Enterprise Architecture

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From the Editor

Digital transformation demands a thorough understanding of technology and impacts. Enterprise architecture (EA) allows companies to model and assess their IT systems, business processes, and distributed services. Authors Ricardo Perez-Castillo, Francisco Ruiz, Mario Piattini, and I dive into EA and state-of-the-practice technologies for EA modeling. As usual, a case study provides direct insight from an ongoing project. I look forward to hearing from both readers and prospective column authors about this column and the technologies you want to know more about. —*Christof Ebert*

ENTERPRISE ARCHITECTURE (EA) allows companies to proactively assess and adjust policies and systems to achieve target business goals that monetize relevant business disruptions. The notion and modeling technologies of EA originally stem from the 1980s. With growing digital transformation needs, today EA is widely used in industry as a technology-driven, continuous-change process for companies and our entire society.[1] It allows companies to model IT and thus evaluate change needs, including traditional IT, business processes, cloud services, and distributed embedded systems. Therefore, it facilitates the growing needs of converging systems, such as IT services and distributed embedded systems, as in automotive electronics.[6]

EA is a coherent set of principles, methods, and models used in designing and comprehending the structure of a company, including their business processes, information systems, and IT infrastructure.[2] It aligns business and the IT landscape in companies concurrently by managing the increasing system complexity. EA management (EAM) provides a way to holistically understand any system's fundamental organization through all embodied elements, such as people and their motivations, processes, services, applications, IT resources, and so forth. In this way, EA increases IT efficiency while continuing business innovation.

EA Frameworks and Modeling Languages

Several EA frameworks and standards have recently emerged and achieved relevance. TOGAF[3] has been widely adopted in the market—currently 80% of Global 50 companies and 60% of Fortune 500 companies employ it—so it can be considered the de facto standard. TOGAF provides the architecture development method (ADM), which is a methodology for the iterative development of EA. Aside from the TOGAF framework, The Open

Group released ArchiMate,[4] a modeling language that represents different architectural information; see "Example of the ArchiMate Model." It allows EA modeling from different viewpoints, in which the position within the cells in Figure 1 highlights the stakeholders' concerns. ArchiMate considers two dimensions: layers and aspects. Core layers represent the three levels at which it is possible to model an enterprise in ArchiMate, i.e., business, application, and technology. *Aspects* refers to the active structure, behavior, and passive structure. The full framework in ArchiMate 3 also includes additional layers for strategy, physical and implementation/migration elements, and a fourth aspect with motivational (why) elements.

Apart from TOGAF, other EA frameworks include DoDAF or MODAF (provided as a defense architecture framework by defense agencies) and the Zachman architecture framework, among other proprietary frameworks and modeling languages used by certain EAM tools or in specific domains.

Benefits of EAM

Companies that implement an EAM can achieve several benefits,[5] which can be classified in benefits for business managers and those for IT practitioners.

Business managers receive the following benefits.

- EAM improves the decision-making process. Since EA models can represent an enterprise's layers and their elements' modularly, managers make decisions in the context of a whole rather than an isolated part.
- Agile adaptability occurs because EAM facilitates the knowledge acquisition that is

necessary for changing systems and adopting new components. In other words, it is a tool for digital transformation.
- There is business process improvement and reengineering since EAM can be used to improve the operating procedures by modeling and understanding business processes.
- EAM handles the impact of staff turnover. EA models can gather knowledge from the staff and then business solutions from third-party organizations are consistently compliant with the current EA models.

The following benefits are for IT and software (SW) practitioners.

- EAM is a tool for managing complexity. It improves the scoping and coordination of software and services, as well as information systems projects in general, by depicting interdependencies in a usable way. New approaches to address the issue of making software, as DevOps or micro services, have important advantages but the tail of the coin is the increased complexity. This is the reason that software development organizations, departments, or teams must increasingly consider EAM.
- EAM can be employed to detect technical resource oversight and, therefore, can identify and remove redundancies.
- EAM controls and shares knowledge modularly. Thus, EA models can be visualized across different levels, which offers different views for different stakeholders according to their concerns while other irrelevant elements are abstracted.

- Since this kind of resources and systems can be aligned to business strategies and are better placed for responsiveness, IT/software visibility improves.

EAM Tools

EAM includes EA modeling, although it is not limited to this activity. EAM also handles the maintenance and continuous improvement of EA models, different kinds of analysis, and a plan for moving forward toward a desired future state of the organization, among other important activities. Companies can address all of these elements because the proliferation of tools covers most of these activities. The following are some common, critical capabilities that must be assessed in any EAM tool.

- *Frameworks and standards*: EAM tools can support different kinds of frameworks and EA methodologies. Thus, they often provide best-practice workflows to enable rapid deployment and implementation. However, many enterprise architects must implement their own workflows. In addition, it is important to consider the available modeling languages that EAM tools support, as well as the repository metamodel used, to manage all the EA information.
- *Modeling*: This capability refers to the extent to which the tool allows modeling of all the concepts and elements depicted by the supported frameworks and standards. Usability makes the difference. Additionally, there are two approaches, integration and single point of truth, regarding the information base the EAM modelers use. It depends on whether or not data is collected from a variety of sources.

EXAMPLE OF THE ARCHIMATE MODEL

The following is a real case study. We supported an IT company in establishing DevOps and migrating their previous enterprise architecture (EA). Figure S1 shows the underlying ArchiMate model to support DevOps in an organization. To address the complexity, which is standard in current software development, EA incorporates the viewpoint mechanism that
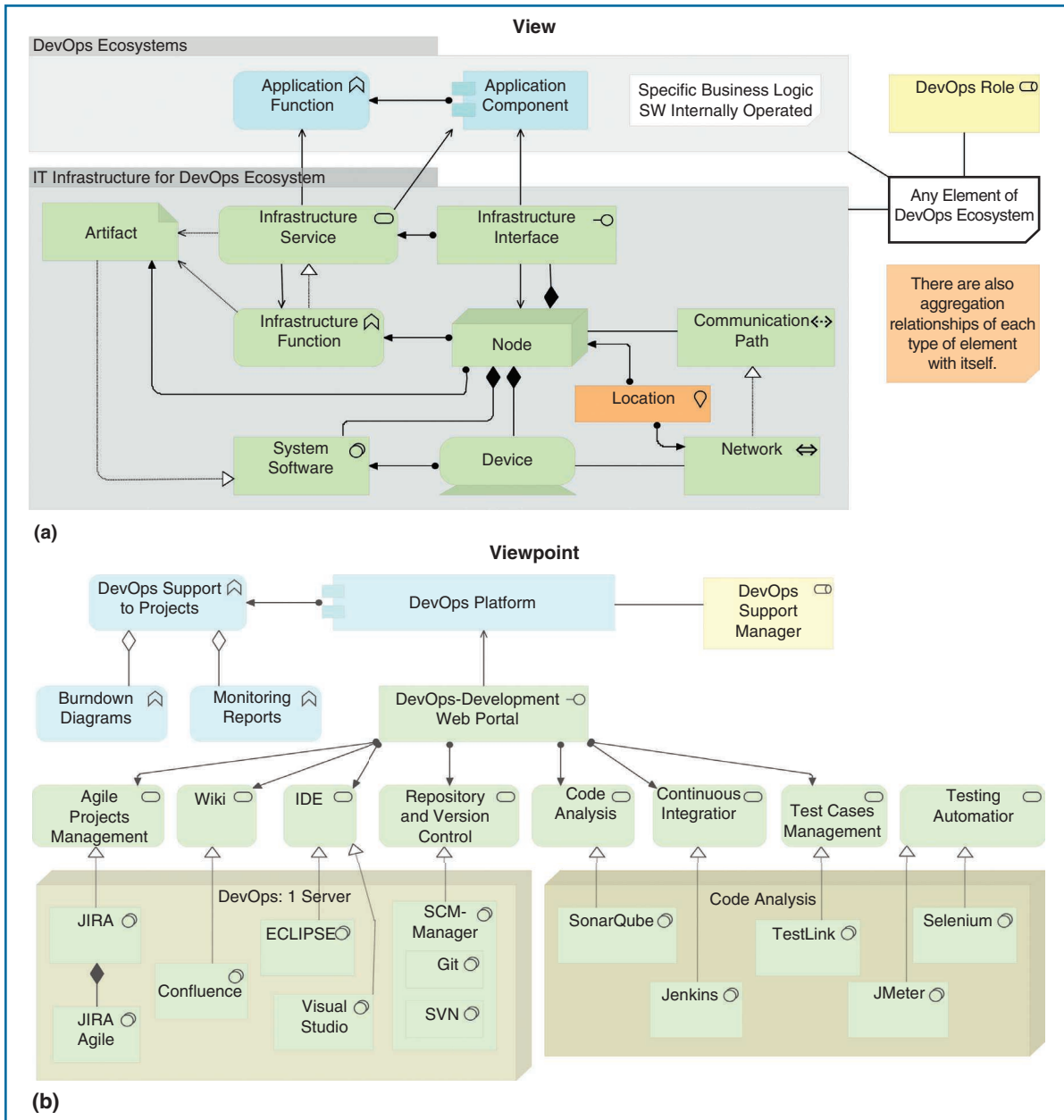

FIGURE S1. An example of the ArchiMate model representing DevOps in an organization. (a) The view and (b) corresponding viewpoint. IDE: integrated development environment; SCM: software control management; SVN: subversion.

EXAMPLE OF THE ARCHIMATE MODEL (CONT.)

is based on the divide and conquer principle, which offers each stakeholder only the aspects that are of interest to their concerns. The top part of Figure S1 shows an ArchiMate 3 model with the architecture to support DevOps in an organization. This model is based on the viewpoint shown at the bottom part of Figure S1, which was devised thinking in a DevOps team, integrating elements of development and operations.

Figure S1 presents relevant elements in every layer of the organization according to those depicted in Figure 1. Notice that the graphical notation of ArchiMate takes

many elements from other well-known modeling languages, such as Unified Modeling Language or Business Process Model and Notation (BPMN). It is relevant to note that ArchiMate is not an alternative to UML or BPMN but an umbrella to integrate UML, BPMN, and any other kind of specific model. For instance, BPMN is the language suitable to represent the internal details (white box) of processes while ArchiMate has been considered to represent the things around each process (black box), expressed in relationships with roles, services, organizational structures, strategies, motivations, data, or applications.
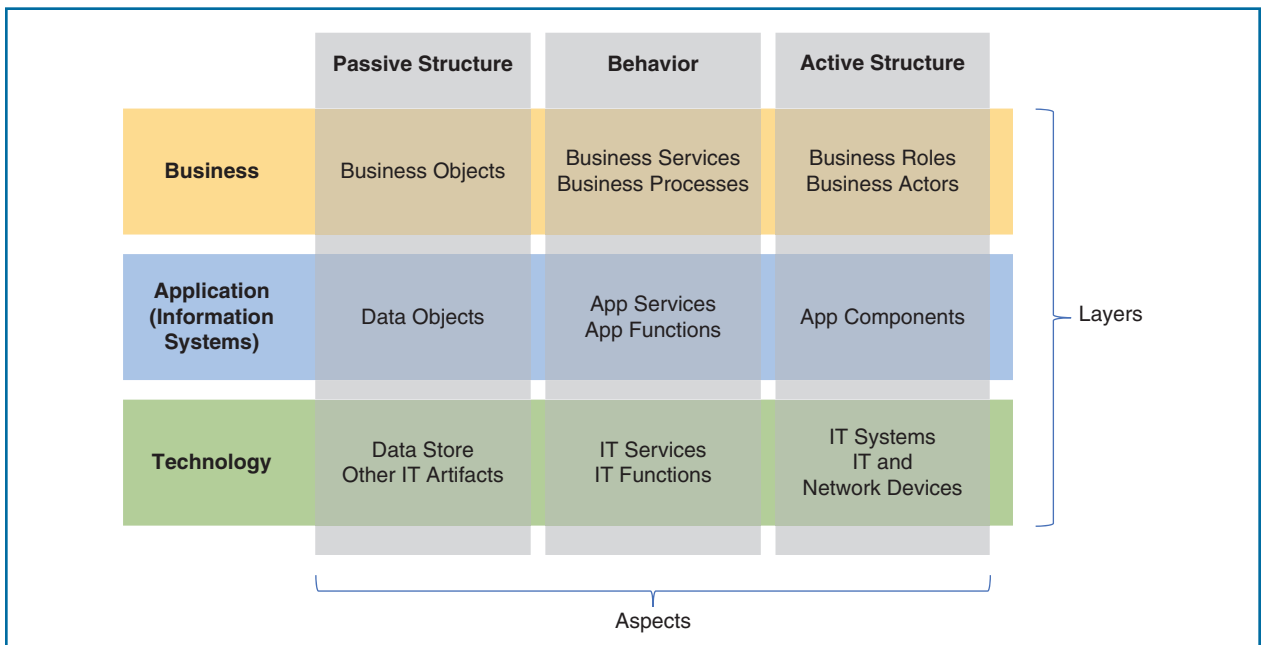
	Passive Structure	Behavior	Active Structure	
Business	Business Objects	Business Services Business Processes	Business Roles Business Actors	⎫
Application (Information Systems)	Data Objects	App Services App Functions	App Components	⎬ Layers
Technology	Data Store Other IT Artifacts	IT Services IT Functions	IT Systems IT and Network Devices	⎭

Aspects

FIGURE 1. The ArchiMate 3 core framework (adapted from The Open Group[4]).

- *Visualization*: This refers to efficiently showing adequate information in an acceptable way to the suitable people. An EAM tool should address enterprise cartography challenges, which are based on the following problems that traditional cartography deals with:
  - representing (map) a real-world object, i.e., an enterprise in EAM

- eliminating irrelevant characteristics of the mapped object to the purpose, which is essential to represent the enterprise in a relevant and useful manner
- orchestrating the elements of the map to best convey its message to its audience according to their specific needs and expectations.
- *Decision analysis*: Models and EA information analyses

are useful for making informed decisions. In this sense, both visualization and collaborative communication capabilities contribute to the success of such decision-making processes.
- *Administration and configurability*: There are two main approaches regarding the functionality provided by the tool out of the box: preconfigured

Table 1. EAM suites.

Tool	Frameworks and standards	Usefulness for enterprise architects	Usefulness for IT/software practitioners	Pricing
Alfabet EAM	• TOGAF/ArchiMate to guide the EA practice, as well as Zachman • Other industry-specific frameworks (e.g., TM Forum or DoDAF)	• Identifies cost drivers to reduce operational expenses and keeps track of IT investments to assure business growth • Master planning provides the IT organization with a clear overview of the relevant aspects of the IT landscape in order to understand how strategic decisions will and should impact the IT's tactics and direction over time • Establishes key elements of EA governance, encompassing enterprise-wide policies for the design, implementation, and automation of EA processes	• IT strategy and planning process • Align IT structures with operational objectives and processes to ensure that IT transformation • Three deployment options: cloud, SaaS, and web	Pricing has to be requested from commercial department
Archi	• ArchiMate (native support) and aligned with TOGAF	• Provides a canvas-modeling toolkit that can be used to design and create reusable canvas templates • Since it is open source, it is free although the support is limited	• Integration with other tools is limited but is based on the Eclipse platform, and several plugins are available to expand the main functionality	Free, OSS
Avolution Abacus	• Over 100 industry-standard modeling frameworks and notations (e.g., TOGAF, ArchiMate, PEAF)	• Offers chart road maps for IT and business systems and processes • Can assess scenarios using algorithms and tradeoff analysis techniques (discrete event, Monte Carlo, and so on) • Advanced visualization models	• Provides a REST API that simplifies external integrations significantly • Integrates different data sources limited	Three pricing plans
BiZZdesign Enterprise Studio	• Strongly focuses on TOGAF, ArchiMate, BPMN, and UML, among others • Native ArchiMate 3 support for consistent modeling	• Strong support and integration with TOGAF ADM • Supports motivational diagrams • Business design capabilities and analyses as well as support for decision making with customizable views and dashboards • Extra features such as transformation road mapping, capability mapping, and risk assessment	• Provides coherent data governance structure with roles and responsibilities linked to your architecture and organization • Some diagrams can be generated automatically	Pricing has to be requested from commercial department
BOC Group ADOIT	• TOGAF and ArchiMate • BizBok, BIAN • COBIT and ITIL	• Support for strategic company planning • Support for cloud migration, which helps to identify and analyze the most valuable IT assets, cost drivers, and the information, technology, and security risks of migrating to the cloud	• Continuously optimize your application and technology portfolio	Pricing has to be requested • Available as a product or SaaS • ADOIT: community edition free
Dragon1	• Proprietary notation but supports TOGAF (ADM) and ArchiMate among others	• Advanced modeling and visualization features • A set of different web-based tools to support decision management, EA, project management, risk management, governance, compliance, IT portfolio management, and business process analysis	• Rationalize applications in a smart way using an application landscape diagram • Advanced importing/exporting functionalities between different EA repositories	Two versions: US$390–3,980/year (individual) US$45,000/year (company)
EAMs	• Customized architectural representations and navigation paths; can extract information from BPMN, UML, ArchiMate, and IDEF, among others	• An EA tool on its own that integrates and harvests operational information to enrich architecture analysis and decision making • Live architecture: see the architecture of the organization as emerging from ongoing into foreseen projects through historization • Support enterprise cartography	• Architectural views must be generated automatically, since "handmade" models do require a major effort to update and refer to a single point in time, especially where software practitioners are not skilled enough in EA	Pricing has to be requested from commercial department. Four different plans.
Essential	• Specific based on the Protégé Ontology Project. Available custom-built Protege extensions	• Provides a flexible and extensible means to generate the views on the model captured using the essential modeler • Allow organizations to define and publish custom views and reports to meet their individual needs	• A Java-based web application that runs on any standard Java server platform • Uses a knowledge repository optionally supported by an RDBMS	Free, OSS
Future tech systems Envision VIP	• DoDAF, pragmatic EA, TOGAF, UML, BPMN, Zachman	• Integrates several kinds of models, not only EA models • Envision your future: "to be" models show the investment required and benefits to be gained by re-engineering	• Practitioners can apply filters and rules to manage and analyze models using techniques such as spreadsheet-like matrix analysis, powerful report writing tools, and SQL queries • Models and other information can be exported to other productivity applications and databases	Pricing has to be requested from commercial department • Available as a product and SaaS

Continued

Table 1. EAM suites (cont.).

Tool	Frameworks and standards	Usefulness for enterprise architects	Usefulness for IT/software practitioners	Pricing
IBM Rational Software Architect	• Proprietary; ArchiMate is supported through third-party plugins	• Allow enterprise analysis for making fast, value-based decisions • This is not only an EAM tool but a general-purpose tool	• Solutions for DevOps and continuous engineering • Provides integration with many other products, especially those from the IBM ecosystem	US$500–2,200/year
Leanix	• Framework and standard independent, but TOGAF can be implemented with Leanix	• Offers the possibility of following the TOGAF ADM methodology and support an agile version of that methodology	• Integration with many other software engineering tools (e.g., GitHub, GitLab, Jenkins, Confluence, Pentaho, Tableau, SAP)	On demand: has to be requested, two pricing plans Advanced features: US$5,700/month
Modelio	• TOGAF • UML, BPMN • SoaML, SysML	• Open source editor supporting TOGAF with an extension mechanism • Not an EAM tool itself, it is a general-purpose modeling tools that supports EA modeling	• Flexible extension mechanism • Scripting language support (Jython)	Free, OSS
Mega Hopex EA suite	• DoDAF, NAF, TOGAF, ArchiMate; different products released for every framework/standard	• Creates graphical representations of ADM phases to use as a guideline for architecture projects • Maps TOGAF ADM steps and deliverables to the corresponding concepts, reports, and diagrams • Complies with the TOGAF architecture content framework	• Helps practitioners to design and implement agile IT systems, streamlined business processes, and optimized operating frameworks aligned with their business strategies • Advanced reporting features	Pricing has to be requested from commercial department
Orbus software iServer	• TOGAF and ArchiMate • DoDAF, MoDAF, FEAF • UML • IT4IT • ITIL	• Leverage predefined meta models for major standards such as TOGAF and ArchiMate accelerating adoption • Communication improved since architecture views, reports, and dashboards can be published out to key stakeholders and the wider business	• Manages the IT Value Chain through the IT4IT Reference Architecture standard • Import and synchronize data via REST API from CMDBs or other modeling tools and systems. • Integration with Office and Visio and other Microsoft tools	Pricing has to be requested from commercial department
Planview Enterprise One	• TOGAF certified; however, it uses a proprietary metamodel	• Supports searchable technology lifecycles and visualizations; EA teams can proactively plan and prioritize technology updates and standardization across the enterprise • Definition of how to achieve the digital strategy with road maps that connect programs, projects, capabilities, IT, and investments • Advanced analysis features for business-capability planning, scenario modeling, and impact analysis	• Manages application portfolios to achieve business goals • Visualizes the complex relationships between business capabilities and technologies • Interactive analysis combined with comprehensive modeling reveals dependencies between applications and IT • Collaboration with stakeholders to create technology plans	Pricing has to be requested from commercial department
Sparx enterprise architect	• TOGAF, ADM, ArchiMate • BPMN • UML	• Not a specific-purpose EAM suite • Provides dynamic model simulation that allows architects to verify the correctness of behavioral models and gain a better understanding of how a business system works • Traceability of EA model elements with code	• An integrated software-development environment with a built-in EA modeling tool • Source code round-trip • Many templates for generating code from models, and reverse engineering from several programming languages • Navigation between models and code	Four versions: US$229–699/license (standard) US$299–899/license (floating)
QualiWare X	• EA³, Zachman, TOGAF, OIO EA, FEAF-II, DNDAF, ArchiMate, EDML, UML, BPMN, DMN	• Provides an overview of how the organization executes its strategy and makes complex processes clear for the employees who perform them • Supports risk management and handling uncertainties related to executing the business strategy	• Manages application lifecycles and creates overviews of where and for what applications are used • Estimates the total cost of ownership, return on investment, and business value of IT • Identify redundant IT and make well-informed strategic decisions on technology investments	Pricing has to be requested from commercial department
Visual Paradigm enterprise edition	• TOGAF, ArchiMate • PMBOK • UML, ER, DFD	• Not an EAM tool itself, it is a general-purpose modeling tools that support EA modeling but it supports TOGAF ADM methodology and is ArchiMate compliant • High usability of the graphical modeler	• Supports project-management lifecycle guide-through with agile development features • Integrates the EA repository with other application elements in UML diagrams	Subscription: US$89/month Perpetual: US$2,000

API: application programming interface; PEAF: pragmatic enterprise architecture framework; BIAN: Banking Industry Architecture Network; COBIT: Control Objectives for Information and Related Technologies; ITIL: Information Technology Infrastructure Library; IDEF: integration definition; REST: Representational State Transfer; RDBMS: relational database management system; SQL: structured query language; OSS: open source systems; SaaS: software as a service; SoaML: service oriented architecture Modeling Language; SysML: systems Modeling Language; NAF: NATO Architecture Framework (In a recursive way. NATO, North Atlantic Treaty Organization); MoDAF: Ministry of Defence Architecture Framework; FEAF: federal-enterprise-architecture-framework; IT4IT: information technology for information technology; EA: enterprise architecture; OIO EA: Enterprise Architecture Method for The Danish Ministry of Science, Technology and Innovation; DNDAF: Department of National Defence/Canadian Armed Forces Architecture Framework; EDML: Everywhere Displays Markup Language; DMN: Decision Model and Notation; PMBOK: Project Management Body of Knowledge; ER: entity-relationship; DFD: data flow diagram; CMDB: configuration management database.

(EAM solutions) and customization (EAM platforms).

Table 1 collects some of these EAM tools by providing the following: name, frameworks and standards supported, benefits for enterprise architects, stronger points for IT/software practitioners, and pricing information. The tools collected in Table 1 were selected according to several industrial reports provided by well-known consulting companies (e.g., Gartner or Forrester, among other) and our personal experience using some of these EAM tools, which are presented in alphabetical order.

Hints for IT and Software Practitioners

EA allows IT and software practitioners to manage the complexity of IS and technologies and to align these systems/technologies with their organization's strategy. Thus, IT and software development teams should integrate people who are skilled and competent for planning and designing EA, as well as for deploying and maintaining it, with an EA profile. This new EA profile for IT/software practitioners should consider the following points.

- EAM can be used for consolidating certain applications and technology in organizations. As a result, technology-management costs can be reduced or at least controlled.
- An appropriate EAM implementation can improve technology-management planning, as well as the effectiveness of IT investments, since these concerns are aligned with the company's strategy.
- EA is an additional tool to manage an application portfolio. Thus, EAM contributes by improving

quality and reducing the risk of software delivery. In a broader point of view, IT asset portfolios can be also managed through a single repository in an EAM tool. Aside from applications, this portfolio also includes infrastructure, IT resources, and services.

- EA improves engagement, analysis, and communication skills. Practitioners can realize and understand the business concerns supported (and aligned with) the applications they developed or IT infrastructures they managed on a daily basis.
- Since EAM is a mechanism for making relevant decisions at the strategical level, IT/software practitioners should be able to model certain EA views from the IT/software assets they manage in an inductive way (e.g., with reverse engineering techniques) while these models are aligned with the overall business strategy.

The Convergence of EA and Embedded IT

The traditional division between IT and embedded systems is disappearing. Increasingly, embedded systems and devices have over-the-air connectivity for software upgrades, feature activation, and cloud services such as predictive maintenance. However, IT solutions connect to devices and create the Internet of Things (IoT). Embedded electronics, such as micro devices with sensors and actuators connected through the IoT, facilitate ubiquity. Data analytics, cloud storage and services, convergent interactivity and cognition, augmented reality with visualization and simulation, pattern recognition, machine learning, and artificial intelligence facilitate a convergence of IT and embedded systems.[1]

Underlying these, we identify enabling methods, techniques, and tools, such as agile scaling and blockchain, to ensure security and trust in distributed transactions, as well as microservices and open application programming interfaces that support software architectures.

EA adoption has been increasing; it can be used for planning, aligning, controlling, and organizing system complexity, which is a growing problem for IT and SW project managers. The increased complexity is due to the convergence of various trends.

- There is a broad spectrum of IT infrastructure that supports IS (e.g., cloud, IoT, edge computing, and so forth).
- The internal structure of SW systems has increased with more layers and new components types or architectural paradigms, such as SOA and microservices.
- Customers are demanding more, in less time and with fewer problems, which has led to work in different ways (e.g., Lean, Agile, and DevOps).

These new software architectures and IT devices cannot be developed in isolation, without paying attention to business goals and enterprise drivers, which makes EAM critical. Actually, the new version 3 of ArchiMate has been extended with a physical sublayer,[4] with which it is now possible to model and manage all kinds of cyberphysical system elements, such as embedded software or IoT sensors, in an integrated way. For example, it can be used for full traceability between all of the components of a car, hardware, software, and other purely physical non-IT applications.

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The convergence of enterprise IT and embedded systems can best be observed in the fast-changing automotive market. A modern car has 50–120 embedded microcontrollers and is connected by various external interfaces to a variety of cloud and infotainment technologies. Onboard software is in the hundred-millions of lines of code range and growing exponentially. Automotive software product lines and variants are among the largest and most complex in all industries. It is said that the automobile is rapidly becoming a "computer on wheels." Automotive original equipment manufacturers are implementing cars with next-generation production processes and vehicles with connected embedded sensors and actuators to obtain better intelligence and control. They adopt information and communication technology workflows from their IT systems to each single car. From a user experience perspective, the evolution is even more drastic. People have been buying cars for decades, but they now want mobility services. The car per se has ceased to attract users. This is best seen at the latest OOP IT conference (#OOPmuc), where global market leader Volkswagen boasted that they are hiring the people who want to get rid of cars. 𝕊𝕋

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