The Digital Diamond Framework: An Enterprise Architecture Framework for the Digital Age

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Abstract—**Enterprise architecture (EA) frameworks of the past have attempted to support the cohesive and comprehensive modeling and documentation of the enterprise, often with a focus on business and information technology (IT). However, the digitalization of enterprises and the complexity of IT have outgrown these matrix box-like frameworks. This paper proposes a digital, holistic, and sustainable EA framework, called the Digital Diamond Framework, to support digitized enterprises in aligning the real EA state with the desired state.**

Keywords- enterprise architecture frameworks; enterprise architecture; enterprise modeling; business architecture; digitalization.

I. INTRODUCTION

Enterprise Architecture (EA) is concerned with comprehensively modeling and documenting the structure and behavior of the business and IT infrastructure of an enterprise in a cohesive way as a set of artifacts in order to communicate, implement change, and develop insights in support of strategic business planning and management science. Historically, EA emerged from a necessity to document information systems for management stakeholders. One of the most well-known EA Frameworks (EAF) is the Zachman Framework, first publicized in 1987 [1]. While one might think that after 30 years the EA area must be mature, Gartner's 2017 Hype Cycle for Enterprise Architecture [2] shows EA and EA Tools within the slope of Enlightenment - not yet in the Plateau of Productivity, and EAFs are in the Trough of Disillusionment.

Currently, enterprises face multiple contemporaneous challenges: 1) A major digital transformation [3] of their industry. While the digitalization rate (digital score) may vary across industries and economies, it is nevertheless impacting business strategies and necessarily EA. As big data, data analytics, business intelligence, and machine learning make inroads into enterprises, improved decision-making capabilities at all levels and across organizational entities empowers employees with new insights and assistance and additional automation. 2) Agility is restructuring internal people-centric enterprise management, processes, and projects to continuously flexible and responsive business forms, accelerating product and service delivery and improving efficiency (e.g., Scrum, DevOps, BizDevOps). 3) Service-networked and mobile software: the IT landscape is rapidly changing from large, siloed, hierarchical, and static deployments to cloud-centric, networked, and containerized micro functionality deployments. Software/data functionality becomes easily reusable and accessible via standard protocols and formats independent of programming language or platform. Its scale can be seen in various "death star"-like microservice network landscape visualizations (see Figure 1)

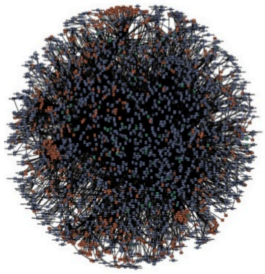

Figure 1. Visualization of microservices at Amazon [4].

In lieu of these major trends, the reality that EA is attempting to comprehensively model, document, and change has become much more complex than in previous decades. The era of siloed functional teams and applications is fading, and a highly networked and integrated digitized era has begun. This challenges currently available EAFs, which were mostly developed before these trends swept into enterprises and typically rely on a simplified box-and-matrix paradigm.

In 2007, Ivar Jacobson reckoned 90% of the EA initiatives he was aware of had not resulted in anything useful, giving big gaps vs. seamless relationships as a primary reason [5]. A 2008 study showed two-thirds of EA projects failing to improve IT and business alignment [6], with the most frequent explanation being that connecting EA to business elements was difficult in practice. Hence, the EA frameworks of the past with their associated paradigms and their models cannot continuously reflect the dynamic enterprise realities, thus they are illusionary, ineffective, inefficient, and no longer viable.

To enable more responsive and agile enterprises with better alignment of business plans and initiatives with the actual enterprise state while addressing the EA needs of digitized enterprises for structure, order, modeling, and documentation, this paper contributes a digitized, holistic, hyper-model EA conceptual framework called the Digital Diamond Enterprise Framework (D^2F), providing a sustainable EA framework for a digital EA future.

Section 2 discusses background material on EA. Section 3 describes the D^2F, which is followed by a conclusion in Section 4.

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II. ENTERPRISE ARCHITECTURE BACKGROUND

EA comprises the structural and behavioral aspects needed for the enterprise to function and their adaptation to align with a vision. It thus covers business (including people), information (data), and technology (IT, hardware and software). EA has been compared to city planning [7], designing in the face of many unknowns.

A. EA Frameworks (EAFs)

EAFs offer structure, associated terminology, and at times processes for EA-related work. Zachman's EAF [1] utilizes a matrix paradigm and has changed over the years, using rows (layers) to address highest level business, then logical to the most detailed technical levels, and columns for the 5W's and H (who, what, where, when, why, how). Many of these EAFs have common ancestors and historical influences. The Open Group Architecture Framework (TOGAF) [8] was first publicized in 1995 and provides a methodology for EA and a boxed architecture. The National Institute of Standards and Technology (NIST) EA Model is a five-layered reference model stemming from the 1980s and formed the basis for the Federal Enterprise Architecture Framework (FEAF) [9]. The Generic Enterprise Reference Architecture and Method (GERAM) [10] is a generalized EAF from the 1990s and focuses on enterprise integration and business process engineering. Most EAFs use a 2D box or 3D cube paradigm in attempting to deal with the inherent complexity.

B. Enterprise Modeling

Modeling abstracts and simplifies an area of interest while maintaining certain its essential characteristics. So, reality is more complex than our models. We model in order to reason or understand within our cognitive limitations and to convey insights to others. Different domains and enterprises have different weightings and expectations as to what and how much, if any, modeling and its associated overhead should occur. The modeling spectrum can span from nothing for small organizations to modeling everything, but usually it is in the area between (see Figure 2). Something is inherently absent and models are imperfect, and manual adjustments may be necessary if the reality changes.

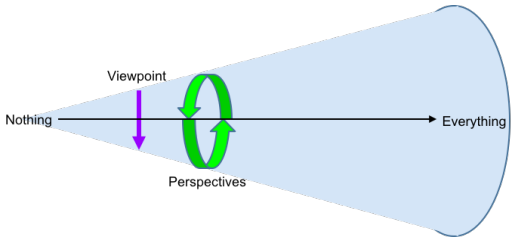

Figure 2. Modeling spectrum.

An international standard for enterprise modelling (EM) and enterprise integration is ISO 19439:2006, which based on GERAM and Computer Integrated Manufacturing Open System Architecture (CIMOSA). It uses a cube paradigm with model phase, model view, and genericity on each axis. As to business modeling, Meertens et al. [11] argue that there is hardly any agreement or standardization in the area as yet.

The reality is enterprise models for dynamic enterprises can become extremely complex and perhaps difficult to maintain, as illustrated in Figure 3 with a CHOOSE semantic meta-model [12] for an SME (small-to-medium enterprise).

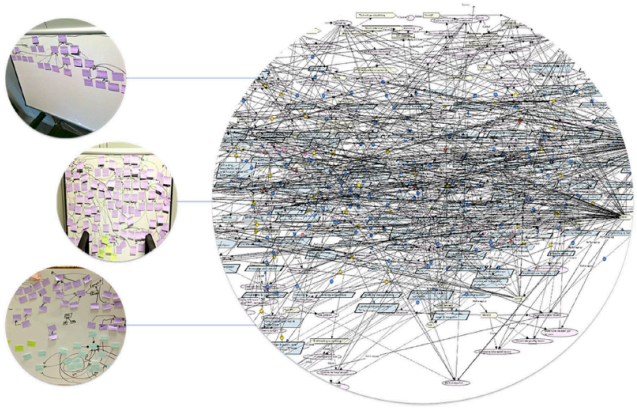

Figure 3. A example CHOOSE enterprise model for an SME, from [12].

C. Related Standards

Related standards in the EA area are ISO/IEC 38500:2008, which deals with corporate governance of information technology. ISO/IEC/IEEE 42010 Systems and software engineering — Architecture description deals with describing system and software architectures. ISACA's COBIT (Control Objectives for Information and Related Technologies) is a good-practice framework for IT management and governance.

D. Summary

John Zachman admitted in 2004 [13] "if you ask who is successfully implementing the whole framework, the answer is nobody that we know of yet." Gartner's 2011 global EA survey showed more than 60 EA frameworks in use, with the most popular being blended followed by homemade [14]. This indicates that none of the current EAFs suffice for enterprise needs, and many were not designed for the new digital enterprise era and lack the ability to leverage its capabilities.

The EAFs and methods mentioned above typically use some layer-and-column matrix and most aspects related to models and views land in a box. This the clean-box paradigm (or syndrome depending on your view). Everything appears nicely modeled, complete, consistent, traceable, and semantically precise. But this apparent harmony is an illusion, the grey areas that cross boundaries or are cross-cutting concerns are not explicitly dealt with. The above EAFs currently lack an integrated digitalized and data-centric concept. They fail to provide real-time dynamic updates and thus reflect stale or inaccurate data. They also require additional manual labor to maintain independent artifact consistency with changing reality or to monitor and detect inconsistencies when they occur since they have independent data sources that are not automatically synchronized.

A new sustainable "out-of-the-box" paradigm for a new era that can deal with digitalization, ambiguity, further IT complexity, and additional automation is needed.

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III. THE DIGITAL DIAMOND EA FRAMEWORK

In the following, the key areas, activities, principles, integrative facets (potentially applicable when applying D²F), maturity levels, and roadmap to D²F are portrayed.

A. D²F Key Areas

Key Areas cluster related facets (concepts or elements) and provide a focus for human thought. In contrast to boxes/levels, here boundaries are intentionally absent, reflecting the lack of boundaries in the digital world, wherein facets can relate to multiple areas. Mind maps can be seen as a useful analogy. Figure 4 shows key areas involved in D²F, with cross-cutting areas shown angled on the left and right:

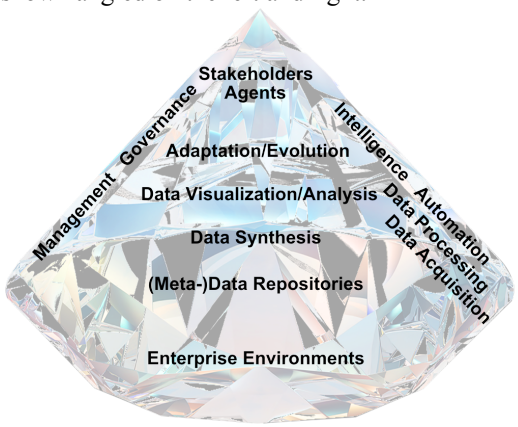

Figure 4. Key areas D²F.

1) Enterprise Environments: comprises all actual human, business, infrastructural, and IT operational objects.

2) (Meta-)Data Repositories: includes all (meta-)data concept repositories in the enterprise from a logical standpoint, reflecting *Enterprise Environments* in a data-centric way in support of higher level data-centric analyses. While such repositories also reside in an *Enterprise Environment*, the focus is support for data acquisition, data processing, and other data-centric higher-level activities.

3) Data Acquisition: involves collecting data and meta-data into *Data Repositories* and making these accessible.

4) Data Processing: includes characterizing, filtering, preparing (e.g., deriving), transforming (e.g., between formats, sorting), and cleansing data, the outputs of which are also stored in *Data Repositories* and hence available to other areas (e.g., automation, synthesis, analysis).

5) Data Synthesis: involves aggregating, clustering, and correlating related or unrelated enterprise data, e.g., for digital key performance indicators (KPIs), dashboards, model conformance, etc. While this area overlaps the previous one, its focus is on determining and structuring aggregates.

6) Data Visualization/Data Analysis: provides data-centric analysis and visualization of data, models, and other EA artefacts for understanding, exploration, and insights.

7) Adaptation/Evolution: includes taking action, responding to issues or concerns, stimulating or commissioning adaptive changes to fix or optimize the enterprise, and creating new initiatives and capabilities that let the enterprise evolve to a new state.

8) Stakeholders/Agents: stakeholders can be viewed as anyone with an interest in the enterprise, and they may have conflicting and overlapping interests and (informational) needs. Agents (human or software) are able to directly effect changes within the enterprise.

9) Automation and Intelligence: automation will increasingly support digital enterprise processes and will leverage data to improve efficiency and effectiveness and is thus explicitly considered. Beyond automation, intelligence utilizes data analysis and machines learning capabilities to assist humans in forming decisions or, via intelligent software agents, directly supporting autonomic decisions in given areas. For instance, automatic real-time adjustment of business product prices based on market movements or IT forecasting of required cloud infrastructure capacities.

10) Management and Governance: involves managing and directing enterprise resources to reach enterprise goals as well as the enterprise governance including controlling, compliance, and assessments at various enterprise levels .

Note that *Key Areas* can overlap (a data or meta-data repository will likely reside in an enterprise environment) and thus may appear redundant or inconsistent, yet this is not problematic and one strength of the D²F paradigm. *Key Areas* may be tailored for a specific enterprise. A prerequisite to a complete implementation of D²F presumes digitalization of EA-relevant areas for any given enterprise. As to scaling, the concept of a connected *D²F Chain (Diamond Necklace)* can be considered for applying D²F within various entities (e.g., divisions) but tied into a larger enterprise organization.

B. D²F Key Principles and Qualities

Key principles and resulting qualities of D²F include:

1) Digitized (digital and networked): data and artifacts are acquired or transformed into a digital and network-accessible form, open and transparent within the enterprise (to the degree feasible from a security standpoint), and preferably retained in some version-controlled repository (database or configuration-management database (CMDB) such as git). Internet-of-Everything and concepts such as digital twins can be used for physical entities to mimic real properties. Standards for data formats and interface access are considered for the enterprise.

2) Meta (self-describing): all (data) elements including artefacts, entities, services, etc. should, as far as feasible, provide (its own) metadata (properties and semantic meaning) that can be integrated in metadata repositories (e.g., federated CMDBs) or searched via metadata networks (e.g., LinkedData), and which can be utilized by data processing and data synthesis. Various technologies such as semantic data graphs, RESTful services, JSON-LD, etc. can be used.

3) Linked: Related networked data and meta-data are (semantically) linked in such a way that related data to some element or concept can be discovered and accessed.

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4) Dynamicity: In an adapting and evolving digital enterprise, all artefacts and enterprise elements (or the digital twins thereof) as well as their relationships are assumed to be dynamic, and configurations are used to "snapshot" a set of element states that can be used in some analysis or communication. Models can be based on functions that transition from simulated to real data rather than static structures detached from external values.

5) Holistic: bottom-up and top-down deep integration of applicable enterprise facets, such that various concepts (e.g., business models, business strategies, policies, architectures) can be tied to various related artefacts, models, operational data, and actual enterprise entities and thus be holistically analyzed across various factors.

6) Hyper-models: embraces many coexistent and co-evolving intertwined models (domain, business, process, software, IT architectures, context), perspectives, viewpoints, and views (not necessarily consistent) supported by data processing. Manual modeling is waning, and automation will also affect modeling, thus we must adapt our tooling and methods towards sustainable integrative modeling. Humans desire simplicity and computers can better deal with complexity and massive data volume, thus a symbiotic relationship should be pursued.

7) Actuality processing (real/continuous/resilient/fuzzy): ongoing data acquisition and processing should be able to continuously access and adjust the data picture to the real live enterprise truth. To have resilient processing (vs. expecting consistency or exact values), data processing should embrace data ranges and the inconsistencies that will occur between data, models (inter- and intra-), reality, etc., and develop (automated) strategies and methods for detecting and working with exceptions, ranges, and thresholds and escalating more serious issues. That may include automated discrepancy monitoring and analysis and criticality weightings based on thresholds, risks, and potential impacts. While data cleansing can remove some of the dirt, rather expect issues to occur and have measures and thresholds in place to detect and govern these and processing that can work with ambiguity such as semantic imprecision.

8) Analytics: data forms the basis for EA decisions. Data-centric processing and analysis capabilities are available for the present, past, and planned enterprise states to determine alignment to expectations. Digital KPIs, dashboards, reports, and visual data analytics enable investigation and exploration of EA-related views, perspectives, viewpoints, and any other factor of interest (X-Factors) to contribute to understanding and insights on various EA factors.

9) Actionable: data is leveraged to support decisions and governance, enabling responsive and predictive adaptation and evolution of the enterprise to a better state.

10) Automation/Intelligence: Data is leveraged for automation to reduce sources of error and improve effectiveness and efficiency. For example, business process management systems and business and IT rules can be utilized. Intelligence via data-centric machine learning is integrated where possible to improve, support, or automate (human and software agent) decision making.

11) Traceability and Logging: mistakes will happen, and people and enterprises can learn from mistakes. To embrace this fact, changes to data, elements, artefacts, and all actions with their associated agents are tracked (and versioned if appropriate), logged, and traced in order to be able to investigate and resolve potential issues that might arise.

C. D^2F Key Activities

Various (ongoing) human and IT activities are involved to apply and maintain D^2F. We use the term activities instead of processes, as processes have a clearly-defined goal and workflow and can be documented with specified artifacts, whereas activities can be agile and integrated where and when needed in whatever agile method is currently being used and done in any order deemed appropriate. They can be recurring and continuous to maintain D^2F capabilities. As shown in Figure 5, key D^2F activities include:

1) Data Acquisition: ensures necessary and desired (meta-)data is collected, characterized, and accessible.

2) Data Processing: ensures data is cleansed, filtered, prepared, and transformed into expected (standard) formats.

3) Data Synthesis: aggregates and correlates data from various repositories for a specific purpose, such as providing data needed for a certain viewpoint or dashboard.

Figure 5. Digital Diamond Framework (D^2F) activities.

4) Data Analysis, Visualization, & Exploration: involves agents (human or software) exploring, forming questions or hypotheses, utilizing various data and visualization analysis techniques from certain perspectives and viewpoints to address the concerns of various stakeholders, developing solutions, detecting opportunities and develop insights.

5) Adapting & Evolving: directing and commissioning change, usually involving the previous activity (4), be it

adjustments to align or to evolve the enterprise, its EA, or its supporting infrastructure. It may utilize effectors available in the enterprise environments and/or human efforts via initiating projects or enacting processes.

6) Modeling & Configuring: involves creating and maintaining (hyper) business, operational, architectural, product and other models (which can be logical in nature) and provide some simplification of some structure of interest and associated properties. These can be for a pre-development, development, or operational stage. While maintaining models is burdensome, incorrect models are worse, thus the basis for models should be tied into current enterprise data. Configuring involves (re)arranging enterprise elements in various ways to optimize certain desired properties.

7) Testing & Simulating: involves testing and/or simulating hypotheses and models with potential real or generated data on virtual or real staged or production elements. The goal is to develop an improved basis for decisions affecting elements of the EA, and might include concepts such as a delivery pipeline. These activities become more important as the systems increase in complexity. Without the data from these activities, decision making at the higher levels can be hampered.

8) Management & Governance: includes setting the vision and goals for the enterprise, perceiving and acting on opportunities and risk, planning, organizing, directing, and managing enterprise resources, making decisions, performing assessments, determining compliance with policies and alignment with expectations, supporting the development and application of strategies, best practices, policies, and guidelines, and making this information available to the enterprise. It is both top-down and bottom-up in its approach. It includes a feedback loop for continuous improvement or adjustment, enabling the enterprise to learn from mistakes and to optimize its future state. It ensures that logging and traceability of the data used for decisions, the decisions made, and the resulting actions are accessible.

9) Intelligence & Automation: involves developing, maintaining, and optimizing automation processes in the enterprise, including EA analysis activity. Activity to support intelligence builds on automation and includes decision assistance for humans and software agents.

D. D²F Enterprise Facets

Any enterprise concept or element can be a facet. To provide further detail on which enterprise facets might be of interest for an enterprise when using D²F, Figure 6 clusters facets near *Key Areas*. Its intent is not to portray every possible facet, or by neglect thereof or apparent inconsistency to negate the entire approach. Rather, it shows that grey or inconsistent areas with which matrix approaches struggle are not as problematic with D²F, since it embraces these types of relations. A short explanation of selected facets follows:

Enterprise Environments can involve a *Business* in a *Market* with *Customers*, involving *Projects*, *Processes* (business, development, agile, IT Infrastructure Library), *Products*, and *Services* (business, IT) together with *Actors* organized in *Teams* utilizing *Infrastructure*, *IT* (cloud, microservices, mobile), *Resources*, *Tools*, and *Technologies*. *Entities* can be organizational units or any other enterprise element not already covered by other facets. *Sensors* permit data about changes in the enterprise state to be acquired, while *Effectors* permit desired changes to be applied. *IT Rules* and *Biz* (Business) *Rules* support automation or escalation.

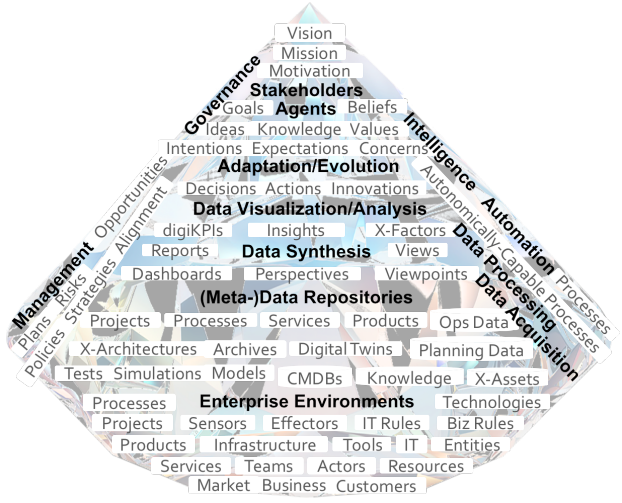

Figure 6. Illustrative enterprise facets when applying D²F.

(*Meta-)Data Repositories* includes data and metadata about *Projects*, *Processes*, *Products*, and *Services* as well as *Planning Data* and *Ops* (Operational) *Data*. *CMDBs* provide data and metadata about the *IT* landscape, *X-Assets* are repositories for data and metadata about other enterprise assets (e.g., program code). *Knowledge* repositories may be used. Archives provide historical data. *Digital Twins* provide a digital representation of real enterprise elements not covered by the above. *X-Architectures* stands for any (enterprise, business, software, IT) architecture, describing the goals and representation of some structure and its properties and involving principles, rules, abstractions, and views. *Models* (conceptual, mathematical, business, data, etc.) are a partial representation of some reality.

Data Synthesis, *Data Visualization*, and *Data Analysis* can be used to develop Insights and can include *digiKPIs* (digital KPIs), *Dashboards*, and *Reports*. *Perspectives* address a particular quality property and have an implicit goal or intention. *Views* (partially) address some concern. *Viewpoints* are a class of views to address associated concerns. *X-Factors* can be qualities, capabilities, properties, aspects, etc. otherwise not addressed by the above.

Adaptation/Evolution includes *Decisions* and *Actions* to respond to disruptions, support change such as enterprise element lifecycle adjustments (acquire, prepare, operate, maintain, retire) as well as discovering and utilizing Innovations and instigating digital transformation initiatives.

Stakeholders/Agents are driven by some *Motivation*, have *Knowledge*, *Values* (what they hold to be good), and *Beliefs* (what they hold to be true), develop *Ideas*, and have future-oriented *Goals* and present-oriented *Intentions* with

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Expectations and *Concerns* they would like addressed, including a (common) *Vision* (future desired state) for the enterprise and some *Mission* (purpose) it intends to fulfill.

Automation involves *Processes*. In an intelligent enterprise, *Autonomically-Capable Processes* (ACPs) [15] will increasingly be desired and expected. These ACPs can be completely autonomic, involve human interaction, or assist human operators in some fashion. These intelligent ACPs are much more complex than normal business processes.

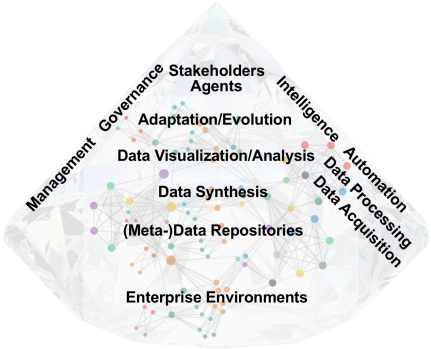

Figure 7. Colored graph showing possible linked facet instantiations.

The random colored node graph superimposed in Figure 7 conceptually illustrates how facet instantiations (data) across various areas could be linked via graph relations to provide various insights addressing stakeholder concerns.

E. D²F Maturity Levels

Because D²F is a digital EAF, to achieve and apply all D²F principles across all levels of any existing large enterprise will require a transformation and enterprises will be in different states of transformation. The following Maturity Levels shown in Table I can be helpful to guide and ensure that requisite capabilities are addressed before focusing on higher level capabilities. Each level subsumes the one below.

TABLE I. D²F MATURITY LEVELS

Level	Label	D²F Qualities	Data Perspective
0	Arbitrary	-	-
1	Digitized	Digitized Meta	Data Acquisition
2	Linked	Dynamicity Linked	Data Processing
3	Analytical	Hyper-models Analytics Actuality processing	Data Synthesis Data Analysis Data Visualization
4	Adaptive	Holistic Actionable Traceability/Logging	Effectors
5	Autonomic /Intelligent	Automation Intelligence	Automation Intelligence

F. D²F Roadmap

Each enterprise and its IT infrastructure are unique. The digital nature of D²F requires access to (semantically annotated) data repositories and software functionality. Various methods and best practices related to enterprise application integration (EAI), EA and other IT tools, protocol standards and formats (JSON/REST), and data visualization techniques can be leveraged to realize D²F in an enterprise.

IV. CONCLUSION

A sustainable EAF is needed that can embrace the digitized enterprise era. This paper described the Digital Diamond Framework (D²F) to support digitized enterprises with the structure, order, modeling, documentation, and analysis needs to enable more responsive and agile enterprises with better alignment of business plans and initiatives with the actual enterprise state. Key areas, principles, activities, facets, and maturity levels were elucidated.

While D²F can be applied at a high-level, as the framework is digital-centric, any concrete application in an enterprise requires concrete and integrated EA tooling utilizing the standards and formats available to that enterprise. Future work includes applying D²F in case studies in various organizations.

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