

Enterprise Architecture: A Comparative Analysis of Validation Semantics and Heterogeneous Model Frameworks

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Abstract

The advancement of Enterprise Architecture modelling techniques and the need to incorporate these models with other Information Systems collaborations require a methodology that ensures the consistency and compatibility of diverse models with shared business objectives. The fulfillment of this requirement is impeded by a notable obstacle, which is the growing intricacy of Enterprise Architecture Framework modelling tools and methodologies. Many organisations that have adopted a variety of methodologies face the difficulty of integrating models because of the existence of inconsistent and diverse modelling artefacts within an unreliable framework, which requires validation. The primary aim of this article is to conduct a comprehensive analysis of the existing methodologies for validating enterprise architecture and propose a new approach that focuses specifically on validating models. This research combines the Systematic Review research approach and meta-analysis research method to provide a systematic and comprehensive review and analysis of multiple studies and combining findings from these studies to synthesize evidence and draw definitive conclusions. The comparative analysis explores validation semantics and heterogeneous model frameworks and delves into different approaches used to validate models in the context of heterogeneous model integration. The study examines the strengths and weaknesses of various validation methods and frameworks for heterogeneous models, considering factors like accuracy, efficiency and scalability. By comparing different validation semantics and heterogeneous model frameworks, the analysis provides valuable insights into selecting appropriate techniques for effectively integrating and validating diverse models in complex systems.

Keywords

Enterprise Architecture, Ontologies, Business Process Management, Validation

1. Introduction

Enterprise Architecture (EA) is the practice of analyzing, designing, planning, and implementing an enterprise. An exhaustive method ensures the implementation and execution of a business strategy by taking into consideration all aspects of the organisation. Enterprise Architecture incorporates a collection of interconnected principles, methodologies, and models that articulate an enterprise's organisational structure, business processes, information, and interdependencies (Golnam et al., 2014). Enterprise Architecture's primary objective is to equip the enterprise with architectural principles, frameworks, methodologies, processes, tools, a knowledge base, and techniques that can effectively support its mission. It is anticipated that the refineries will facilitate the alignment of artefacts, guarantee the traceability of relationships, localization, harmonisation of interactions, and visualisation with perspectives to increase the enterprise's overall productivity and efficiency. The most important aspect of validation is the EA methodology's capacity to determine the necessary procedures for producing each deliverable of EA development or progression. A practitioner must be able to quickly identify and implement the necessary steps for attaining a specified goal or incentive. Most Enterprise Architecture methodologies are intended to expedite the EA creation and evolution processes (Schekkerman, 2004). Compatibility is a vital aspect of frameworks that employ a variety of modelling tools. Such frameworks must have a broad scope that accommodates a variety of techniques and technologies for process design, methods, and repositories. This assertion should be supported by pragmatic evidence that demonstrates its completeness, brevity, and skill in facilitating perspective visualisation without undue complexity.

Despite the fact that numerous definitions of Enterprise Architecture describe a methodical approach to acquiring, organising, and presenting information, they frequently omit an explanation of the taxonomy's validation capability (Schekkerman, 2004). Numerous techniques for validating models rely heavily on subjective measurements. To establish correlations among disparate enterprise architecture frameworks and to draw conclusions about their validation techniques, it is necessary to include the fundamental aspects of comparison, correlation, and differentiation in the frameworks' descriptions (Schekkerman, 2004). The ubiquitous prevalence of ambiguities and lack of semantic integrity have hindered the implementation of EA modelling and validation (Zachman, 2003). A strategy that consolidates and formalises Enterprise Architecture Framework (EAF) can provide a significant advantage by promoting a precise standard that facilitates traceability and goal achievement. Additionally, it has the potential to establish a fundamental basis for the harmonisation of enterprise architecture abstractions with technological infrastructures, facilitate adaptability to change, and permit the gradual development of enterprise architecture modelling techniques in tandem with emerging technologies such as cloud computing, linked data, and strategic business transformations.

2. Related Literature Review

The examination of various theoretical frameworks that underpin the development and flexibility of Enterprise Architecture artefacts yields certain findings regarding the manner in which design theories for Information System Design Theories (ISDT) should be delineated and validated. According to Bley (2021), it is essential to explicitly define the states of a system that will be encompassed within a theory when formulating ISDT components. The provided annotations illustrate the direct correlation between these components and the modification of EA artefacts, suggesting a likely presence of uncertainty regarding their life cycle and current condition. It has been contended that the enhancement of ISDT is directly correlated with the magnitude of change that designers expect for their created artefacts (Urbaczewski & Mrdalj, 2006). An additional intriguing inference can be derived through meticulous examination of the characteristics of the modifications that align with these theories, particularly in relation to meta-requirements (Cameron & McMillan, 2013). The theories substantiate the notion that alterations can occur not only in the states of a system, but also in its fundamental structure (Sessions, 2006). One possible approach to conceptualising the various ways in which information systems undergo change is to consider an information system schema or model, which encompasses the system's structure and functions, in conjunction with the different states that the system can assume at different points in time. When considering the evolution of an information system, it is important to examine changes in both its model/schema, which refers to its fundamental structure and functional capabilities, and its state and relationships, which pertain to the system's transitions from one state to another over time (Bley, 2021). While the relationship between EAF models and its validation is a topic of interest in the field of Information Systems (IS) design theory, it is equally important to acknowledge the impact of changes in artefact relationships on the system's state. For a system to possess the ability to modify its structure, it is necessary for the system to exhibit a reflective capability that can be traced through associations.

Other studies have emphasised the diverse levels at which IS/IT and EA artefacts can be crafted, as well as the manner in which these artefacts can be perceived as occupying a position within IS design theories along a spectrum that spans from artificial, fully designed artefacts (Goethals et al., 2006; Urbaczewski & Mrdalj, 2006). The changeability properties exhibited by IS/IT artefacts are recognised as a direct result of the dynamic nature of the business environment and strategy. Different forms of changeability have been examined, incorporating research from various unrelated fields such as Information systems theory, kernel theories, and IS/IT design theories (Urbaczewski & Mrdalj, 2006). In recent years, there has been a significant increase in the recognition and interest surrounding Enterprise Architecture within both professional and scholarly communities (Cameron & McMillan, 2013). This aligns with the belief that the application of EA principles can greatly enhance the comprehension of the dy-

namics within organisations and the business environment. Nevertheless, the primary focus of research in the field of enterprise architecture (EA) has predominantly revolved around the creation and design of artefacts, with comparatively less emphasis placed on the evaluation of the models' quality (Lankhorst & Lankhorst, 2013). Few researches carried out to explore the challenges associated with Enterprise Architecture validation identified Critical Success Factors (CSF) that can facilitate the alignment between the business vision, business requirements, and information systems (Zhang et al., 2018; Bley, 2021). Enterprise Architecture is commonly understood as a methodology that aims to identify the crucial elements of an organisation and their interconnections, with the intention of achieving desired business goals (Kotusev, 2018). The current focus in the field of enterprise architecture is primarily on its development and modelling, as evidenced by the works of Zachman (2003), The Open Group (Kotusev, 2018) and Lankhorst & Lankhorst (2013). However, there has been a recent increase in attention towards the quality and assessment aspects of EA, particularly through the use of maturity models and assessments (Bley, 2021). The maturity models commonly rely on qualitative analysis, as noted by (Schneider et al., 2014; Calhau et al., 2021), primarily due to their simplicity. The concept of maturity in enterprise architecture pertains to an organization's ability to effectively oversee the process of creating, implementing, and sustaining architecture that encompasses multiple perspectives (Zhou et al., 2020). Commonly, the perspectives taken into account encompass business, information, systems, and technical architecture. This is demonstrated by the utilisation of the Federal Enterprise Architecture Framework (FEAF), the Department of Defence Architecture Framework (DoDAF), and the Systems Engineering Assessment Methodology (SEAM) (Zhang et al., 2018). The purpose of these maturity models is to systematically evaluate the progression of enterprise architecture (EA) from its current state to its desired future state, and from a broader conceptual level to a more specific level of implementation. This approach represents the most definitive method of conveying the excellence of EA. However, there has been a lack of empirical studies addressing the questions surrounding the definition of a high-quality in the context of EA (Sessions, 2006). Furthermore, the notion of critical success factor (CSF) has been regarded as desirable characteristics in evaluating the effectiveness of enterprise architecture models, serving as indicators of the key areas that require exceptional performance in order to achieve success (Schekkerman, 2004; Kotusev, 2018). This statement pertains to the necessity of assessing the performance status in various areas of specification at each milestone, in order to validate the attainment of desired outcomes in specific key indices. The concept of Critical Success Factors (CSF) has been widely embraced in various domains of project management, and it has also generated considerable interest for research within the context of Enterprise Architecture (EA). One limitation in utilising CSF in conjunction with EA is the potential for challenges in attaining a high-quality EA model if the measurable indices associated with CSF are not accu-

rately identified and implemented. The aforementioned challenges will be examined in the following sub-sections.

This following subsection provides a comprehensive overview of commonly used enterprise architecture frameworks and their respective capabilities. A comprehensive analysis of the methodologies and a critical evaluation of their limitations are presented in this paper. The discussion includes multiple facets, including validation, structure, scope, and adaptability. This article provides an overview of numerous EA validation techniques, such as maturity matrices, reference models, architecture content framework, balanced scorecard, and capability test methodology. The article also provides an analysis of the challenges and critical success factors associated with enterprise architecture model validation. This includes the dissemination of their terminology and concepts, operational framework, procedural methodology, model representation, ability to monitor and verify, regulatory compliance, corporate ethos, evaluation, and analysis parameters.

3. Review of Enterprise Architecture Frameworks

Several contemporary architectural frameworks are presently employed to resolve specific organisational requirements or issues. Despite the possibility of overlap between frameworks, as well as similarities or distinctions in certain aspects, they provide a method for implementing and integrating the fundamental components of an organisation.

3.1. The Zachman Framework

Zachman Framework (ZF) is widely regarded as a foundational model in Enterprise Architecture (Zachman, 2003). It is based on the fundamental principles of classical architecture and offers an exhaustive set of perspectives for describing complex enterprise systems. The Information Systems Architecture (ISA) framework for Enterprise Architecture is by nature limitless and generic. This utility facilitates the categorization of expansive and exhaustive representations of enterprise architectures, thereby facilitating the evaluation of corresponding architectural configurations. It has been suggested that the Zachman Framework provides a mechanism for organising architectural artefacts such as design documents, specifications, and models based on their support and design. Schekkerman (2004) proposed a structure based on complexity and value addition. This discussion presents an alternative, composition- and structure-based analytical perspective for commonly used enterprise architecture models. The purpose of this review is to provide a comprehensive comprehension of their validation capabilities and to support the approach advocated within.

Several methodologies have been identified to resolve the wide variety of EAFs in use today. Enterprise architecture frameworks include the Zachman Framework, The Open Group Architecture Framework (TOGAF), Gartner Enterprise Architecture Framework (GEAF), Federal Enterprise Architecture Framework

(FEAF), Generic Enterprise Reference Architecture and Methodology (GERAM), Systemic Enterprise Architecture Methods (SEAM), Dynamic Architecture (DyA), Integrated Architecture Framework (IAF), ISO's RM-ODP, ISO/IEC/IECE Standards, and Department of Defence (DoD) Standards (Cameron & McMillan, 2013). Initial research indicates that the fundamental concepts, composition, relationships, instruments, and methodologies for combining elements from select frameworks have the potential to constitute a viable, effective, and congruent organisational classification system, as defined by a variety of interpretations. The frameworks listed above are ZF, TOGAF, FEAF, DoDAF, and SEAM (Schekkerman, 2004). The ISO/IEC/IEEE Standards are regarded significant because they provide guidance on the suggested method for describing the architecture of complex systems. The Zachman Frameworks addressed comprehensively and appropriately the elements of strategy, modelling, the entire EA process, methods and techniques, standards, and tools that facilitate the harmonisation and implementation of the diverse elements that make up the Enterprise Architecture in the enterprise. Moreover, they demonstrate consideration for objectives and incentives.

However, implementing the Zachman Framework is a difficult and extensive endeavour, primarily due to the complex cellular structures and large number of cells involved (Riwanto & Andry, 2019). Despite the fact that certain cells can be successfully modelled using established and structured methodologies, other cells are not amenable to such modelling. In actuality, the modelling of specific cells within the ZF remains a challenge for scientists. In particular, there is a paucity of established modelling language for accurately depicting the involved technical infrastructures. The Zachman framework lacks comprehensive coverage of essential aspects of EA modelling, such as a systematic approach for developing an architecture and guidance on evaluating the applicability and effectiveness of an architecture (Schekkerman, 2004). Moreover, the intercellular relationships between the constituents of the framework are completely disregarded. The use of heterogeneous modelling techniques to populate individual cells, along with their respective sub-details, makes it impracticable to identify similarities or commonalities between cells. Therefore, delineating the relationships between cells becomes a difficult task. The ZF is predicated on the principle of separating the organisation into discrete and distinct entities. According to the Zachman Framework, there are six distinct perspectives, each of which corresponds to a specific role: planner, proprietor, designer, builder, programmer, and user (Schekkerman, 2004). This strategy does not prioritise the cultivation of diverse EA perspectives that account for the concerns of various stakeholders. The inability to achieve symmetry or alignment is due to the absence of hierarchical levels among the rows that distinguish the perspectives. The ZF addresses contemporary concerns including security, governance, validation, artefact orientation, and change management. The dynamic nature of businesses renders the ZF framework's prescriptive capacity inadequate due to its inherent

flaws. Scholars have argued that despite its popularity and extensive acceptance by multinational corporations, the ZF lacks scientific validity because it is founded on subjective and untested observations (Goethals et al., 2006). Due to the multitude of tools available for representing structural components, the implementation of validation at ZF is challenging. It is challenging to establish a consistent relationship between all objects due to the inconsistency of component descriptions across the framework's various layers.

3.2. The Open Group Architecture Framework

TOGAF is an architectural framework that is developed and maintained by The Open Group (TOG). The current framework is based on the Technical Architecture Framework for Information Management (TAFIM), which was developed by the United States Department of Defence in 1995. Multiple iterations of TOGAF have emerged over time, resulting in a framework that is progressively more comprehensive and adaptable. TOGAF's widespread adoption as a method for designing, planning, implementing, and governing enterprise information architecture can be attributed to its structural maturity and reliance on effective, modularized, and standardised existing technologies. The TOGAF framework has been designed with four distinct levels that are intended to encompass the various facets of Enterprise Architecture, including Business, Application, Data, and Technology (Sessions, 2006). TOGAF consists of explanations of an Architecture Development Method (ADM) and is associated with other methodologies defined in its Architecture Content Framework (ACF), Enterprise Continuum (EC), TOGAF Reference Models, and a Capability Framework, among other enhancements. Their respective online platforms provide access to additional TOGAF-related information and the most recent advancements.

However, there are disadvantages associated with the use of TOGAF. During implementation, one such endeavour involves attempting to execute each phase, deliver each artefact, and establish all repositories in accordance with TOGAF (Kotusev, 2018). To maximise the creation of tangible business value, which is a critical success factor, TOGAF places a heavy emphasis on making choices and adapting the framework to the specific context. The perception that TOGAF is overly technical and focused on the production of models in numerous disciplines is an additional limitation. To facilitate effective communication with stakeholders, architects need models, technology, instruments, languages, and deliverables, among other resources. However, it is notable that TOGAF does not provide comprehensive documentation production guidelines. According to the available literature, the resource under consideration provides few prescriptive document templates (Sessions, 2006; Bley, 2021). Concerning validation, it has been suggested that while TOGAF integrates with the ACF to articulate a content metamodel that defines all potential architecture building block types, the ACF may lack the necessary adaptability to accommodate the various organisational contexts. The ACF's representation of the entire organisation may be con-

sidered excessive in terms of the quantity of information conveyed. To accomplish optimal communication with stakeholders and participants, it is essential to present architecture content in perspectives that address the unique concerns of each interest group. The Architecture Content Framework has been criticised for its inability to validate, quantify, and communicate the effects of implementing The Open Group Architecture Framework.

3.3. Federal Enterprise Architecture Framework

The Federal Enterprise Architecture Framework includes a comprehensive taxonomy comparable to that of the Zachman Framework and an architectural process comparable to that of The Open Group Architecture Framework. The Federal Enterprise Architecture Framework (FEAF) and the Zachman Framework cooperate in three of the six fundamental perspectives, namely the “what,” “how,” and “where” divisions. However, the remaining three perspectives—“who,” “when,” and “why,” are not adequately considered. In contrast to the ZF, which is associated with three main aspects, these three collaborations exhibit an additive nature in terms of their respective constraints (Bley, 2021). In other words, the restrictions imposed by the rows above have an effect on the rows below, whereas the opposite may not be true. In the absence of exhaustive cell modelling, the additive character of the Federal Enterprise Architecture Framework entails a risk of generating erroneous assumptions. Through the implementation of five Finite Element Analysis (FEA) reference models, the Federal Enterprise Architecture Framework is pursuing the standardisation of a common language. Excluding models, the aforementioned references are a collection of interconnected resources designed to facilitate interagency examination and the identification of redundant investments, deficiencies, and opportunities for collaboration. According to some sources, the reference architecture provides an exhaustive depiction of key elements of the Federal Enterprise Architecture in a uniform and coherent manner, thereby promoting effective communication, coordination, and partnership across diverse political jurisdictions (Bley, 2021). However, after evaluating the five Finite Element Analysis reference models in terms of their validation proficiency, it was determined that the Federal Enterprise Architecture Framework possesses an inordinate amount of adaptability. The freedom given to federal agencies to define their own EAF through the use of preferred methods, work products, and tools (Urbaczewski & Mrdalj, 2006) renders the uniform validation of the EAF impossible and impractical. Consequently, it can be inferred that the FEAF and its Reference models are subject to change and not relevant to all domains.

3.4. Systemic Enterprise Architecture Methods

Systemic Enterprise Architecture Methods (SEAM) is a collection of methodologies designed to facilitate strategic thinking, promote alignment between business and IT, and aid in requirements engineering. SEAM’s distinctiveness relies

in its capacity to combine general system thinking principles with discipline-specific methods (Zhou et al., 2020). Compared to alternative frameworks, SEAM is able to establish connections between diverse disciplines of study by utilising systemic principles that are shared. This allows for the systematic representation of business, organisational, and IT concepts via a universally shared modelling ontology. The aforementioned advantage derives from a subject's capacity to assimilate specific knowledge through the use of shared terminology and problem-solving techniques from the various integrated disciplines (Kotusev, 2018). Golnam et al. (2014) provide an exhaustive explanation of the SEAM family of methods. SEAM has been criticised for its narrow focus on functional analysis, which prioritises cost and security over other essential dimensions such as technology, business conduct, and knowledge and information management (Schneider et al., 2014). In addition, SEAM prioritises the characteristics of constructed functional models over the modelling process's skills and procedures. In this context, the use of disparate modelling tools to design its architecture only serves to exacerbate the complexities involved. In contrast to numerous alternative frameworks and methodologies, SEAM provides an exhaustive evaluation of the environment using the Reference Model for Open Distributed Processing (RM-ODP) approach. The objective is to develop a meticulous ontology for system modelling that can effectively incorporate the entire enterprise architecture (Calhau et al., 2021). One argument in favour of the SEAM methodology is that it permits the concurrent modelling of business, operational, and IT aspects using the same concepts and principles. The contextual modelling of processes is intricately intertwined with the modelling of behaviour, segmentation, and objectives.

SEAM is frequently used in project scoping processes. Despite the hierarchical structure of Enterprise Architecture Frameworks that facilitates cross-sectional analysis of various layers and aspects, SEAM's taxonomy does not prioritise technology (Calhau et al., 2021). Golnam et al. (2014) is a prominent figure in the development of SEAM, and his article and work are extensively cited. It does not, however, provide a comprehensive discussion on the validation of SEAM-created models. The only mention of SEAM is its iterative nature, which permits the model to be adapted to reflect changes within the organisation. Users can be utilised to evaluate the model's hypotheses in order to accomplish model validation and testing. Agievich et al. (2013) conducted a case study using the SEAM methodology to investigate the implementation of an enterprise architecture methodology for business-IT alignment. The study centred on the perspectives of adopters and developers and involved determining the extent of relationships between constructs and formulating intensity indices for each construct using a questionnaire instrument. Thus, the validity of SEAM was impacted by these factors. This is comparable to the use of the balanced scorecard methodology. Golnam et al. (2014) introduced a problem structuring method (PSM) known as "Value Map" in a study involving Golnam et al. (2014) in order to authenticate

the SEAM's output artefacts. As a supplement to the Supplier-Adopter-Relationship taxonomy within the SEAM framework, a Value Map was created. The objective is to facilitate the comprehension, analysis, and formulation of strategies for value creation and appropriation in service-oriented systems. An empirical study was also conducted to determine the effectiveness of the Value Map in SEAM (Calhau et al., 2021). The objective of the study was to demonstrate that the Value Map can aid business practitioners in understanding and analysing customer value, customer value creation, and value capture processes. The study's findings contradict its intended purpose, as they indicate that the Value Map functions only as a visual representation of concepts associated with value creation and acquisition, and not as a means of validating model artefacts (Riwanto & Andry, 2019).

3.5. Department of Defence Architecture Framework

The Department of Defence Architecture Framework (DoDAF) is an established architecture framework intended for use by the Department of Defence (DoD) of the United States (Kotusev, 2018). The system is structured based on perspectives and incorporates a wide variety of system architecture frameworks. In addition, it provides a visualisation infrastructure that facilitates the development and documentation of the primary armaments and information technology systems utilised by the United States Department of Defence. Despite its primary concentration on military systems, the DoDAF framework has broad applicability and utility in numerous sectors, including private, public, and voluntary domains worldwide (Schekkerman, 2004). The DoDAF Meta-Model (DM2) functions as the ontology foundation for the DoDAF meta-model. Conceptual data models, logical data models, and physical exchange specifications are included. This fundamental concept supports the DoDAF framework by outlining the categories of modelling components pertinent to each perspective and their interconnections (Cameron & McMillan, 2013). The DoDAF framework provides a unique perspective on the creation of artefacts that facilitate the visualisation, comprehension, and integration of an architectural description's extensive range and complexities. These artefacts are created using various techniques, such as tabular, structural, behavioural, ontological, pictorial, graphical, probabilistic, and conceptual (Cameron & McMillan, 2013). DoDAF is ideally adapted for addressing the integration and interoperability challenges of complex systems because it provides a shared framework for understanding, comparing, and integrating architectures across organisational and multinational boundaries.

DM2 has established a validation strategy for its models, which consists of defining vocabulary constraints for linguistic context and describing DoDAF models pertinent to the six fundamental processes. This statement outlines the semantics and format that govern the exchange of federated Enterprise Architecture data among architecture development, analysis tools, and architecture databases within the Community of Interest (COI) of the Department of Defence

(DoD) Enterprise Architecture (Agievich et al., 2013). In addition, it has been noted that DM2 facilitates the identification and comprehension of enterprise architecture data through the use of DM2 information categories, precise semantics, and linguistic traceability (Cameron & McMillan, 2013). Consequently, it is generally acknowledged that while DM2 provides a method for attaining semantic accuracy in architectural descriptions and facilitates the integration and analysis of heterogeneous architectural descriptions, it does not validate the model's artefacts. The Department of Defence Architecture Framework (DoDAF) incorporates a substantial quantity of comprehensive data in practise. The lack of clarity between the planning and development phases results in substantial duplication of effort on the part of both the planning and development teams. A significant number of professionals lack a comprehensive understanding of DoDAF's scope, including the formalisation of models, levels of interoperability, and applicable validation or reference architecture types.

4. Enterprise Architecture Validation Techniques

The effectiveness and quality of EA depend on a variety of interconnected factors. The efficacy of validating Enterprise Architecture is contingent upon the degree of dedication and effective communication among stakeholders, facilitated by the utilization of a common language (Cameron & McMillan, 2013). Furthermore, it has been observed that the clear delineation of enterprise architecture objectives in accordance with business objectives can enhance the acquisition of support and approval from senior management and other stakeholders within the organization. The proposition has been made to employ metaphorical measures in the context of Enterprise Architecture modelling in order to identify critical success factors that can be used for validation purposes (Oussena & Essien, 2013). Despite assertions made by advocates of the Enterprise Architecture Framework methodology regarding their adherence to established principles, a differential analysis exposes a notable absence of a validation approach for the artefacts generated by many EAFs (Regev et al., 2013). Reference models are commonly employed in a variety of contexts, including TOGAF, FEAF, DODAF, TOGAF and FEAF. In isolation, reference models do not offer annotations or correlations for output artefacts (Schneider et al., 2014). Instead, they function to authenticate the attainment of objectives rooted in subjective dimensions that hold significance within the realm of implementation. In order for a reference model to demonstrate systemic and pragmatic attributes, it is crucial that it incorporates a clear and comprehensive explanation of the problem it intends to tackle, as well as the concerns of the stakeholders who seek the resolution of said problem. The following sections outline contemporary methodologies for validating enterprise architecture and the limitations associated with them.

4.1. Maturity Matrices

Maturity matrices function as a valuable instrument for assessing the level of

enterprise architecture progress within organizations. Often, it consists of a comprehensive list of essential areas that encompass various aspects within the enterprise architecture. Within the domain of Enterprise Architecture, researchers have proposed multiple levels of system maturity governance. In specific cases, it is crucial to enhance the current frameworks, as exemplified by the implementation of the Architecture Content Framework by the TOG consortium (Regev et al., 2013), or to integrate principles that facilitate validation, as illustrated by the utilization of assessment frameworks with reference models in the FEAF. Maturity matrices have been employed in multiple instances of enterprise architecture implementations, and have been assigned different names such as the Dynamic Architecture Maturity Matrix (DyA MM), Capability Maturity Matrix (CMM), Risk Maturity Matrix (RMM), and Test Maturity Matrix (TMM) (Goethals et al., 2006). While some maturity matrices have been characterized as straightforward, many others have been regarded as complex, permeable, and inappropriate for the purpose of validating Enterprise Architecture in various contexts. However, an important constraint of maturity matrices relates to the subjective nature of prioritizing essential evaluation criteria that are linked to the identified objectives and issues of the organization (Ansyori et al., 2018). The application of the maturity scale as a quantitative measure for assessing progress in graduation may present difficulties in determining its accuracy. In certain instances, management may exhibit a tendency to prioritize the resolution of immediate issues over the strategic pursuit of high-value objectives and adherence to constraints. In specific instances, a noteworthy iteration possessing substantial strategic significance may be temporarily halted in order to reallocate its resources towards a comparatively less significant matter. The purpose of this endeavor is to optimize the rate of advancement on the maturity matrix (Golnam et al., 2014). It has been suggested by scholars that the assessment of enterprise architecture EA maturity often relies on cognitive perspectives that are derived from hypothetical compilations.

In summary, maturity matrices used in enterprise architecture validation are evaluation instruments that measure and evaluate the level of enterprise architecture maturity within an organization. These matrices offer a structured framework for evaluating various aspects of enterprise architecture, including processes, methodologies, governance, and technology adoption. The purpose of maturity matrices is to identify the organization's enterprise architecture capabilities' strengths, weaknesses, and development opportunities. Using these matrices, organizations can evaluate their progress and make informed decisions to improve their enterprise architecture practices and better align them with their strategic objectives.

4.2. Reference Models

The Reference Model (RM) is a widely adopted abstract framework that is utilized by a variety of businesses (Goethals et al., 2006). It consists of a collection

of interconnected, well-defined concepts that facilitate effective communication between Enterprise Architecture Frameworks. The reference model comprises all Enterprise Architecture Framework constituent elements, from business functions to system components (Schneider et al., 2014). It functions as a reference point for communicating concepts between components and a means of indicating their interdependencies. Specifically, a Reference Model is accountable for defining the criteria for the model's constituent elements and their interrelationships. In the process of validating Enterprise Architecture, a Resource Model is utilized, which includes a collection of business metrics that are essential for establishing a well-rounded scorecard (Urbaczewski & Mrdalj, 2006). The assignment of each measurement to specific business positions facilitates the assignment of responsibilities for the production of high-quality output. Some have argued that Reference models are inadequate for validating EA models, despite the fact that RM is a popular method among EA practitioners for assessing enterprise maturity. They do not provide an exhaustive description of the archetypes that can arise in an EA environment. In addition, it is important to note that RM's list of entity types and constraints must adhere to a Reference Architecture.

In summary, Reference Model is a standard blueprint or framework that provides a common language and structure for describing and organizing the components and relationships within an enterprise architecture. It serves as a guide to assure organization-wide consistency, interoperability, and alignment of IT systems, processes, and data. Typically, a reference model defines standard concepts, principles, and best practices, facilitating the evaluation and substantiation of an enterprise architecture against industry standards and benchmarks. By utilizing a reference model, organizations are able to evaluate their architecture's conformance with established standards and identify areas for refinement in order to achieve more efficient, effective, and integrated business processes and systems.

4.3. Content Architecture Framework

TOGAF is an example of an architectural strategy that includes content categorization. The ArchiMate Enterprise Architecture Modelling Language was designed to facilitate the TOGAF Architecture Development Method (ADM). It illustrates and depicts the various architecture domains with an all-encompassing architectural approach (Vicente et al., 2013). TOG released ArchiMate to address the need for validating and evaluating EAF's effectiveness. This revision incorporates tools for modelling motivation and assessing the Architecture Content Framework. Motivational concepts are used to represent the underlying intentions and justifications that guide the development or modification of enterprise architecture. Motivations play a crucial role in shaping and restricting the design process, allowing the model to be validated (Kotusev, 2018). According to TOG, the ACF incorporates the models that define a typical EA, as it in-

cludes EA artefacts and definitions, processes, standards, and guidelines for artefact development, in addition to the associated modelling notations that facilitate mutual understanding and cooperation. The essence of ACF is a concept that defines a distinct content specification that conforms to the four principal dimensions of its associated modelling language, ArchiMate (Lankhorst & Lankhorst, 2013). The selection and customization of these dimensions, which include business, application, information, and technology, are driven by particular factors. Although numerous enterprise architecture frameworks continue to use maturity matrices as a pragmatic method for evaluating gaps between business vision and capabilities, TOGAF's Architecture Content Framework represents a significant advancement.

In summary, the ACF was developed with the purpose of offering a systematic metamodel for architectural artefacts, along with a comprehensive checklist of architectural deliverables. According to The Open Group, it is asserted that the utilization of consistent architecture building elements by Architecture Content Framework enables the seamless integration of architectural work products and offers a comprehensive open standard for the definition of architectures (Lankhorst & Lankhorst, 2013). However, the lack of integration between the evaluation methodology and ArchiMate Core has prevented the establishment of a comprehensive verification of this assertion. The Architectural Compliance Framework is not the sole tool utilized by TOGAF for assessing the congruence between the business vision and capabilities. Maturity matrices are also pertinent in this context.

4.4. The Balanced Scorecard

The Balanced Scorecard is a commonly employed strategic planning and management framework within the domains of business, industry, and government. The primary objective of this process is to ascertain that the operational endeavors of a business are aligned with the overarching vision and strategic direction of the organization. The Balanced Scorecard is commonly extended to include the improvement of both internal and external communication, as well as the monitoring of organizational performance in relation to strategic objectives. The effectiveness of the Balance Scorecard in assisting planners in determining the appropriate metrics and actions to be taken has been a topic of discussion (Schneider et al., 2014). The Balanced Scorecard is commonly structured into four discrete perspectives, specifically learning and growth, business process, customer view, and strategy mapping, with the purpose of effectively communicating its intended message. As a result, the process of establishing measurement metrics for it involves analyzing collected data related to each of these perspectives (Calhau et al., 2021). The Balanced Scorecard is a valuable instrument for organizations to elucidate their financial vision and strategy, and proficiently convert them into implementable measures. Various frameworks make use of a checklist for the balanced scorecard. While these approaches may achieve a cer-

tain level of comprehensiveness during the initial phases of implementing Enterprise Architecture, their main focus is on comparing the expected functionalities or outcomes of the desired process, rather than verifying the models or artefacts of the Enterprise Architecture Framework (Klein & Gagliardi, 2010). The checklist functions as a valuable instrument for identifying potential domains in which to develop evaluation criteria, metrics, and methods for the evaluation of enterprise architecture frameworks from diverse perspectives. It offers a structured framework for assessing business conduct.

Nevertheless, the Balanced Scorecard is subject to various limitations. In the realm of practical implementation, the evaluation of both the process and outcome involves the integration of numerous assumptions (Qurratuaini, 2018). It is commonly assumed that individuals possess a thorough understanding of the terminologies used. Furthermore, it is presupposed that the management has effectively devised the strategic direction of the organization and that the business plan aligns suitably with this strategy. However, empirical evidence has shown that these assumptions are not without error (Vicente et al., 2013). Another constraint that must be considered is the requirement for a significant number of participants in order to ensure comprehensive representation across all domains (Chapurlat & Braesch, 2008). The underlying justification for this phenomenon frequently originates from a conscious endeavor to meet the anticipated requirements of every individual involved and capitalize on their extensive knowledge and skills. The Balanced Scorecard methodology has been criticized for its potential susceptibility to subjectivity due to its heavy reliance on qualitative analysis.

In summary, the Balanced Scorecard has been deemed unsuitable for model validation due to the perceived absence of clear correlation between model artefacts, relationships, and motivation (Armour & Kaisler, 2001). There has been a contention regarding the limited applicability of the balanced scorecard approach in effectively validating scenarios that encompass traceability within the domain of enterprise architecture and the interdependencies among various model artefacts (Franke et al., 2009). Academic scholars have proposed that the effectiveness of a scorecard in achieving strategic goals may be diminished when financial and non-financial objectives are not included. Maintaining a continuous update of the balanced scorecard is crucial in order to ensure its alignment with the evolving dynamics of the organization. Smaller organizations may encounter constraints in terms of time, resources, and labour, which may hinder their capacity to generate proportional visible added value.

4.5. Capability Test Methodology Approach

To enhance the effectiveness and efficiency of the Department of Defence Architecture Framework (DoDAF) through capability appraisal and assessment, new enterprise initiatives were introduced within the Department of Defence (DoD). The Capability Test Methodology (CTM) was developed with the pri-

mary objective of imparting a vital proficiency in conducting joint capability assessments and evaluations during the entire acquisition life cycle of the Department of Defence Architecture Framework. The accomplishment was facilitated through the utilization of the Joint Test and Evaluation Methodology (JTEM) (Van Grembergen et al., 2004). The main aim of the project was to identify shortcomings, incongruities, and duplications related to testing in a collaborative DoDAF environment. Comprehensive documentation regarding deviations in policy, organizational or resource implementation, and modifications that extend beyond the boundaries of the test is a crucial component of this methodology.

Despite the potential advantages and capabilities of the extended Department of Defence Architecture Framework, certain limitations have been identified that hinder its effectiveness. The use of sporadic and incongruous CTM templates in DoDAF models, which aim to represent important CTM concepts such as joint mission concepts, measurement metrics for metamodel and model performance, task performance, and goals actualization levels, has been a topic of contention (Van Grembergen et al., 2004). Therefore, the taxonomy demonstrates inherent structural inadequacies. Another significant deficiency that has been identified relates to the suboptimal integration of assessment and evaluation metrics in the relevant Department of Defence Architecture Framework model and the CTM test plan test matrix. Observation has been made regarding the disparities that exist between the model design techniques and the Department of Defence artefacts, despite recognizing the usefulness of DoD Architecture Framework (DoDAF) artefacts in the development of the CTM's Joint Mission Environment (JME) (Gerber et al., 2020).

Summarily, the Department of Defence Architecture Framework Capability Test Methodology Approach is a structured approach used in enterprise architecture validation, particularly in the context of defense and government organizations. It aims to assess the capability of an organization's enterprise architecture to support its mission requirements effectively. However, discrepancies have been observed when comparing the evaluation business rule structures of the Capability Evaluation Metamodel with the data model of the Core Architecture Data Model (Cameron & McMillan, 2013).

4.6. Ontology-Based Validation

Despite the increasing demand for an evaluation approach in ontology development since its inception (Franke et al., 2009) and the existence of numerous methods and tools for ontology transformation and integration, a comprehensive and universal approach for addressing this issue within the context of EA models has not yet been proposed. Due to the anticipated significance of ontologies as a key component in the use of other technologies, such as cloud computing, big data, and change management, the development of semantics capable of managing interconnectivity of semantics has attracted considerable attention. The lack of universally accepted and exhaustively defined criteria for evaluating

and validating ontologies has impeded the transition of ontological systems from cryptic symbolic structures to reliable enterprise postulates. Diverse studies aimed at proposing a formal methodology for ontology evaluation and substantiation have identified three primary measures (Agievich et al., 2013). Typically, the ontologies presented as graphs fall into three categories: structural measures, functional measures, and usability profiling measures. The first pertains to the structure of the ontology, while the second and third pertain to the intended application of the ontology and its components, and the annotation level of the contemplated ontology, respectively (Fischer et al., 2010). The use of ontologies to validate model structures and their ramifications is widely recognized as a means of preserving the domain-specific quality of the model. The fulfilment of domain-specific criteria in the model signifies the domain-specific incentive.

As noted by Schneider et al. (2014), the evaluation of ontology in praxis is typically executed as a diagnostic task that relies on ontology descriptions for models. This study proposes a transmutation of EA models into ontologies, as no prior research has proposed this particular method for profiling EAF for validation purposes. The depiction of models used in ontology validation includes explicit information about the model artefacts and is of uttermost significance when evaluating the ontology's effectiveness based on its structure, role, and function. In many cases, the quality of an ontology is determined by the hierarchical arrangement of the parameters used to describe it (Goethals et al., 2006). When validating ontologies, developers consider a number of factors, including the capability of ontological categories to be classified based on specific criteria, the correlation between the elements of ontology categories, and the formalization of the visual model using a standardized notation that is understandable to stakeholders. Through the comparison of structures, objects, and compliances, this facilitates the identification of differences in the model, particularly among dissimilar composites. The use of heuristic techniques broadens the principles. This allows for the deduction of inferences from defective or incomplete patterns.

In summary, a common method for evaluating the quality of ontology artefacts is the construction of a quality model, which is typically formulated in the early phases of ontology development and serves as a guide for the duration of the project (Oussena & Essien, 2013). Comparable to the synthesis or derivation of a quality model from motivation is this method. In this context, the development of ontologies entails a transformation from EA models that emphasize particular parameters during the phase of development. This transformation method includes validation attributes that facilitate testing. In the form of patterns, the ontology would include both qualitative and quantitative measurements of diverse aspects. In the context of EA, objectives and constraints are recognized as crucial factors. According to Goethals et al. (2006), the quality of an ontology can be measured along two dimensions: precision and comprehensiveness. The preponderance of conventional programming testing techniques, such as consistency testing, integrity testing, validation testing, and redundancy

testing, can be used to evaluate the validity of the ontology.

4.7. Enterprise Architecture Validation Ontology

The majority of ontology evaluation literature focuses on generic functionality dimensions rather than structural composition. Ontology refers to a formal representation of knowledge or concepts within a specific domain. It defines the relationships and interactions between different entities and serves as a common vocabulary to express ideas. Informal verification of the correctness of intended model design and logic underlying a metamodel and model with regard to motivation or constraints is deemed inappropriate within the context of enterprise architecture (Sessions, 2006). To ensure exhaustiveness, the theoretical principles regulating validation rules in EA outline two fundamental levels of validation (Bley, 2021). These levels represent the active and passive forms. Enterprise Architecture Model Validation Ontology refers to a formal representation of the concepts and relationships involved in validating and ensuring the correctness and effectiveness of enterprise architecture models. Such ontology includes definitions for various elements, validation methods, evaluation criteria, and relationships between them.

In summary, the implementation of these regulations within EA improves the quality of its artefacts and fosters a more unified validation methodology applicable to all levels of the architecture. The division of classification into two distinct levels facilitates the incorporation of parallelism in the validation procedure, resulting in a thorough and unbiased examination. The visual representation of data across these strata employs immediate adjacent connections that enable coherent and analogous perception of conceptualizations throughout the model iterations that result.

5. Critical Success Factors for Enterprise Architecture Validation

In order for an enterprise architecture model to be considered of high quality, it is essential that it conforms to established business requirements, motivation, and governance processes that provide a structured framework for its design and validation. The concept of Critical Success Factors relates to the identification of fundamental characteristics that need to be validated in order to ensure the quality of an Enterprise Architecture model (Urchold & Gruninger, 2004). The statement emphasizes the importance of effectively addressing specific factors in order to achieve a high level of maturity in Enterprise Architecture. In the present context, the term “maturation” refers to the organizational ability to proficiently manage the advancement, achievement, and recognition of constraints within enterprise architecture models in alignment with business goals. In the domain of EA, the Critical Success Factors approach places significant emphasis on the utilization of measurable metrics that can be effectively employed to ascertain the achievement of successful validation. Hence, this paper aims to provide a

more comprehensive examination of the aforementioned challenges and essential factors for achieving success.

5.1. Communicating EA Terms and Concepts

While some practitioners have established a shared and precise lexicon of terminology and concepts (Uschold & Gruninger, 2004; Ylimäki, 2008), it is essential to establish a distinct and documented definition of the fundamental architectural concepts, as well as the sources from which the model is derived. This is necessary due to the frequent complications that arise as a result of inadequate communication or delineation of implemented plans and tactics. Additionally, it has been observed that the communication channels used and the temporal parameters regulating the communication in relation to the architecture are frequently not specified.

5.2. Model Driven Approach

Examining business processes and applying a model-driven methodology comprise the prevalent method for developing EA. Establishing the relationship between enterprise architecture initiatives and the overarching business strategy (Sessions, 2006) is the most important step in ensuring the validation of EA. The central issue is determining how the business strategy and its associated requirements are incorporated into the architectural framework development. Accurate delineation of the structure, establishment of perspectives, and gradations of conceptualization rely heavily on the identification and documentation of the commercial requirements for architectural design.

5.3. Architecture Process for Model validation

This concept requires the application of suitable methodologies for EAF validation. Morganwalp & Sage (2004) identified a significant issue pertinent to the validation of enterprise architecture models and associated artefacts. Identifying a flexible analytical approach that can accurately represent predetermined perspectives of an enterprise architecture while taking into account germane frameworks, limitations, and theories is the primary challenge. In many instances, there is a paucity of guidance regarding the formulation and documentation of architectural decisions. There is need to document support processes including procedures, directives, prototypes, and other tangible validation artefacts.

5.4. EA Models and Artifacts

The comprehensive definition and documentation of models and artefacts are essential in effectively communicating architecture to a wide range of stakeholders, as they play a significant role in conveying the intended meaning accurately. Models play a crucial role in effectively conveying a comprehensive and well-structured depiction of an enterprise (Morganwalp & Sage, 2004). Therefore, it is imperative to proficiently convey these models to pertinent stakeholders in a

manner that is both lucid and comprehensible. This entails emphasizing the pertinent viewpoints, composite objects, and interdependencies within the models. The models should include both the current state (descriptions of how things currently are) and the future state (descriptions of how things should be) in alignment with the established principles and standards of architecture.

5.5. Enterprise Architecture Traceability

The task of the Enterprise Architect is to ensure complete traceability from the analysis of requirements and design artefacts to the stage of implementation and deployment. Formal definition of traceability entails the capacity to establish a connection between requirements and stakeholders' justifications, which can be linked progressively to corresponding design artefacts, code, and test cases. Traceability is a crucial aspect of Enterprise Architecture that facilitates numerous activities, such as change impact analysis, compliance verification, constraints testing, and requirements validation. Traceability is frequently interpreted differently within the context of Enterprise Architecture. Practitioners frequently view enterprise model traceability as evidence of alignment with business objectives (Fischer et al., 2010). This requires end-to-end traceability to business requirements and processes as well as a matrix connecting system functions to operational activities. It also entails referencing multiple artefacts, such as services, business processes, and architecture, and establishing a link between a technical component and a business objective. This evaluation facilitates the recognition of misalignments and the need for corresponding adjustments. Unfortunately, establishing and maintaining traceability, particularly in the form of a matrix, is a laborious endeavor. In addition, the traces have a tendency to degrade and become inaccurate over time if they are not appropriately date/time stamped or versioned.

5.6. Enterprise Architecture Governance

Depending on the specific context in which they are being discussed, governance and management have been defined in numerous ways. Typically, in academic discourse, "governance" refers to the management and organizational aspects of architecture (Chapurlat & Braesch, 2008). However, it can also include the governing principles an organization uses to make decisions, set priorities, allocate resources, and supervise its architectural processes.

5.7. Organizational Culture

In order to achieve an optimal organizational and cultural fit, it is essential to consider the organization's culture when developing an EA (Schneider et al., 2014). Changes in culture are often unavoidable, especially in the development and implementation of Enterprise Architecture. The concept of organizational culture incorporates a variety of components, such as the attitudes of stakeholders towards change, the communication environment, technological advance-

ments, and economic dynamics. Organizational structure has a significant bearing on the impact of an enterprise architecture's success. Some authors have argued that it is essential to transform the perception of Enterprise Architecture from a mechanism for auditing or regulating to one that can effectively guide both business and IT decision-making processes (Goethals et al., 2006; Kotusev, 2018). A trusting organizational culture is conducive to transparent communication, cross-functional collaborations, impartial assessment, and productive feedback, thereby enhancing the enterprise architecture framework's overall effectiveness.

5.8. Assessment, Evaluation Criteria and Scope

According to Uschold & Gruninger (2004), the assessment and evaluation of Assessment, evaluation criteria, and scope are essential components in the validation and quality assurance of enterprise architecture models. By considering assessment, evaluation criteria, and scope, organizations can ensure that their EA models are well-structured, aligned with business goals, and capable of driving effective decision-making for the organization's growth and success. These elements play a crucial role in the validation and continuous improvement of enterprise architecture to meet the evolving needs of the organization. The validation of ontology encompasses the determination of the boundaries of the domain of knowledge. This is achieved by verifying the consistency of the ontology with an established knowledge repository.

Furthermore, the aforementioned feature not only improves the dependability of validation during the design phase but also facilitates its reusability by incorporating relevant data within the model. In contrast to alternative methodologies that adopt a black box approach and heavily rely on external rational agents for validating EA models, the proposed method utilizes an ontology-based strategy that incorporates an explicit knowledge base containing the internal structure of the model (Ansyori et al., 2018). The primary objective of the data sets is to extract a representative sample from the model's knowledge repository. By accurately summarizing the internal structure of the model, this approach establishes a standard against which anticipated outcomes or incentives can be assessed. The validation boundary also facilitates the assessment of the model's usability profiling. This is because the ontology's knowledge repository includes relationship dimensions and annotations that are critical for traceability.

Depending on the objective of the design, the scope and criteria for validation can range from the motivation to guide the EA model to the maintenance of the metamodel or even an abstract meta-metamodel. Validation via ontology might not always establish the complete connotation and traceability as conveyed by their respective metamodels and frameworks. The effectiveness of this methodology is contingent on the willingness to perform extensive formalization prior to transformation, with the goal of preserving the semantics and underlying principles of domain-specific constructs and translating them into unambiguous

depictions of their concepts in the ontology.

6. Findings and Discussions

The findings and results derived from a comparative analysis of validation semantics and heterogeneous model frameworks yield valuable insights into the efficacy and appropriateness of various validation methodologies. The methodology employed involved a methodical examination of various approaches and techniques utilized to validate models within the framework of integrating heterogeneous models. The examination uncovers a wide array of validation semantics employed in various heterogeneous model frameworks, encompassing formal methods, heuristic techniques, and rule-based validations. The research also conducted a comprehensive analysis of the different validation methods utilized in the chosen frameworks, emphasizing their respective advantages and disadvantages. The evaluation of performance metrics, including accuracy, scalability, and efficiency, was conducted to assess the practicality of each framework in real-world scenarios. This study identified and analyzed the best practices employed in the validation of semantics and model integration. By examining successful frameworks, this research provides valuable insights into the strategies employed to effectively address the challenges associated with these processes.

In summary, the comparative analysis yields a thorough evaluation of diverse validation semantics and heterogeneous model frameworks. This research enhances the overall comprehension of model-driven engineering and its influence on the integration of intricate systems. The analysis findings can be utilized to enhance the validation processes, improve the quality of models, and optimize model-driven projects in diverse domains and industries. These findings can be utilized by researchers, practitioners, and decision-makers to make well-informed decisions when choosing validation techniques and frameworks that are most suitable for their particular needs and project prerequisites.

7. Conclusion

The validation of enterprise architecture frameworks is essential to ensure their effectiveness, relevance, and practicality in real-world organizational settings. This study offers insights into potential strategies that can be employed to achieve congruence between Enterprise Architecture and organizational objectives. The process of validation is essential in ensuring that the enterprise architecture framework is in accordance with the particular objectives, vision, and mission of the organization. Through the process of validation, organizations are able to ascertain whether the framework in question effectively caters to their specific requirements and aligns with their overarching strategic goals. A verified enterprise architecture framework establishes a robust basis for making well-informed decisions. This facilitates stakeholders in making informed decisions regarding investments in information technology, implementation of technology, improvements in processes, and allocation of resources. The process of validation en-

hances the qualities of resilience and adaptability. The implementation of a validated framework guarantees that the IT and business capabilities of an organization are capable of effectively responding to and accommodating dynamic and uncertain environments. The process aids in the identification of possible risks and vulnerabilities, thereby allowing organizations to take proactive measures in addressing these challenges.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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