POLITECNICO DI TORINO

Master's Degree in Management Engineering

Master of Science Thesis

How does enterprise architecture help businesses achieve a balance between environmental sustainability and financial performance?

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Abstract

A Growing number of companies have implemented enterprise architecture (EA) to align technology with business goals. EA is not just about modeling systems; it is about delivering measurable, tangible value that organizations can clearly demonstrate. EA is a strategic framework that helps companies in coordinating their corporate strategies, IT infrastructure, business processes, and supply chain operations to accomplish their long-term goals.

In recent years, the focus of an organization's overall sustainability-related topics has changed from cost drivers and compliance priorities to a competitive advantage and differentiation. EA can help in achieving these Sustainable Development Goals (SDGs) by mapping prioritized business capabilities for sustainability and developing the transformation roadmap that integrates advanced technologies like IoT, AI, and blockchain to improve supply chain visibility and traceability. From a financial perspective, EA helps cut expenses, improve operational effectiveness, and supports digital transformation projects that give businesses an advantage over their competitors.

The primary issue that businesses have to cope with is finding a balance between environmental sustainability and financial profitability. My thesis addresses this gap by examining how EA can generate balance between these goals. The research adopts a qualitative multiple-case approach supported by a systematic literature review. The literature review synthesizes existing research papers on sustainable enterprise architecture and empirical evidence from leading global companies such as Unilever and IKEA.

The results indicate that EA acts as an intermediate framework that connects sustainability objectives with financial performance through mechanisms of traceability, standardization, optimization, and lifecycle management. This research contributes to both theory and practice by demonstrating how EA transforms sustainable development from a compliance commitment into a strategic driving force for value creation and long-term competitiveness.

Contents

List of Abbreviations

ADM Architecture Development Method

AI Artificial Intelligence

ArchiMate ArchiMate Modeling Language

EA Enterprise Architecture

EFRAG European Financial Reporting Advisory Group

ES Environmental Sustainability

ESG Environmental, Social, and Governance

EU European Union

UN United Nations

ERP Enterprise Resource Planning

GRI Global Reporting Initiative

IoT Internet of Things

IPCC Intergovernmental Panel on Climate Change

ISO International Organization for Standardization

ISSB International Sustainability Standards Board

IT Information Technology

KPIs Key Performance Indicators

LEAF Lean Enterprise Architecture Framework

OPEX Operating Expenditure

OT Operational Thechnology

ROI Return on Investment

SDG(s) Sustainable Development Goal(s)

TBL Triple Bottom Line

TOGAF The Open Group Architecture Framework

Zachman Zachman Framework

Introduction

Enterprise architecture is a strategic framework for a company that shows how its employees, business processes, and technologies interact with each other to achieve business goals. It acts as a strategic map, allowing the organization's IT infrastructure to be aligned with its overall strategy, helping it to run smoothly, make more effective decisions, and be adaptable to changes in the business environment.

From Efficiency to Sustainability

In recent years, however, the concept of sustainability has now become one of the important elements of EA. This means developing and implementing IT strategies and systems that are beneficial for the environment, socially responsible, and economically sound, ensuring stability with minimal impact on it. The decision to include sustainability in EA happened because of the increased number of global environmental challenges and the benefit from the cost savings.

Sustainability in EA is now about integrating technology and architecture practices to create systems that are not only efficient and effective but also adaptable to changing environmental conditions and capable of contributing to society.

Benefits of using EA:

- *Improved efficiency.* EA optimizes supply chain processes by reducing resource waste, energy usage, and costs.

- *Increased transparency.* With effective data monitoring and integration, companies can track and report on their sustainability efforts, ensuring accountability.

- *Reduction of risks.* EA increases supply chain resilience, and for this reason companies can anticipate and reduce risks.

- *Regulatory compliance.* Real-time compliance monitoring helps organizations to ensure their supply chain follows rules of sustainability.

- *Customer trust and brand loyalty.* A sustainable supply chain increases the reputation of brands and builds customer trust in an era of consumer environmental awareness.

Financial consequences

EA enables organizations to achieve cost effectiveness, support digital and innovation projects that provide for them a competitive advantage, and explore new revenue streams through data-driven decision-making.

- *Revenue creation.* EA helps to find new revenue streams by effective customer engagement and data-driven decision-making, which directly contribute to revenue growth.

- *ROI.* EA directs decision-makers to allocate capital for projects that will provide the highest return on investment. This includes assessing the long-term financial impact of technological investments.

Recent research in both science and industry literature suggests that EA can expand its role beyond digital harmonization and become an effective tool for sustainable transformation by integrating environmental goals in corporate design and management. However, despite growing recognition of its potential, the mechanism by which EA can balance sustainable development goals and financial performance remains not well known. Most past studies have focused

either on the contribution of EA to operational efficiency or on isolated sustainability initiatives, leaving a significant conceptual gap regarding their intersection.

My thesis solves that gap by asking the research question:

How does enterprise architecture help businesses achieve a balance between environmental sustainability and financial performance?

This question is significant as it aims to combine two global principles: corporate sustainability and financial performance, viewed through the prism of architectural coherence. Thesis work integrates a comprehensive literature review and real-world case studies of well-known global companies, like IKEA and Unilever. These case studies evaluate how EA principles-traceability, standardization, optimization, and lifecycle management-enable organizations to connect sustainability goals with economic value creation. These cases provide

The structure of the thesis is as follows. Chapter 1 introduces the theoretical background of EA. Chapter 2 is the core relationship between EA and digital transformation. Chapter 3 discusses environmental sustainability in the business context. Chapter 4 describes EA for Environmental Sustainability. Chapter 5 provides the empirical case analyses of IKEA and Unilever. Chapter 6 shows findings, theoretical contributions, and practical recommendations for future research. Chapter 7 introduces case studies. Chapter 8 includes summary that answers research questions and suggestions for future research.

In essence, this thesis illustrates the EA as a strategic integrator that aligns sustainable development and financial performance within a unified management system. Research aims to demonstrate that environmental and financial objectives are not contradictory but synergistic when guided by coherent architectural design.

Literature review

EA has evolved from a technical project to a comprehensive strategic discipline. Initially established in 1980, EA focused on standardizing IT infrastructure and managing technological complexity to achieve operational efficiency and cost savings (Ross, Weill, & Robertson, 2006). Systems such as Zachman provided a structured classification system for documenting IT assets, integrating EA as a tool for IT management and control.

In 2000 EA became a mechanism for integrating business strategy. Scholars have begun to recognize that the true value of EA lies in its ability to bridge the gap between business objectives and IT capabilities (Shanks et al., 2018). During this period, the TOGAF framework from The Open Group gained prominence with their iterative architecture method, which provided a structured process for translating strategic intent into coherent business data, applications, and technological architecture (The Open Group, 2021). This evolution demonstrates EA as a critical discipline for organizational flexibility and informed decision-making.

We are now witnessing the third phase of evolution of EA as a driving force for the transformation of sustainable development (Cutter, 2022). Driven by global issues such as climate change and resource scarcity, EA is expanding its functions to integrate environmental, social, and governance considerations directly into the architectural structure of the organizations. This new paradigm, often called Green EA or Sustainable EA, moves from creating efficient systems to making sustainability a fundamental property of the enterprise's design (Iseke, 2020). This progress of EA from IT harmonization to strategic integration and sustainable transformation makes it a dynamic potential uniquely suited to solving sophisticated business problems.

In parallel with the evolution of EA, the business world is being transformed by the dual forces of digital transformation and the need for sustainable development. The integration of technologies such as IoT, AI, and big data

analytics into all business areas is not only a competitive advantage but also the possibility of sustainable development (Andre Christ, Forbes). These technologies provide tools to optimize resource consumption, improve supply chain transparency, and reduce environmental impact.

However, serious challenges remain. Digitalization initiatives often fail to realize their full potential when they lack a coherent framework for aligning technology investments with strategic objectives, including sustainable development (Anup). This is where EA provides the necessary foundation for continuous transformation. With EA, digital initiatives are not implemented in isolation but towards common goals (Ardoq, 2023). EA provides clear roadmap and management and ensures that investments in innovative technologies are systematically aligned with both business and environmental goals (Hindarto, 2023).

Uysal and Mergen (2021) demonstrate how EA supports smart manufacturing by creating compatible systems that allow real-time monitoring and predictive maintenance, resulting in a reduction in energy consumption and material waste. As a result, EA emerges not only as a tool for digital transformation but also as a critical discipline directing the digital power to achieve sustainable results.

According to a PwC research report from 2021, 73% of consumers around the world are willing to change their consumption habits to help the environment, and 86% expect companies to invest in sustainability. This tendency creates a paradigm of market-driven sustainability instead of voluntary corporate responsibility, because sustainable performance directly affects brand reputations, loyalty of customers, and investor confidence.

However, the majority of companies are under increasing pressure to find balance between financial performance and environmental sustainability. The interdependence of environmental integrity, social justice, and economic

success has become one of the most important challenges for modern businesses (Gampfer and Müller 2018).

The preceding sections lay the foundation for the main argument of this thesis. EA acts as a key function that can resolve the tension between environmental sustainability and financial indicators. Literature suggests that this balance occurs through interrelated mechanisms. EA provides structural traceability by creating operational processes and data systems (Hindarto, 2023; Laumann & Tambo, 2018). Furthermore, EA drives standardization and optimization by rationalizing application portfolios and standardizing data models. This directly reduces operational costs. In addition, EA enables lifecycle management and circular management principles. Laumann and Tambo (2018) propose a Circular Economy EA Framework, where EA acts as a coordination layer to track materials and products throughout their entire lifecycle.

Although this emerging body of literature is promising, there is still a clear gap. Numerous studies examine EA's role in sustainability or its impact on financial performance; however, few offer a complex analysis of the specific architectural mechanisms that align the two. As noted by Gamferer et al. (2018), sustainable development is one of the fastest-growing areas of EA research, but unfortunately it still lacks the empirical depth of traditional EA domains. This thesis work will build on this foundation; by using mechanisms of standardization, traceability, optimization, and the life cycle as an analytical lens, it will explore how this balance is implemented in practice through case studies from IKEA and Unilever. Thus, this study aims to provide empirical depth and concrete models for achieving value between environmental and profit objectives.

Table of most relevant papers in literature about EA and case studies:

Author(s) & Year	Title / Source	Focus of Study	Methodology / Framework	Relevance to Research Question
Ross, Weill & Robertson (2006)	*Enterprise Architecture as Strategy*	EA as a strategic framework linking business and IT	Conceptual framework	Baseline for EA as an efficiency and financial performance enabler.
Shanks et al. (2018)	*How Enterprise Architecture Leads to Organizational Benefits*	EA benefits and governance	Empirical study	Links EA governance to measurable financial and sustainability outcomes.
The Open Group (2021)	*TOGAF Standard*	EA methodology and iterative governance	Framework (ADM)	Shows EA ensures continuous alignment with sustainability and financial goals.
Zachman (2019)	*Framework for Information Systems Architecture*	Conceptual structure for EA design	Taxonomy model	Forms theoretical base for aligning sustainability across enterprise layers.
Laumann & Tambo (2018)	*Enterprise Architecture for a Facilitated Transformation from a Linear to a Circular Economy* (MDPI Sustainability)	Circular economy and EA integration	Conceptual + case analysis	Defines EA's role in enabling circular economy and sustainable value creation.
Hindarto (2023)	*Enterprise Architecture Development to Strengthen Sustainability in the Supply Chain*	EA for sustainable supply chain management	Case-based research	Illustrates EA as an operational mechanism balancing sustainability and financial resilience.
Liao & Wang (2021)	*Lean Enterprise Architecture Framework (LEAF)*	EA in chemical industry for sustainability and efficiency	Case study (chemical sector)	Shows how EA simultaneously enhances resource efficiency and profitability.
Uysal & Mergen (2021)	*EA in Smart Manufacturing Development Framework (SMDF)*	EA for innovation, predictive maintenance, and energy optimization	Empirical case study	Demonstrates EA's ability to align digital transformation with sustainability and profit.
Iseke (2020)	*An Enterprise Architecture Approach Towards Sustainability and Environmental Performance*	Integration of ISO, GRI, and EMAS into EA modeling	Conceptual + modeling study	Provides technical method for embedding environmental KPIs into EA models.
Gampfer & Müller (2018)	*Enterprise Architecture and Sustainability*	Systematic review of EA research evolution	Literature analysis	Defines research gap: lack of empirical depth linking EA, sustainability, and finance.
Cutter Consortium (2022)	*Sustainable EA: Is It Possible?*	EA adaptation to ESG frameworks	Industry analysis	Establishes EA as mediator between ESG and profitability.
Finextra (2023)	*Greening the Blueprint: Transforming EA for a Sustainable Future*	EA and environmental governance	Industry report	Shows how EA embeds sustainability into enterprise blueprints for financial resilience.
SAP (2023)	*Enterprise Architecture for Sustainable Enterprise*	Linking EA with ESG data management	Practitioner framework	Practical confirmation of EA mechanisms in balancing sustainability and finance.
Planview (2022)	*Definitive Guide to Digital Transformation*	EA as foundation of digital sustainability	White paper	Demonstrate digital transformation as an enabler of sustainable growth through EA.
PwC (2021)	*Global Consumer Insights Survey*	Consumer expectations for sustainability	Global survey	Illustrates market pressure driving EA-enabled sustainability integration.

Haghighathoseini et al. (2018)	*EA in Healthcare Sector (Procedia Computer Science)*	EA for system consolidation and performance	Case study	Shows direct link between EA, cost optimization, and resource efficiency.
Boh & Yellin (2022)	*EA and Dynamic Capabilities*	EA as an enabler of business agility and resilience	Theoretical model	Provides theoretical support for balancing EA financial and environmental goals.
Tutaj et al. (2021)	*Sustainability in Enterprise Architecture: From Optional to Essential*	EA integration with sustainability goals	Systematic review	Conceptually supports EA's mediating role between sustainability and profitability.
García-Callón (2021)	*EA for Sustainable Business Models*	EA maturity and sustainability	Conceptual model	Connects EA governance maturity to sustainability performance and financial control.
IKEA (2023)	*IKEA Sustainability Report FY23*	*IKEA*	*Corporate sustainability reporting and performance review*	*Demonstrates how architecture-like governance and data integration balance environmental and financial performance through standardization, data traceability, and renewable investment.*
Unilever (2022)	*Unilever Compass Strategy and Financial Report*	*Unilever*	*Corporate strategy report*	*Shows financial gains through EA-aligned sustainability governance — embedding ESG targets in enterprise-level systems.*

Research Background

In the modern global economy, the joint analysis of EA and environmental sustainability is considered as an important element of a deeper understanding of how organizations can reach and find long-term balance between financial performance and environmental responsibility. Studying this relationship allows researchers and companies to find out if integrating sustainability into EA frameworks is a reactive adaptation to market pressure or, on the other hand dynamic and beneficial strategic choice that creates long term value. With the fast acceleration of digital transformation and also increased focus on sustainability metrics, companies are being forced to remodel their operational, strategic, technological, and financial systems in order to achieve global sustainability objectives while maintaining profitability.

1.1 Definition of Enterprise Architecture

EA is characterized as a comprehensive management method that brings together strategy, processes, information and technology to ensure coherent management and predictable value creation.

According to Ross, Weill, and Robertson, EA is a high-level framework for business processes and IT by reflecting organizations' models and requirements for integration and standardization. The main goal of EA is translating strategy into design processes data, and platforms of the company (Ross, Weill & Robertson, 2006).

Open Group defines EA as a systematic methodology and comprehensive knowledge base, which includes models, standards, roadmaps, and models. Together these elements drive the design, planning, implementation, and organizations management through a series of iterative development cycles. In addition, ensures vital alignment and integration between business objectives and IT capabilities.

Ardoq (2023) describes EA as a methodology of planning, understanding, and improving. EA logically provides organization's work by linking people, processes, data, applications, and technologies into traceable models that support risk, cost, flexibility, and change decisions.

Iseke (2020) underlines EA as a socio-technical coordination mechanism that aligns business intent with digital capabilities in challenging environments.

1.2 Difference between EA and ERP

EA and ERP are often used together in transformation of organizations, but they operate at different levels of strategy and implementation. Both of them fundamentally concept to achieving alignment between business and IT and sustainable performance, but their goals, scope, and outcomes differ.

According to Busch & Zalewski, EA is a systematic approach to designing and managing an organization's information systems, promoting resource optimization, and risk management. In addition, Putro et al. emphasize that one of the main functions of EA is aligning information technology. On the other hand, ERP is a software application that integrates and automates core business processes such as finance, HR, and supply chain into a unified system. As described by Kashyap (2025), ERP platforms serve as the digital foundation for integrating core business functions. ERP is thus a tool for operational execution, while EA provides architectural design.

EA has broad coverage across the entire enterprise. This encompasses the entire organization and its ecosystem, including business architecture, application architecture, data architecture, and technology architecture.

ERP has a focused and process-oriented scope. It deals specifically with standardization and the execution of core operational processes. Its scope penetrates deeply into specific functional areas, but it is not intended to model the entire enterprise context. It is concreated and executable, consisting of program modules, configurations, and databases.

Dimension	Enterprise Architecture (EA)	Enterprise Resource Planning (ERP)
Nature	Conceptual and strategic framework	Integrated software system
Purpose	Aligning business strategy with IT capabilities	Execute and automate business operations
Focus	Architecture design, governance, and transformation	Day-to-day transactional efficiency

Key Frameworks	TOGAF, Zachman, ArchiMate, FEAF	SAP, Oracle, Microsoft Dynamics
Outcome	Standardization, interoperability, strategic agility	Operational integration, process automation

Kashyap (2025) notes that ERP implementations without an architectural foundation often face misalignment and failures. For instance, failed Lidl SAP project, which cost 500 million EUR. In this way, EA provides a level of governance and alignment, ensuring that ERP implementation remains consistent with the strategy of organization.

Research work from Kashyap (2025) clearly illustrates that EA and ERP are not competitors but complementary forces. EA provides strategic framework for successful ERP implementation.

1.3 Frameworks of Enterprise Architecture

EA frameworks:

1. TOGAF (The Open Group Architecture Framework) is defined as an Architecture Development Method (ADM), a structured method that progresses from identifying the architectural vision through the business, information systems, and technology architectures, ultimately closes the loop with management and continuous improvement. Its primary purpose is traceable alignment between operational execution and strategic intent. TOGAF can be effectively implemented to integrate sustainability objectives into supply chain and environmental performance monitoring (Hindarto, 2023).

2. Zachman is a complex matrix for classifying EA descriptions according to planner, owner, designer, builder, operator, and fundamental interrogatives –what, how, where, who, when, and why. This framework

ensures that all aspects of the business are represented consistently and coherently. As noted by Shanks et al. (2018), the framework of Zachman has laid the foundation for the evolution of EA from IT documentation to an enterprise planning discipline and a more practice-oriented framework.

3. ArchiMate is a modelling language specifically designed for EA. It creates a coherent visual representation of enterprise architecture to describe, analyze, and visualize the relationship between different architectural domains (The Open Group).

1.4 Core components of Enterprise Architecture

Most popular EA frameworks, including TOGAF, break down EA into four interdependent areas that together give a complete picture of the enterprise (The Open Group).

1. *Business architecture* outlines how and why organizations create value, which includes strategy, processes, policies, capabilities, value streams, and operating models (Shanks et al., 2018).

2. *Data architecture*–describes what information is necessary: data domains, semantics, quality rules, lineage, and access (Finextra, 2023).

3. *Application architecture*–defines which applications automate or support processes and how application portfolio, services/APIs, and integration patterns interact.

4. *Technology architecture*–detailed information about the platforms and infrastructure on which applications are working computing, networking, cloud services, storage, intermediate software, security controls, and tools.

The practical strength of EA is coming from traceability–the ability to align strategic intentions at the business layer to the process and capabilities, supported by relevant applications, data, and underlying technology services (Shanks et al.).

TOGAF makes this traceability by using phase results like catalogues, matrices, and diagrams and controls points - architectural review boards, conformity assessment. Hindarto (2023) in his research implements this by demonstrating how TOGAF phases can be used to add sustainability criteria to architectural solutions.

Interrelationships between architectural layers play a crucial role in solving sustainability development challenges. The business layer sets the organization's environmental goals, while data and application layers are responsible for collecting, demonstrating, and monitoring the progress of achieving these goals. The technical layer provides infrastructure that is necessary to ensure that operations remain reliable and efficient (Niels Vandevenne et al., 2023).

Linking each layer to sustainable development practice

The business layer serves as a basis for implementing sustainable development within the organization. It translates carbon targets and circularity goals into opportunities, policies, and process changes (Laumann & Tambo, 2018).

The data layer guarantees that ESG and LCAs are measurable through well-defined data models (Iseke, 2020; García-Callón, 2021).

The application layer helps to reach sustainability objectives by implementing systems that enable carbon accounting, energy monitoring, and scenario tools. These rationalizations reduce maintenance costs and IT energy consumption (Shanks et al., 2018).

The technology provides sustainable data centers, efficient cloud systems, and virtualization, which reduces emission and total cost of ownership (Rogier van de Wetering et al., 2020).

1.5 Role of Enterprise Architecture in the modern world

In the contemporary world, EA is considered as the discipline that structures and aligns companies' business processes, IT, applications, and technology infrastructure to achieve strategic coherence (Elena Kornyshovaa, Rébecca Deneckèreb, 2022). Essentially, EA is a blueprint for how an organization operates and develops. Ensuring that every component from strategy to IT implementation contributes to the achievement of strategic objectives.

Ross, Weill, and Robertson identified EA as a high-level logic for business processes and IT infrastructure, reflecting the requirements of integration and standardization of the company's operating model. This integration ensures consistency of decision-making, efficiency, and speed. Meanwhile, the TOGAF Standard (2021) defines EA as a methodological framework that defines the design, planning, and management of corporate structures.

The modern business environment is becoming more complex day by day, EA can offer transparency, alignment, and operational control. According to Ardoq (2023), EA acts as the link between business and technology, since it provides coordination and measurement of transformation initiatives. In addition, Ardoq (2023) emphasizes that EA connects people, data, and business processes, enabling companies to reduce and manage risks, align sustainability and financial performance objectives within a single unified model.

The strategic value of EA lies in its ability to match the technical structure of organizations with their strategic objectives. EA plays a fundamental role in digital transformation because it provides a framework that translates strategy into execution (Heather Westmoreland, 2022). Without EA, sustainability initiatives are under risk of being fragmented–implemented as a technological project without connection to the company's strategic vision. Through structured modelling and management, EA ensures that investments in sustainability are value oriented, measurable, and scalable.

1.6 Evolution of Enterprise Architecture

The evolution of EA from IT alignment to sustainability transformation can be divided into three eras starting from 1980 to the present.

1. EA as IT alignment (1980-2000s). First, EA emerged as a tool for standardization and harmonization of IT. Early versions of frameworks like Zachman and TOGAF focused on integrating disparate systems and providing operational efficiency. EA is primarily a technical discipline connected to design infrastructure and data consistency (Ross et al., 2006).

2. EA as business strategy integration (2000-2015). With the rise of global competition and digital transformation increasing, organizations have started to recognize that EA can reduce the gap between business strategy and IT. Heather Westmoreland (2022) notes that during that period EA evolved from an IT management tool to a strategic management practice, which supports business flexibility and process optimization. In addition, researchers like Shanks et al. (2018) identified the important role of EA in improving decision-making, project management, and organizational flexibility.

3. EA as a sustainability transformation (2015-present). The last era extends EA functionalities beyond operational alignment to encompass environmental and social responsibility. According to Cutter (2022), Sustainable EA, or Green EA, is emerging as a new paradigm in which architectural principles drive sustainable business transformation. This method integrates ESG elements into architectural layers such as business, application, and technology. Furthermore, Cutter (2022) says that sustainable EA is not about making systems greener, but it is about making sustainability a part of the organization's design. This means that sustainability becomes a fundamental element of enterprise design rather than an additional initiative.

Thus, modern business environments consider EA as a dynamic capability that can be helpful with achieving adaptability and long-term value creation (Boh & Yellin, 2022). EA supports organizations to manage tradeoffs between sustainability and other business goals, keeping their environmental objectives in the same line with financial objectives. This holistic potential makes EA the cornerstone of sustainable digital transformation, in which environmental and financial performance reinforce each other rather than competing for priority.

Digital transformation and Enterprise Architecture

Digital transformation is an integration of digital technology into all business areas. Moreover, it is a strategic reconfiguration of business processes and models in order to achieve long-term competitive advantage and operational excellence. It includes the integration of digital technologies such as artificial intelligence (AI), Internet of Things (IoT), cloud computing, and big data analytics into all layers of organization to improve flexibility, quality of customer service, and resource efficiency. According to Planview (2022), digital transformation is not about the implementation of a single technology but continuous potential that aligns business strategy with measurable results through portfolio management, standards, and governance.

2.1 EA as the foundation for digital transformation

EA is the methodological and structural foundation for digital transformation. It brings together capabilities, processes, data applications, and technology into coherent traceable models that link business strategy to IT execution. Ardoq (2023) argues that EA acts as a bridge between strategic intent and operational implementation, allowing organizations to visualize interdependence, identify risks, and guarantee that all digital initiatives contribute to the achievement of strategic objectives.

Modern EA frameworks like TOGAF, Zahman, and others provide iterative management processes that start with architectural vision and end with technology integration. This structured approach makes sure that developing digital capabilities are at the same level with business objectives, and it also keeps the system's accuracy and compliance over time.

Ensuring strategic and sustainable coherence

Andre Christ from Forbes Technology Council emphasizes that sustainability and digitalization are now simultaneously important. Organizations risk undermining both financial and stakeholder trust if they do not integrate sustainability into the digital roadmap. EA finds the solution for this problem by including sustainable development principles such as energy-efficient roadmaps, tracked data management, and ESG accountability into the one framework that manages digital investments.

Empirical studies of Shanks et al. (2018) verify that EA provides organizational value when it functions as a governance capability rather than as documentation. EA makes sure that digital initiatives are not completed in isolation but instead are coordinated actions that align with the company's and environmental objectives through portfolio oversight and recycling management. In addition, Hindarto (2023) exemplifies how EA principles can

be integrated into supply chain digitalization to introduce environmental indicators such as waste reduction and energy optimization directly into the architectural phases by turning sustainable development goals into actionable design criteria.

The role of EA in management covers the entire digital life cycle. It defines decision-making rights, sets standards, and integrates sustainable development metrics into project evaluation frameworks. EA ensures that investment decisions such as cloud migration, data analytics, and process automation are connected to both strategic objectives and sustainability commitments. In this way, EA acts as a gatekeeper for value creation, ensuring that digital transformation attempts bring tangible business benefits and results in terms of cost effectiveness, risk mitigation, and measurable environmental improvements.

2.2 Enterprise Architecture as a factor of innovation

EA provides an operational and conceptual infrastructure that promotes innovation in organizations. It standardizes core systems. In the context of Industry 4.0, EA acts as a coherent framework for the integration of lean manufacturing, digitalization, and sustainability, guaranteeing that process improvements and technological innovations align with long-term strategic and environmental goals. EA promotes ongoing improvements across organizational boundaries by linking lean manufacturing principles with data-driven optimization (Liao and Wang, 2021).

Moreover, according to Uysal and Mergen (2021), EA supports smart manufacturing to generate new ideas by ensuring system architecture works together throughout the production process. Their research shows that EA makes interoperability easier in real time monitoring and predictive decision-making. Through these mechanisms EA is becoming a driving force for eco-innovations, turning technical progress into benefits for both operational and environmental purposes.

Business flexibility is the ability to sense and respond quickly to changes. Digital transformation should lead to business flexibility. In their research, Shanks et al. (2018) demonstrate that companies with mature EA competencies are more flexible due to clear roadmap architecture and standardized integration schemes. In addition, EA reduces complexity and allows companies to quickly change business processes and digital services in response to changing market conditions or regulatory requirements.

SAP product expert Anup notes that EA provides sustainable flexibility when business flexibility and environmental responsibility coexist. By collecting sustainability data with financial and operational KPIs, EA enables managers to make real-time decisions based on facts that balance innovation and resource efficiency.

EA plays a crucial role in IoT integration, automation, and analytics to improve visibility and control. EA provides continuous data flow from sensors to business panels in manufacturing, facilitating real-time power management and circular resource utilization. Cutter (2022) calls it architectural intelligence, where architecture itself evolves to support systems. This integration is an example of how digital transformation led by EA provides cost-effectiveness and efficient sustainable development.

2.3 Barriers and facilitators of Digital Transformation

Barriers to digital transformation

Digital transformation has an incredible amount of potential; however, it often faces organizational and technical challenges that limit its success. Limitations:

1. Organizations sometimes put short-term gains ahead of long-term digital results, which reduces their long-term environmental and financial benefits.

2. Many organizations continue to use fragmented and outdated architectures in which systems function independently of each other without interoperability. This disconnection limits data integration and reduces transparency between functions.

3. Organizational resistance to change, unclear communication, and insufficient understanding of architecture-based methods slow down transformation.

4. In the absence of a robust management system, digital transformation projects lead to development in isolation, leading to misalignment and missed sustainability opportunities.

Facilitates digital transformation

EA directly solves these barriers through its integrative and systematic approach.

1. EA creates shared repositories and model standards, which unify information flows and business capabilities.

2. Architectural review boards and portfolio management structures ensure that projects meet corporate principles and sustainability standards (Shanks et al., 2018).

3. EA collaboration bridge between IT and business. Promote transparency, shared accountability, and a unified understanding of transformation goals.

4. EA aligns innovation with responsible resource management by linking sustainable development indicators with digital KPIs (Anup).

Environmental sustainability in the context of business

3.1 Understanding environmental sustainability

Environmental sustainability is no longer optional but mandatory. It is starting to be prescribed by social expectations, regulatory frameworks, and careful monitoring by investors. However, businesses are still evaluated by their financial results, operational efficiency, and returns to shareholders. The requirement of being both environmentally friendly and profitable calls for new approaches to management and the implementation of new solutions that can combine environmental responsibility with the creation of economic and financial value. This pressure appears to be due to the growing number of environmental degradations, scarcity of resources, and climate change. According to the Intergovernmental Panel on Climate Change (IPCC) and the Paris Agreement (2015), global warming should be below 1.5°C, requiring industrial companies to implement sustainable practices that reduce emission and resource consumption. In addition, Goal 12 (Responsible Consumption and Production) and Goal 13 (Climate Action) from the United Nations Sustainable Development Goals (UN SDGs) emphasize calling for corporate sectors to integrate sustainability into strategic and operational decision-making. Governments are turning these frameworks into practical rules in the form of carbon taxes, mandatory sustainability reports, and extended producer responsibility.

Hindarto (2023), Tutaj et al. (2021), and Uysal & Mergen (2021) in their research papers emphasize that sustainability should be seen not only as a

regulatory requirement but also as an architectural and operational capability. By aligning strategy, data, and technology throughout the value chain, organizations can use EA to convert sustainability objectives into tangible results.

PwC's 2021 Global Consumer Insights Pulse Survey found a market increase in eco-conscious consumer behavior and expectations for sustainable brands.

However, the path to adopting sustainability is still complicated. Although many organizations report on sustainable development, there is a gap between strategic intent and operational execution. This gap exists because of inadequate data management, fragmentation of systems, and cultural resistance to change. Overcoming these challenges requires a structural approach. EA provides this structure by tracking sustainability indicators from strategic vision to technological implementation and enabling organizations to track progress at all levels of architecture.

3.2 Key drivers of sustainable development implementation

1. *Regulatory compliance and disclosure*. More and more, signals are required from companies to measure, manage, and disclose environmental performance. Although ISO (International Organization for Standardization) 14001 is voluntary, it often becomes a de facto license to work in supply chains. On the other hand, GRI (Global Reporting Initiative) becomes the basic framework for disclosure across multiple jurisdictions. Agreed UN agendas (SDGs 12 and 13) inform national policies like an ERP rule, carbon pricing, and reporting mandates. All of this together creates powerful incentives for the establishment of verifiable emission, waste, and resource management systems (ISO 14001 authors). Uploaded Hindato research (2023) finds out that EA can be the best tool for these challenges.

2. *Stakeholders' expectations and market incentives*. From the PwC report (2021), brands that can demonstrate emission and waste reduction, ensure premium positioning, reduce product flow, and win sustainable tenders. In addition, Anup describes that EA can translate sustainability priorities into data models, applications, and investment portfolios.

3. *Strategic motives*. EA-based initiatives help organizations reduce energy and material consumption, thereby reducing operating costs (OPEX), while standardizations of integrations minimize IT service costs. In addition, EA allows for new business models and innovations that open up additional sources of income. Andre Christ emphasizes that EA is a practical way to translate sustainable development goals into roadmaps.

The SMDF (Uysal & Mergen) approach uses EA to create reusable digital building blocks and variability points, speeding up experimentation (analytics, predictive maintenance) while maintaining architecture consistency. Essential basis for scaling ES improvements without inflating technical debt.

External pressures as well as internal economics create a powerful business example for environmental sustainability adoption.

EA acts as a central mechanism for enterprises to set priorities, structure and implement their sustainable development responses. Turning environmental goals into concrete, traceable actions (Hindarto, 2023).

3.3 Obstacles to sustainable development

1. *High cost of implementation and complexity of legacy systems*. Sustainability principles often require new data collection, technology upgrading, and integration between systems. However, outdated systems and fragmented business processes often increase initial investment requirements. EA can reduce costs through the principles of reuse, modularization, and standardization. This increases the adoption period of sustainable digital solutions (Uysal & Mergen, 2021).

2. *Indicators and data quality gaps*. Organizations have difficulties in identifying indicators of decision-making (emission areas, waste, circularity) and establishing reliable channels from shop floors and suppliers into the reporting system. Hassan Alghamdi (2024) argues for the importance of multilevel models to make ESG indicators computable and verifiable within architecture. In addition, Hindarto (2023) shows how EA is developing monitoring of Dev-Sec-Ops needed to incorporate metrics into daily operations.

3. *Mass cultural resistance and weak management.* Without portfolio management and clear decision-making rights, sustainable development is pushed into the background under pressure. Practitioners note that many firms prepare excellent reports but do not have the capacity to execute them promptly. Cutter, in his research, and Heather Westmoreland emphasize that EA should manage standards, models, and roadmaps so that sustainability design choices are preserved during implementation.

Thus, in business, digital maturity, coherent architecture, and environmental sustainability go together. Organizations that use EA to align strategic intent, data management, and technology modernization are better equipped to balance environmental and financial performance. This alignment not only contributes to compliance and operational efficiency but also strengthens organizational resilience, allowing firms to innovate and thrive in the economy.

Enterprise Architecture for Environmental Sustainability

As global industries face increasing pressure from climate change, regulatory requirements, and resource constraints. The role of EA has expanded beyond its traditional focus on information technology alignment and operational efficiency. Organizations recognize that sustainable transportation can not be achieved through only isolated green initiatives; it requires a structural architectural response that includes environmental sustainability at the core of business strategy (Cutter, 2022).

4.1 Concept of Sustainable Enterprise Architecture

The accelerating urgency of climate change, combined with growing demands for corporate responsibility, is forcing organizations to expand their digital transformation strategies in the area of environmental sustainability. The concept of Green Enterprise Architecture, also called Sustainable EA, has emerged as a holistic management and technology approach that integrates environmental, social, and managerial considerations into the core of business strategy (Cutter, 2022; Finextra, 2023; Laumann & Tambo, 2018; Iseke, 2020).

According to Ross, Weill & Robertson, 2006, and Shanks et al., 2018, sustainable EA extends the traditional EA approach beyond its traditional focus on IT alignment and operational efficiency to encompass the integration of sustainability data, carbon management, and life cycle management in architectural practice.

Moreover, Cutter Consortium (2022) emphasizes that Sustainable EA functions as a structural factor that translates sustainability requirements into architectural principles, management processes, and reference models. This happens because it ensures that each change initiative contributes not only to financial and strategic goals but also to long-term environmental value.

Similarly, Finextra (2023) describes the Sustainable EA as "greening the blueprint", where sustainability indicators and environmental constraints fit directly into organizations' roadmaps, decision-making frameworks, and investment portfolios.

Laumann and Tambo (2018) offer the Circular Economy Enterprise Architecture Framework, which shows that EA needs to go beyond the limits of organization. Their research defines EA as a framework that can coordinate resource flows and manage environmental data across linked ecosystems.

Iseke (2020) advances this perspective by integrating ISO 14001, EMAS, and GRI reporting structures into ArchiMate, effectively making sustainable metrics computable and verifiable.

Hindarto (2023) illustrates EA as a mechanism for managing sustainability in supply chain networks by using blockchain, IoT, and DevSecOps practices to achieve transparency, accountability, and continuous monitoring of environmental performance.

All these studies demonstrate Sustainable EA as a system potential that translates sustainable development goals into operational architecture, bringing digital transformation in line with the principles of resource efficiency and environmental guidelines.

4.2 Mechanisms of EA for sustainable development

Although the concept of Sustainable EA is valuable for its integrated approach, combining business goals and sustainable development. Sustainable EA works through a set of specific architectural mechanisms that help organizations implement, manage, and track sustainable development objectives within their operations.

A review of collected research highlights four main mechanisms that determine how EA supports the achievement of sustainable development goals, which are *traceability, standardization, optimization, and life-cycle management*.

1. Traceability

EA establishes traceable relationships that link environmental goals with operational processes.

- Anup from SAP EA provides a structured method of linking carbon accounting, supplier risk management, and product design with relevant applications and data. Through this mapping, organizations can be sure that investment in sustainability is measurable and transparent, and also ESG data flows regularly from operational systems to reporting and decision-making at the executive level.

- Hindarto (2023) builds on this approach in the context of supply chains by developing IoT-based telemetry and process mapping frameworks that allow for real-time collection and transmission of data on waste generation, emissions, and resource usage.

- In addition, Lamann and Tambo (2018) emphasize that effective traceability in a circular economy requires comprehensive life cycle data to allow stakeholders to track material flows and environmental impacts.

2. Standardization

EA facilitates standardization and rationalization of systems. It helps organizations to reduce unnecessary duplication, harmonize data between departments, and optimize existing technology infrastructure.

- Shanks et al. (2018), in their studies, show that value of EA in its service potential.

- From the perspective of sustainability, standardization minimizes excessive computing and storage resources. Standardization reduces IT energy consumption and OPEX (Shanks et al., 2018; Hindarto, 2023; Uysal & Mergen, 2021).

- In the research of Liao & Wang (2021), it has been shown that standardized architectural components streamline data flows between analytical and production platforms.

3. *Optimization*

EA enables data-driven optimization by structuring data pipelines, integration layers, and analytical platforms. They link physical operational processes with environmental data analysis and performance monitoring.

- Uysal and Mergen (2021), in his research, merged EA with Software Product Line Engineering to create reusable digital assets and controlled points of variability. This structure supports companies using digital twins and predictive service models that optimize material efficiency and energy use.

- EA provides a governance structure that allows IoT sensors and data analytics systems to work together (Hindarto 2023).

4. *Life cycle management*

EA also functions as a lifecycle management system. It models the flow of materials and products through the value chain.

- Laumann and Tambo (2018) show circular economy transition through life-cycle traceability models, in which EA serves as a coordination layer. Layer link design, production, and recovery systems. This architectural approach provides continuous data exchange and collaboration throughout the whole product lifecycle.

- Hindarto (2023) accompanies this approach with the use of blockchain and RFID technologies within EA to ensure falsification of product history records.

In conclusion, through these mechanisms EA serves as the basis for sustainable transformation, working not just as a system integration tool but as a management system.

4.3 Implementation of Enterprise Architecture frameworks for sustainable transformation

1. TOGAF

Research papers confirm that TOGAF can be used for sustainable development.

- Liao and Wang (2021) and Hindarto (2023) use TOGAF to integrate sustainability into the architectural lifecycle. In their works, environmental principles are integrated at the architectural vision stage. These principles are translated into measurable sustainable development opportunities and performance indicators within business architecture and after that implemented with appropriate data, application, and technology architecture. TOGAF's iterative management cycle ensures that only emerging sustainable development goals are aligned with broader

corporate transformation goals. This allows organizations to adapt and improve their environmental strategies over time.

2. *Zachman*

The Zachman framework is structured as a matrix of five stakeholder perspectives such as, Planner, Owner, Designer, Builder, and Operator, and six fundamental questions, like What, How, Where, Who, When, and Why. This framework allows companies to align different viewpoints of business operations, which makes it valuable for modelling sustainability-related information across hierarchical layers.

- Haghighathoseini et al. (2018) emphasize that the Zachman framework is one of the foundational methodologies for developing coherent enterprise information architectures. It has prioritization in clarifying the relationships between strategic intent and operational execution, which allows decision makers to clearly allocate responsibility for environmental data and manage the use of resources and performance across all departments of business. The Zachman framework improves data management and helps to establish accountability and systematic integration of sustainability objectives at operational and management levels.

3. *ArchiMate*

ArchiMate is traditionally used to visualize relationships between business, application, and technology layers. The flexibility of ArchiMate allows it to be extended beyond operational tasks to cover environmental efficiency.

- Iseke (2020) shows the potential of ArchiMate as a modelling language for sustainability computation and visualization. Iseke, in his work, integrates environmental standards such as ISO 14001, EMAS, and GRI into ArchiMate. This allows environmental attributes to be directly linked to processes and applications, which makes it possible to carry out a quantitative analysis of sustainability indicators at the architecture level.

Enterprise Architecture and Financial Performance

The financial performance of the organizations always remains the most fundamental indicator of strategic success and long-term viability. Although environmental sustainability has become a central pillar of corporate responsibility, companies still need to ensure that sustainability initiatives contribute positively or at least are financially neutral.

5.1 EA as a cost optimization tool

The main contribution of EA is its ability to reduce costs and increase operational efficiency through standardization and rationalization of resources.

The core value of EA is how it can create and enforce standardized processes and shared technology platforms that minimize transaction costs across the organization (Ross, Weill, and Robertson, 2006).

Shanks et al. (2018), in their empirical analysis of EA benefits, indicate that cost optimization is achieved when EA functions not as a documentation system but as a service capability.

Haghighathoseini et al. (2018) show that the implementation of TOGAF in the health sector reduced system fragmentation by consolidating applications, data flows, and integration layers. This has led to a significant improvement in the interoperability of system and service efficiency; all of these bring measurable cost savings.

Research by Uysal and Mergen (2021) in the manufacturing sector demonstrates that the combination of Software Product Line Engineering

(SPLE) with EA in the Smart Manufacturing Development Framework (SMDF) reduces rework, shortens implementation cycles, and minimizes the cost of technological upgrades.

In addition, Liao and Wang (2021) describe how a Lean Enterprise Architecture Framework (LEAF) in the chemical industry directly reduces IT redundancy and resource waste by aligning lean process principles, TOGAF principles, and sustainability practices.

EA can minimize organizations' costs by three mechanisms:

1. Economies of scale (shared services and reusable architectural components)

2. Elimination of redundancy (consolidation of duplicate systems and processes)

3. Improved management (investments in technology and processes were aligned with strategic goals and avoided additional IT costs)

5.2 EA as a tool for value creation

EA evolves from a traditional IT governance mechanism to a comprehensive value creation system. It enhances the organization's ability to implement innovative technologies and compete in dynamic markets.

Boh and Yellin (2022) emphasize that EA can increase an organization's digital dynamic potential, like the ability to sense opportunity, use innovative solutions, and reconfigure resources. All these leads to business value creation.

According to Uysal and Mergen (2021), EA provides modularization in smart manufacturing by predictive maintenance and optimization based on IoT without compromising system stability.

The research work of Haghighathoseini et al. (2018) in the healthcare sector demonstrates the implementation of a structured EA framework that improves strategic planning, risk management, and quality of service.

5.3 Financial risks of ignoring EA

Organizations without architecture-driven management often face proliferation of system, data inconsistency and inefficient integration that increase operational costs and reduce response.

Haghighathoseini et al. (2018) clearly shows in his work that without a suitable EA framework, an organization does not have formal structures and procedures, which leads to uncontrolled proliferation of systems and high maintenance expenses.

A systematic review of the implementation of EA in the public sector (Procedia Computer Science, 2021) also identifies methodological shortcomings, unclear scope, and insufficient management as the main causes of project failures and cost overruns.

In today's business environment, EA neglect exposes organizations to regulatory and sustainability risks. When disseminating environmental disclosure standards like GRI, CSRD, and ISO 14001, the absence of implemented architecture for managing ESG data can lead to incomplete reporting and financial sanctions.

5.4 Financial impact of EA implementation

Health care sector

A study by Haghighathoseini et al. (2018) shows that the implementation TOGAF framework reduced maintenance costs and integration errors and also improved IT service reliability. With the consolidation of applications and clarification of interdependence between systems, the hospital was able to avoid cost avoidance and increased ROI from digital health initiatives.

Manufacturing Sector

The SMDF model (Uysal & Mergen, 2021) in smart manufacturing illustrates that the integration of EA with SPLE principles reduces their development costs by reusing digital components and accelerating cycles.

Chemical industry

Liao and Wang (2021) confirm that by merging lean manufacturing and EA, the company achieved significant reductions in resource consumption and operational waste. In addition, aligning IT investments with strategic sustainable objectives reduced OPEX and improved capital efficiency.

Thus, EA provides strategic visibility and architectural structure needed to maintain financial stability in a changing business area.

Balancing Environmental Sustainability and Financial Performance through Enterprise Architecture

In the modern global economy, the majority of companies are under increasing pressure to find balance between financial performance and environmental sustainability. The interdependence of environmental integrity, social justice, and economic success has become one of the most important challenges for modern businesses (Gampfer and Müller 2018). Environmental sustainability is no longer optional but mandatory. It is starting to be prescribed by social expectations, regulatory frameworks, and careful monitoring by investors. However, businesses are still evaluated by their financial results, operational efficiency, and returns to shareholders. The requirement of being both environmentally friendly and profitable calls for new approaches to management and the implementation of new solutions that can combine environmental responsibility with the creation of economic and financial value.

6.1 Mediation in ensuring sustainability and profitability

EA functions as a balancing tool that aligns environmental objectives with financial performance through a set of integrated architectural and management capabilities. It provides balance via three interdependent dimensions.

1. *Standardization.* EA codifies the principles of sustainable development, such as zero-waste process design, and energy aware design in architecture, and after translating them into applicable management standards and principles. This codification guarantees that environmental objectives are considered as a mandatory architectural constraint (The Open Group, 2021).

2. *Data and traceability.* EA ensures that data related to sustainability, like emissions, waste, energy use, and resource recovery, are verified and

linked to decision-making structures, making ESG information valuable in financing planning (Hindarto, D., 2023).

3. *Roadmaps and capabilities*. The principles of sustainable development become operational thanks to the business and technology capabilities built into the organization's roadmaps of EA that link environmental goals with cost efficiency, ROI, and innovation results (Liao and Wang, 2021).

Shanks et al. (2018) emphasizes that EA can be a balancing tool for aligning environmental objectives with financial performance if it functions as a governance mechanism rather than a technical documentation tool.

Integration of the Triple Bottom Line TBT (people, planet, and profits) in EA is a central strategy in achieving balance. Within this framework, EA views sustainability not as a separate function but as an architectural property that has impact on all levels of the enterprise. Liao and Wang (2021) demonstrate this strategy integration in their research works.

According to Tutaj et al. (2021), EA reduces transition costs and at the same time increases social and environmental performance. This conclusion demonstrates that the three pillars of TBT are not trade-offs but interdependent outcomes when functionalized through EA.

6.2 Mechanisms of balance

Literature and case analysis indicate that EA can achieve balance through several mechanisms like *decision support, portfolio management, and modelling of scenarios.*

Decision support

EA provides a structural and informational framework for decision support systems that link sustainable development data with financial indicators.

- Anup in his 2023 report highlights how EA aligns sustainability with the applications and data. By establishing data provenance and traceability, EA transforms sustainability information into actionable analytics for financial decision-making.

- In addition, Hendarato (2023) confirmed that integrating IoT and blockchain into EA provides real-time information about energy consumption, emission, and waste in supply chains. The data collected through these architectures is verifiable and directly used in strategic decision-making, allowing managers to evaluate sustainable development initiatives financially. In this sense, EA acts as a cognitive infrastructure for balancing sustainability with profit.

Portfolio management

The EA portfolio management function provides a second balance mechanism.

- Research papers of Shanks et al. (2018) demonstrate that the financial benefits of EA are realized when it directly affects investment prioritization, standardization, and asset reuse. The EA portfolio approach allows organizations to allocate resources to projects that deliver maximum environmental impact and financial returns.

- In addition, Liao and Wang (2021) describe how a Lean Enterprise Architecture Framework (LEAF) in the chemical industry aligns lean process principles, TOGAF principles, and sustainability practices with business process improvements by ensuring the translation of environmental goals into budget-oriented road maps.

Modelling of scenario

EA modelling capabilities provide organizations with tools for scenario analysis and cost-benefit assessment of sustainable development initiatives.

- Uysal and Mergen (2021) demonstrate that the combination of EA and Software Product Line Engineering enables companies to test the financial and environmental impact of digital transformation before implementation. Through architectural simulations, organizations can assess trade-offs between system consolidation cost, energy efficiency, and expected ROI.

6.3 Circular economy and EA

The circular economy is a model of production and consumption where materials never become waste. Managerial and integrative capabilities of EA are indispensable for a circular economy. The transition from traditional linear value chains to circular business models requires continuous monitoring of material and energy flows and full tracking of the life cycle of products and resources. EA provides the structural and information coherence needed to provide these functions, also ensuring the systematic integration of circular strategies into business processes, data architecture, and management structures.

EA as a tool to ensure traceability and life cycle management

- Laumann and Tambo (2018) demonstrate the Circular Economy Enterprise Architecture Framework (CEEAF), which shows EA as a central coordination layer that connects product design, production, and recovery. In this framework, EA supports lifecycle traceability by maintaining data on product transformation and environmental impact. This shows that sustainability performance can be monitored across organizational and supply chain boundaries.

- In addition, Hindarto (2023) expands this logic with the introduction of RFID and blockchain technologies into supply chain architecture. The obtained date ensures traceability of the product throughout its life cycle, allowing them to meet the requirements of Enterprise Resource Planning (ERP) and Digital Product Passport (DPP). As a result, EA reduces information asymmetry and financial risks associated with sustainability audits.

EA enables the implementation of circular principles by linking sustainable development goals with resource flows, IT systems, and management models. EA supports product recycling and remanufacturing by linking digital capabilities to lifecycle management processes. It creates new value streams by demonstrating that sustainability can become a source of financial advantage rather than cost.

6.4 Empirical evidence

Empirical results after deep analysis of research works indicate that there are consistent co-benefits between environmental and financial efficiency when EA is used as a management tool.

Supply chain. The use of EA for waste and energy mapping, IoT-based monitoring, and collaborative management reduces material losses and increases energy efficiency by improving environmental and financial outcomes (Hindarto, 2023).

Chemical industry. Liao & Wang (2021) demonstrate that integrating sustainability with the TOGAF framework reduces operational waste and IT redundancy and at the same time improves process performance and profitability.

Smart manufacturing. Uysal and Mergen (2021) emphasize that the modular architecture of the Smart Manufacturing Development Framework significantly reduces the marginal cost of digital innovation.

6.5 How EA achieves the balance

Data from both academic and professional sources converge in the same conclusion that EA is an organizational mechanism that guarantees a balance between sustainability and profitability. This is achieved through a combination of structural, informational, and managerial mechanisms.

1. *Integration*

EA connects sustainability principles directly with business capabilities, portfolios, and data systems. This alignment ensures that environmental objectives are systematically integrated into all levels of enterprise.

2. *Data for decision-making*

Through analytics, IoT integration, and management EA transforms sustainability metrics into verifiable and auditable financial data.

3. *Cost and risk optimization*

Standardization and reuse of components within EA reduces transaction costs and increases process efficiency.

4. *Realization of circular value*

EA provides life cycle visibility and interorganizational collaboration that allow circular business models to generate ecological and economic returns.

EA rethinks sustainability not as an external constraint but as an architectural property of enterprise management. Because of its ability to integrate, standardize, and monitor, EA creates a structurally architected sustainability balance between environmental and financial objectives.

Case study analysis (IKEA)

IKEA is one of the most mature examples of how EA can achieve sustainability at all levels of an organization. Although IKEA does not formally call its internal frameworks an EA program, the structure, management, and technological principles it applies reflect the principles of TOGAF form the Open Group Architecture Framework and ArchiMate modeling standards. Its sustainable development initiatives are organized and managed through interrelated architectural levels and technology that are systematically aligned with corporate strategy and financial objectives.

IKEA's FY2023 sustainable development strategy explicitly includes environmental, social, and economic performance in the company's long-term mission in order to become eco-friendly and circular by 2030. IKEA's approach demonstrates how EA acts not as a separate IT function but as a strategic backbone that aligns business strategy, operational processes, data flows, and technology. This case study analyzes how IKEA uses this architectural discipline to successfully mediate the balance between environmental sustainability and robust financial performance.

Aligning vision with architectural layers.

IKEA's sustainability strategy is fully integrated into its core business strategy. This reflects the Business Architecture layer of EA, where high-level goals are connected to operational strategies and working models.

The link with the thesis is "The business layer sets the organization's environmental goals," and IKEA exemplifies this. Their goals of becoming a

circular business and climate positive by 2030 are not secondary, but they are central drivers of innovation and operational design. This strategy clarity ensures that every subsequent architectural decision is made considering sustainability and profitability.

My thesis identifies four mechanisms through which EA enables sustainability: traceability, standardization, optimization, and lifecycle management. IKEA's report provides empirical evidence for each.

Traceability

IKEA invested in systems that create traceability across its extensive value chain, which is one of the core functions of Data and Application layers. This directly supports the argument from the thesis that "EA ensures that data related to sustainability are verified and linked to decision-making structures, making ESG information valuable in financial planning" (Hindarto, 2023).

- Global wood supply maps provide unprecedented transparency in the origin of wood. This enables IKEA to test sustainable sources, mitigate deforestation risks, and build consumer confidence.

- Material tracking and circular design. Products like the SUVERSIDA tableware series, made from 65-70% ceramic waste, and the kitchen front part VOXTORP, made from >50% recycled wood, require detailed tracking of material flows. This traceability is crucial for a circular economy that turns waste into a resource and reduces the cost of new materials.

Standardization

IKEA's strength has always been in standardization, and it applies the same principle to its transformation of sustainable development, the key advantage of unified EA.

- IWAY standard. It is a powerful tool for standardizing the social and environmental practices of thousands of suppliers. It mandates responsible forestry, waste management, energy efficiency, and fair labor practice. This creates a more sustainable and efficient supply chain.

- Circular product design principles. By standardizing design principles around circularity, IKEA ensures that sustainability is built into every new product. This action reduces future waste disposal and procurement costs.

These findings from the report repeat thesis conclusions that "EA facilitates standardization and rationalization of systems... minimizing excessive computing and storage resources... reduces IT energy consumption and OPEX" (Shanks et al., 2018; Hindarto, 2023). IKEA extends this principle not only to IT but also to the eco-system of physical products.

Optimization

IKEA continuously optimizes its operations for both environmental and financial gain through data-driven insights and integrated systems. This demonstrates the mechanism of data-driven optimization from literature review, where EA structures data pipelines, integration layers, and analytical platforms to link physical operations with environmental performance monitoring (Uysal and Mergen, 2021).

- Energy efficiency. The 12.5% reduction in absolute climate impact was achieved by optimizing energy use. This includes increasing the share of renewable electricity in production from 61% to 71% and retail from 75% to 77%. These measures directly lower OPEX.

- Logistics and product use. Switching to alternative transport fuels and developing cost-effective products such as ABACKEN (saving up to 95%

of piped water) and energy-efficient applications optimize resource consumption for both IKEA and its customers.

Lifecycle management

IKEA's circularity program is an example of life cycle management using EA that links design, retail, and end of life in a continuous cycle. This is a perfect example from the thesis that "EA functions as a life cycle management system. It models the flow of materials and products through the value chain" (Laumann and Tambo, 2018). Thus, IKEA's circular model shows how lifecycle management creates both ecological and economic value.

- Providing 23.2 million assembly parts extends product life, increases customer loyalty, and reduces the environmental impact of replacement production. This is a direct application of the concept of life cycle.

- Buyback and resell services in 28 markets create a new revenue stream from used products, keep products in use, and reduce waste. This service requires a logistic system and data management, provided by coherent architecture.

Direct links to financial performance

IKEA's architectural approach translates sustainable development into tangible financial benefits, proving that the two principles are complementary.

OPEX reduction

Reduced energy consumption, lower waste management fees, and more efficient use of materials directly improve profits.

Risk mitigation

IKEA mitigates the risks associated with scarce resources, commodity prices, and future carbon taxes by using responsible and renewable materials. In addition, standardization through IWAY reduces compliance and reputation risks.

Revenue generation and brand value

Services like Buyback, Resell, and IKEA Energy Services open up new sources of income. A strong reputation for sustainability promotes brand loyalty and attracts eco-friendly consumers, directly supporting sales growth to 47.6 billion EUR in a challenging year.

Innovation and competitiveness

The pursuit of circularity has spurred material innovation, positioning IKEA as a market leader and protecting its business model from future regulatory changes.

The IKEA case study provides a strong answer to the thesis question. EA is the invisible framework that allows IKEA to:

1. Translate the high-level concept of sustainable development into concrete operational capabilities across the global value chain

2. Integrate environmental indicators like CO2 emissions and recycled materials directly into business decision-making processes and performance monitoring

3. Organize complex interactions between business strategy and supply chain

management, product design, customer service, and data systems to achieve systematic changes.

IKEA does not choose between planet and profit; it uses the disciplinary power of EA to ensure that every action taken for the benefit of one simultaneously contributes to another. The company's ability to increase its sales while significantly reducing its absolute impact on climate is not a coincidence but the direct result of a deeply embedded architectural approach to business. This is a convincing empirical confirmation of the main argument of the thesis: that EA is an indispensable intermediary structure to achieve a sustainable and profitable enterprise.

Case study analysis (Unilever)

The Unilever Sustainable Living Plan represents one of the most complete corporate attempts to build a sustainable business model. Although Unilever does not formally label its system as EA, the USLP design, with its clear pillars, cross-functional integration, and roadmap, illustrates the core principles of sustainable enterprise architecture.

Aligning vision with architectural layers.

It serves as a perfect case study for my thesis work, demonstrating how a structured architectural approach can systematically lead the global corporation to sustainable development goals while bringing financial achievements. This analysis will reveal the USLP through the architectural layers and mechanisms.

Traceability

The thesis states: "EA establishes traceable relationships that link environmental goals with operational processes."

Unilever proof: The USLP required a data system to track sustainability indicators from sourcing to consumer use.

- Sustainable sourcing. Unilever tracked its purchases of agricultural raw materials and achieved 67% sustainable sourcing by 2020. This required data architecture to track the origin of materials while ensuring compliance with environmental and social standards.

- Environmental impact monitoring. The plan set targets to halve the environmental impact "per consumer," which required application and data architecture to measure and analyze indicators such as greenhouse gas emissions (-10% change), waste (-32% change), and water consumption (0% change) throughout the product lifecycle.

Standardization

The thesis states: "EA facilitates standardization and rationalization of systems by reducing IT energy consumption and OPEX."

Unilever proof: Unilever extended this principle beyond IT to standardize sustainable practices in its global operations and supply chains.

- Supplier governance. The plan ensured the implementation of sustainable procurement practices by effectively standardizing the environmental and social performance of suppliers and encouraging the adoption of green practices.

- Functional area integration. The USLP standardized goals in R&D, production, and logistics. This created a common language and sets sustainable development priorities for the company.

Optimization

The thesis states: "EA structures data pipelines, integration layers, and analytical platforms to link physical operations with environmental performance monitoring" (Uysal and Mergen, 2021).

Unilever proof: The USLP investment in sustainability is constantly driven by operational optimizations that reduce cost.

- Manufacturing efficiency. A 65% reduction in GHG emissions from manufacturing and a 49% reduction in water abstraction per ton of production are direct results of optimizing energy and resource use. As a result, Unilever avoided spending more than 1 billion EUR.

- Waste reduction. Achieving zero discharge of non-hazardous waste to landfill in all plants is the pinnacle of operational optimization, transforming waste from a cost into a managed resource.

Lifecycle management

Thesis States: "EA functions as a lifecycle management system. It models the flow of materials and products through the value chain."

Unilever proof: The USLP laid the foundation for lifecycle management.

- Sustainable sourcing. By focusing on the beginning in the sourcing of suppliers and in improving the living conditions of small farmers, Unilever has demonstrated a holistic view of the impact of its value chain.

- Consumer use stage. Promoting the use of concentrated forms of products to reduce waste and energy consumption demonstrates an awareness of the product life cycle beyond the factory.

Direct links to financial performance

The Unilever case provides compelling evidence that a sustainable development strategy based on EA is a powerful driver of financial performance.

OPEX reduction

As mentioned, Unilever avoided spending more than 1 billion EUR on energy,

water, and energy efficiency. In addition, investments in energy-efficient assets reduced long-term operational costs.

Revenue generation and value creation

Unilever's "Sustainable Living" brands grew 46% faster than the rest of the business and delivered 70% sales growth. This is the most important point, proving that architecture designed to support sustainable development directly contributed to revenue growth. Moreover, this growth strengthens brand loyalty and enables Unilever to differentiate in the market, creating a strong marketing and competitive advantage.

Risk mitigation

Unilever built its resilience to future regulatory requirements and resource scarcity through proactive management of its environmental impact and supply chain risks.

The Unilever case study provides a strong and distinct answer to the thesis question, complementing the IKEA analysis. Unilever demonstrated that balance is not a zero-sum game.

Comparison table of IKEA and Unilever:

Dimension	IKEA	Unilever
Corporate Sustainability Vision	To become climate positive and circular by 2030	Embedding sustainability within business strategy via the *Unilever Sustainable Living Plan (USLP)*.
Traceability	100% traceable wood and cotton sourcing; digital product passports under the *ESPR* pilot; supplier audits via IWAY standard.	99.6% of palm oil, 100% of sugar, and 98% of rapeseed oil sourced sustainably; satellite and blockchain traceability for deforestation-free supply chains
Standardization	Global IWAY standard for suppliers and product compliance; modular production standards across countries.	Responsible Sourcing Policy (83% supplier compliance); globally standardized human rights, safety, and product formulation frameworks.
Optimization	71% renewable energy in operations (FY23); >1 TWh renewable generation; 25% reduction in operational energy intensity since 2016. Water use per product reduced by 32% since 2018. Zero waste-to-landfill maintained.	75% CO_2 reduction in manufacturing per ton since 2008; 49% reduction in water abstraction; 96% waste reduction; zero non-hazardous waste to landfill achieved in 2014; 51.9% renewable energy share in 2020.
Lifecycle Management	Circular design through *Buyback & Resell* and *As-is* services; product repair and reuse architecture; 15% of sales from circular business models (FY23).	Lifecycle management through reformulation and sustainable sourcing; "less plastic, better plastic, no plastic" design model; 52% recyclable or compostable packaging (2020).
Social & Livelihood Impact	Fair wage initiative across suppliers; >650,000 workers covered under fair pay verification; inclusive employment for refugees and people with disabilities.	1.3 billion people reached through hygiene and health programs; 2.63 million women empowered; 832,000 smallholder farmers supported; 1.83 million retailers trained.
Digital Transformation & Data Integration	Uses AI-based logistics optimization and cloud-based carbon tracking (in partnership with Microsoft Cloud for Sustainability).	Digital ESG dashboards and lifecycle analytics for emissions, sourcing, and human rights tracking; integrated with ERP and sustainability reporting architecture.

Governance and Reporting	ESG performance governed by the *IKEA Sustainability Committee*; annual external assurance aligned with GRI and CSRD.	The *USLP* is monitored by the Sustainability Board; PwC assurance for all major environmental and social KPIs.
Key Achievements	85% renewable materials; 20% recycled materials in products; 5.6% sales growth with 12.5% reduction in absolute emissions.	61% portfolio met nutritional standards; 67% sustainable sourcing achieved; €1B savings from sustainability initiatives; 70% sales growth from sustainable brands.
EA Mechanisms in Practice	Strong in **Lifecycle Management** and **Optimization,** uses architectural frameworks to align sustainability KPIs across supply chain and product systems.	Strong in **Traceability** and **Standardization,** the structured EA governance applies to align supply networks, digital systems, and sustainability objectives.
Balance Between Sustainability & Financial Performance	Achieves synergy via resource efficiency, reduced costs, and new business models (circular resale, renewable energy generation).	Achieves synergy via portfolio transformation, sustainable brands deliver 70% of growth and outperform the market in profitability.

Discussion of findings

The discussion chapter that follows will include an academic analysis aimed at evaluating how the study fills the identified gaps in the literature, as evidenced by the findings related to the research question. Furthermore, the limitations that are present in this research will be clarified, which will be concluded by outlining potential avenues for further research.

8.1 Answering the research question

How does enterprise architecture help businesses achieve a balance between environmental sustainability and financial performance?

The findings from the literature review and case studies demonstrate that EA serves as a central integrating framework that addresses the contribution between environmental sustainability and financial sustainability. It achieves this by turning sustainable development from a cost center into an engine of value creation. Balance is realized through four interdependent architectural mechanisms: traceability, standardization, optimization and lifecycle management.

1. EA creates data-driven connection between sustainability goals and operational execution. It delivers verified ESG information by mapping data flows from source to end-of-life. This minimizes greenwashing, ensures accurate reporting and allows managers to make final decisions based on specific environmental data, thereby reducing risk. For example, IKEA's traceability of wood and recycled materials reduced raw material costs and risks to its supply chain, while Unilever's tracking of sustainable sources supported its brand strategy and growth of revenue.

Both companies have advanced data architecture and mature sustainability management structures. EA ensures reliable data collection and integration across business layers. On the other hand, organizations with weak data infrastructure or fragmented IT systems, traceability mechanisms often collapse because of inconsistent metrics and data silos (Alghamdi, 2024).

2. EA codifies circular design principles, energy-savings operations, and responsible procurement standards into reusable architectural components and management processes. Elimination of redundant systems leads directly to reduction of IT costs and OPEX. For instance, IKEA's IWAY standard and Unilever's sustainable purchasing guidelines are creating efficient and compliant global operations that reduce costs and at the same time ensure sustainable performance.

Standardization works effectively in firms with global management and centralized decision-making. In consequence it reduces redundancy and

OPEX through uniform systems (Shanks et al., 2018). However, over-standardization may reduce local innovation flexibility.

3. EA provides the structural foundation for data-driven optimization. It allows rea-time monitoring of resource consumption, waste, and emission by integrating IoT, analytics, and data pipelines. This gives companies the opportunity to identify and eliminate inefficiencies also minimizing their environmental footprint and operating costs. Results from case studies show that IKEA's optimization of energy use through renewable energy sources reduces its impact on climate and energy bills. In addition, Unilever saved more than 1 billion EUR in GHG emissions and water use.

Optimization thrives in companies with real-time data analytics and strong cross-functional collaboration. Without coherent data management and clear KPI's, optimization projects may remain isolated, leading to short-term savings but no long-term transformation (Cutter, 2022).

4. EA allows to move from the linear model "take-make-dispose" to circular economy. It supports product repair, resale, and remanufacturing by modelling flow of materials and products. This action creates new revenue sources and increases resilience to resource scarcity. IKEA's Buyback program and Unilever's full product lifecycle, including consumer use, demonstrate how lifecycle management changes environmental responsibility into profit.

Lifecycle management requires architectural maturity, circular design principles, and cross-boundary collaboration. EA supports this by connecting design, production, and processes. In less mature organizations, lifecycle approaches are limited by supply chain visibility (Laumann & Tambo, 2018)

In conclusion, EA achieves the balance by connecting sustainability indicators directly into the organization's operation models. It ensures that each strategic development goal is translated into proper capabilities, data, and technologies that also provide financial benefits. The cases of IKEA and Unilever prove and

show that with EA, environmental and financial objectives are not a trade-off but synergy of a well-connected and designed enterprise.

8.2 Research contribution

This thesis makes a visible and significant contribution to both scientific and business practice.

Theoretical contribution

This research goes beyond the claim that EA supports sustainability to provide validated explanation of how it happens. It offers a concrete theoretical structure by identifying the four main mechanisms, like traceability, standardization, optimization, and lifecycle management.

In addition, study provides real-world evidence from global leader companies, like IKEA and Unilever to establish sustainable EA. Furthermore, the research connects EA theory with the principles of the circular economy and the triple bottom line. It demonstrates how EA implements these high-level concepts into organizations systems, data, and processes, thereby enriching the theoretical dialogue between IT management, sustainability, and strategic management.

Practical contributions

This thesis work provides a blueprint for managers, enterprise architects and sustainability officers. It puts theory into practice by showing how to use traceability, standardization to cut costs, apply optimization for efficiency, and implement lifecycle management to product circulation. This provides a clear vision of how sustainably developed strategies are financially profitable.

By demonstrating EA's direct role in reducing OPEX, generating revenue, and mitigation risks, the study provides a powerful evidence-based argument for investing in EA. Moreover, the in-depth analysis of IKEA and Unilever emphasize a set of tangible practices that companies across all sectors can implement.

8.3 Limitations and future research

This research offers valuable insights into how EA reaches the balance between environmental sustainability and financial performance; it is important to acknowledge its limitations and consider areas for future development.

Limited integration of ESG into existing EA frameworks. Although studies such as Laumann & Tambo (2018) and Hindarto (2023) have introduced sustainable oriented extensions, which are conceptual and have no formal validation from companies. Future research should be related to development of EA-ESG model that integrates environmental, social, and management principles into EA layers.

This research identifies the main four mechanisms such as traceability, standardization, optimization and life cycle management, through which EE affects both sustainability and financial results. However, the causal relationship remains difficult to isolate as these variables often evolve together. Possible future research can be conduction of quasi-experimental studies to measure the timing and impact of EA on sustainability KPIs and financial metrics.

The case analysis relies on public sustainability reports rather than on direct access to internal organization data. Corporate self-reporting may increase progress or apply different measurable boundaries. Future research: Incorporate primary data collection through interviews and internal management documents. In addition, the study focuses on large companies with mature EA practices. The findings may not apply to SMEs, public sector organizations, or firms in emerging economies, where resources, governance maturity, and technology infrastructure differ significantly. Future research can be conducting comparative studies across industries to identify specific success factors and barriers.

Limited integration of AI in the study. EA researchers must include AI driven decision layers that connect data, applications, and business capabilities within a framework. Future research should: Exploration of AI driven meta-architectures that is capable autonomously monitor energy usage to achieve a balance between environmental and financial goals in real world.

Conclusion

This thesis aims to study the critical and increasingly relevant challenge in modern business: How does enterprise architecture help businesses achieve a balance between environmental sustainability and financial performance? The journey to answer this question went through the evolution of EA, theoretically its mechanisms, and empirically confirmed them through the case analysis of two global leaders, IKEA and Unilever. The research concludes that EA achieves the balance by functioning as the central integration layer and control system. It operates as an engineered system that directly manipulates operational variables through integrated data pipelines, automated governance, and closed-loop feedback systems.

The primary contribution of this thesis is the development and validation of a coherent model that explains how EA achieves this balance. The answer lies not in a single intervention, but in a synergistic function of four interdependent architectural mechanisms.

Traceability provides the foundational data architecture that transforms environmental impact into measurable, verifiable information. EA first creates a unified data architecture, which removes data fragmentation between ERP, PLM, and sustainability reporting tools and allows companies to calculate operational indicators such as CO_2 and energy per unit produced. This moves sustainability from abstract commitment to managed reality, as seen in IKEA's

wood supply maps and Unilever's supply chain tracking. Once these data flows are architected, environmental KPIs become auditable values.

Standardization codifies this reality in business architecture, translating principles into applicable rules and reusable components across the organization and its ecosystem. Unilever's "sustainable sourcing" KPI was operationalized by introducing validation logic into the API gateway between its procurement and finance systems. When a purchase order is created in the SAP ERP system for a raw material like palm oil, an API call is automatically triggered to a sustainability database. The order is only approved for payment if the supplier ID returns a valid certification status. This architectural pattern directly lowers operational risk and reduces the OPEX associated with manual compliance audits.

Optimization uses standardized and tracked data within the application and technology architecture to drive continuous, data-driven improvements. EA designs the infrastructure for IoT by integrating sensor data from operational technology (OT) with analytical applications in information technology (IT), creating self-optimizing systems. The result is the powerful convergence of environmental and financial efficiency, where reductions in energy, waste and emissions, as demonstrated by both companies, lead directly to lower OPEX.

Lifecycle management represents the culmination of this process, using architectural coherence to transition from a linear model to a circular one. In IKEA's case a product designed for disassembly in the CAD/PLM system has a digital material passport stored in a centralized database. The Buyback & Resell service is a separate microservices-based platform that exposes APIs to the core ERP for inventory checks and to the CRM for customer history. EA ensures these systems interoperate seamlessly, creating a new business capability. This is where sustainability development evolves from cost avoidance to value creation, generating new sources of income.

This cycle demonstrates that the relationship between environmental and financial performance is not a zero-sum game, but synergistic tool. Each mechanism reinforces each other by increasing efficiency on both fronts.

The implications of this research are important for both theory and practice. Theoretically, this thesis fills a critical gap in literature. It goes beyond the established understanding of EA as a tool for IT efficiency (Ross et al., 2006) and conceptual calls for sustainable EA (Gampfer & Müller, 2018), to provide mechanism-based theory. Practically, this study provides a clear and actionable blueprint for leaders. For executives and board members, this is a compelling, evidence-based argument to see EA not as IT expenses but a strategic investment in sustainability and competitive advantage, for navigating the dual pressure of profitability and environmental responsibility. For enterprise architects and operation managers, it provides a validated framework, to structure transformation roadmaps, justify investments and explain their role in achieving key business objectives.

This thesis confirms that the organizations that will thrive in the coming decades will be those that recognize sustainability not as a separate agenda, but as an essential quality of a well-designed enterprise. IKEA and Unilever are pioneers, their success is not accidental, but built upon a foundation of coherent processes, unified data, and aligned technologies that ensure that every strategic decision considers both environmental impact and its economic value. Looking ahead, the research does not end here. As technologies like AI mature, the next frontier will be to develop cognitive EA: self-optimizing systems that can autonomously balance environmental and financial KPI's in real-time, predicting failures and dynamic reconfigurations. This represents the next evolution of the mechanisms explored in this work.

This thesis concludes that achieving a balance between environmental sustainability and financial performance is the defining strategic challenge of our time. EA provides the necessary discipline, the blueprint, and the tools to tackle this challenge. It is the framework through which companies can

systematically design a future where corporate success, and environmental responsibilities are not in conflict but mutually reinforced and linked.

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