agriculture strategic framework using TOGAF.

2.4. Agriculture Challenges

The agricultural sector faces several significant challenges that impact productivity and food safety. Many farmers, especially in rural areas, lack direct access to up-to-date agricultural information and best practices, resulting in suboptimal farming techniques and reduced productivity. The agricultural supply chain is complex, involving multiple stakeholders from production to consumption, making traceability and accountability difficult, leading to inefficiencies and food safety risks. Additionally, adhering to national and international food safety standards requires consistent monitoring and documentation, often challenging for small-scale farmers and producers due to limited resources and knowledge.

Integrating modern technologies such as IoT, AI, and data analytics [31] into agricultural practices is another hurdle, particularly due to rural areas' lack of technical expertise and infrastructure. Effective data management is crucial for decision-making in agriculture, yet many enterprises lack the systems and processes to collect, store, and analyze data efficiently. Moreover, balancing agricultural productivity with environmental sustainability poses a significant challenge, as practices that ensure long-term soil health, water conservation, and biodiversity must be integrated into farming operations.

An EA approach offers numerous benefits in addressing these challenges. EA can help design and implement comprehensive information systems that give farmers real-time access to critical agricultural data and best practices, enhancing decision-making capabilities. It can streamline the agricultural supply chain by integrating various IT systems, improving traceability, and ensuring efficient coordination among stakeholders, thus reducing food safety risks. EA also supports the development of systems that automate compliance monitoring and reporting, making it easier for farmers and producers to adhere to food safety regulations.

Furthermore, EA provides a structured approach to integrating modern technologies into agricultural operations, facilitating precision farming, predictive analytics, and smart resource management. It enables the establishment of robust data management systems, supporting better decision-making and strategic planning. By incorporating sustainability goals into the agricultural enterprise's strategic blueprint, EA ensures that environmental considerations are integrated into every aspect of farming operations, from planning to execution. Through a strategic EA approach, the agricultural sector can enhance productivity, ensure food safety, and achieve sustainable growth, aligning with the broader objectives of modernization and transformation into a high-income sector.

3. Framework Analysis

This study's research process follows a structured methodology, as illustrated in Figure 2. The study begins with defining the research problem, aim, and objectives, followed by a comprehensive literature review those grounds the study in existing knowledge. Subsequent analysis evaluates the ZFEA Framework, TOGAF, FEAF, and DoDAF frameworks specifically for their applicability and effectiveness in integrating digital technologies within the agricultural sector.

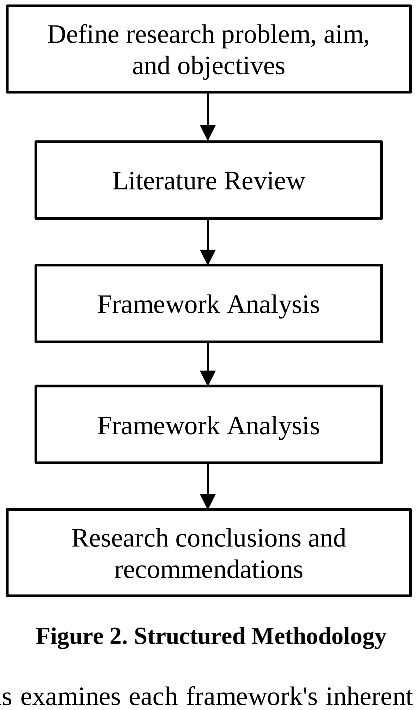

Figure 2. Structured Methodology

This theoretical comparative analysis examines each framework's inherent capabilities to ascertain their alignment with agricultural needs. Key to this evaluation is a set of comprehensive criteria, including adaptability, scalability, ease of implementation, support for modern technologies, cost-effectiveness, compliance with standards, traceability, and risk management [20, 23, 32]. These criteria are selected to address agriculture's challenges, such as variable market demands, diverse operational scales, and stringent regulatory standards. Therefore, an effective EA framework must be adaptable to rapid changes, scalable across different farm sizes, easy to implement with minimal disruption, and supportive of modern agricultural technologies. Also, it should offer cost-effective solutions, help comply with national and international standards, provide robust traceability for food safety, and include risk management capabilities to handle the unpredictable nature of farming. These comprehensive criteria, detailed in Figure 3, are essential for ensuring that the selected framework can effectively enhance efficiency and sustainability while addressing the unique challenges and requirements of the agricultural sector.

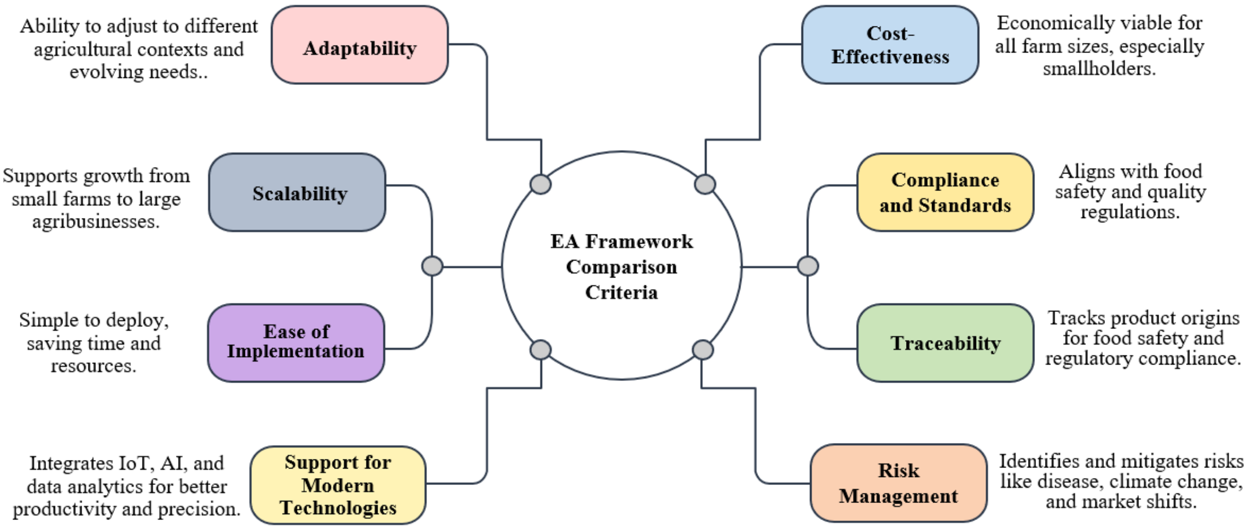

Figure 3. Criteria for Comparison

It is also important to note that the study does not prioritize any criterion over others; instead, each is considered essential for the holistic evaluation of each framework's capacity to support and enhance agricultural operations effectively. This approach ensures a balanced view of how well each framework can meet the diverse and complex requirements of the agricultural sector.

This study aims to identify the most suitable EA framework for digitalizing the agricultural sector in Malaysia by systematically analyzing these criteria. With the evaluation criteria established, the next step is to compare the various EA frameworks. This analysis is detailed in Figure 4.

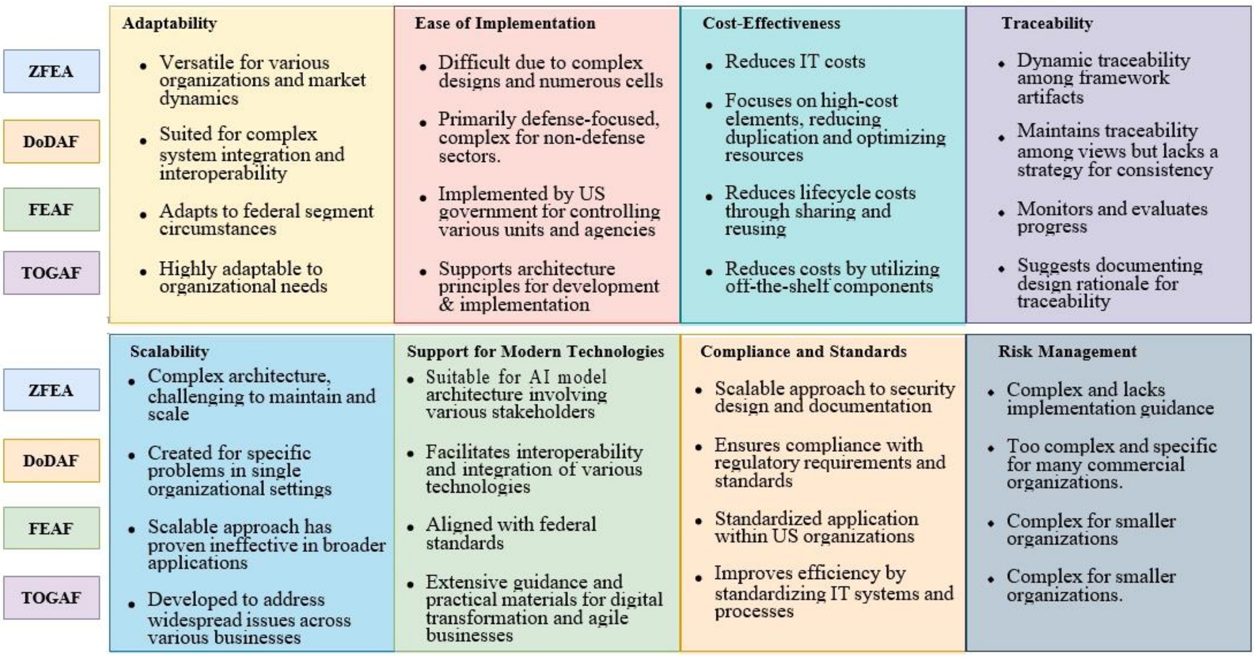

Figure 4. Comparative Analysis of EA Frameworks

Based on Figure 4, ZFEA is highly adaptable, effectively responding to shifts in customer demands and technological changes due to its versatility [20]. However, its scalability is hindered by a complex architecture that is challenging to maintain and expand [33]. In contrast, DoDAF excels in complex system integration within defense settings but suffers from limited adaptability and scalability in broader applications, restricting its use outside specialized contexts [34, 35]. FEAF shows strong adaptability within federal environments, yet it encounters scalability challenges in larger organizations due to its increased complexity and resource demands [9]. On the other hand, TOGAF is designed to be both adaptable and scalable, making it well-suited for various industries and diverse organizational needs [34, 35].

Implementing ZFEA is challenging due to its complex design and multiple components, contributing to its complexity [33]. DoDAF, while moderately easier to implement due to its specialization, still remains complex [34]. FEAF offers more ease of implementation within U.S. government operations but continues to pose moderate challenges [9]. TOGAF, in contrast, simplifies development and implementation by supporting core architecture principles, making it particularly beneficial for integrating technologies like IoT, AI, and cloud computing [35, 36]. Although ZFEA provides moderate support for AI model architecture [16], DoDAF enhances interoperability among various technologies. However, FEAF, despite its alignment with federal standards, lags in supporting modern technologies [35, 36].

In terms of cost-effectiveness, ZFEA excels through structured planning, while FEAF also performs well by promoting cost efficiency through shared services and reuse [36]. DoDAF focuses on optimizing high-cost elements, which, although effective, do not reach the efficiency levels achieved by ZFEA or FEAF [35]. TOGAF effectively manages development expenses by utilizing off-the-shelf components and balancing cost and performance [36]. Regarding compliance, ZFEA and DoDAF provide scalable security designs that adhere to regulatory standards, while FEAF is extensively utilized within U.S. agencies due to its standardized approach. TOGAF's standardized IT systems and processes significantly enhance operational efficiency [35, 36].

In traceability, ZFEA provides dynamic traceability, enhancing change management capabilities [32]. DoDAF, while maintaining traceability among views, struggles with strategic consistency in this regard. Both FEAF and TOGAF monitor progress effectively, with TOGAF emphasizing the documentation of design rationales, thereby improving traceability and accountability [35].

Before presenting the comparative analysis in Table 2, it is important to outline the scoring system based on references [37, 38], which ensures a systematic and transparent evaluation of EA frameworks. In Figure 5, based on references [39], all the EA frameworks are quantitatively assessed against key criteria relevant to the agricultural sector—Adaptability, Scalability, Ease of Implementation, Support for Modern Technologies, Cost-Effectiveness, Compliance & Standards, Traceability, and Risk Management. Each criterion is scored on a scale from 1 to 3, with 3 indicating great performance and 1 indicating negligible performance. This scoring system not only enhances transparency but also provides a well-founded rationale for our analysis. The results are comprehensively depicted in Table 2 and further detailed visually in Figure 6, offering a clear and systematic comparison of the performance of each framework.

TOGAF emerges as the most robust and balanced EA framework, scoring the highest score. It excels in adaptability, scalability, support for modern technologies, compliance, and traceability, making it highly suitable for a wide range of applications. TOGAF’s extensive guidance and practical materials for digital transformation further bolster its applicability across various industries.

Despite its many strengths, TOGAF does face challenges with moderate ease of implementation and cost-effectiveness, crucial considerations for agricultural enterprises operating under tight margins. In response, it is advisable for agricultural organizations to adopt phased implementation strategies and seek partnerships for funding and technical support. This approach helps to mitigate initial financial and logistical burdens, facilitating smoother integration across various agricultural contexts.

Great Performance:3	Moderate Performance:2	Negligible Performance:1
Indicates that the framework excels in the criterion, offering comprehensive, robust, and highly effective support, ideal for diverse applications.	**Represents adequate performance with some limitations; suitable for most applications but may require extra resources or customization.**	**Poor performance with major shortcomings; minimal support, requiring significant modifications for effective use.**

Figure 5. Performance Levels

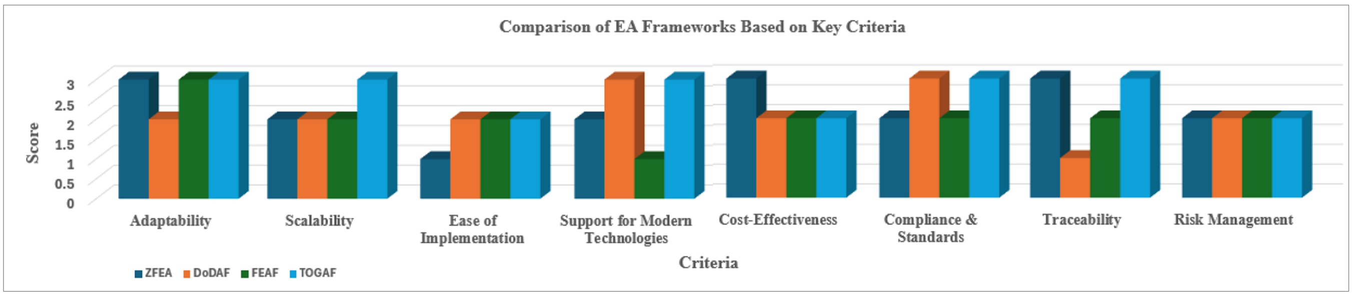

Figure 6. Comparative Analysis Scores of EA Frameworks

Table 2. Comparative Evaluation of EA Frameworks Based on Key Criteria

Criteria	ZFEA	DoDAF	FEAF	TOGAF
Adaptability	3	2	3	3
Scalability	2	2	2	3
Ease of Implementation	1	2	2	2
Support for Modern Technologies	2	3	1	3
Cost-Effectiveness	3	2	2	2
Compliance & Standards	2	3	2	3
Traceability	3	1	2	3
Risk Management	2	2	2	2
Total Score	**18**	**17**	**16**	**21**

Comparatively, other frameworks such as ZFEA, DoDAF, and FEAF each show distinct strengths but also possess limitations that affect their suitability for agriculture. ZFEA demonstrates strong performance with a total score of 18, particularly in adaptability, cost-effectiveness, and traceability. However, its complex architecture complicates implementation and hampers scalability, limiting its broader application. DoDAF, with a score of 17, excels in integrating modern technologies and ensuring compliance but lacks the adaptability and scalability needed outside of defense applications, making it less suitable for the diverse needs of agriculture. FEAF, scoring 16, shows high adaptability and moderate ease of implementation but falls short in supporting modern technologies and scalability. This shortfall can restrict its effectiveness in larger agricultural settings where technology integration is crucial for operational success.

While ZFEA, DoDAF, and FEAF each offer specific strengths, TOGAF distinguishes itself with comprehensive capabilities and balanced performance across crucial criteria, underscoring its versatility across various industries. This makes it the most effective framework for agricultural applications. Employing a quantifiable scoring system, this analysis provides clear guidance for selecting the most suitable EA framework, firmly establishing TOGAF as the preferred choice for comprehensive EA deployment in the agricultural sector.

4. Discussion

In our study, we compared four models—ZFEA, DoDAF, FEAF, and TOGAF—and identified TOGAF as the most suitable for a range of sectors, with potential adaptation for agriculture. The successful adoption of TOGAF frameworks in agricultural enterprises is essential for unlocking the full potential of digital transformation. Ensuring that these enterprises have access to the necessary tools and resources is crucial for effectively leveraging TOGAF. The framework's high adaptability, scalability, and support for modern technologies make it well-suited for Malaysia's agricultural sector. TOGAF's comprehensive guidance and practical materials facilitate the integration of IoT, AI, and cloud computing—key technologies for modernizing agricultural practices, improving efficiency, and enhancing the agriculture sector.

The case studies summarized in Table 3 illustrate TOGAF's application across different contexts, such as its use in MSMEs, as explored by Marselina et al. [40], and in the management of cacao crops in Colombia, as detailed by Guevara et al. [41]. However, while these strengths offer significant opportunities, they also introduce challenges that must be carefully managed when implementing TOGAF in agriculture. The initial high costs and the operational complexity required for TOGAF can be particularly challenging for small and medium-sized farms, raising concerns about its practicality in resource-constrained agricultural settings.

Table 3. TOGAF Implementation in Agricultural Context

No	Reference	Explanation
1	Marselina et al. (2021) [40]	This study conducted an experiment on the implementation of enterprise architecture models, specifically the ZFEA framework and the TOGAF framework. The author demonstrates the implementation of TOGAF in MSMEs within the manufacturing sector
2	Guevara et al. (2022) [41]	This study explains the development process of technology solutions for the pre-planting, planting, maintenance, production, and post-harvest phases of Theobroma cacao crops in Colombia using the TOGAF framework.
3	Madyatmadja et al. (2020) [42]	This study will use the TOGAF framework as a modeling tool to design the process of developing an enterprise information system for a distribution company. The framework has been adapted to align with the company's business processes and needs.
4	Rubhasy & Hasibuan (2012) [30]	This study explains the Indonesian E-Agriculture Strategic Framework (IESF) by utilizing the TOGAF framework.
5	Ovalle et al. (2021) [43]	This study explains the successful implementation of TOGAF in a fast-food SME, leading to improvements in the sales process, order management, complaint resolution, and overall sales growth.

To overcome these challenges and ensure the successful adoption of TOGAF, it is essential to develop strategies that capitalize on its potential to enhance digital transformation in the agricultural sector. Addressing both technical and human factors through strategic adaptations is crucial to unlocking this potential. This involves customizing the framework to align with the specific needs of agriculture, strategically planning to manage costs, and engaging stakeholders comprehensively to build capacity and foster acceptance. By concentrating on these areas, agricultural enterprises in Malaysia can successfully bridge the gap between TOGAF's theoretical advantages and its practical application. Such strategic efforts will enable them to fully leverage TOGAF's strengths, leading to more efficient, modernized, and sustainable operations.

5. Conclusion

The comparative analysis reveals that TOGAF is the most suitable EA framework for driving digital transformation in Malaysia's agricultural sector. With its strengths in adaptability, scalability, and support for modern technologies make it ideal for addressing the sector's diverse needs. While it poses challenges in ease of implementation and cost-effectiveness, its extensive capabilities of integrating advanced technologies like IoT, AI, and cloud computing outweigh these hurdles. In contrast, other frameworks exhibit more significant limitations: ZFEA, despite its theoretical strengths, struggles with practical implementation and scalability; DoDAF's focus on defense applications limits its adaptability for agricultural contexts; and FEAF, though adaptable and moderately easy to implement, does not adequately support the necessary modern technologies for scalable agricultural modernization. Our future research will explore the application of TOGAF to develop specific digital solutions within Malaysia's agriculture sector, such as pest and disease detection in coffee crops, enhanced food traceability, and improved food handling practices. This strategic implementation of TOGAF will boost resource management and crop yields and augment food safety and quality through improved traceability and transparency, thus fostering technological empowerment and promoting sustainable growth in the agricultural sector. This approach will enable Malaysia's agricultural sector to capitalize on technological advancements, promoting sustainable growth and improving food security.

6. Declarations

6.1. Author Contributions

Conceptualization, K.S.M.A., S.M., and S.T.; methodology, K.S.M.A., S.M., and B.B.; validation, S.T., B.B., and Y.Y.; investigation, S.T., SU.M. and B.B.; resources, K.S.K.; writing—original draft preparation, K.S.M.A., and S.T.; writing—review and editing, Y.Y.; S.U.M., and K.S.K.; visualization, S.T. and B.B. All authors have read and agreed to the published version of the manuscript.

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Data sharing is not applicable to this article.

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Not applicable.

6.5. Informed Consent Statement

Not applicable.

6.6. Declaration of Competing Interest

The authors declare that there are no conflicts of interest concerning the publication of this manuscript. Furthermore, all ethical considerations, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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