# Enterprise Architecture for Equipment Performance Analysis Based on Internet of Things (IoT) Technology in the Semiconductor Manufacturing Industry

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**Abstract**

*This study proposes a concept for establishing an Enterprise Architecture in the semiconductor manufacturing industry for equipment performance analysis using Internet of Things (IoT) technology. The plan is to implement The Open Group Framework approach as Enterprise Architecture in the manufacturing analytics department. The TOGAF approach improves data governance in the business process and analytics department. Manufacturing focuses on providing excellent and high-quality products to customers. As a result, the manufacturer must use a data analytics application to monitor the performance of the equipment. The performance of the equipment is monitored around the clock to ensure that it meets the requirements and does not exceed the threshold. The business process, data from the warehouse, and how it is processed will be discussed. Implementing Enterprise Architecture in manufacturing will also be discussed, focusing on the three layers of the TOGAF Architecture Development Method (ADM). The three layers are business, technology, and application. The Enterprise Architecture framework is a blueprint for the architecture used to align the business and information technology. Enterprise architecture optimises business processes and structures processes and functions to integrate information technology into the business. The proposed Enterprise Architecture for equipment performance analysis in the semiconductor manufacturing industry can be used as a guideline for implementing a comprehensive framework for tool performance monitoring.*

***Keywords:*** *Data Analytics, Enterprise Architecture, Internet of Things (IoT), Semiconductor Manufacturing*

## 1. Introduction

The semiconductor industry is a formidable leader in the global market, serving as the foundation of modern technology and life itself. The integrated circuit (IC) chip is at the heart of this industry, a semiconductor product constructed with billions of transistors on a silicon substrate. Such chips empower virtually every new technology available today, revolutionising various domains including mobile phones, computers, automobiles, and more[1]. Moreover, advanced applications such as the Internet of Things (IoT) and artificial intelligence (AI) have ignited a fresh wave of innovation within the semiconductor realm[1]. In the forthcoming markets, dominance will be bestowed upon manufacturers capable of meeting the burgeoning demand for AI and IoT semiconductor chips. Additionally, the rapid



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expansion of the 5G network concurrently fuels the need for swifter, high-performance computing equipment[2].

Semiconductors hold immense potential for growth in this evolving landscape, provided they can effectively meet customer demands through unwavering innovation. The semiconductor industry engages in a meticulous fabrication process that encompasses several intricate steps. This manufacturing journey unfolds within a meticulously controlled, dust-free environment, where cutting-edge facilities automate the production line. For instance, material handling systems orchestrated by automation shuttle the wafer seamlessly between different equipment nodes. The specifics of the equipment employed along the production line vary depending on the process involved. Regular monthly or quarterly maintenance is indispensable to ensure the equipment achieves its full lifespan potential, enabling organisations to save both time and resources while safeguarding the well-being of machine operators[3].

To secure substantial output of the highest quality, manufacturing operations must meticulously oversee the performance of the equipment operating on the production line. This necessitates continuous monitoring and tracking, accomplished through data analysis. Sensor data from the equipment is collected by Internet of Things (IoT) devices and transmitted to the cloud or a dedicated database for comprehensive analysis[4]. Employing this monitoring system empowers manufacturers to proactively mitigate any unfavorable issues affecting both equipment and product quality. By leveraging efficient data analytics, manufacturing enterprises can significantly reduce manufacturing-related waste, while precisely assessing equipment performance to enhance overall production efficiency.

The fundamental objective of this paper is to propose an innovative Enterprise Architecture (EA) approach, centring on IoT, to analyse equipment performance within the semiconductor manufacturing industry[2]. This groundbreaking research serves as a comprehensive guideline, empowering manufacturers to meticulously plan, design, and implement EAs utilising The Open Group Architectural Framework (TOGAF), with a particular focus on the initial phase of the Architecture Development Method (ADM). Furthermore, this study explores how EA, employing TOGAF principles, can be effectively employed within the semiconductor manufacturing domain, thereby fueling confident strides towards future advancements.

## 2. Literature Review

EA plays a critical role in aligning business and technology, enabling the evolution and transformation of an organisation by delivering stakeholder services via business processes and multiple IT systems[1]. EA incorporates the organisation's architecture, including its interconnected components, their relationships, the surrounding environment, and the governing design principles. It aids various stakeholders in comprehending and documenting the enterprise's complexity, analysing current and potential future scenarios, planning and designing future strategies, and effectively communicating the current and future situations to all stakeholders within the organisation. As businesses undertake digital transformation initiatives and recognise the significance of aligning IT strategy with broader business objectives, the demand for skilled EA professionals increases. These specialists are indispensable for reducing complexity, establishing robust technology processes, and ensuring consistent technology utilisation across all business units and functions[3]. EA provides a logical business organisation, supporting data, applications, IT infrastructure, and clearly defined future success goals and objectives.

One study investigated the adoption of The Open Group Architectural Framework (TOGAF) and its Architecture Development Method (ADM) to enhance services and harmonise business processes with IT within Indonesian institutions. Additionally, the study highlighted the role of EA in facilitating face-to-face learning during the Covid-19 pandemic, when institutions had to adjust to remote work and study environments. The authors incorporated TOGAF into the institution's operations to ensure a streamlined procedure, addressing issues such as the lack of a specific financial system and the absence of detailed information and functionalities in the staffing system. Another focus of [5] 's research was evaluating EA implementation to support Industry 4.0. Interviews and surveys were used to assess the planning and capabilities of EA in this context. The study revealed that while some EA implementations could support Industry 4.0, most lacked the requisite competence, contingent on the EA's capabilities and the tools or applications used. In addition, a study by [6] revealed that EA could be a solution for organisations dealing with the complexities of administering the Internet of Things (IoT). Given the intense market competition and the need to remain relevant, many businesses are employing IoT, and implementing EA is viewed as an effective strategy for attaining IoT and sustainability alignment.

In pursuance of digital transformation in industrial systems, [7] presented TOGAF as a framework for developing automation-driven solutions. The researchers emphasised the applicability of the EA approach, emphasising its capacity to address stakeholder concerns and support complex automation systems, thus sustaining manufacturing systems during the industrial revolution. In a separate iteration, [8] utilised EA at an energy company to increase profitability via technological advancement. The EA strategy facilitated the incorporation of information technology with essential business processes, such as purchase orders, inventory management, finance, marketing, and product distribution. This integration streamlined the business process by leveraging information technology to manage and process pertinent data.

However, before implementing EA, a number of crucial organisational issues must be resolved. Among these is the lack of an Enterprise Architect tasked with managing business, data, applications, and technology. Inadequate documentation, such as an equipment manual, also presents obstacles. The organisation lacks a comprehensive document describing how the business is structured to support technology within its overall business strategy. In addition, employees lack knowledge of application design in manufacturing and how different applications interact. Also absent is essential documentation regarding data storage, organisation, and accessibility. The organisation lacks a document describing how hardware and software interact to support the utilised applications.

EA plays a crucial role in aligning business and technology, fostering digital transformation, and ensuring that organisations can adapt to the complexities of the contemporary landscape. The application of EA facilitates the integration of IT systems, optimises processes, and improves overall performance using frameworks such as TOGAF. To fully leverage the benefits of EA, however, organisations must address issues such as the dearth of specialised roles, deficient documentation, and a lack of employee comprehension. Enterprises can realise the true potential of EA and embark on a path of sustainable development and success by evaluating and resolving these challenges.

## 3. Methodology

This section presents a step-by-step research methodology for evaluating the integration of IoT with the TOGAF framework in the semiconductor industry. By adhering to this methodology, we intend to investigate the findings, identify literature gaps, assess risks and challenges, and propose potential solutions. Enterprise Architecture (EA) frameworks, such as TOGAF, facilitate digital transformations by providing a structured method for aligning IT and business objectives. In the context of the semiconductor industry, which significantly relies on Internet of Things (IoT) technology, it is essential to have a well-defined methodology for implementing the TOGAF framework. This methodology includes the Preliminary Phase, Architectural Vision, Business Architecture, Information System Architecture, Technology Architecture, Opportunities and Solutions, Implementation Governance, and Architecture Change Management. By adhering to this methodology, semiconductor companies can effectively address the unique challenges and requirements of integrating IoT into their enterprise architecture, ensuring a successful digital transformation journey. Figure 1 depicts the methodology of this study.

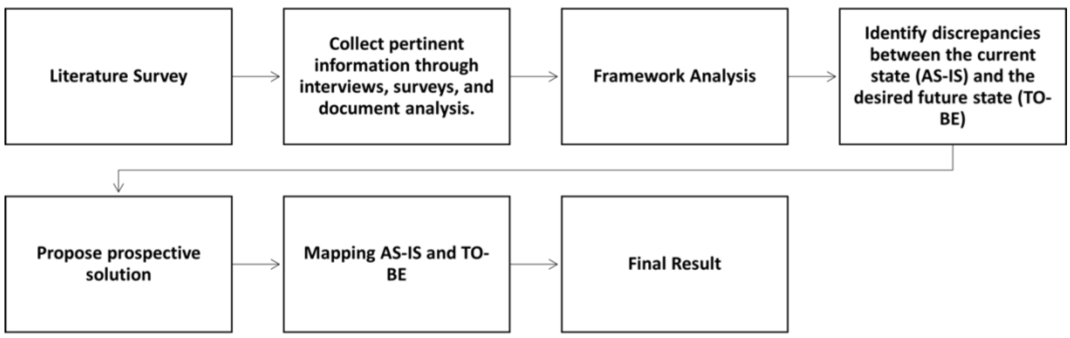


**Figure 1: This Study Methodology**

1. Literature Survey: Conduct a comprehensive literature review on Enterprise Architecture (EA), TOGAF, IoT integration, and the semiconductor industry.

Identify the gaps, hazards, and obstacles associated with implementing TOGAF with IoT integration in the semiconductor industry.

2. Collect pertinent information through interviews, surveys, and document analysis. Interview stakeholders, decision-makers (such as CEOs), and enterprise architecture teams to comprehend their perspectives, requirements, and expectations regarding the TOGAF framework's IoT integration implementation. Collect information regarding the current state of the semiconductor industry, including its obstacles, IT infrastructure, and data management practices.

3. Framework Analysis: Analyse the TOGAF Architecture Development Method (ADM) phases and stages and the semiconductor industry- and IoT-specific components. Examine the preliminary phase, architectural vision, business architecture, information system architecture, technology architecture, opportunities and solutions, migration planning, implementation governance, and architecture change management of the TOGAF ADM.

4. Identify discrepancies between the current state (AS-IS) and the desired future state (TO-BE) regarding IoT integration and EA implementation for the semiconductor industry. Analyse the deficiencies in data management, security, speed, hardware performance, data governance, and business strategy alignment.

5. Propose prospective solutions for addressing the identified gaps and difficulties. Examine how the TOGAF framework, particularly TOGAF ADM, can enhance the architecture, scope, transition, and governance of IoT integration in the semiconductor industry. Discuss the relationship between the four EA framework layers and the development of architectural views and artefacts.

6. Mapping AS-IS and TO-BE: Map the current enterprise data architecture (EDA) and technology layer of the semiconductor industry to the desired future state with IoT integration. Identify areas for enhancement in IoT application software, hardware, data management, and employee awareness. Create process maps to illustrate the proposed TO-BE state, highlighting future process impacts and aligning IT, business strategy, and data delivery systems.

7. Final Result: Summarise the research findings, including the benefits of implementing the TOGAF framework with IoT integration in the semiconductor industry and the associated challenges and potential solutions. Highlight the importance of enterprise architecture in facilitating successful digital transformation and suggest additional research directions for enhancing IoT industry implementation.

## 4. Results and Discussions

This section concentrates on the implementation of the TOGAF framework in conjunction with the integration of the Internet of Things and the semiconductor industry. It examines the findings, identifies voids in previous literature reviews, emphasises the risks and difficulties associated with this implementation, and investigates potential solutions. By incorporating information technology, business data, and requirements, EA provides companies seeking digital transformation with the opportunity to address various problems[1]. However, it is essential to recognise that the application of EA is subject to certain limitations and criticisms. It is essential to evaluate its effectiveness in reducing complexity, standardising component functions, promoting interoperability, enhancing collaboration, and aligning IT with business objectives, despite its reputation for resolving critical issues and implementing business strategies. Moreover, despite documentation, there may still be obstacles to eliminating redundancy and minimising risk within the organisation. Therefore, selecting the most suitable EA framework is crucial for effectively addressing complex problems.

The role of the Enterprise Architect is crucial for governing the architecture and achieving effective execution outcomes. As depicted in Figure 1, the Enterprise Architect is responsible for identifying current gaps and ensuring the successful delivery of objectives. Nevertheless, it is essential to recognise that the efficacy of the Enterprise Architect's function can vary depending on the specific context and organisational structure. Despite the importance of the Enterprise Architect, implementing and executing the architecture may present obstacles, particularly when integrating the TOGAF framework with IoT and the semiconductor industry. Technical complexities and the need for cross-functional collaboration and coordination may be among these obstacles. To ensure a successful implementation of the TOGAF framework in conjunction with IoT integration in the semiconductor industry, it is essential to consider the aforementioned challenges and potential hazards. Organisations can improve the efficacy and effectiveness of their digital transformation initiatives by addressing these challenges and implementing the appropriate solutions, as shown in Figure 1.


**Figure 2: A gap analysis in the EA approach**

The semiconductor business has roughly thirty-five factories worldwide, with the largest facility, TSMC factories, in Taiwan. As a key industry with high worldwide demand, optimising the manufacturing process and guaranteeing a seamless workflow is important. A completely automated approach that merges IT technologies, applications, and data layers is required to do this. The TOGAF framework, established by Open Group in 1995, becomes significant in this situation. TOGAF seeks to decrease mistakes in organisational processes, enhance time management, regulate project budgets, and, most importantly, align the IT and business layers to achieve high-quality results. The use of TOGAF's Architecture

Development Method (ADM) steps and phases, as shown in Figure 2, is required for the goals of this research.

However, it is necessary to critically analyse the TOGAF framework's usefulness and limits in the semiconductor sector. While TOGAF provides an organised approach to enterprise design, it may encounter difficulties when dealing with the specific intricacies of semiconductor production. The semiconductor business is subject to demanding quality, accuracy, and technical progress standards. Implementing TOGAF's ADM stages and phases may necessitate extensive customisation and adaption to accommodate the particular demands and intricacy of the semiconductor manufacturing process. Furthermore, the industry's dynamic nature, characterised by fast technical breakthroughs and changing market needs, presents hurdles to properly integrating IT and business layers. As a result, it is critical to properly investigate the constraints and potential dangers of using the TOGAF framework in the semiconductor sector to ensure its applicability and effectiveness in generating desired outcomes. Figure 2 shows the TOGAF ADM Steps and phases used in this study.

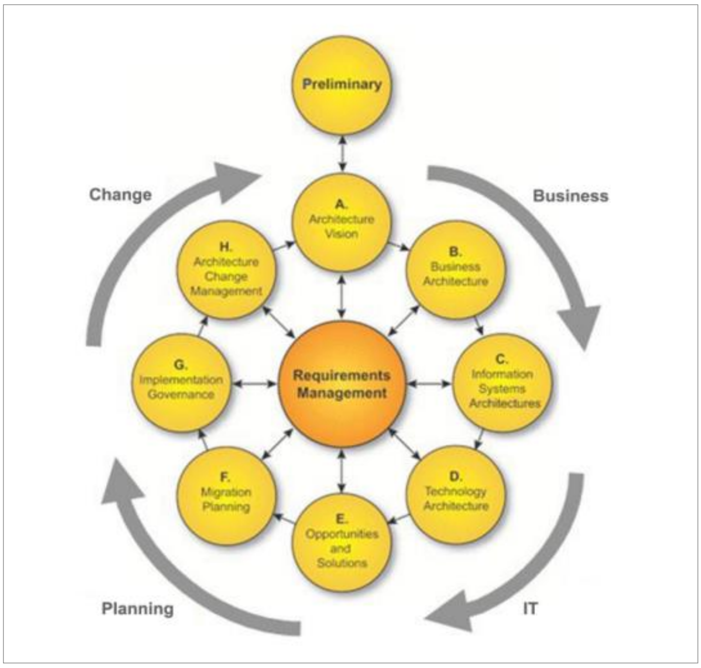


**Figure 3: TOGAF ADM Steps and Phases[15]**

**Preliminary Stage**

To implement the EA framework for the semiconductor company, the Preliminary Stage of TOGAF must be completed as the initial step. At this stage, the framework must be situational and will concentrate on resolving the fundamental questions regarding framework development, such as who will be involved, why we need a new framework, and what the new framework should provide. How is it constructed? What equipment and instruments will be utilised?

Applying all possibilities for higher-level elements to the low-level elements that impact the processes of the enterprise. These will aid in defining the framework's scope, identifying the problem type in the factory, and preparing the TOGAF framework plan. However, this is an iterative procedure while implementing the TOGAF framework phases.

**Architectural Vision (Phase A):**

In the initial phase, the framework must be situational and centred on addressing the fundamental concerns regarding framework construction, such as who will be involved, why we need a new framework, and what the new framework should provide. How is it constructed? What equipment and instruments will be utilised? Putting all possibilities for higher-level elements into low-level elements affects the processes of an enterprise. These will aid in defining the framework's scope, identifying the problem type in the factory, and preparing the TOGAF framework plan. However, this is an iterative procedure while implementing the TOGAF framework phases. Moreover, these must all contribute to the mission and vision of the enterprise. During this process, stakeholders will be interviewed by decision-makers such as CEOs, and EA teams will be assigned a mission and timeline for implementing the blueprint.

**Business Architecture (Phase B):**

The business architecture domain and the objective will be prioritised in this phase. Concurrently, this phase will develop the baseline and target business architectures and the interconnections between business components. In this step, the architecture definition and requirements must determine and produce the disparity between AS-IS and TO-BE, which will be carried out in subsequent steps.

**Information System Architecture (Phase C):**

Similar to the previous phase, this one pertains to the Data layer in enterprises, and its primary objective is to establish a baseline for the current architecture and the desired architecture. In addition, this phase will seek to design a comprehensive system approach for data management, governance, and migration.

**Technology Architecture (Phase D):**

The IT hardware architecture is the baseline during this phase. However, technology devices and physical software must be aligned for optimal performance to support the operation of software and data per an enterprise objective. Due to IoT requirements, this phase will receive more attention, as the infrastructure that incorporates IT, applications, and data must be planned with greater care. Figure 3 depicts the most common components required to integrate the Internet of Things and industries, such as semiconductors.

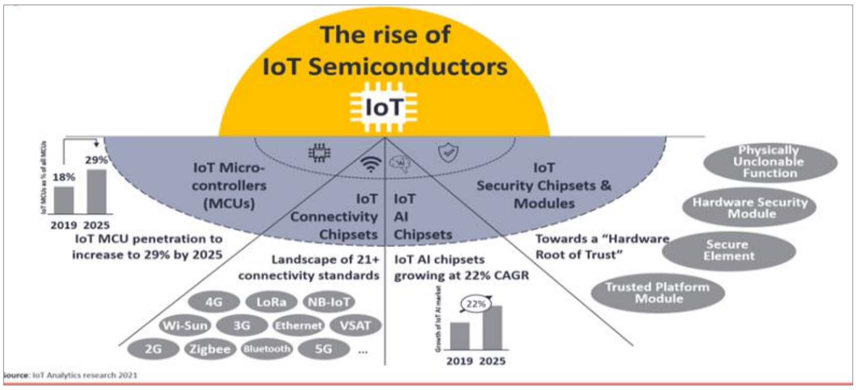


**Figure 4: IoT Ecosystem in Semiconductor Industry [3]**

**Opportunities & Solutions and migration planning (Phase E, F)**

A suitable solution will be selected in this phase following a review and analysis of the disparity between AS-IS and TO-BE. A collection of proclaimed initiatives, including the objective, constraints, resources, and start and end dates. Typically, the two layers with the most significant gaps are the Application Layers and the Technology layer. The infrastructures and applications implemented in IoT, particularly with 5G services, necessitate a potent application to manipulate large data at a high rate of speed since IoT 5G transport speeds are ten times faster than 4G LTE. Moreover, the applications that can synchronise this enormous amount of data require robust applications of current software and applications on which the factory relies. During this phase, efforts and interdependencies between tasks must be based on a transparent methodology.

**Implementation Governance (Phase G):**

During this phase, the execution team executes the necessary modifications to reach the target state while adhering to the objectives and constraints. Due to IoT techniques' direct access to the internet, data governance is the most important aspect of IoT; access to the data must be governed at a high level of security and disseminated only when necessary. The party involved in How stakeholders' preferences change in response to success, value, effort, and risk of change.

**Architecture Change Management (Phase H):**

During this phase, the implementation of the architecture will commence. The differences between AS-IS and TO-BE in the addresses and foreseen deficiencies in Enterprises in relation to stakeholder references. To effectively implement the EA, it is necessary to consider the enterprise's structure, procedures, functions, responsibilities, and skills to achieve Architecture Capability. Figure 4 depicts the phases and stages for each point.

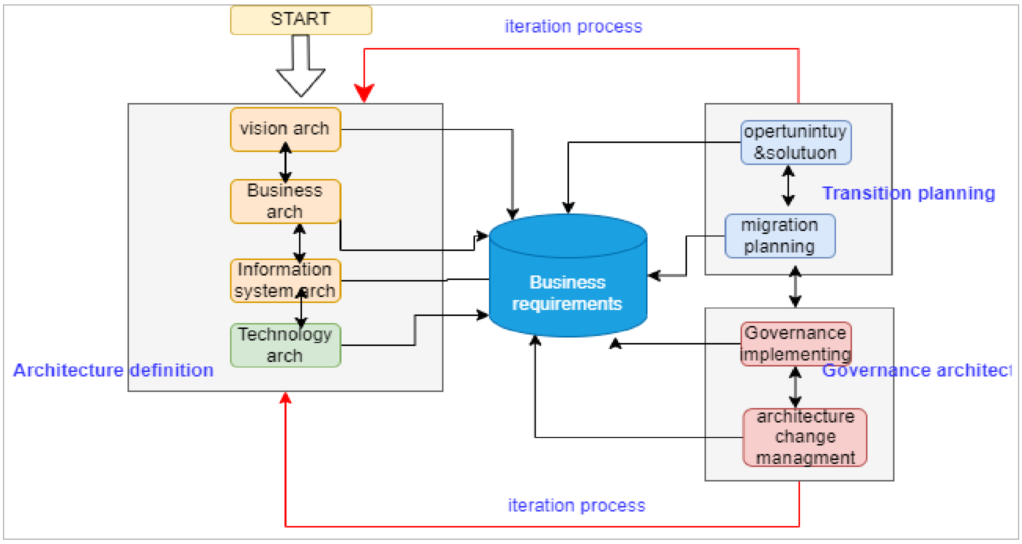


**Figure 5: Steps of Implementing EA Framework in Semiconductor Factory**

Analysis of the current state of the organisation reveals that there are no specific data management deficiencies. In addition, with the IoT principles incorporated into the EA framework, the primary issues will be data governance, data security, data capacities, process speed, and hardware performance. Figure 5 and Table 1 depict analytical specifics.

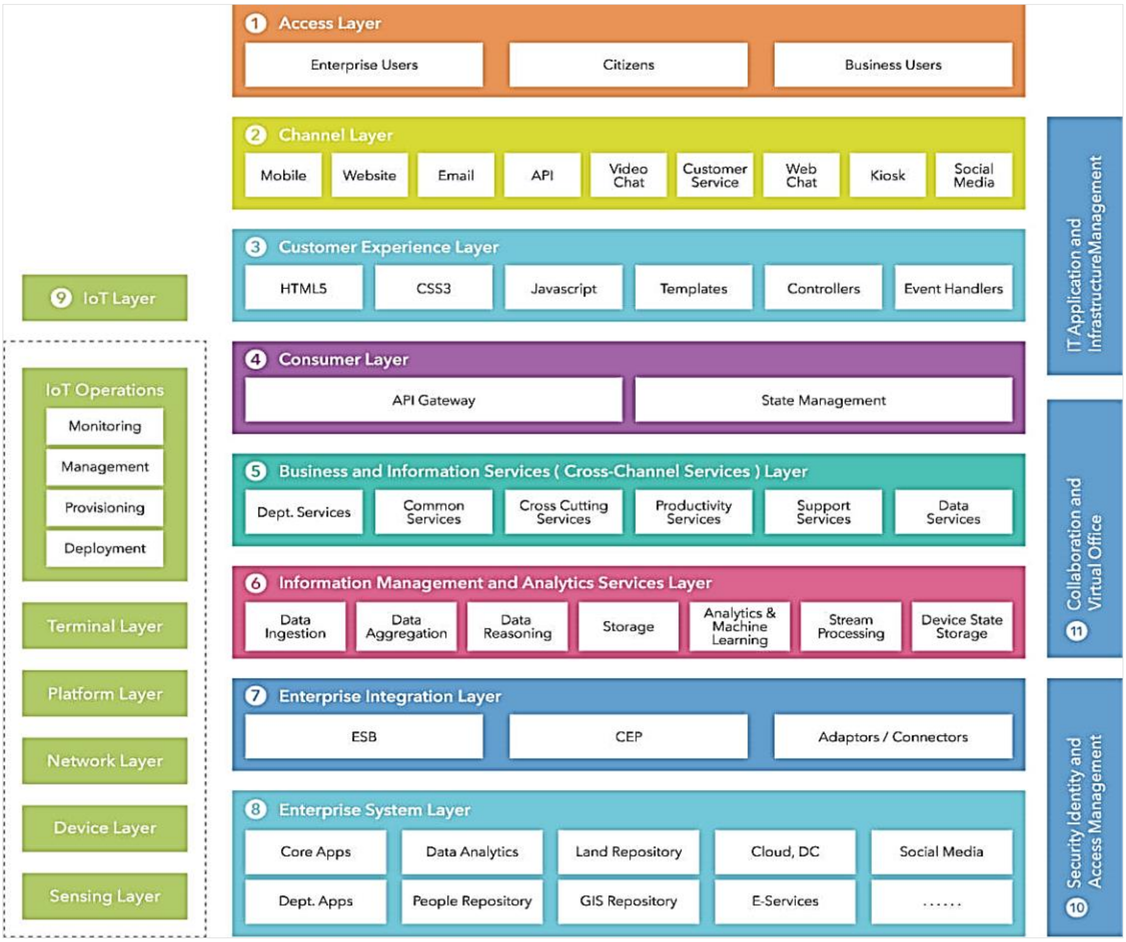


**Figure 6: Enterprise reference architecture on IoT-based [9] [16]**

**Table 1: Layers Within the Connected Enterprise**

| | Layer name | Layers description |
|---|---|---|
| 1 | Access Layer | End users –interior and exterior to the enterprise – interact with channel(s) and play a role in the overall customer journey [16]. |
| 2 | Channel Layer | End-users conduct media to interact with the enterprise over multiple physical and digital channels [16]. |
| 3 | Customer Experience Layer | A collection of presentation components and services, the enterprise uses critical systems to engage with end-users [16]. |
| 4 | Consumer Layer | Acts as a gateway for channels and aggregates functionalities through composition and orchestration, mediation, and routing [16]. |
| 5 | Business and Information Services Layer | It Provides cross-channel capabilities. Its design is based on micro-services architecture principles [16]. |
| 6 | Information Management and Analytics Services Layer | Data ingestion, complex event processing, and real-time analytics and insights [16]. |
| 7 | Enterprise Integration Layer | provides mediation, transformation, protocol and routing capabilities, aggregation, and broker communications [16]. |

| | Layer name | Layers description |
|---|---|---|
| 8 | Enterprise Systems Layer | collection of enterprise back-office core systems and applications that house business logic and data [16]. |
| 9 | IoT Layer | IoT Operations, Platform Layer, Network Layer, and Physical Devices Layer [16]. |
| 10 | Security | manages single sign-on, authentication, encryption, and authorisation capabilities [16]. |
| 11 | Collaboration & Management | infrastructure-as-a-service and platform-as-service technologies require large computing capabilities [16]. |

Previous studies demonstrate significant disparities between integrating the Business and IT with IoT principles in a semiconductor factory. These voids pertain to the appropriate and efficient execution of business functions. Currently, IoT architecture is more complex and speed-reliable, and cloud computing has become an integral part of IoT. Several sections, including governance, data tracking, and application access, require prompt decisions, but the structures and procedures to manage the new inputs are opaque. For future research, an enterprise framework with flawless outputs must manage all IoT inputs and produce the desired output swiftly and securely.

Integrating IoT with the Enterprises' Technology layer necessitates faultless procedures to manage IoT challenges such as security, privacy, volume, speed, and complexity. The preponderance of work platforms in semiconductor factories will be sterile and dust-free. Inside the factory sections, PLC-controlled robotics and machinery are utilised. The input value will be immense, necessitating devices with the ability to process this volume of data in a fraction of a second. In addition, integrating the three tiers of EA IT (hardware such as sensors and robots), application (such as artificial intelligence operating systems), and business will present a challenge for enterprise architecture development while accomplishing the IoT's sustainability objective.

Potential solutions: Implementing TOGAF ADM can offer the enterprise a tried-and-true method for enhancing the architecture, such as establishing an EA framework, revising the factory architecture scope, transitioning, and, most importantly, governing EA realisation in IoT. These are the alignments between the four layers of the EA framework. Additionally, architectural views will include one or more component models. During the EA's development, stakeholder concerns are extensively discussed. Creating models with a variety of tools. In addition, creating artefacts from the existing viewpoint library to fulfil the requisite views for architecture. Coverage of the requisite perspectives and concerns of stakeholders for creating viewpoint templates. IoT artefacts, such as ISO IoT RA or RAMI 4.0, can provide high-quality viewpoint references for IoT principles [15].

Improving business processes is crucial for semiconductor manufacturing facilities. The first stage is to comprehend the current state of the enterprise and its Enterprise Data Architecture (EDA) flaws. The company has no data management infrastructure in existence. In addition, the Technology layer must enhance software and hardware to align IoT benefits such as speed and performance.

Additionally, address IoT issues such as data capacity, security, and governance. In addition, they are enhancing workers' awareness of IoT applications. Creating documents that capture visual representations of the enterprise business process and segmenting the risk area are crucial aspects. These process maps will depict the proposed TO-BE to enhance the AS-IS by updating the modelling to influence the future process positively and creating fundamental blueprints to align IT, business strategy, and an effective data delivery system.

## 5. Discussion and Conclusion

This study aimed to propose an EA framework for IoT integration in the semiconductor manufacturing industry, emphasising real-time data analytics. The objective was attained by presenting a comprehensive understanding of the role of enterprise architecture (EA) in aligning business processes and information technology (IT), addressing implementation challenges, and highlighting the potential benefits of leveraging IoT for equipment performance analysis.

In conclusion, as business processes and information technology continue to evolve, it becomes imperative for organisations to implement key concepts in order to remain relevant and efficient in the increasingly competitive global industry. Enterprise Architecture (EA) has emerged as a proven method for integrating modern business processes with cutting-edge IT systems. However, difficulties and discrepancies may arise during the early phases of EA implementation, necessitating extensive discussions and analysis between the business and IT departments to achieve alignment. Nonetheless, the proposed EA for IoT-based real-time data analytics in semiconductor manufacturing holds promise and can provide valuable insights for organisations attempting to establish a robust architecture for monitoring equipment performance.

While this research has significantly advanced the understanding and application of EA in the semiconductor industry, there are numerous avenues for future study. Due to the unique complexities and requirements of semiconductor manufacturing, it is necessary to conduct additional research into the customisation and adaptation requirements of the TOGAF framework. In addition, an in-depth analysis of the risks and limitations associated with implementing EA and strategies for mitigating these obstacles would provide valuable insight for organisations launching comparable initiatives. In addition, investigating the incorporation of emergent technologies such as artificial intelligence and machine learning into the EA framework could improve its capabilities in the semiconductor industry. Overall, future efforts should concentrate on refining and expanding the proposed EA framework to accommodate the changing requirements and dynamics of the semiconductor manufacturing industry.

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