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Validating and Evaluating a Dynamic Enterprise Architecture Model: A Case Study

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Abstract: In today's rapidly changing business environment, adapting to evolving circumstances is a fundamental capability for organizations. Enterprise Architecture (EA) provides a holistic view of an organization's structure, processes and technology, ensuring alignment with strategic objectives. However, traditional EA frameworks often lack the flexibility to dynamically respond to both predictable and unpredictable internal and external changes. This study proposes a novel, multidimensional evaluation framework for assessing the dynamic aspects of EA, structured around four axes: Dimensions (e.g., flexibility, Modularity), the six-step dynamic EA process, architectural layers and categories of dynamic metrics. The framework leverages the Goal-Question-Metric (GQM) methodology, allowing for a structured, goal-driven approach to measuring the adaptability and responsiveness of EA. We applied the proposed framework to a use case involving a Multinational Corporation (MNC) operating in a highly dynamic environment to validate it. This real-world scenario demonstrates the framework's ability to identify strengths and areas for improvement in the organization's architecture, particularly regarding flexibility, Extensibility and strategic alignment. Additionally, we discuss the framework's limitations, including the complexity of managing multiple axes and the challenges of continuous data collection. Nevertheless, the proposed model provides a robust, actionable tool for evaluating EA dynamism, with significant potential for guiding organizations in making goal-oriented improvements. Future research will focus on refining the framework's application and improving data collection methods to enhance scalability and generalizability.

Keywords: Dynamic, Enterprise Architecture, Evaluation, Metrics, Dimensions

Introduction

The relentless rate of change within the modern business environment continues to challenge the classical approaches of enterprise architecture (Kotusev, 2018). These traditional frameworks typically shift the organization's focus towards the static qualities of efficiency or uniformity and put less emphasis on change in an organization driving architecture in a changed or changing landscape (van de Wetering, 2021). This results in rigidity that may lead to missed opportunities, inefficiency, or continuously expanding misfits between business objectives and the underlying architecture (Ross *et al*., 2006). To fill this critical gap, there is a need for a paradigm shift into understanding and measuring dynamism in EA.

A framework to measure dynamism in EA adds value beyond any mere assessment; it enables organizations to pinpoint where and how they can do better and to take goal-oriented investments regarding their ability to adapt themselves through practice and tools (Marwick, 2003). An ideal enterprise architecture should enable an organization to exhibit high exploitability of emergent technological paradigms, such as cloud computing or blockchain (Gartner, 2024). This further translates to easy integration with use enterprises' novel process methodologies, typical of the agile development (Bente *et al*., 2012). Ultimately, such an architecture fosters a culture of continuous optimization that is always in line with the changing business priorities, for example, enhanced customer focus or data-driven decision-making. This agility translates to a significant competitive advantage in the dynamic

markets that characterize today's business environment. Such a framework enables organizations to be more proactive in moulding their working future rather than becoming slaves to change.

Assessment against dynamism is not relevant for short-term gain alone. Through a culture of learning and adaptation, an organization will position itself for long-term success. The framework supports identifying and harvesting value-generating knowledge from past experiences, such as the successful incorporation of a new CRM system, together with failures, such as a highly rigid architecture that fails to offer support for a new mobile strategy. This forms the basis for further adoption, assuring an alignment of EA to proposed modifications within the business's goals and industrial trends (Marwick, 2003). Advanced dynamism would also follow a future-proof architecture in terms of how the system works and with additional flexibility to change to face up to unanticipated challenges and opportunities.

Another area of impact that does not directly involve the technical aspect is the enhancement in resource allocation. Many traditional, static architectures translate to the misuse of resources. Rather than maintaining an irrelevant system, money could be better spent continuously adapting and improving the EA. With the measurement of dynamism and how it shall be prioritized, organizations are afforded opportunities for managed resource allocation to finally be on track in investing resources into capabilities that ensure success in the future.

This measurement framework is relevant as it enables improved communication and collaboration between the business and IT teams since it should provide a common understanding of the dynamic capabilities of organizations and their coordination in identifying and prioritizing needs in adaptation. This builds a working environment where business goals are realized in terms of EA changes to be made.

Finally, dynamism should measure EA not just in its present state but also in its ability to forge an architecture sufficiently future-proof to allow organizations to flourish in an ever-dynamic business environment. The lessons from this framework make a case for proactive investment in agility and adaptability to render an organization more resilient and, at the same time, more competitive.

Our paper tries to answer the following research question: "What methodological approach can be employed to construct a multidimensional framework for assessing the dynamism of enterprise architecture? This framework should rely upon a granular categorization of dynamism metrics. Furthermore, how can these metrics be effectively leveraged to quantify the degree of dynamism inherent in the various layers of enterprise architecture?"

This study introduces a novel framework to evaluate the dynamic aspects of Enterprise Architecture (EA) by integrating the Goal-Question-Metric (GQM) approach and focusing on critical dimensions such as flexibility, Modularity and adaptability. The framework is validated through a real-world case study, demonstrating its practical applicability in a multinational corporation and offering a quantitative scoring system to measure and improve EA's responsiveness to change. This study fills a significant gap in EA literature by providing both theoretical insights and actionable metrics for enhancing EA dynamism in volatile environments.

Backgrounds

Dynamic Enterprise Architecture

Enterprise Architecture (EA) is among the strategic assets and forms a blueprint for aligning business processes, information systems, and technology infrastructure toward organizational goals (Zachman, 1987). However, under the skewed business scenario, framed by EA, many at times fail to deal with dynamic challenges like disruptive technologies, market uncertainties and changing expectations of the stakeholders (Ross *et al*., 2006). Therefore, such a gap highlights the problem of understanding the theoretical underpinnings of dynamic EA to be able to develop effective evaluation frameworks.

As we have argued in an earlier publication (Ettahiri *et al*., 2022), we conceive our Dynamic EA approach through five central dimensions: Flexibility and adaptability, Modularity, Expressiveness, Extensibility and durability and prediction. Those dimensions (Baldwin and Clark, 2000) are theoretically grounded in systems theory and organizational theory to grasp the core features of an EA being able to react to change (Simon, 1996). Flexibility would be the potential to change EA components with little effort; adaptability would mean the ability to change after unexpected developments; Modularity would provide a way for the decomposition of the large system into manageable components; Expressiveness would allow EA to express the different views and needs of stakeholders; and Extensibility would add new capabilities as required (Ross *et al*., 2002).

In addition, six major processes form dynamic EA workflow, which has been elaborated on in our previous publications (Ettahiri and Doumi, 2024a): monitor, compare, analyze, plan, execute, and update knowledge. These processes support, among each other (Spewak and Hill, 1993), the principles of continuous improvement and organizational learning, which together form the philosophy of dynamic EA assessment (ISO/IEC/IEEE, 2018). Monitoring is concerned with the real-time tracking of performance indicators; comparison means

benchmarking against industry standards and best practices; analysis is in the identifying of patterns and trends; planning deals with strategic decision-making from analysis results; execution translates plans into action and knowledge update guarantees that EA remains relevant and up to date (Kotter, 1996).

The theoretical underpinnings for dynamic EA combine a variety of different disciplines that involve system theory, organizational behaviour and strategic management information technology, among others. They coalesce insights from these basic disciplines to provide a broad understanding of the complex nature of dynamic EA. Systems theory informs a holistic framework for the understanding of interdependencies and interactions within complex systems; organizational behaviour theories bring an understanding of human factors that affect EA adoption and adaptation. Strategic management views preside over the formulation of goals and objectives about EA and aligning them with organizational strategy in much the same way as information technology theories concerning the design and implementation of IT systems in support of the same initiatives.

The theoretical background of dynamic EA is composed of five key dimensions and six key processes based on such eclectic theories as systems theory, organizational behaviour, strategic management and information technology. In this regard, drawing from such eclectic theories, researchers and practitioners can develop comprehensive frameworks for the assessment and improvement of the dynamic capabilities of enterprise architecture.

Literature Review

The dynamic nature of business environments has increased the need to evaluate the adaptability and responsiveness of Enterprise Architecture (EA) frameworks. Traditional EA models, such as TOGAF, FEAF and Zachman, primarily focus on achieving structural alignment between business strategies and IT systems, often overlooking the need for flexibility and responsiveness. Ross *et al*. (2006) argue that static frameworks can lead to inefficiencies in addressing market disruptions, regulatory changes and technological innovations. Consequently, the assessment of dynamic aspects in EA has become a crucial area of research, with several frameworks now being developed to evaluate EA's capacity to adapt to continuous change.

One of the widely recognized methods for evaluating dynamic aspects in EA is through Enterprise Architecture Maturity Models. These models assess the overall maturity of an EA, focusing on the ability to adapt, evolve and maintain alignment with organizational goals in a changing environment. Ross *et al*. (2006) propose that as EA matures, its flexibility increases, enabling organizations to better handle change. Maturity models use a phased approach, typically including levels such as initial, managed, defined, quantitatively managed and optimizing. These levels help organizations understand where their EA stands in terms of adaptability and identify areas for improvement. This structured progression provides a roadmap for enhancing EA's dynamic capabilities over time.

Another significant framework for evaluating dynamic aspects of EA is Capability-Based Planning (CBP). This approach focuses on identifying and developing the core capabilities of an organization to ensure it can adapt to both internal and external changes. (Pulkkinen, 2006) emphasizes that capability-based planning allows organizations to align their EA with strategic priorities by identifying key capabilities needed to achieve business goals and adjusting those capabilities to meet emerging requirements. CBP facilitates the integration of new technologies and processes while preserving the overall coherence of the EA. This adaptability is vital for organizations aiming to remain competitive in environments characterized by rapid technological advancements and market shifts.

The Balanced Scorecard is a strategic performance management tool that has been adapted to evaluate dynamic aspects of EA. Initially developed by (Kaplan and Norton, 1992) for performance management, the Balanced Scorecard has since been applied to EA evaluation by incorporating perspectives such as financial, customer, internal processes and learning and growth. In the context of EA, the Balanced Scorecard helps assess how well an architecture supports the organization's ability to react to change and align with long-term objectives. For example, the learning and growth dimension can be used to measure how well the EA supports continuous improvement and innovation, while the internal process dimension can evaluate its flexibility and efficiency in executing change initiatives.

Across all the mentioned frameworks, metrics play a crucial role in evaluating EA's dynamic capabilities. For instance, Enterprise Architecture Maturity Models often measure flexibility, Modularity and alignment with business strategies. In Capability-Based Planning, metrics like time-to-market, resource allocation efficiency and capability readiness are critical indicators of how effectively the EA supports adaptability. Similarly, the Balanced Scorecard integrates both qualitative and quantitative metrics such as response time to market shifts, technological integration rate and strategic alignment. These metrics enable organizations to gauge the extent to which their EA is responsive to evolving business needs, ensuring that it remains relevant in dynamic environments.

While the enterprise architecture maturity models, capability-based planning and balanced scorecard provide valuable frameworks for evaluating dynamic aspects of

EA, they have notable limitations that can be addressed by a more structured and tailored approach, such as the Goal-Question-Metric (GQM) methodology. One key gap in these existing methods is the lack of a systematic, customizable mechanism for linking specific organizational goals with relevant evaluation metrics. Maturity models tend to follow rigid, predefined stages, which may not fully capture the nuances of an organization's evolving needs (Ross *et al*., 2006), while Capability-Based Planning often focuses on strategic alignment without sufficiently quantifying adaptability through operational metrics (Pulkkinen, 2006). Similarly, the Balanced Scorecard emphasizes high-level perspectives but can fall short of providing detailed, actionable insights on how specific EA components contribute to overall flexibility and agility (Kaplan and Norton, 1992).

In contrast, the GQM approach directly addresses these gaps by offering a goal-driven framework that links strategic objectives to specific, measurable questions and metrics (Basili and Rombach, 1988). This methodology enables organizations to tailor their evaluations, ensuring relevance and applicability.

Materials and Methods

Methodology

The Goal-Question-Metric (GQM) is a methodology that offers a structured manner of evaluating the dynamic aspects of the enterprise architecture. It follows a top-down approach, where organizational goals are linked to specific questions and metrics aimed at providing the stakeholders with information on the effectiveness of EA in supporting changes in the environment. In this section, we use the GQM methodology to evaluate dynamics in enterprise architecture.

The first step (Basili and Rombach, 1988) is to define organizational goals concerning dynamic aspects like flexibility and adaptability, Modularity, durability and prediction. This forms the basis of the subsequent evaluations. For instance, a goal could be set to increase adaptability in the presence of market discontinuities. Then, depending on these goals, relevant questions are developed to check whether those goals have been met. Questions must be measurable and actionable, and they guide what metrics may be appropriate. Questions that can exist as exemplary may include: "How quickly does the organization react to changing customer demands?" or "To what extent does the EA support experimentation and innovation?" Metrics are selected to quantitatively or qualitatively measure the aspects that the formulated questions will be addressing. The Key Performance Indicators need to be in tandem with these goals and bring out meaning about EA dynamics (Solingen and Berghout, 1999). Examples of the metrics are the time taken to respond to market changes, the rate of success in the process of innovation, and the satisfaction of stakeholders with EA capability. Each of the goals has been positioned against questions and metrics, through which the interlinkages between the organizational deliverables and the assessment parameters are given precise definitions. This helps the process of evaluation to stay focused on the intended results. These relationships might be better explained through visual representations, such as matrices or diagrams.

After goals, questions and metrics have been defined and duly mapped, the actual evaluation process takes off the road. Data collection may take different means. It can be through surveys, interviewing, or automated monitoring tools for that cause. This is an essential step and needs stakeholder engagement to allow data collection and interpretation to be realistic. Data collected is analyzed to come up with meaningful interpretations of the occurring dynamic realities of EA. The results are interpreted regarding organizational goals and objectives, indicating the areas of strength and the areas that need improvement. Identifying trends and patterns also serves to inform decision-making and strategic planning.

The methodology enables continuous improvement loops, where the output from an evaluation leads back to improved EA practice (Kitchenham and Pfleeger, 2002). It makes sure that further adaptions continuously take place to align the EA efforts with changing organizational needs and external dynamics.

The GQM methodology, therefore, gives a structured way of applying dynamic evaluation to enterprise architecture. The linkage of goals with questions and metrics will enable organizations to systematically assess their fitness and systematically improve on them for adaptability and innovation in such a movable business landscape.

Proposed Evaluation Framework

Proposed Framework Overview

Most of the traditional EA frameworks cannot pace up with the dynamic business environment and respond to emerging challenges. Given this limitation, a pressing need exists to have a comprehensive framework for the evaluation of dynamic aspects of EA. The proposed Dynamic EA framework aims at a comprehensive approach toward the evaluation with the integration of five dimensions and six key processes. The dimensions of flexibility and adaptability, Modularity, Expressiveness, durability, prediction, and Extension capture essential features of an EA that can react to change (Bente *et al*., 2012). Six key processes: Monitoring, comparison, analysis, planning, execution and knowledge update compose the skeleton for dynamic evaluation, enabling continuous improvement and adaptation (Ettahiri and Doumi, 2024a).

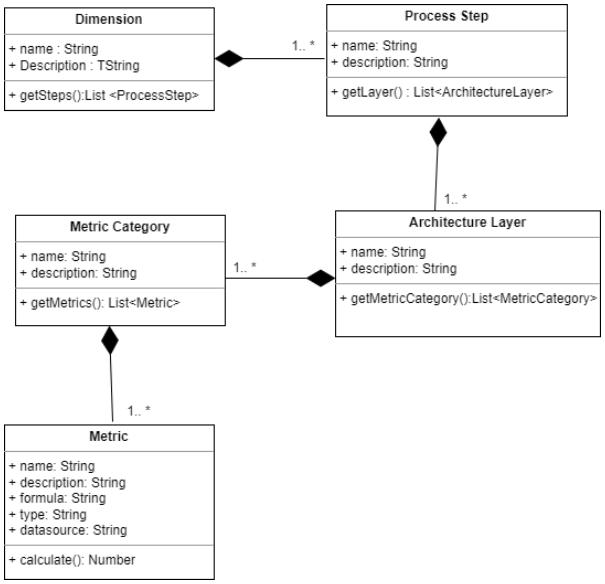

Fig. 1: The class diagram of the evaluation framework of dynamism in the enterprise architecture

The Model of Proposed Evaluation Framework

In a modeling approach, we propose to use the UML 2.0 class diagram, represented below, in Fig. (1), for the evaluation framework of DyEA.

We describe hereafter the diagram's entities:

- Dimension: Represents a dimension of dynamism (e.g., Flexibility, Modularity). It can have several categories of metrics
- MetricCategory: Represents a category of metrics (e.g., Structure, Quality). Each category contains several metrics
- Metric: Represents a specific metric with a name, a description, a calculation formula, a type and a data source
- ArchitectureLayer: Represents the different layers of the enterprise architecture (e.g., Business, Strategy, Motivation, Infrastructure, Application, Context Awareness, Holistic). Each layer can have several dimensions.
- ProcessStep: Represents the steps of the process (e.g., Monitor, Compare, Analyze, Plan, Execute, Update Knowledge Base). Each step can be associated with several metrics.

For the relations between the entities:

- A dimension can have several process steps
- A process step can correspond to several architectural layers
- An architectural layer can include several metric categories
- A metric category can contain several metrics

The Process of Evaluation: Construction of the Framework

In this sub-section, we outline the proposed process for constructing an evaluation of Enterprise Architecture (EA) dynamism, adhering to the Goal, Question, Metric (GQM) methodology, we present hereafter, in Fig. (2), the whole process composed of 8 steps.

First, one needs to identify the pertinent dimensions of dynamism in the EA. Our framework uses basic dimensions: Flexibility and adaptability, Expressiveness, Modularity, Extensibility, durability and prediction. These are made into a high-level set of goals. In turn, for each of the six steps in our defined process of dynamism, the Monitor, Compare, Analyze, Plan, Execute and Update Knowledge Base sub-goals are identified. These sub-goals focus more on the details of how each step of the process would contribute towards the realization of the set goals on dynamism. Having structured the high-level and sub-goal, the next stage involves defining objectives at different architectural layers, including business, strategy, motivation, infrastructure and application.

These objectives ensure that the review will address the impact of the dynamism across different levels of the organization.

Questions are then derived based on the GQM approach. These questions point to some metric category quality or performance, etc. and help connect the objectives to the metrics themselves. In this step, the process identifies certain metrics that correspond to each question.

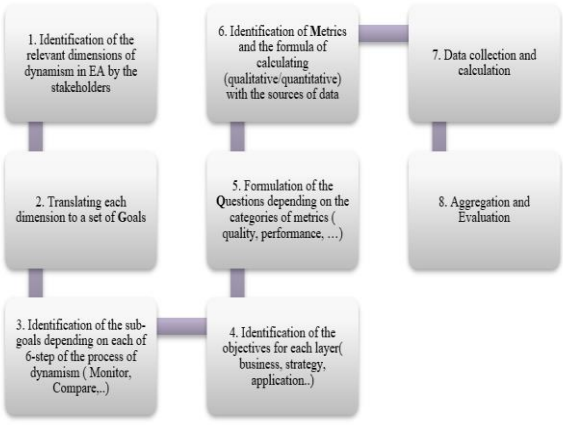

Fig. 2: The process of construction of the evaluation framework of dynamism in the enterprise architecture

These metrics can be qualitative or quantitative, depending upon the nature of the data measured. The source of data for each metric is also identified to make the evaluation process armed with reliable data points. Using this structured approach, the GQM methodology provides a solid framework for building up an effective EA dynamism evaluation that will conform to the standards of ISO/IEC 42030. This holistic approach will ensure that the review covers different architectural layers, key stakeholders' concerns, and objective data, which will project an accurate picture of the EA's ability to respond to change. It then identifies specific metrics against each such question, and this hierarchical construction is shown in Fig. (3). Data collection and calculation: This is the seventh step. Data is collected from various sources, such as performance monitoring tools, process logs and feedback from stakeholders. Calculations of metrics are done using the identified formulae. Finally, the calculated metrics are aggregated to present an overall assessment of the EA's dynamism.

It is a weighted sum of metrics in which the importance of each one is weighed against the others and then combined to derive an overall dynamism score. This score reflects the capability of EAs concerning adaptation and symmetric response to dynamic environments.

In the following sub-sections, let us expose the details of each of the four axes of projection of the metrics.

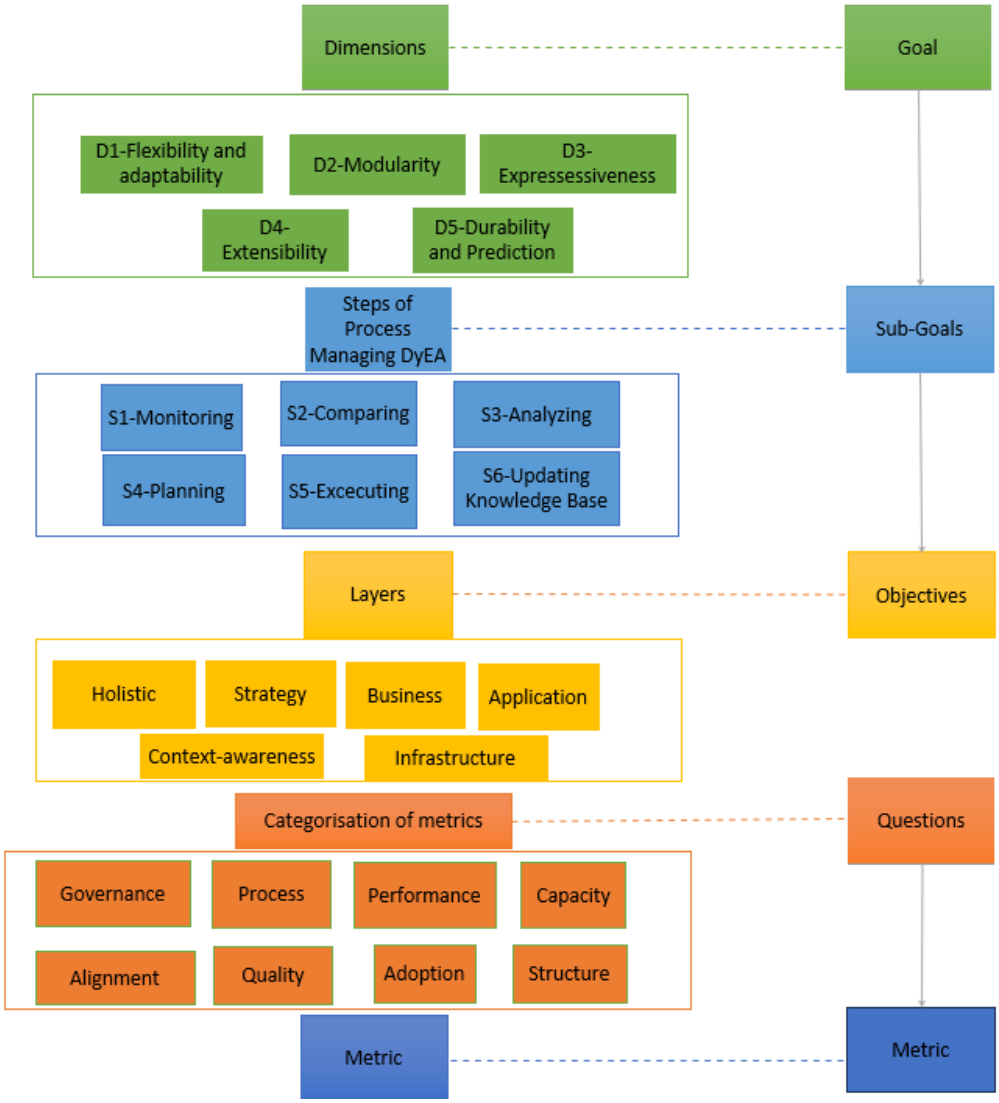

Fig. 3: The evaluation framework of dynamic aspects in Enterprise architecture hierarchical construction, mapping between axis levels and GQM methodology

Axis 1: Dimension Evaluation

The dimensions identified for our approach of dynamic aspect in (Ettahiri *et al*., 2022). DyEA approach comes because of a study of the leading architectural principles to which our model of dynamism should comply and, hereafter, our dimensions, as presented in Fig. (4):

- Flexibility: Refers to the ability of the EA to accommodate changes in business processes, technologies and requirements (Smith and Jones, 2018). Flexibility can be measured by metrics such as the ease of changing EA components, the response time to change requests, and the degree of automation achieved in processes for changing management. Formulas for calculating flexibility metrics could use the number of change requests that go through processing within a unit of time, the percentage of automated change approvals and the average time taken to effect changes.
- Adaptability: An EA can adapt to sudden and unexpected changes and disruptions (Smith and Jones, 2018). A few of the metrics for estimating adaptability may be how well the organization would be ready to support 'pivoting' in response to market shifts, how various categories of contingency plans function in times of crisis and agility in reconfiguration or other components of the EA to satisfy some rising need. The adaptability metric formulae could include the frequency of unplanned changes, the success rate of the adoption of contingency measures, and recovery time from disruptions.
- Modularity: Characterizes whether an EA consists of independent and interchangeable components (Sarkar *et al*., 2005). Modularity metrics can be measured in terms of the component reuse rate, granularity level of interfaces, encapsulation, and abstraction (Brown, 2019). Modularity metrics can be formulated in consideration of the percentage of the reusability of the component, cohesion and coupling of the component interfaces and complexity of dependencies between components
- Expressiveness: It deals with the ability of the EA to express different views and requirements. Some metrics that could be used in assessing Expressiveness include the completeness of the EA documentation, the clarity of the communication among the stakeholders and the level of compliance of the EA artifacts toward the stakeholder's needs (Niemi and Pekkola, 2017). Metrics for Expressiveness would calculate formulas such as the percentage of stakeholders that are satisfied with the EA document, the frequency of feedback from stakeholders, or the degree of alignment between EA artifacts and business objectives
- Extensibility: It refers to the ability of the EA to accommodate newer capabilities and functionalities. Extensibility can be measured using metrics such as ease of integration of third-party systems, scalability of the EA infrastructure and availability of extensibility mechanisms like APIs and plug-ins (Alreffaee *et al*., 2021).The formulae for extensibility metrics may be determined by parameters such as time to onboard new technologies, cost of integration of external systems, or scalability of the resources of the EA
- Durability: To see whether the architecture is resilient and long-lasting. This is a dimension that investigates how far the architecture will maintain its functionality and stability in the changing business environment, shifting technology, and transforming organizational preferences and priorities. The metric used to determine durability is system reliability, which refers to the degree to which an architecture can continue supporting operations without failure or shutdown for an extended period. Component Life Expectancy: This is the life expectancy of architectural components given variables like the frequency of maintenance, rate of obsolescence and retirement schedules. Adaptability to new technologies: The ability of the architecture to adopt and incorporate new technologies in a way that ensures existing functionality and invested assets are protected
- Prediction: Evaluate the degree to which the enterprise architecture predicts future trends, challenges and opportunities. This dimension considers the organization's ability to predict any future change and to proactively plan or adapt its architecture. The metrics that could be used in evaluating prediction include the following: Forecast accuracy: The degree of accuracy in the prediction of future trends as assessed by a retrospective analysis and then compared to actual outcomes. Scenario Planning Effectiveness: How well the organization is in developing and testing alternative scenarios and future states of the architecture, evaluated through exercises and simulations on scenario planning. Early Warning Systems: Extent to which mechanisms are in place and adequate for identifying and alerting relevant stakeholders of the advent of disruptions or opportunities, including by such means as trend analysis tools or environmental scanning processes

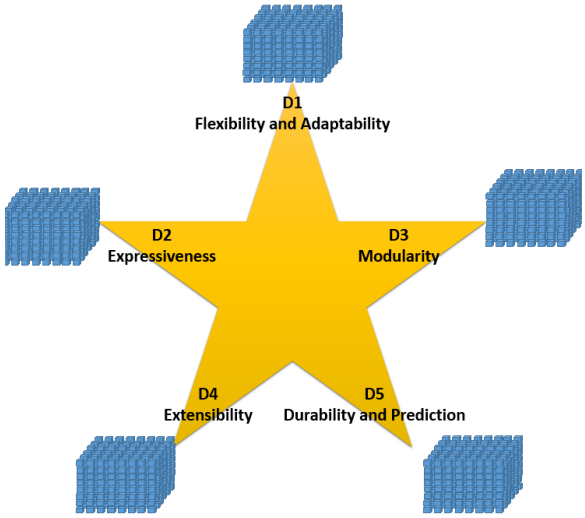

Fig. 4: The evaluation framework of dynamic aspects in enterprise architecture, emphasizing the five values of the first axis "Dimensions"

A dimension evaluation involves assessing the flexibility, adaptability, Modularity, Expressiveness and extent of the EA using specific metrics and formulas. By quantifying these dimensions, organizations can gain insights into their EA capabilities and identify areas for improvement.

Axis 2: Process Integration

The six-stepped process is also integrated as an axis with the dimension evaluation; the layers and categories give a practical structured approach to our dynamic EA evaluation; we expose hereby the six steps:

1) Monitoring: Monitoring shall constantly observe as well as capture relevant contextual data from varying layers in the enterprise architecture. This step is needed for the system to be aware of the environment and to distinguish changes or anomalies in real-time. According to (Zaslavsky *et al*., 2013), context-aware systems are defined to be the ones that perceive data, understand and respond to information, therefore enriching business process life cycles within the company's architecture. As said, the GQM method is also used to identify metrics; for instance, we aim to ensure real-time awareness of environmental changes affecting business operations. The main question marks: How efficiently can the system capture real-time contextual data? To quantify, we take the metric Real-time Context Data Capture Rate (CDCR), which is a function of the other parameters (Layer, Category, Dimension)
2) Comparison: Comparison is the activity of approximating the captured contextual data with standards, norms, or the expected value; any deviation is to be addressed. This phase will allow the system to recognize whether an operation is regular or a problem. Enterprise architectures must have that dynamic adaptation that induces the comparison of contextual data; this is an agreement by (Bauer and Spiekermann, 2011), which states that the system needs to detect the response when presented with a deviation from the normal one. Among the proposed metrics, some can be maturity level, standards conformance, and benchmark achievement tuned to measure the goal: "Benchmark EA Performance against standards"
3) Analysis: That is, analysis means interpreting one's identified deviations or trends by comparison for their meaning to be understood and for the response to be determined. This is the stage that provides the processing of raw data into something that action can be taken. Contextual data analysis is key for decision support and is elaborated by (Poland *et al*., 2012), who states that practical analysis of contextual information leads to better strategic planning and operational adjustments. Key analytics measures should include trend identification, which is the ability to identify upcoming trends and patterns from past/old data. Evaluate potential impacts in the form of changes or disturbances on the working of EA. Measure the Quality of Data- Analyze the quality and validity of the data using data completeness, consistency and validity
4) Planning: Planning is to develop policies and detailed programs of work that meet the understanding achieved from analysis. This step allocates resources, schedules tasks, and prepares the organization for implementation. Planning, in terms of CA, is done through contextual analysis, as mentioned by (Pulkkinen, 2006), which points out that strategic planning aligns IT with business goals. In other words, planning involves strategic decision-making through insights derived from EA analysis. Planning performance metrics might be strategic alignment, The alignment in the plan of EA relative to the goals and objectives of the organization; Resource Allocation: Effectiveness in the allocation of resources that support their strategic initiatives; and the Initiative Success Rate: Success in strategic initiatives which is based on the attaining of the expected results
5) Execution: This could be regarded as the implementation of change. This is where one gets to implement or execute the plans actual. This could involve the implementation of new processes, affecting system changes and rolling out new technologies, among others. There must be good change management in enterprise architecture frameworks, as asserted by Ross *et al*. (2006), who

argue that "one of the most critically important parts of dynamism is the successful execution of planned changes." Now consider the loophole in those cases of change execution: The question to be answered: How successful are the executed changes in achieving the desired outcomes? Goal to achieve: Implement planned changes effectively and efficiently. Metric: Execution Success Rate (ESR)

6) Knowledge update: Capturing the results of the implemented change, lessons learned and any newly acquired data, which becomes part of the knowledge base update, will then feed into the organization's knowledge repository. That makes learning and continuous improvement part of the process. The process of knowledge integration and continuous learning is described to be at the core of an adaptive enterprise architecture; (Alavi and Leidner 2001) describe knowledge management within processes of organizational learning and adaptation. This could, perhaps, be something like "Keep EA relevant through continuous learning." Associated metrics for updating knowledge might be further detailed as follows: Review Frequency: The frequency with which EA is reviewed and updated to include new knowledge and insights. Knowledge Sharing: The effectiveness of the mechanisms of knowledge sharing is measured through participation and feedback. Lessons Learned Adoption: The extent to which lessons learned from the past are integrated into future EA practices

Axis 3: A Layered Architecture

The framework adopts a layered architecture approach, drawing upon the ArchiMate standard to structure the EA into multiple layers (The Open Group, 2019). These layers include the business, application, technology, physical, implementation and migration, motivation, context awareness and holistic layers. Each layer represents a different perspective of the organization, enabling comprehensive evaluation from various angles. In addition to the traditional ArchiMate layers, the framework incorporates a holistic layer to capture cross-layer elements and overarching principles. This holistic perspective ensures that evaluations consider the interconnectedness of different EA components and their collective impact on organizational dynamics. Furthermore, the framework integrates a context-aware layer to account for external influences and environmental factors that shape EA effectiveness.

Axis 4: Categorization of Metrics for Calculating Dynamism in Enterprise Architecture

As presented in our previous paper (Ettahiri and Doumi, 2024b), the proposed categorization of our evaluation framework is as follows:

- Structural metrics focus on the composition and arrangement of EA components, providing insights into the organization's architectural integrity and coherence (ISO/IEC/IEEE, 2018). Examples of structural metrics include Component Count, which is the number of distinct components within the EA. Layer Complexity: The complexity of interactions between different layers of the architecture. Standards Compliance: The degree to which EA components adhere to established architectural standards and guidelines
- Process metrics evaluate the effectiveness and efficiency of EA-related processes and workflows, highlighting areas for optimization and improvement (Basili and Weiss, 1984). Examples of process metrics include Change Request Cycle Time, which is the average time taken to process and implement change requests. Development Pipeline Throughput: The number of development tasks completed within a given time frame. Process SLA Compliance: The percentage of processes that meet predefined Service Level Agreements (SLAs)
- Performance metrics: Measure the operational performance and reliability of EA components and systems, ensuring that they meet predefined quality of service requirements (ISO/IEC 9126, 2001). Examples of performance metrics include System Uptime, which is the percentage of time that systems are available and operational. Response Time: The average time taken to respond to user requests or system queries. Throughput Capacity: The maximum volume of transactions or data that can be processed by the system within a given period
- Quality metrics: evaluate the overall quality and robustness of the EA, ensuring that it meets organizational standards and stakeholder expectations (ISO/IEC 9126, 2001). Examples of quality metrics include defect density, which is the number of defects identified per unit of architectural components. User Satisfaction: Stakeholder satisfaction with the functionality and performance of the EA. Compliance Rate: The percentage of architectural components that comply with quality standards and regulations
- Alignment metrics: Assess the degree to which the EA supports and aligns with the organization's strategic goals and objectives (Kazman and Bass, 2002). Examples of alignment metrics include Strategic Goal Achievement: The extent to which EA initiatives contribute to achieving organizational strategic goals. Business-IT Alignment: The degree of alignment between business processes and IT systems within the EA. Value Contribution: The perceived value and benefits derived from EA initiatives are measured through stakeholder feedback
- Capacity metrics: Evaluate the scalability and resource utilization of the EA, ensuring that it can

support current and future demand (Buckl *et al.*, 2008). Examples of capacity metrics include Resource Utilization, which is the efficiency of resource usage measured by factors such as CPU, memory, and network bandwidth utilization. Scalability Index: The ability of the EA to scale resources up or down in response to changing demand. Capacity Utilization: The percentage of available capacity that is actively utilized by the EA

- Governance metrics: assess the effectiveness of governance structures and practices in overseeing and managing the EA (Lange *et al.*, 2016). Governance Review Frequency: The frequency of governance reviews and audits conducted to ensure EA compliance. Decision-Making Efficiency: The efficiency and effectiveness of decision-making processes within the EA governance framework
- Adoption metrics: Evaluate the uptake and utilization of EA practices and components by stakeholders, ensuring that they are embraced and effectively used within the organization (Proper and Lankhorst, 2014). Examples of adoption metrics include User Adoption Rate, which is the percentage of users actively utilizing EA components and practices. Training Participation: The participation rate in EA-related training and development programs. Adoption Feedback: Stakeholder feedback on the ease of use and effectiveness of EA components and practices

The Mathematical Representation

To evaluate the dynamism of an enterprise architecture, we can calculate an overall dynamism score of D_{global}. This score is derived from metrics evaluated across the different layers of the extended ArchiMate model, metric categories and the five dimensions of dynamism using the Goal, Question and Metric (GQM) approach.

The overall dynamism score D_{global} is calculated as a weighted sum of the metrics across all relevant axes. The formula can be expressed as:

$$D_{global} = \sum_{i=1}^{D} \sum_{j=1}^{S} \sum_{k=1}^{L} \sum_{s=1}^{C} w_{i,j,k,s} M_{i,j,k,s}$$

where:

- D is the number of dimensions
- S is the number of steps
- L is the number of layers
- C is the number of categories
- $w_{i,j,k,s}$ is the weight assigned to the metric $M_{i,j,k,s}$
- $M_{i,j,k,s}$ is the metric associated with the Dimension $D(i)$, step $S(j)$, layer $L(k)$, Category $C(s)$

Figure (5) brings a better comprehension of the matrix representation of the cube related to each value of the dimension axis $D(i)$.

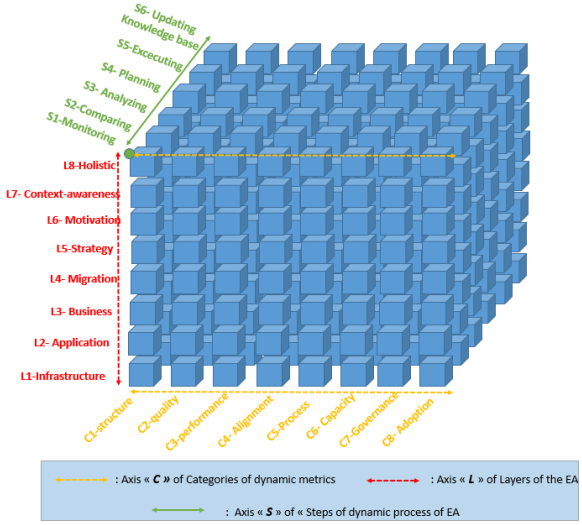

Fig. 5: The Evaluation Framework of dynamic aspect in Enterprise architecture for a fixed value of the axis dimension $D(i)$ emphasizing the other three axis values

Validation: Use Case

Validation Methodology

The validation of the proposed Evaluation Dynamic Enterprise Architecture (DyEA) framework was conducted through its application to a real-world use case involving a Multinational Corporation (MNC) operating in the technology sector. This empirical case study provided a practical context for testing the framework's applicability and effectiveness in evaluating the dynamic capabilities of the organization's EA. The validation process was grounded in the Goal-Question-Metric (GQM) methodology, which allowed us to assess the framework across multiple dimensions: Flexibility, Modularity, Expressiveness, Extensibility, durability and prediction.

The case study validation involved mapping the MNC's processes and architectural components to the framework's defined dimensions and calculating the corresponding metrics. This structured approach enabled a detailed evaluation of how the organization's EA performs under dynamic conditions, revealing both strengths and areas for improvement. The results demonstrated that the proposed framework is capable of capturing the organization's dynamic aspects, such as its ability to adapt to internal and external changes, integrate new technologies and maintain long-term architectural stability.

By applying the framework in a real-world context, we were able to verify its utility and relevance in operational scenarios. The use case not only validated the theoretical underpinnings of the framework but also provided actionable insights into improving the

organization's EA. This method ensured that the proposed dimensions and processes accurately reflect the needs of a dynamic enterprise environment, thereby confirming the framework's robustness and scalability for broader applications.

Relevance and Significance

The proposed use case of a Multinational Corporation (MNC) serves as a highly relevant and significant validation of the multidimensional evaluation framework for Dynamic Enterprise Architecture (EA). This MNC operates in a complex and rapidly changing environment, making it an ideal candidate for testing the framework's ability to assess the EA's adaptability across the four axes dimensions, steps, layers and metric categories. The organization's diverse global operations, coupled with frequent regulatory shifts and technological innovations, provide a rich context for evaluating the dynamic aspects of EA, such as flexibility, Modularity and Extensibility. Moreover, the use case offers a real-world application that highlights how the framework can identify specific strengths and weaknesses in the architecture, offering actionable insights for improvement. By applying the framework in such a complex, dynamic scenario, the validation not only demonstrates the model's robustness and scalability but also ensures that the framework is practical and applicable to organizations facing similar challenges in navigating unpredictability and continuous change.

The consistency and reliability of the results produced by the framework are ensured by the metric consistency and data integrity checks. We employed standardized metrics (e.g., time to integrate new technologies, component quality index) across all dimensions, which were derived based on established evaluation methodologies like the GQM approach. This guarantees that the evaluation process remains consistent across different framework applications. Also, data collection processes were standardized through the use of automated monitoring tools and manual data validation checks. These measures ensured that the data feeding into the evaluation was accurate, reducing the risk of errors that could compromise the consistency of the results.

Application of the Evaluation Framework of DyEA on a Use Case

To exemplify the construction of our evaluation framework of the DyEA, let us consider the case of a Multinational Corporation (MNC) operating in the technology sector, with subsidiaries and operations spread across various continents. The company aims to streamline its operations, enhance adaptability to market changes and integrate innovative technologies. The MNC seeks to evaluate its Enterprise Architecture (EA) using the proposed dynamism evaluation framework to ensure it supports these objectives.

Step 1: Input identification (Dimensions of Dynamism) from Stakeholders

In our use case, the stakeholders from the healthcare organization are the chief technology officer (CTO), regional IT directors, business unit leaders, and compliance officers; all these staff members work together to identify the relevant dimensions to evaluate the EA's dynamism. Let us consider that the selected dimensions are the five dimensions of our framework: Flexibility and Adaptability, to evaluate the ability to respond to market dynamics and regulatory changes; Modularity for diverse and scalable business units; Expressiveness to ensure a clear representation of global business processes and data, Extensibility, to evaluate the ability to integrate new technologies and services across regions and finally, Durability and Prediction, for a long term sustainability of IT systems and Predictive analytics for market trends and business outcomes.

Step 2: Translation of the Dimensions to Goals

The next step in our framework construction process is to translate the dimensions onto goals for Flexibility and Adaptability: "Rapid adjustments to market strategies and compliance requirements." For the D2 Modularity, the fixed goal is" Develop a modular architecture to support various regions and business units." for the D3-Expressiveness: "Create clear models of global business processes." For the D4 – Extensibility, "Ensure seamless integration with emerging global technologies." In D5-Durability and Prediction, the fixed goal is to "Maintain robust and reliable IT infrastructure and implement predictive analytics for market and operational trends."

Step 3: Identification of Sub-Goals

Each goal is broken down into sub-goals aligned with the six-step process in step 3. Let us take the example below in Table 1.

Step 4: Identification of Objectives

Each sub-goal is mapped to specific objectives across the EA layers as presented in Table 2.

Step 5: Formulation of Questions

Questions are formulated to address each category of metrics as presented in Table 3.

Step 6: Identification of Metrics and Formulas

Metrics are identified based on the questions. We take the example in Table 4.

Step 7: Data Collection and Calculation

To analyze and interpret the results, data will be collected for each metric and a radar graph will be used to visualize the performance across the different dimensions.

Table 1: Sub-goals corresponding to each of the six steps per dimension

Dimension	Monitor	Compare	Analyze	Plan	Execute	Update knowledge base
Flexibility	Track market changes	Assess adaptability	Identify barriers	Develop strategies	Implement changes	Document updates
Modularity	Monitor components	Compare Modularity	Analyze components	Plan modular	Deploy new modules	Update modularity
Expressiveness	Monitor workflows	Compare with standards	Analyze workflows	Plan improvements	Execute workflows	Document workflows
Extensibility	Monitor new tech	Compare integration	Analyze integration	Plan integration	Implement tech	Update integrations
Prediction	Monitor market trends	Compare predictions	Analyze outcomes	Plan analytics	Deploy analytics	Update models
Durability	Monitor system health	Compare with lifespan	Analyze durability	Plan maintenance	Execute plans	Document durability

Table 2: Objectives corresponding to each of the EA-layer

Layer	Flexibility	Modularity	Expressiveness	Extensibility	Prediction	Durability
Business	Adjust global processes	Modular business units	Clear global processes	Integrate new business models	Predict business outcomes	Sustainable global practices
Strategy	Agile strategy adaptation	Modular strategic components	Expressive strategic plans	Extend strategy with new trends	Predict strategic success	Durable strategic planning
Motivation	Flexible motivation models	Modular motivational components	Expressive motivational models	Extend motivation with new goals	Predict motivation outcomes	Durable motivation framework
Infrastructure	Adaptive infrastructure	Modular IT components	Expressive IT architecture	Integrate new IT systems	Predict infrastructure needs	Durable IT infrastructure
Application	Flexible applications	Modular application components	Expressive application design	Extend applications	Predict application usage	Durable applications
Context	Adapt to context changes	Modular context components	Expressive context representation	Integrate contextual data	Predict context changes	Durable context management
Holistic	Overall adaptability	Overall Modularity	Overall Expressiveness	Overall Extensibility	Overall prediction ability	Overall durability

Table 3: Questions corresponding to each of the metric categories

Metric Category	Sample Questions
Structure	How adaptable is the current EA structure to market changes and regulations?
Quality	What is the quality of the modular components in the EA across regions?
Alignment	How well are the global business processes aligned with the EA goals?
Adoption	How effectively are new technologies integrated into the EA globally?
Performance	What are the predictive analytics performance metrics for market outcomes?
Capacity	What is the capacity of the IT infrastructure to support new applications globally?
Governance	How robust are the governance mechanisms in maintaining EA durability globally?
Process	What processes are in place to ensure continuous updates to the EA knowledge base globally?

Table 4: Final List of metric results of the process GQM

Metric Category	Metric Name	Formula/Calculation	Data Sources
Structure	Adaptability Score	(Number of Changes Adapted/Total Changes) * 100	Change Management Logs
Quality	Component Quality Index	(Component Quality Ratings/Number of Components)	Quality Assessment Reports
Alignment	Process Alignment Index	(Aligned Processes/Total Processes) * 100	Process Documentation
Adoption	Technology Adoption Rate	(New Technologies Adopted/Total Technologies) * 100	Technology Implementation Records
Performance	Predictive Accuracy	(Correct Predictions/Total Predictions) * 100	Predictive Analytics Reports
Capacity	Infrastructure Utilization	(Current Utilization/Total Capacity) * 100	IT Infrastructure Monitoring Tools
Governance	Governance Compliance Rate	(Compliant Practices/Total Practices) * 100	Governance Audit Reports
Process	Update Frequency	Number of Updates Per Year	Knowledge Base Logs

Table 5: Values of the metrics per dimension

Dimension	Adaptability score	Component quality index	Process alignment index	Technology adoption rate	Predictive accuracy	Infrastructure utilization	Governance compliance rate	Update frequency
flexibility	80	-	-	-	-	-	-	-
modularity	-	75	-	-	-	-	-	-
expressiveness	-	-	70	-	-	-	-	-
extensibility	-	-	-	85	-	-	-	-
prediction	-	-	-	-	90	-	-	-
durability	-	-	-	-	-	95	80	65

Step 8: Aggregation and Evaluation

The calculated metrics presented in Table 5, are aggregated to provide a comprehensive evaluation of the EA's dynamism. This involves weighing each metric based on its importance and combining them to derive the overall dynamism score. This score reflects the EA's capability to adapt and respond to dynamic environments effectively.

To derive the overall dynamism score, we aggregate the calculated metrics using their respective weights. Assuming equal weights for simplicity, the aggregated dynamism score is calculated as follows:

$$D_{global} = \sum_{i=1}^{D} \sum_{j=1}^{S} \sum_{k=1}^{L} \sum_{s=1}^{C} w_{i,j,k,s} M_{i,j,k,s}$$

D_{global} = 1/5 * [(80+75+70+85) + ((95+80+65+90)/4)]
D_{global} = 78,5

By following this structured process, organizations can systematically evaluate their EA's dynamic capabilities, ensuring alignment with stakeholder needs and compliance with industry standards. This approach not only provides actionable insights but also enhances the EA's ability to thrive in rapidly changing environments.

In the following section, we discuss and analyze the obtained results.

Results and Discussion

The application of the proposed multidimensional evaluation framework to the use case of a Multinational Corporation (MNC) demonstrates its effectiveness in assessing the dynamism of an Enterprise Architecture (EA). The overall dynamism score of 78.5, derived from assessing multiple indicators across five key dimensions (Flexibility and Adaptability, Modularity, Expressiveness, Extensibility, Sustainability and Prediction), provides a comprehensive view of the EA's adaptability and readiness for continuous change. This finding directly addresses the research question by validating the framework's ability to quantify the degree of dynamism through a granular categorization of metrics applied across various architectural layers.

In alignment with the literature, the flexibility dimension, with an adaptability score of 80, reflects a solid capability to respond to both internal and external changes, though there is room for improvement. According to Ross *et al*. (2006), flexibility is crucial for maintaining competitiveness in volatile environments, and the result indicates that the organization's EA is mainly able to accommodate these demands. However, the score suggests a need for further improvements, such as refining change management processes and enhancing the automation of adaptability, as proposed by (Jones, 2018).

The modularity score of 75 highlights a moderate degree of decomposition within the EA, allowing the architecture to be broken into manageable components. This finding is consistent with (Baldwin & Clark, 2000), who argue that Modularity enables architectural agility by facilitating quick updates and integration of new elements. However, the result also suggests areas for improvement, specifically in component reuse and interface granularity, which could be optimized to enhance the system's modular nature further.

The expressiveness score of 70, indicated by gaps in process alignment, emphasizes the need for better synchronization between the EA and the organization’s business processes. (Niemi and Pekkola, 2017) point out that Expressiveness is essential for accurately representing stakeholders' needs. A score of 70 reveals that the organization may experience challenges in translating business requirements into architectural components, underlining the importance of refining communication and documentation strategies within the EA.

With an extensibility score of 85, the results show that the organization has effectively integrated new technologies and is prepared for future technological advancements. This finding aligns with the work of (Alreffaee *et al*., 2021), who stress that Extensibility is critical for maintaining long-term architectural relevance. The high score reflects a well-managed capacity for scaling and integrating new functionalities but suggests

that continued monitoring is required to ensure sustained Extensibility as new technologies emerge.

The prediction dimension, scoring 90, indicates a strong capability for forecasting future trends and disruptions, which is essential for maintaining a proactive EA. This score reinforces the importance of predictive analytics in EA, as highlighted by Ross *et al*. (2002) and demonstrates that the organization is well-equipped to anticipate and adapt to market shifts. The high sustainability score of 95, particularly in terms of infrastructure utilization, further emphasizes the EA's durability, though the update frequency score of 65 suggests a need for more frequent revisions to maintain architectural relevance. This aligns with (Pulkkinen, 2006), who argues that continuous updates are crucial for sustaining alignment with evolving business and technology environments.

Overall, these findings connect directly to the research question by illustrating how the framework's granular categorization of metrics applied across dimensions, steps, layers and metric categories can effectively quantify the dynamism of the EA. The radar chart visualization reinforces this, offering clear insights into which areas of the architecture require immediate attention and which areas are well-aligned with strategic goals.

To address the observed trends, several key improvements are recommended. Enhancing staff training to better adapt to regulatory changes and market dynamics will improve flexibility. Increasing the modularization of components will enhance system agility and quality. Refining business process models will improve Expressiveness and alignment with EA objectives. Continuing to integrate and monitor new technologies will help maintain a high level of scalability. Additionally, maintaining and expanding predictive analytics capabilities will further strengthen forecasting accuracy while increasing the frequency of knowledge base updates, which will ensure the EA remains up-to-date and relevant.

The use case evaluation showcases the full scope of the proposed multidimensional framework and its capacity to provide actionable insights for improving the dynamism of EA in practice. By applying the Goal-Question-Metric (GQM) methodology, the framework has been successful in identifying both strengths and areas for improvement within the organization's EA. This detailed assessment underscores the value of using a structured, multi-axis approach to refine the EA in a rapidly evolving environment continuously.

To graphically visualize these results, we can draw a radar chart that shows scores on the five dimensions of dynamism as outlined in Fig. (6).

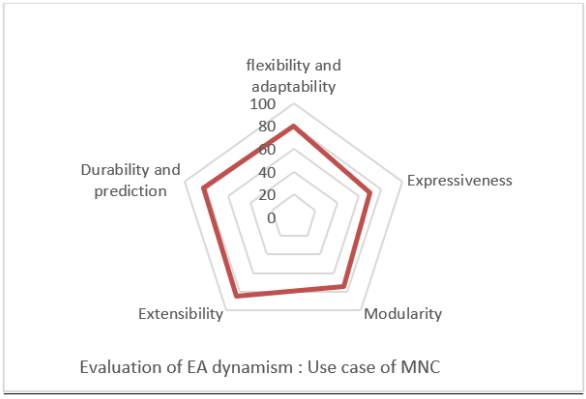

Fig. 6: Radar Graph of the evaluation of EA dynamism for the use case of MNC

Conclusion

This research proposed a multidimensional framework based on the Goal-Question-Metric (GQM) methodology to evaluate the dynamic capabilities of Enterprise Architecture (EA). The framework assesses EA dynamism through four key axes: Dimensions, the six-step dynamic EA process, architectural layers and metric categories. Applied to a case study of a Multinational Corporation (MNC), the framework demonstrated its capacity to identify strengths and areas for improvement, such as high flexibility and extensibility scores, indicating adaptability and stability in competitive environments. This aligns with the core research question by providing a granular categorization of dynamism metrics, enabling organizations to quantify the degree of adaptability across various layers of their architecture.

The findings from the use case suggest that the framework effectively captures the dynamic aspects of EA, offering valuable insights for enhancing strategic alignment and operational agility. For instance, the evaluation pointed to gaps in process alignment and the need for more frequent updates to maintain architectural relevance, emphasizing the framework's ability to pinpoint critical areas for improvement. By linking specific organizational goals to measurable outcomes, the GQM approach has shown its utility in providing a structured, goal-driven methodology for assessing EA's adaptability and resilience in real-world scenarios.

However, the proposed framework is not without its limitations. One of the primary challenges lies in the complexity of managing the four intersecting axes (dimensions, steps, layers and metric categories). Organizations may struggle with the extensive customization required to balance all axes consistently, leading to variations in the application of the framework across different contexts. Additionally, the subjectivity in goal and metric definition can result in inconsistencies that limit comparability across different organizations or

departments. This is compounded by the resource-intensive nature of data collection, which may require sophisticated tools and significant personnel involvement, making it challenging to maintain up-to-date evaluations, particularly in rapidly evolving environments.

Moreover, while the customizability of the framework offers flexibility, it can also introduce a narrow focus on short-term operational goals at the expense of broader, long-term adaptability metrics such as innovation capacity or future-proofing potential. This risk of misalignment underscores the importance of developing standardized best practices to guide the application of the GQM methodology, ensuring that both short-term flexibility and long-term strategic objectives are adequately addressed.

Looking ahead, several avenues for future work emerge from this research. First, expanding the framework's application to a broader set of case studies across different industries would allow for comparative insights and further validation of the framework's generalizability. Additionally, refining the goal-setting process and metric development to minimize subjectivity and ensure more consistent, standardized results is crucial for making the framework more accessible and scalable. Statistical reliability testing, such as Cronbach's alpha, can also be introduced to assess the internal consistency of the evaluation framework quantitatively.

Furthermore, streamlining the data collection process is essential to enhance the framework's efficiency in environments where EA is subject to frequent changes. This could involve integrating more automated tools for real-time monitoring, reducing operational overhead and ensuring that updates to the evaluation are timely and less resource intensive. Future research should also explore the inclusion of metrics related to technological readiness and innovation capacity, ensuring that the framework remains relevant for organizations aiming to future-proof their enterprise architecture.

In conclusion, the proposed multidimensional GQM-based framework successfully addresses the gaps left by existing models by providing a structured, granular approach to assessing EA's dynamic capabilities. Nevertheless, its complexity, subjectivity and resource requirements call for further refinement and standardization to ensure broader applicability and consistency across diverse organizational contexts.

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Author's Contributions

Imane Ettahiri: Substantial contributions to the conception of the work, acquisition, analysis and interpretation of data, drafted and critically reviewed.

Latifa Rassam: Substantial contributions to the conception of the work, interpretation of data, and critical review.

Karim Doumi: Substantial contributions to the conception of the work, final approval of the version to be published, accuracy and integrity of the work.

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Ethics

This article is original and contains unpublished material. The corresponding author confirms that all the other authors have read and approved the manuscript. No ethical issues are involved.

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