Rethinking Enterprise Architecture Frameworks for the Digital Age: The Digital Diamond Framework and EA Tool

Roy Oberhauser
Computer Science Dept.
Aalen University
Aalen, Germany
email: roy.oberhauser@hs-aalen.de

***Abstract* - Enterprise Architecture (EA) Frameworks (EAFs) have attempted to support comprehensive and cohesive modeling and documentation of the enterprise. However, these EAFs were not conceived for today's rapidly digitalized enterprises and the associated IT complexity. A digitally-centric EAF is needed, freed from the past restrictive EAF paradigms and embracing the new potential in a data-centric world. This paper proposes an alternative EAF that is digital, holistic, and digitally sustainable - the Digital Diamond Framework. D^2F is designed for responsive and agile enterprises, for aligning business plans and initiatives with the actual enterprise state, and addressing the needs of EA for digitized structure, order, modeling, and documentation. The feasibility of D^2F is demonstrated with a prototype implementation of an EA tool that applies its principles, showing how the framework can be practically realized, while a case study based on ArchiSurance example and an initial performance and scalability characterization provide additional insights as to its viability.**

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

I. INTRODUCTION

This paper contributes a digitized, holistic, hyper-model EA conceptual framework called the Digital Diamond Enterprise Framework (D^2F) to provide a fundamentally digital and sustainable EA framework for a digital EA future. It extends [1] with an analysis of other EAFs and describes a prototype implementation of the Digital Diamond Enterprise Framework (D^2F) to show its feasibility.

Enterprise Architecture (EA) concerns itself with comprehensively and cohesively modeling and documenting the structure and behavior of the business and IT infrastructure of an enterprise 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 [2]. While one might think that after 30 years the EA area must be mature, Gartner's 2017 Hype Cycle for Enterprise Architecture [3] 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.

Enterprises now face multiple contemporaneous challenges:

1) A major digital transformation of their industry [4]. 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).

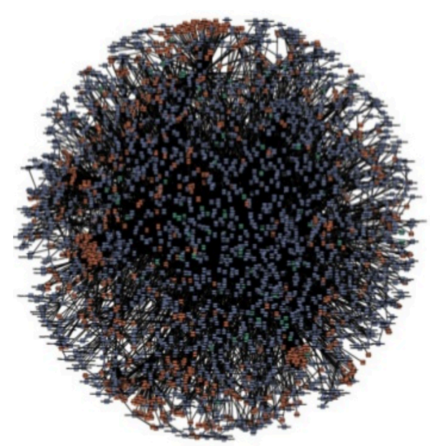


Figure 1. Visualization of microservices at Amazon [5].

Considering 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 being superseded by a highly networked and integrated digitized era.

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.

As to the use of EAFs in industry, in 2007 Ivar Jacobson reckoned 90% of the EA initiatives he was aware of had not resulted in anything useful, stating big gaps vs. seamless relationships as a primary reason [6]. A 2008 study showed two-thirds of EA projects failing to improve IT and business alignment [7], with the most frequent explanation being that connecting EA to business elements was difficult in practice. Hence, the EAFs of the past with their associated paradigms and their models cannot continuously reflect the dynamic enterprise realities in this digital age, thus they are illusionary, ineffective, inefficient, and no longer viable.

The application of EA and an EAF typically involves some kind of EA tooling. Considering the support for EA provided by EA Management (EAM) tools, Jugel el al. [8] investigated their visual analytics capabilities and collaborative decision-making support. Their findings identified the following five challenges and needs for EAM tools:

1. *View configuration*: An easy way to configure views is needed to react to dynamic information demands.
2. *View consideration*: A method is needed to consider several views in parallel to avoid losing the overall context. Additionally, views should always be kept up to date.
3. *Interacting with views*: Stakeholders need more interaction and visual analytics capabilities to analyze and plan EAs more efficiently.
4. *Communication & collaboration*: Methods are needed to better support communication & collaboration, e.g. by adding additional knowledge to views.
5. *Stakeholder identification*: There is a need for methods to identify stakeholders that have to be involved in decision-making processes.

The following research questions guided our investigation:

RQ1: Are there obvious deficiencies in the EAF and EA tool landscape, and if so, how can these be characterized?

If a new EAF and/or EA tool appear justifiable:

RQ2: What should a digital EA framework address?

RQ3: What requirements and viewpoints should an associated digital EA tool implementation support?

RQ4: Is it feasible for a digital EAF graph-centric EA tool implementation to flexibly support the ArchiMate ArchiSurance case study examples across the various viewpoints?

RQ5: Does a graph-centric EA tool implementation appear viable based on an initial performance and scalability characterization?

This paper contributes a description of our digital EAF proposal D^2F. We also contribute a demonstration via case study of the feasibility of D^2F by describing an implementation of an EA tool prototype based on D^2F principles and having the following features that address the above five EAM tool challenges:

- enterprise information model agnostic,
- flexible meta-model,
- supports tagging can be used to add knowledge to elements/views,
- (re)configurable interactive dynamic (up-to-date) views,
- visual analytical capabilities,
- and cross-platform and web-centric to more easily involve and be accessible to diverse stakeholders.

This paper is organized as follows: Section II discusses background material on EA and related work. Section III describes the D^2F. In Section IV, we describe our prototype tool that demonstrates how D^2F can be implemented. Section V evaluates the implementation, and is followed by a conclusion in Section VI.

II. Background and Related Work

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 [9], designing in the face of many unknowns.

A. EA Frameworks (EAFs)

EAFs offer structure, associated terminology, and at times processes for EA-related work. The Zachman Framework [2] 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) [10] 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) [11]. The Generic Enterprise Reference Architecture and Method (GERAM) [12] 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 when attempting to deal with the inherent complexity. Stroud and Ertas [13] developed a taxonomy for EAFs to show their interrelationships (influence, chronology, evolution). Sultanow et al. [14] classified 55 EAFs based on multidimensions (size, architectural domain scope, mutability, alignment, intention, chronology). Lim et al. [15] did a comparative study of five well-known EAFs, extracting and reifying them based on four dimensional concepts: view, perspective, scope, and time. In order to provide an impression of the extent and breadth of EAFs, Table I provides a consolidated list of acronyms and names of EAFs or architecture frameworks (AFs) and the source list used, which can be used to find more information about it. Due to space limitations, this is not intended to be a complete nor comprehensive list. Since various AFs could also be applied in the context of EA as well, no differentiation between AF and pure EAFs was attempted. The sources provided can be referred to for additional details.

TABLE I. LIST OF EAFS* AND AFS*

Acronym	Name	Source
4+1	Kruchten's 4+1 view model	[16]
AAF	Automotive AF	[16]
ADS	Architecture Description Standard von IBM	[17]
AF-EAF	Air Force EAF	[16]
AF4MgtSys	AF for Management Systems	[16]
AFIoT	IEEE P2413 AF for the Internet of Things	[16]
AGA	Australian Government Architecture Reference Models	[16]
AGATE	Atelier de Gestion de l'ArchiTecturE des Systemes d'Information et de Communication (AGATE)	[16][17]
AM	Avancier Methods	[16]
ARCHI	ArchiMate	[16][17]
ARIES	Architecting Innovative Enterprise Strategies	[16]
ARIS	Architektur integrierter Informationssysteme	[17]
AUSDAF	Australian Defence AF	[16][17]
BCA	Business Capability Architecture	[16]
BDAF	Big Data AF	[16]
BEAM	Business Enterprise Architecure Modeling	[16]
BPEAM	iteratec best-practice enterprise architecture management (EAM) method	[16]
C4IF	Connection, Communication, Consolidation, Collaboration Interoperability Framework	[17]
C4ISR		[17]
CAFCR	Customer Objectives, Application, Functional, Conceptual, and Realisation model	[16]
CAFEA	Common Approach to Federal Enterprise Architecture	[16]
Casewise	Casewise Framework	[17]
CBDI-SAE	CBDI Service Architecture & Engineering (CBDI-SAE™) for SOA	[16]
CEA	CEA Framework: A Service Oriented EAF (SOEAF)	[16]
CEAF	Commision Enterprise IT Architcture Framework (CEAF)	[16]
CIAF	Capgemini Integrated AF	[16]
CIMOSA	CIM Open System Architecture	[17]
CLEAR	Comprehensive, Landscaped, Enterprise Architecture Representation Framework	[17]
DNDAF	Department of National Defence and the Canadian Forces AF	[16][17]
DoD TRM	Technical Reference Model	[17]
DoDAF	US Department of Defense AF	[16] [17]
DRA1	Dragon1	[16]
DYA	Dynamic Architecture	[16]
e-GIF	UK e-Government Interoperability Framework	[17]
E2AF	Extended EAF	[16][17]
EAAF	OMB Enterprise Architecture Assessment Framework	[17]
EAB	Enterprise Architecture Blueprinting	[16]
EAMMF	GAO Enterprise Architecture Management Maturity Framework	[17]
EAP	Spewak's Enterprise Architecture Planning	[17]
EEAF	US OMB Enterprise Architecture Assessment Framework	[16]
EIF	European Interoperability Framework des IDABC-Programms	[17]
EPCAF	The EPCglobal AF	[16]
ESAAF	European Space Agency AF	[16]
ESSAF	Essential AF	[16]
eTOM	Business Process Framework (eTOM)	[16]
EXAF	Extreme AF	[16]
FEAF	US Federal EAF	[16][17]
FESS	Framework of Enterprise Systems and Structures	[16]
FFLV+GODS	Functions-Flows-Layers-Views + Governance-Operations-Development-Support	[16]
FMLS-ADF	FMLS Architecture Description Framework 3.0 (SE)	[16]
FSAM	Federal Segment Architecture Methodology (FSAM)	[16]
GA	Garland and Anthony	[16]
GEA-NZ	All-of-Government (AoG) Government Enterprise Architecture for New Zealand	[16]
GEAF	Gartner's EAF	[16][17]
GERA	ISO 15704 Generic Enterprise Reference Architecture	[16]
GERAM	Generalised Enterprise Reference Architecture and Methodology	[17]
GIM	GRAI Integrated Methodology	[17]
HEAF	Health EAF	[16]
HIF	Healthcare Information Framework (DIN V ENV 12443)	[17]
IADS	IBM Architecture Description Standard	[16]
IAF	Index AF	[16]
IAF	Integrated AF (Capgemini)	[17]
ICODE	iCode Security AF	[16]
IFW	IBM Information FrameWork (IFW)	[16]
IFW	Information FrameWork	[17]
IIRA	Industrial Internet Reference Architecture	[16]
ISO/IEC 42010	Recommended Practice for Architectural Description	[17]
IT City Planning	IT City Planning AF (Gartner)	[17]
JTA	DoD Joint Technical Architecture	[17]
LEAD	Leading Enterprise Architecture Development (LEAD)ing Practice	[16]
MACCIS	An Architecture Description Framework for Technical Infostructures and their Enterprise Environment	[16]
MEGAF	MEGAF	[16]
MIKE2.0	Method for an Integrated Knowledge Environment	[17]
MODAF	(UK) Ministry of Defence AF	[16][17]
NAF	NATO Architectural Framework	[16][17]
NEA	National EAF	[16]
NIH	(U.S. National Institutes of Health) EAF	[17]
NIST	(U.S. National Institute of Standards and Technology) Enterprise Architecture	[16][17]
OBASHI	ownership, business process, application, system, hardware and infrastructure framework	[17]
OIO	OIO Enterprise Architecture Method	[16]
OSSAF	Open Safety & Security AF	[16]
PEAF	Pragmatic EAF	[16]
PERA	Purdue Enterprise Reference Architecture	[17]
OSE RM	ISO/IEC TR 14252, IEEE Std 1003.0 & ISO/IEC 9945	[17]
PPOOA	Processes Pipelines in Object Oriented Architectures	[16]
PRISM	Partnership for Research in Information Systems Management	[16]
QGEAF	Queensland Government EAF	[16][17]
RASDS	Reference Architecture for Space Data Systems	[16]
RM-ODP	ISO Reference Model for Open Distributed Processing	[16][17]
RWSSA	Rozanski and Woods	[16]
S4V	Siemens 4 Views	[16]
SABSA	Sherwood Applied Business Security Architecture	[16][17]
SAGA	Standards and Architectures for eGovernment Applications	[17]
SAP EAF	SAP EAF	[17]
SASSY	Self-Architecting Software SYstems	[16]
SGCAF	Smart Grid Conceptual AF	[16]
SQUID	Specification Quality In DevOps	[16]

Acronym	Name	Source
t-eam	toolbox for enterprise architecture management	[17]
TAFIM	Technical Architectural Framework for Information Management	[17]
TEAF	(US) Treasury EAF	[16]
TEAF	Treasury EAF	[17]
TISAF	Treasury Information AF	[17]
TOGAF	The Open Group AF	[16][17]
TRAK	The Rail AF	[16][17]
UADF	Universal Architecture Description Framework	[16]
VERAM	Virtual Enterprise Reference Architecture and Methodology	[17]
xAF	Extensible AF	[16][17]
XAF	eXtreme Enterprise Architecture Framework	[17]
ZF	Zachman Framework	[16][17]

*AF = Architecture Framework; EAF=Enterprise AF

Considering that Gartner's 2011 global EA survey showed more than 60 EA frameworks in use, with the most popular being blended followed by homemade [18], it is indicative that the current state of EAFs is deficient, fragmented, and in need of rethinking from its core. To the author's knowledge, none of the EAFs in Table I meet all three essentials requirements: 1) conceived as purely digital in their essence for a digitized enterprise, are 2) domain and intention agnostic to be widely applicable for EA, and 3) provide the necessary visualization and tooling for digitized modeling and EA-centric data integration.

B. Enterprise Modeling

Modeling abstracts and simplifies an area of interest while maintaining certain its essential characteristics. Consequently 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.

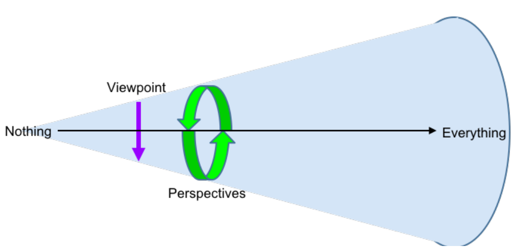


Figure 2. Modeling spectrum.

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. [19] 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 [20] for an SME (small-to-medium enterprise).

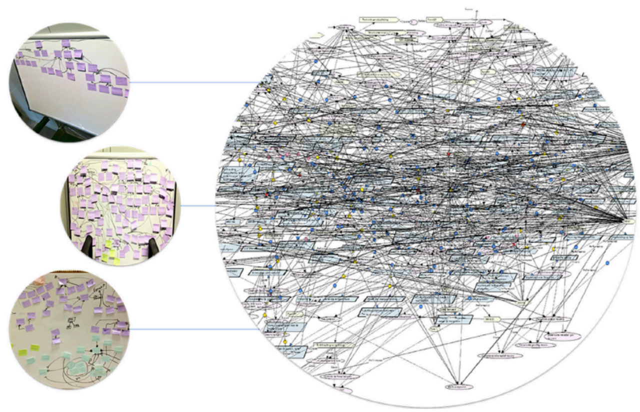


Figure 3. An example CHOOSE enterprise model for an SME, from [20].

C. EA Tool Landscape

As enterprises consist of a complex set of systems, processes, resources, organizational structures, and technologies with various interdependencies, EA Management (EAM) attempts to provide an integrated view of these various aspects to enable alignment of the business with IT capabilities and support change and optimization. In order to assist with and provide insight for EAM, EA tools typically provide various visualization capabilities.

Matthes et al. [21] evaluated nine EA tools in detail, while Matthes et al. [22] evaluated four additional EA tools using the same criteria. A scenario-based approach with a consistent information model of a fictitious organization was used. The first part deals with specific functionality such as adapting the information model, supporting multiple users and collaborative work, visualizing the application landscape, or usability. The second part assesses the EAM support of the tools, e.g. landscape management, demand management, project portfolio management, synchronization management, strategies and goals management, business object management, IT architecture and infrastructure management, and service-oriented architecture (SOA) transformation.

Sultanow et al. [23] studied and compared 34 EA tools, basing their comparison criteria on that of Matthes et al. [21] and Filss [24]. They found that a complete evaluation and in-depth look at each tool is both difficult and time-consuming. This is due to the fact that the tools are advertised and described with relatively little detailed technical depth and a lack of transparency. Many of the tools do not offer a test version for trying out and comparing them. The authors were able to use questionnaires and direct contact with the vendors to gather certain information. One of the conclusions of the study is that the tools in the EA segment do include a basic set of capabilities, but these vary considerably in scope. Most tools can be customized to the customer's needs. The organization of and access to EA data is similar, and most support TOGAF, Zachman, and/or ArchiMate. Some tools are quite flexible and offer additional visualizations that the other tools do not offer. The comparison criteria categories and subcategories used in the study were:

- Management functions: infrastructure, IT architecture, business/object, goal, strategy, synchronization, project portfolio, demand, landscape, and SOA transformation
- Visualization types: 3D, bubble charts, business model canvas, EPC, ERD, Cluster Card, dashboard, line charts, pie charts, timeline, tree view, matrix, geographic map, flow diagram, UML, BPMN
- Layout: manual, semi-automatic, or fully automatic
- Programming paradigms: structured, modular, object-oriented, component, scrum
- Automation: manual, formatting, consistency checks, generating, inter-productive

The Enterprise Architecture Visualization Tool Survey by Roth et al. [25] surveyed 18 EA tool vendors (over 50 invited) and 109 EA experts (out of 1200 invitations). Here is an excerpt of some of their findings, and our view on possible implications considering D^{2}F:

- The reported tools EA experts use most frequently are Visio (87%), Powerpoint (86%), Excel (74%), then to a much smaller degree Enterprise Architect (33%), ARIS (25%), iteraplan (23%), and Archi (20%) followed by the rest. Our interpretation of this is that most of the participants (mostly enterprise architects) were not using comprehensive EA tools, nor were most using EA tools with a direct access to IT infrastructure (digitally integrated).
- Less than 20% were dissatisfied with their current EA tools (16% dissatisfied and 3% very dissatisfied), 49% were neutral, 24% satisfied, and only 9% were very satisfied. Considering the non-EA-centric tools mentioned above (like Microsoft Office), we interpret this as an indication that the EA digitalization challenges described in our paper had not yet fully materialized for the participants involved at the time of this study. Since 69% were neutral or dissatisfied with their currently available EA tools, it indicates that the EA tool market still has significant growth potential towards clear EA-specific tool market leaders that show high adoption and high satisfaction rates for EA architects (the go-to EA tool for them).
- The visualization update frequency required by enterprise architects was reported as primarily quarterly (22%), monthly (20%), weekly (17%), daily (13%), and semi-annually, annually, and other were 10% or less. Thus, we see that the pace of digitalization and the degree of change with which they needed to cope was relatively slow. When we compare this to the number of deployments of software between 2014 and 2019, we also see that the reported software deployment frequency in the 2017 State of DevOps Report [26] for high performers jumped from about 200 to 1600 annually between 2015 and 2016. In turn, we can speculate that today's enterprise architect must also deal with much faster software-centric change cycles and associated information models.

The above EA tool surveys show a large set of different capability profiles among vendors (as can be seen by the Kiviat diagram profiles in the Matthes et al. studies [21] 22]), a high degree of market fragmentation, high degrees of organizational customization, and a relatively low EA-centric tool adoption rate by enterprise architects. This is indicative that none of the current EA tools appears completely satisfactory.

D. Summary

As to one of the more well-known EAFs, John Zachman admitted in 2004 "if you ask who is successfully implementing the whole framework, the answer is nobody that we know of yet" [27]. And considering Gartner's 2011 global EA survey showing more than 60 EA frameworks in use, and the most popular being blended followed by homemade [18], it 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. E.g., automation, notification, policies, common vs. specific services, testing, staging, DevOps, etc.

Considering the EA tool popularity, satisfaction, and update rates, and the issues found when assessing the EA tools in detail, there is potential for the EAF landscape to offer a purely digital EAF and supportive EA tooling.

Thus, EAFs currently lack an integrated digitalized and data-centric concept from the ground up. They fail to provide real-time dynamic updates and thus reflect stale, inaccurate, or inconsistent data. They also require additional manual labor to maintain independent artifact consistency with a changing enterprise reality.

III. The Digital Diamond EA Framework

The depth and breadth of the digital impact and the deep integration of complex IT into all aspects of the enterprise calls for a new and digitally sustainable 'boxless' EA framework paradigm for this new era that can deal with digitalization, ambiguity, further IT complexity, and further automation. In the following subsections, the key areas, activities, principles, integrative aspects (potentially applicable when applying D^{2}F), maturity levels, and roadmap to D^{2}F are portrayed.

A. D^{2}F 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 D^2F, with cross-cutting areas shown angled on the left and right.

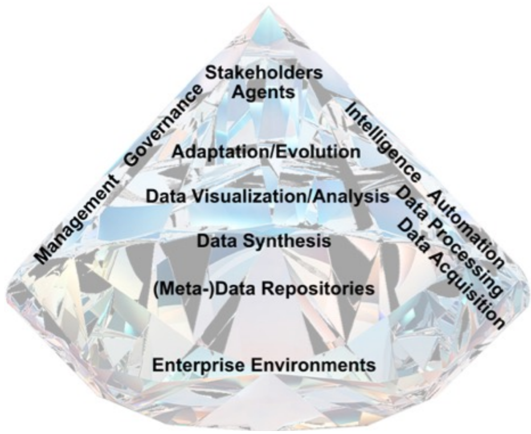


Figure 4. Key areas D^2F.

The key areas are:

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 D^2F paradigm. *Key Areas* may be tailored for a specific enterprise. A prerequisite to a complete implementation of D^2F presumes digitalization of EA-relevant areas for any given enterprise. As to scaling, the concept of a connected *D^2F Chain (Diamond Necklace)* can be considered for applying D^2F within various entities (e.g., divisions) but tied into a larger enterprise organization.

B. D^2F Key Principles and Qualities

Key principles and resulting qualities of D^2F 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.

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. Automation will also affect how EA models are generated (manual vs automatic), 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 [28].

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 of interest to a stakeholder.

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

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

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.

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 (referred to below in italics), 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, be they local or holistic in nature. 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 *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) [29] 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.

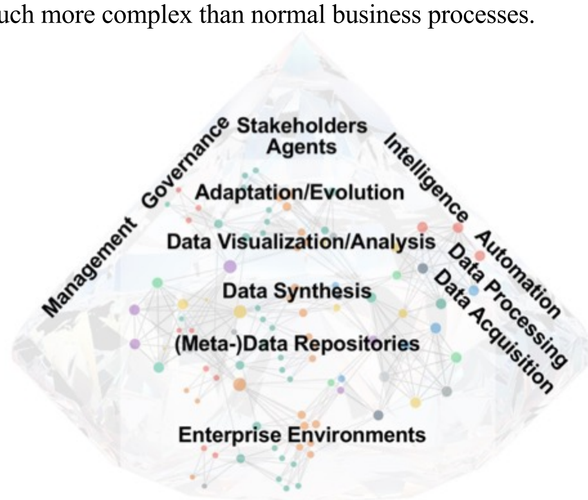


Figure 7. Colored graph showing possible linked facet instantiations.

The random colored node graph superimposed in Figure 7 conceptually illustrates how facet instantiations (data) across various areas could be linked via graph relations (lines in Figure 7) to provide various insights addressing stakeholder concerns. Consequently, queries can be used to find or determine relations that may otherwise not be apparent or would be ignored.

E. D^2F Maturity Levels

Because D^2F is a digital EAF, to achieve and apply all D^2F principles across all levels of any existing large enterprise will require a transformation and enterprises will be in different states of digital transformation. The following Maturity Levels shown in Table II 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 II. D^2F MATURITY LEVELS

Level	Label	D^2F 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. D^2F Roadmap

Each enterprise and its IT infrastructure are unique. The digital nature of D^2F 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 D^2F in an enterprise.

IV. D^2F EA TOOL IMPLEMENTATION

This section describes a D^2F EA tool prototype we developed. In contrast to the professional EA tools discussed in the prior section, this tool is not intended to be a professional EA tool nor to provide or compete with any of their features. Rather, the focus and point of this prototype is to demonstrate the practical feasibility of the D^2F approach and to show one possible implementation approach. D^2F approach is independent of any specific EA tool, and any EA tool could incorporate D^2F or some subset thereof. ArchiSurance data is used here to help illustrate the implementation.

A. D^2F EA Tool Requirements

To develop our D2F EA tool and show its feasibility, we solicited our requirements from sources in the literature to ensure we use a sufficiently generalized set of requirements.

1) EA visual requirements: Naranjo et al. [30] describe general visual requirements for EA tools summarized in Table III. We oriented our implementation on these EA tool visual requirements.

TABLE III. EA TOOL VISUAL REQUIREMENTS

ID	Name
MVE	Maximize Visual Economy
EVE	Enhance Visual Expressiveness
MN	Minimize the Noise
NI	Navigate and Interact
KC	Keep the Context
DNI	Derive New Insights
GSC	Guarantee Semantic Correspondence

2) EA analysis requirements: Naranjo et al. [30] describe general analysis requirements that EA tools should support, and is summarized in Table IV. We oriented our implementation on these EA tool analysis requirements.

TABLE IV. EA TOOL ANALYSIS REQUIREMENTS

ID	Name
IRD	Identify and Relate Domains
EKE	Emphasize Key Elements
OFI	Offer a Focus of Interest
FSD	Facilitate Structural Diagnosis
DSC	Display Semantic Characteristics
UAQ	Uncover Architectural Qualities
PFM	Provide a Flexible Metamodel

TABLE V. IMPLEMENTED EA VIEWPOINTS AND ASSOCIATED STAKEHOLDER CONCERNS FROM [31]

ID	Name	Concerns
V-107	Business application technical or business status	See subviewpoint
V-107.1	Complexity of business applications	C-124 Reduce application landscape complexity
V-108	Physical component status	See subviewpoint
V-108.2	Evaluate potential removal candidates	C-129 Remove monolithic applications
V-108.4	Increase transparency of application landscape	C-34 Look of long-term application landscape C-62 Determine business capabilities of application landscape C-119 Definition of target application landscape C-157 Detection of consolidation potential
V-109	Transparency about which physical components are used by which business applications	C-41 Determine used infrastructure for applications C-147 Merge two different application landscapes C-169 Architectural assessment of change requests
V-111	Business application status within a specific business capability	See subviewpoint
V-111.1	Use of business applications	C-62 Determine business capabilities of application landscape C-142 Map business applications to business capabilities
V-111.2	Relation between business capability and business application	C-147 Merge two different application landscapes C-157 Detection of consolidation potentials
V-113	Technical or business status of business application	See subviewpoint
V-113.1	Complexity of business applications	C-124 Reduce application landscape complexity
V-114	Layer diagram to visualize IT landscape status	C-98 Determine shutdown impact of infrastructure component
V-119	Number of infrastructure components used by a business application	C-120 Measure changes in application landscape C-124 Reduce application landscape complexity C-141 Get transparency about IT costs

the configurable mapping of EA data to visualization types and a filtering capability. For determining initial viewpoints to consider implementing in our prototype and prove the feasibility of D^{2}F, we used Khosroshahi et al. [31] as a reference. It provides a best-practice Enterprise Architecture Management Pattern Catalog (EAMPC) that describes concern-specific viewpoints (V-Patterns), which can be used as best-pattern reusable building blocks to tailor an organization-specific EAM approach. These viewpoint patterns (V-patterns) were analyzed, and due to project time and resource constraints we limited our initial support to the subset shown in Table V. This in no way indicates an inherent limit of D^{2}F nor the EA tool to not support the other viewpoints, but rather this set is sufficient to demonstrate key viewpoint capabilities and show that D^{2}F can be practically applied. Those not initially implemented due to time and resource constraints for the prototype are:

- V-110 Business application usage
- V-112 Application costs
- V-115 Number of interfaces per business application
- V-116 Number of redundant business functions per business application
- V-117 Number of business applications used within a functional domain
- V-118 Standard conformity of business applications
- V-120 Functional scope of a business application

4) *D^{2}F-based requirements*: Requirements based on the D^{2}F principles and qualities described in Section III.B and listed in Table V should be shown to be feasible or supported and P:Trc (shown in italics) were not specified or yet implemented for the prototype due to time and resource constraints.

TABLE VI. D^{2}F SUPPORT REQUIREMENTS

Acronym	Principles and Qualities
P:Dig	Digitized
P:Meta	Meta (self-describing)
P:Lnkd	Linked
P:Dyn	Dynamicity
P:Hol	Holistic
P:Hyp	Hyper-models
P:ActProc	*Actuality processing*
P:Anyltcs	Analytics
P:Act	*Actionable*
P:AI	*Automation/Intelligence*
P:Trc	*Traceability/Logging*

5) *EA data model requirements:* the tool should support the import of common EA information models and flexible information schemas. In particular, the popular ArchiMate [32] EA modeling language, which can model the motivation, structures, and behavior related to strategy, business, application, technology, physical, and implementation aspects for business organizations, and BPMN, which can model business processes at a technical detailed level.

B. D^{2}F EA Tool Architecture

The following architectural principles, based on the expected features and functionality and in consideration of the requirements mentioned above in Section IV.A, played a significant role in structuring the implementation solution:

- AP:enterprise information model agnostic
    - Supports EA information model data interchange.

  - Supports flexible meta-models or schemas.
- AP:flexible metadata relation and tagging capabilities
  - Enables additional knowledge to be flexibly joined to any elements/views.
- AP:flexible visualization
  - Support various visual types and parameterization.
  - Support the configuration and mapping of EA data to visualization types and filtering.
  - Provide interactive and dynamic visual analytical capabilities.
- AP: client web-centric cross-platform access
  - Supports access and involvement of diverse stakeholders from anywhere on any platform.
- AP: cloud data/service backend access
  - All data needed for EA tool is accessible and integratable, to minimize the inconsistency and redundancy issues resulting from locally-installed applications or isolated data.
- AP:internal common simple data format (JSON)
  - All data can be converted to/from this format.
- AP: graph database
  - Supports flexible (re)structuring of data dependencies between elements via a graph structure.

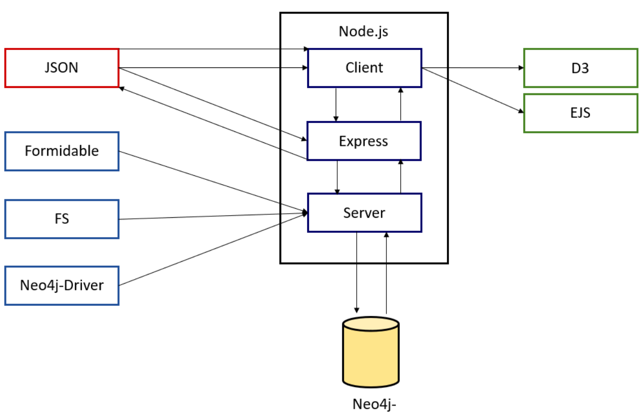


Figure 8. D²F EA Tool Architecture.

As shown in the diagram in Figure 8, the following technologies were chosen:

- Node.js was chosen as a runtime environment due to its popularity and to maintain front and backend in JavaScript.
- Neo4j: graph database that supports the Cypher Query Language (CQL). Neo4j was chosen due to its popularity as a graph database.
- D3: JavaScript library for dynamic and interactive data visualizations, chosen due to its popularity and the available functionality.
- EJS: embedded JavaScript templating engine.
- Express: Node.js web application server framework handling GET/POST requests from the client.
- Formidable: Node.js module for parsing form data
- FS: Node.js file system module

C. D²F EA Tool Implementation

On the main page when loaded by a browser, the following four main tabs as shown in Figure 17 are provided:

- *Load data*: provides the ability to import data from various sources.
- *Connection*: provides the ability to manage and connect data with metadata
- *Analysis*: provides pre-defined EA Viewpoints and filtering options.
- *Visualization*: provides a flexible visualization option to provide custom search and filtering options

Information about an element can be retrieved by clicking on its ID within a table or in a visualization. A new view is opened which shows the ID, Name, and Creation timestamp as shown in Figure 18.

The following Cypher statement supports data retrieval for this view:

```
MATCH (n{id:{idParam}})
RETURN n
```

1) Load data tab. This tab supports importing metadata, infrastructure data, BPMN diagrams, and ArchiMate data in JSON format (see Figures 17 and 9). Any other formats such as XML must be converted beforehand and any special characters in keys or values (such as punctuation symbols) removed. Metadata can be imported as well from schema.org (e.g., we utilized PhysicalComponent and BusinessProcess) or similar sites. Since some of the metadata may not be applicable (since they may cover various domains or branches of industry), we provide a whitelist and blacklist in config.json in order to exclude inapplicable elements and thus reduce metadata clutter. The whitelist is for explicit inclusion with the assumption that the rest is not applicable, whereas the blacklist specifies elements to remove and allowing the rest.

```
{
    "archimatemodel":{
        "xmlns:xsi":"http://www.w3.org/2001/XMLSchema-instance",
        "xmlns:archimate":"http://www.archimatetool.com/archimate",
        "name":"Archisurance",
        "id":"11f5304f",
        "version":"3.1.1",
        "folder":[
            {
                "name":"Business",
                "id":"8c90fdfa",
                "type":"business",
                "folder":[
                    {
                        "name":"Actors",
                        "id":"fa63373b",
                        "element":[
                            {
                                "xsitype":"archimateBusinessInterface",
                                "id":"1544",
                                "name":"mail"
                            },
                            {
                                "xsitype":"archimateBusinessInterface",
                                "id":"1540",
                                "name":"phone"
                            },
                            {
                                "xsitype":"archimateBusinessInterface",
                                "id":"1542",
                                "name":"GIM"
                            },
                            {
                                "xsitype":"archimateBusinessInterface",
                                "id":"1538",
                                "name":"e-mail"
                            },
```


Figure 9. Example ArchiMate data.

Each element has a name, creation date, and a unique id to avoid inconsistencies. Metadata should also provide the subclass, type, description, and layer.

ArchiMate data involved additional folders and subfolders analogous to its layers: Business, Application, Technology, Motivation, Implementation and Migration, Relations and Views. While software to transform an ArchiMate model to a Neo4j database model exist, we were not satisfied with the conversion results using an Archi plugin [33]. The resulting structure differed from the original model while relations were converted into nodes. We thus chose to do our own mapping. The information about ArchiMate layers are stored via a property in the Neo4j database. One challenge was to find the individual elements in the various subfolders. The following Cypher statement is used to import ArchiMate data:

```
CREATE (node:Archi
{foldername:{folderNameParam}, folderid:
{folderidParam}, foldertype: {foldertypeparam},
instancename:{instanceNameParam},
instanceid:{instanceIdParam}, id: {nameParam},
identifier:{idParam}, name:{xsitetypeParam},
time:{timeParam}})
```

2) Connection tab. Metadata can be added or changed as seen on the right side of the screenshot shown in Figure 19. Once one of the fields is active, applicable context-specific recommendations are provided. A single node can be associated with metadata by providing a node ID in the top field, providing a Meta field, and then pressing the upper “Create metaconnection” button. Similarly, to associate a set of nodes, the bottom Name field provides a category to select the set of nodes, and the bottom Meta field specifies the metadata node to which it should be associated.

```
MATCH (a {id: {originalIdParam}})
SET a.meta = {metaParam}
RETURN a, {originalIdParam: nodeMetaId,
metaParam: metaMetaId}
```

As seen to the left in Figure 20, metadata associations are visualized with data elements as blue squares and metadata as green triangles. The following Cypher statement supports this visualization:

```
MATCH (n)
WHERE EXISTS (n.meta) AND NOT ((n:Meta) OR
(n.meta = "To be specified"))
RETURN (n)
```

3) Analysis tab. This tab provides those predefined EA viewpoints listed in Table V. In our implementation of these viewpoints, options for filtering the elements by “IT Infrastructure”, ArchiMate, or All are provided via the respective “Show” buttons in the upper left of the view in Figure 21.

a) V-107 Business application status. In this viewpoint business applications are clustered by organizational unit and can be allocated multiple times, while color is used to visualize some status such as complexity that can be based on various metrics. Variants include architectural fit or architectural health.

V-107.1 Complexity of business applications was implemented (see screenshot in Figure 21), which deals with the following stakeholder concern:

- C-124 Reduce application landscape complexity

In our implementation, the complexity is based on the metric of the number of associations between architectural elements. These colors are associated with complexity: green (low), yellow (medium), red (high), white (unknown). In config.json the thresholds can be adjusted.

To realize this viewpoint, the following Cypher statement is used to find all applications `a` and their associated business unit(s) `b`:

```
MATCH (a) -[] ->(b)
WHERE ((a.name ="Application") OR
(a.name="BusinessService") OR
(a.name="ApplicationFunction") OR
(a.name="ApplicationService") OR
(a.name="SystemSoftware") OR
(a.name="InfraStructureService"))
AND ((b.name ="BusinessActor") OR
(b.name="BusinessObject") OR
(b.name="BusinessProcess") OR
(b.name="Project"))
RETURN a, b, labels(a), labels(b) ORDER BY b
ASC)
```

The following Cypher statement finds applications that are only indirectly associated via some other node. Due to the time needed to execute, it is limited to the first 500:

```
MATCH (a) - [] ->(c) - [] -> (b)
WHERE ((a.name ="Application" OR a.meta
="SoftwareApplication" OR a.meta
="MobileApplication" OR a.meta =
"WebApplication") AND b.name ="Project")
RETURN a, b, labels(a), labels(b) ORDER BY b ASC
LIMIT 500')
```

The following Cypher statement then counts the number of relations for each found node:

```
MATCH (c {id:{idparam}})-[r]-()
RETURN count(r)
```

b) V-108 Physical Component Status. In this viewpoint business applications are clustered by business capability, and physical components can be assigned to a business application. Color is then used to convey the technical status of a physical component.

V-108.2 Evaluate potential removal candidates was implemented (see screenshot in Figure 22), which deals with the following stakeholder concern:

- C-129 Remove monolithic applications

Via the respective “Show” buttons at upper left, the elements can be filtered by “IT Infrastructure”, ArchiMate, or All.

In contrast to [33], in our implementation of this viewpoint we show all elements that are isolated and that are not Metadata, and for this we use the Cypher statement:

```
MATCH (a)
WHERE NOT(a)-[]-() AND NOT a: Meta
RETURN DISTINCT a, labels(a)
```

V-108.4 Increase transparency of application landscape was implemented (see screenshot in Figure 23), which deals with the following stakeholder concerns:

- C-34 Look of long-term application landscape

- C-62 Determine business capabilities of application landscape
- C-119 Definition of target application landscape
- C-157 Detection of consolidation potential

The following Cypher statement finds infrastructure components based on metatags b which are associated with capability c:

```
MATCH (n) – [] – (b) – [] – (c)
WHERE (b.meta = 'SoftwareApplication' OR b.meta
= 'MobileApplication' OR b.meta =
'WebApplication' OR b.foldername = 'Application'
OR b.name = 'Software ' OR b.name =
'Application') AND (n.foldername = 'Technolo-
gy' OR n.name = 'PhysicalComponent' OR n.meta =
'PhysicalComponent') AND (c.meta = 'Capability'
OR c.foldername = 'Business' OR c.name =
'Capability')
RETURN n, b, c, labels(n), labels(b), labels(c)
ORDER BY c ASC
```

4) V-109 Transparency about used physical components for business applications. In this viewpoint, which physical components are used by which business applications are shown (see screenshot in Figure 24). Since multiple relations can exist between elements, we chose to use graphs using the D3 forced graph layout. Green triangles are used for physical components and yellow crosses for applications. The viewpoint deals with the following stakeholder concerns:

- C-41 Determine used infrastructure for applications
- C-147 Merge two different application landscapes
- C-169 Architectural assessment of change requests

To realize this viewpoint, the following Cypher statement is used:

```
MATCH (n) - [r] - (b)
WHERE ((n.name ="Application" OR n.foldername
="Application" OR n.name ="Software" OR n.meta
="SoftwareApplication" OR n.meta
="MobileApplication" OR n.meta =
"WebApplication") AND (b.name =
"PhysicalComponent" OR
b.meta="PhysicalComponent" OR b.foldername
="Technology"))
RETURN n, r, b, labels(n), labels(b)
```

5) V-111 Business application status within a specific business capability. In this viewpoint, a matrix is used to depict business capabilities as rows and business applications as columns, while a business or technical status is depicted at their intersection.

Viewpoint 111.1 Use of business applications was implemented (see screenshot in Figure 25), which deals with the following stakeholder concerns:

- C-62 Determine business capabilities of application landscape
- C-142 Map business applications to business capabilities

To realize this viewpoint, the following Cypher statement is used:

```
MATCH (n) -[r]- (b)
WHERE (n.foldername = "Business" OR n.meta
="Capability" OR n.name = "Capab-ility") AND
(b.name = "Application" OR b.foldername =
"Application" OR b.meta = "SoftwareApplication"
OR b.meta = "MobileApplication" OR b.meta =
"WebApplication")
RETURN n, r, b, labels(n), labels(b)
```

V-111.2 Relation between business capability and business application was implemented (see screenshot in Figure 26), which deals with the following stakeholder concerns:

- C-147 Merge two different application landscapes
- C-157 Detection of consolidation potentials

6) V-113 Status of business application. In this viewpoint business applications are listed in a tabular format with a column that indicates a business or technical status.

Viewpoint 113.1 Complexity of business applications was implemented (see screenshot in Figure 27), with the number of relations used as a metric for depicting the complexity of a business application. These colors are associated with complexity: green (low), yellow (medium), red (high), white (unknown). In config.json the thresholds can be adjusted. The viewpoint deals with the following stakeholder concern:

- C-124 Reduce application landscape complexity

To realize this viewpoint, the following Cypher statement is used:

```
MATCH (a)-[c]-()
WITH a, count(c) as relation
WHERE (a.meta ="SoftwareApplication" OR a.meta
="MobileApplication" OR a.meta =
"WebApplication" OR a.name="Application" OR
a.name="Software" OR a.foldername
="Application") AND NOT a: Meta
RETURN a, relation, labels(a)
```

7) V-114 Layer diagram to visualize IT landscape status. In this viewpoint, business processes are depicted in the top layer, supported by various business applications in the middle layer, and the required physical components are visualized in the bottom layer (see screenshot in Figure 28). In contrast to Khosroshahi et al. [31], we chose to use colors and symbols instead of spatially separate layers to differentiate the layers, using green triangles for physical components, yellow crosses for applications, and red circles for business processes. The arrows in the relations show the direction of information flow. The viewpoint deals with the following stakeholder concerns:

- C-98 Determine shutdown impact of infrastructure Component

To realize this viewpoint, the following Cypher statement is used:

```
MATCH (n) - [] -(b) - [] - () - [] - (c)
WHERE ((n.meta ="PhysicalComponent" OR n.name
="PhysicalComponent" OR n.foldername
="Technology") AND' (b.foldername ="Application"
OR b.name ="Software" OR b.meta
="SoftwareApplication" OR b.meta
="MobileApplication" OR b.name =
"WebApplication") AND (c.foldername = "Business"
AND c.instancename = "Processes"))
RETURN n, b, c
```

8) V-119 Number of infrastructure components used by business application. This viewpoint depicts the number of infrastructure components used by a specific business application (see screenshot in Figure 29), using the number and variety of components as a measure. It can be sorted by clicking on a column header. The viewpoint deals with the following stakeholder concerns:

- C-120 Measure changes in application landscape
- C-124 Reduce application landscape complexity
- C-141 Get transparency about IT costs

To realize this viewpoint, the following Cypher statement is used to find all physical components or applications that are used by a business application:

```
MATCH (n) – [] – (b)
WHERE ((n.meta ="PhysicalComponent" OR n.name
="PhysicalComponent" OR n.foldername
="Technology") AND (b.foldername ="Application"
OR b.name ="Software" OR b.meta
="SoftwareApplication" OR b.meta
="MobileApplication" OR b.meta =
"WebApplication" OR b.name="Application"))
RETURN b.id
```

Then using the application ID, all components and applications associated with it are counted:

```
MATCH (b {id: {idparam}}) – [r]– (n)
WHERE (n.name ="PhysicalComponent" OR
n.foldername ="Technology")
RETURN b.id, count(r), labels(b)', {idparam:
record._fields[0] }
```

9) Visualization tab. The fourth and final tab provides customizable graph-based visualization as shown in the screenshot in Figure 30, supporting analysis and exploring. Elements are differentiated by both color and shape. Initially only the first 200 nodes are loaded to limit the response time, since initially one is unclear about the actual interest of the user.

The Cypher statement used to support this visualization is:

```
MATCH (n) – [r] – (b)
WHERE NOT n:Meta
RETURN n, r, b, labels(n), labels(b) LIMIT 200
```

The resulting JSON is then processed by the D3 JavaScript library using forced layout, and an SVG is created. Each node supports mouseover, mousedown, mouseup, and mouseout events. The interface supports zoom. Search is supported in the upper right of the visualization tab, and supports any Cypher query, while past queries are shown in a dropdown list (see Figure 10). Pressing search sends a POST to app.js.

Filtering is provided to support users who are not familiar with Cypher. It supports element labels, names, and IDs via checkboxes, while metadata is not supported. First a label from the list of possible labels is selected as shown in Figure 11.

The Cypher statement used to support filtering is:

```
MATCH (n)
WHERE NOT n:Meta
RETURN DISTINCT labels(n)
```

After a label is selected, a name selection dialog as shown in Figure 12 is displayed. Then a list of matching IDs is offered as shown in Figure 13.

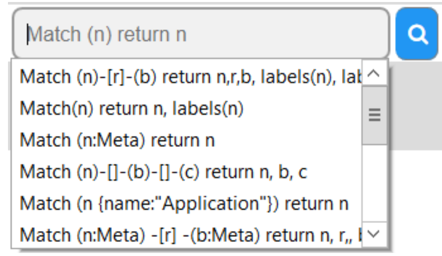


Figure 10. Search functionality.

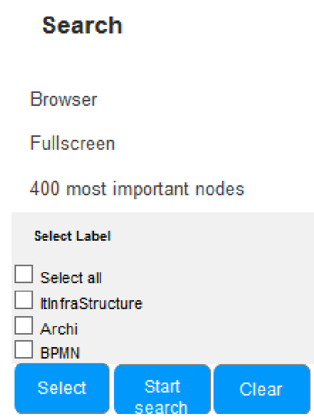


Figure 11. Filtering label selection dialog.

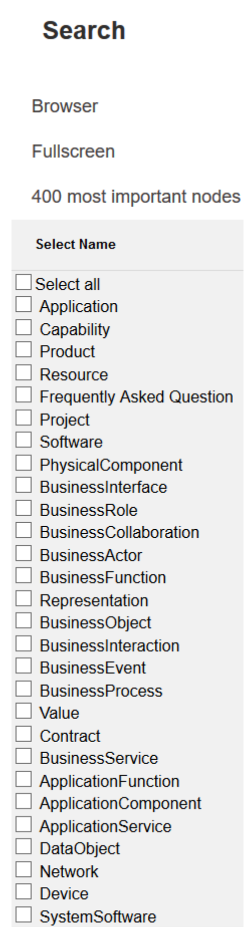


Figure 12. Filtering name selection dialog.

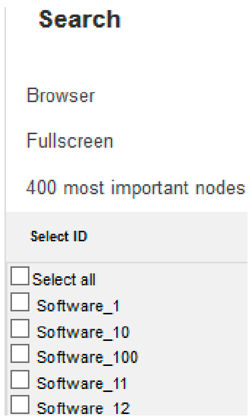


Figure 13. Filtering ID selection dialog.

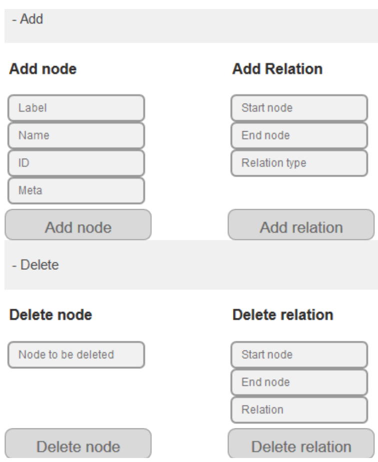


Figure 14. Dialog for manually adding or deleting a node or relation.

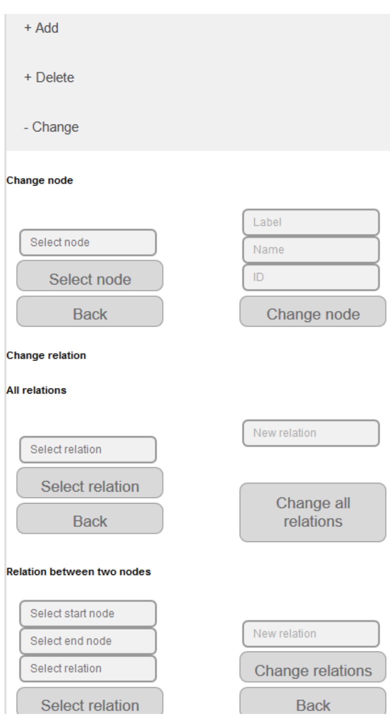


Figure 15. Dialog for manually changing a node or relation.

Adding or deleting a node or relation is also supported via the dialog shown in Figure 14, while changing a node or relation is supported with the dialog shown in Figure 15.

D. D^{2}F EA Tool Validation

To validate the implementation against requirements, we refer to the requirements described in Section IV.A. As to EA visual requirements (see Table III):

- Maximize Visual Economy (MVE): the implementation was able to demonstrate that concepts can be differentiated with a concrete syntax for specific concepts, e.g., with colors and shapes in V-109 (Figure 24) and V-114 (Figure 28).
- Enhance Visual Expressiveness (EVE): multiple visual attributes can be used together to assist with differentiating concepts, e.g., both colors and shapes were used in V-109 (Figure 24) and V-114 (Figure 28) to differentiate the same concepts. ´
- Minimize the Noise (MN): only a single ID was used to identify an element visually, minimizing irrelevant information (Figure 20).
- Navigate and Interact (NI): various common user navigation techniques support analysis.
- Keep the Context (KC): we applied self-organizing layouts to deal with placement and relatedness issues in large models (Figure 20).
- Derive New Insights (DNI): our implementation supports new insights via ad-hoc queries, e.g. via Cypher statements (Figure 10).
- Guarantee Semantic Correspondence (GSC): legends are provided to support graphic and conceptual correspondence (e.g., as in Figure 23).

As to EA analysis requirements (Table IV):

- Identify and Relate Domains (IRD): multiple domains, such as BPMN for process and ArchiMate for EA models can be differentiated and related (see Figure 28).
- Emphasize Key Elements (EKE): visual emphasis or distinction for elements of high structural or semantic importance is provided, for instance by interactive support via node selection (emphasizing relations of a node to its neighbors) or by color (green, yellow, red) as in Figure 21.
- Offer a Focus of Interest (OFI): spatial proximity is used to tie or cluster similar elements (e.g., Figure 24).
- Facilitate Structural Diagnosis (FSD): the visualization tab provides various structural diagnosis opportunities (e.g., Figures 23 and 28).
- Display Semantic Characteristics (DSC): semantic characteristics can be displayed that are not directly in the model, as the viewpoints showed with the relational complexity metrics (Figure 27).
- Uncover Architectural Qualities (UAQ): various supported viewpoints can be helpful in uncovering architectural qualities, such as frequency of use, isolation, etc. (Figure 21).

- Provide a Flexible Metamodel (PFM): our visual model and mapping is decoupled from the conceptual models, allowing for flexible visualization opportunities (Figure 19).

Various EA viewpoints from EAMPC as listed in Table V were demonstrated to be supported, and the rest appear supportable with additional effort, indicating the flexibility of the D^{2}F approach and the EA tool implementation architecture.

Various D^{2}F principles and qualities are shown to be supported, namely digitized data and models, support for flexible metadata (self-describing), the elements are easily linked, dynamicity is supported should an element change, the various models are holistically viewed, hyper-models are supported, and analytics are shown.

In summary, the D^{2}F EA tool was able to fulfill the given requirements with this prototype and show the feasibility and practicality of implementing the Digital Diamond Framework principles in an EA tool. The supported viewpoints showed the diversity of viewpoints and stakeholder concerns that could be addressed with the approach.

V. Evaluation

A case study and performance measurements provide initial insights into the practicality of our solution. Because of security concerns, it is difficult to receive permission to access company internal IT infrastructure data and be able to publish any related visualization and evaluation data. We thus chose to use fictional data for our evaluation case study.

A. Case Study with ArchiSurance

The Open Group created the ArchiSurance case study [34] as a fictitious example to illustrate the realistic use of the ArchiMate enterprise modeling language. It is considered in the context of the Open Group's TOGAF Framework, which is a method for EA. In this case study, we ignore the TOGAF method aspects and instead focus on the use of the ArchiSurance data. It is modeled using ArchiMate 3 and incorporates EA elements from the baseline and target business, application architecture, data architecture, and technology architecture. The fictitious ArchiSurance is the result of a merger of three previously independent insurance companies:

- Home & Away, specializing in homeowners' insurance and travel insurance
- PRO-FIT, specializing in auto insurance
- Legally Yours, specializing in legal expense insurance

The data consists of 120 elements and 176 relations and is available in an XML data format. We converted the data format to JSON, removing special characters present in the keys. The following screenshot in Figure 31 shows the actor cooperation view for ArchiSurance in the tool ArchiMate.

A sample subset of stakeholder concerns from Khosroshahi et al. [31] as shown in Table VII will be used in conjunction with the Viewpoints of Table IV to show how the ArchiSurance data can be analyzed with the D^{2}F prototype.

TABLE VII. CONCERNS

ID	Name
C-41	Determine used infrastructure for applications
C-62	Determine business capabilities of application landscape
C-98	Determine shut-down impact of infrastructure component
C-124	Reduce application landscape complexity
C-129	Remove monolithic applications

1) Determine used infrastructure for applications (C-41): V-109 can be used as shown with ArchiSurance data in Figure 32 to show what infrastructure is used by which applications.

2) Determine business capabilities of application landscape (C-62): to show the business capabilities of the business applications, V-111 can be used as shown with ArchiSurance data in Figure 33.

3) Determine shut-down impact of infrastructure component (C-98): to show the shutdown impact of an infrastructure component, V-114 can be used as shown with ArchiSurance data in Figure 28.

4) Reduce application landscape complexity (C-124): to reduce the application landscape complexity, the following viewpoints shown with ArchiSurance data can be used to provide insights: V-107.1 (see Figure 34) complexity of business applications, V-113.1 (see Figure 35) complexity of business applications in tabular form by business application, and V-119 (see Figure 35) number of infrastructure components used by a business application.

5) Remove monolithic applications (C-129): V-108.2 Evaluate potential removal candidates provides information useful for this concern. E.g., in Figure 22, the Unix Server 1059 has no relation to any other element, and is thus a possible candidate for removal.

B. Performance and Scalability of Graph Database

An initial characterization of the performance and scalability of our prototype implementation used an Acer Aspire X3-710 notebook with a i5-6400@2.7GHz CPU, 4GB RAM, Win10x64, Firefox, and Neo4j Community Edition (note that the Enterprise Edition this is intended for scalable commercial deployments). Thus, this is not an ideal or typical cloud deployment server setup, but rather a setup to investigate our implementation and characterize how the graph database behaves as we increase nodes. For any serious evaluation, real enterprise data and equivalent cloud and enterprise versions of components and databases should be used.

We measured the latency, CPU utilization, and RAM utilization based on this Cypher query to find all elements with relations as we increased the number of nodes:

```
MATCH (n) – [r] – (b)
RETURN n, r, b, labels(n), labels(b)
```

The resulting measurements are shown in Table VIII and plotted in Figure 16. We note that the latency did not automatically go up as the number of nodes increased from 250 to 1750. As the nodes increase from 250 to 2500, the latency goes from 32 to 79 seconds. Between 1250 to 1500 nodes we note significant changes in CPU utilization, between 1750 and 2000 nodes significant changes in latency, and between 2250 and 2500 nodes significant changes in RAM.

TABLE VIII. QUERY LATENCY (IN MILLISECONDS), CPU UTILIZATION (IN %), AND RAM (IN MIB) AS THE NUMBER OF NODES INCREASES.

Nodes	CPU	RAM (MiB)	Latency (ms)
250	38%	47	32650
500	25%	50	35812
750	26%	57	34000
1000	38%	56	35479
1250	55%	59	34000
1500	82%	63	44495
1750	79%	65	36186
2000	85%	69	60832
2250	87%	72	66644
2500	73%	123	78580

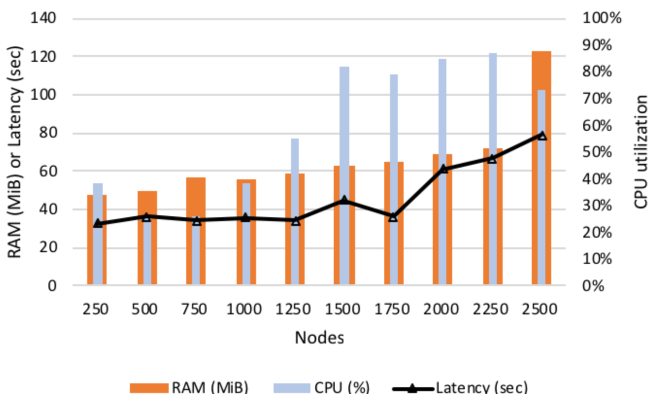


Figure 16. RAM (MiB), Latency (seconds), and CPU (%) vs. number of nodes.

This indicates that especially as CPU utilization increases beyond 50%, performance impacts may become noticeable; thus, deployment planning should consider the maximum number of expected nodes and plan sufficient CPU and RAM with appropriate load-balancing techniques, or attempt to use the Enterprise Edition of Neo4j. On a positive note, below these thresholds increasing the number of nodes does not automatically have an equivalent impact on query latency.

C. D^{2}F Assessment

In summary, the D^{2}F prototype shows that D^{2}F can be supported by any EA tool willing to adopt the D^{2}F principles. Specifically, our prototype furthermore supports the Jugel el al. [8] visual EAM analytic tool findings mentioned in Section I, namely:

View configuration: views can be easily configured to react to dynamic information demands. Furthermore, complete flexibility and interaction for queries is provided.

View consideration: a method is provided via multiple browser tabs, such that several views can be considered in parallel to avoid losing the overall context. Additionally, the views can be kept up to date since they are based on a datastore that can extract, transform, and load enterprise data.

Interacting with views: additional interaction and visual analytics capabilities are provided to help analyze and plan EAs more efficiently.

Communication & collaboration: to better support communication & collaboration, additional knowledge can be added to views via its flexible (meta)tagging capability.

Stakeholder identification: by providing enhanced visual analytic capabilities with real EA data, actual stakeholders that have to be involved in decision-making processes can more readily be identified.

Other EA tool implementations could be implemented to support the D^{2}F, our prototype implementation and performance characterization shown here is primarily intended to show that it is feasible and that graph-based implementation approaches can also work.

VI. CONCLUSION

A sustainable EAF is needed that can embrace the digitized enterprise era. This paper described the Digital Diamond Framework (D^{2}F) to support digitized enterprises with structure, order, modeling, documentation, and analysis 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.

The D^{2}F EA tool prototype showed the feasibility of D^{2}F, and that an EA tool based on D^{2}F can support important features for enterprises in the digital age: enterprise information model agnostic, flexible meta-models, tagging for adding knowledge to elements/views, easily create and (re)configure interactive dynamic views, support visual analytical capabilities, and via a web-centric implementation diverse stakeholders can be incorporated. The implementation also demonstrated the power of graph databases for accessing and conveying facets in a very flexible manner. Furthermore, hyper- models were demonstrated, incorporating BPMN and ArchiMate models in one repository.

To be of significant value for enterprises in the digital age, integration and customization of EA tools to each specific enterprise is required. Future work includes studying the D^{2}F EA tool prototype in industrial case studies.

APPENDIX

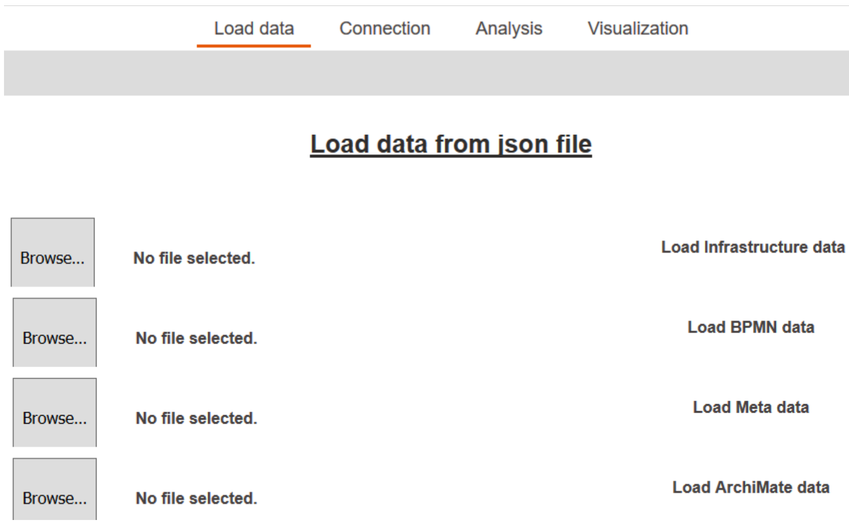


Figure 17. Load data tab and other tabs.

ID	Name	
Unix Server	Device	2018-10-30 16:18:07

Figure 18. Additional element information.

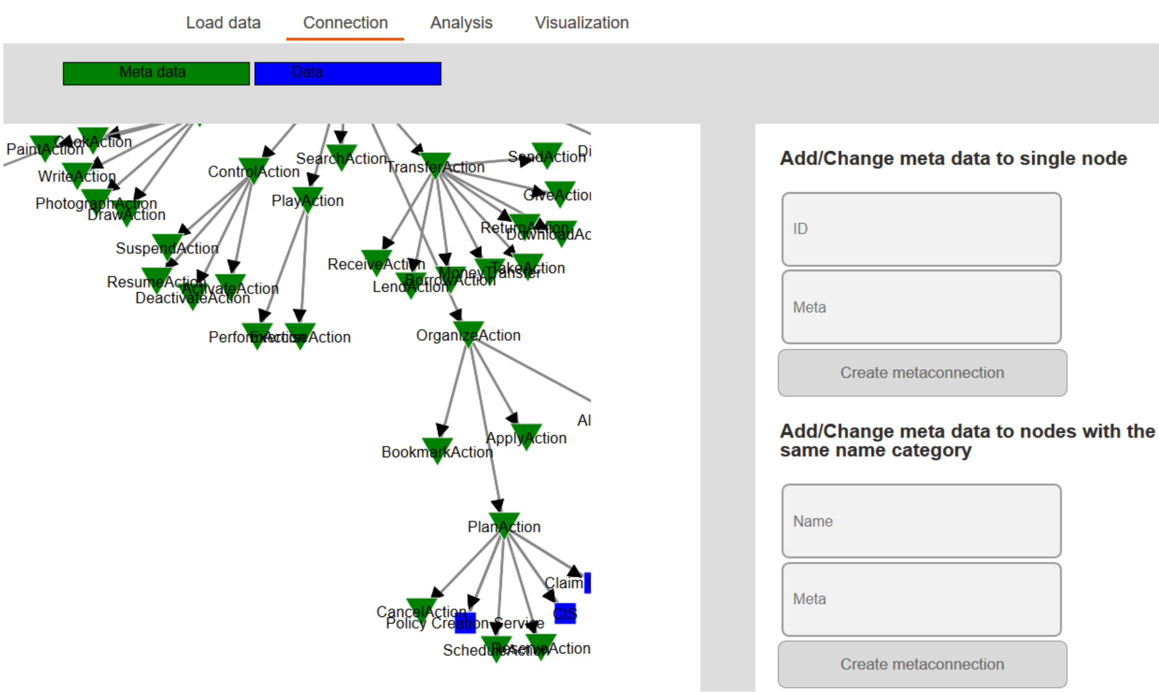


Figure 19. Metadata to data association screen.

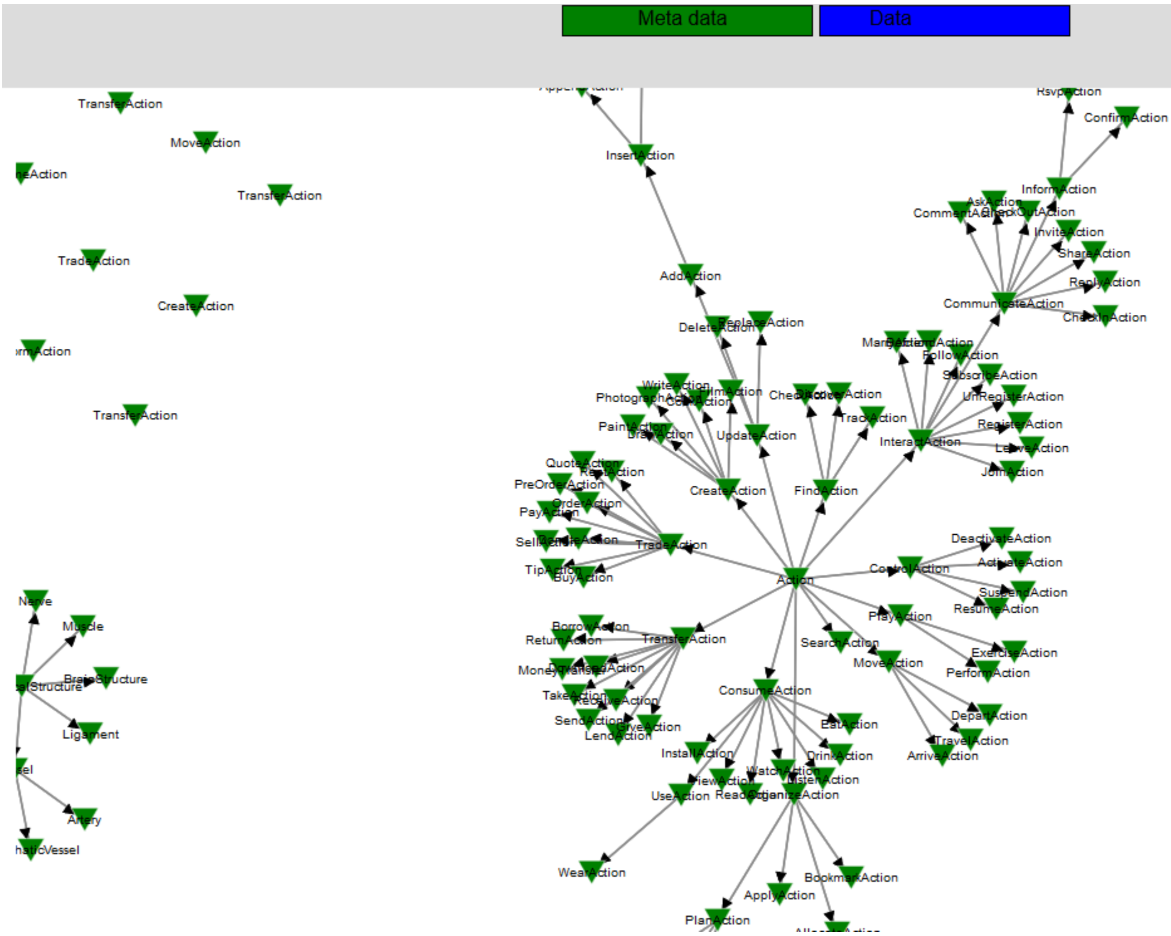


Figure 20. Metadata association visualization.

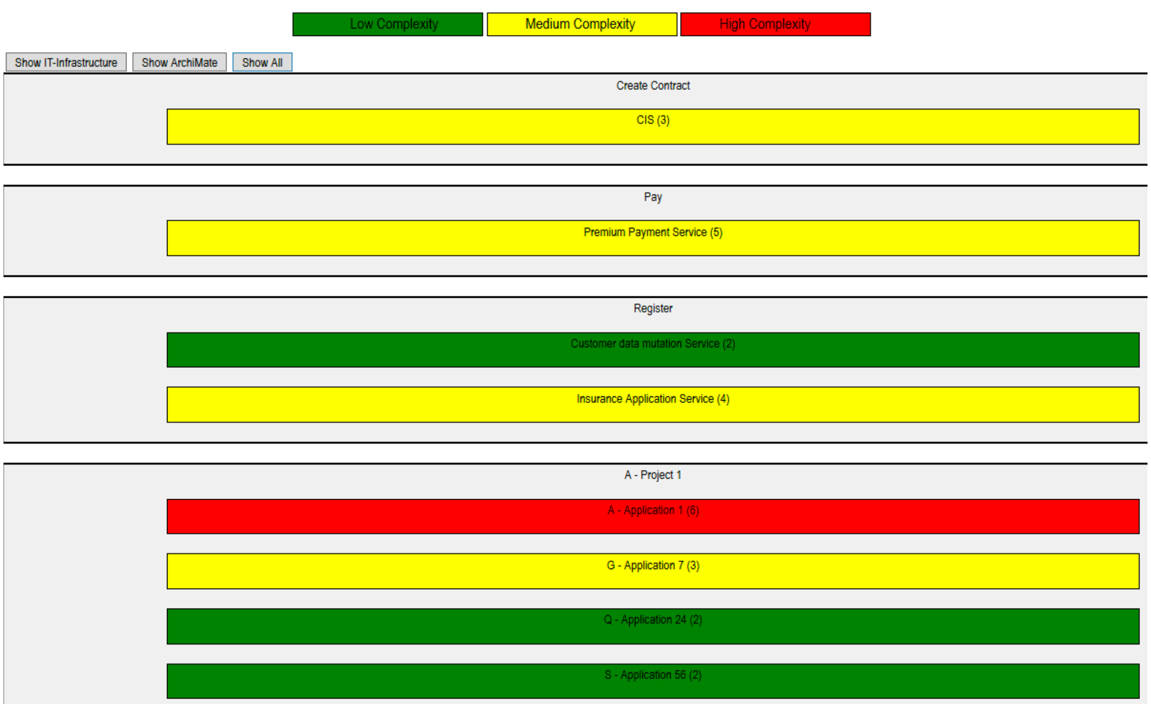
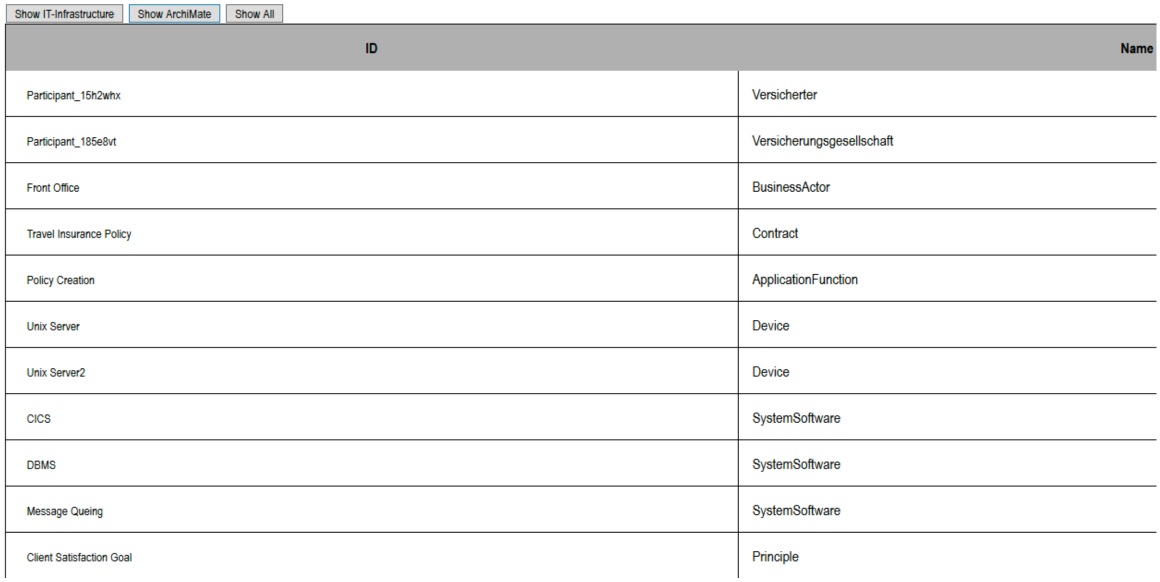


Figure 21. V-107.1 Complexity of business applications.



Show IT-Infrastructure | Show ArchiMate | Show All

ID	Name
Participant_15h2whx	Versicherter
Participant_185e8vt	Versicherungsgesellschaft
Front Office	BusinessActor
Travel Insurance Policy	Contract
Policy Creation	ApplicationFunction
Unix Server	Device
Unix Server2	Device
CICS	SystemSoftware
DBMS	SystemSoftware
Message Queing	SystemSoftware
Client Satisfaction Goal	Principle

Figure 22. V-108.2 Evaluate potential removal candidates.

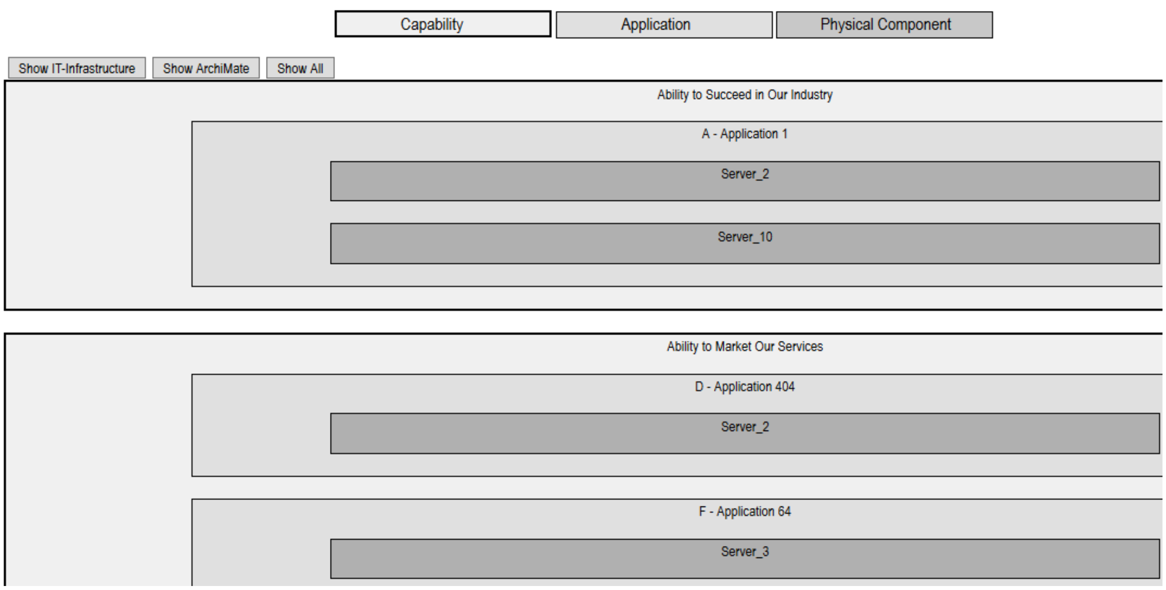


Figure 23. V-108.4 Increase transparency of application landscape.

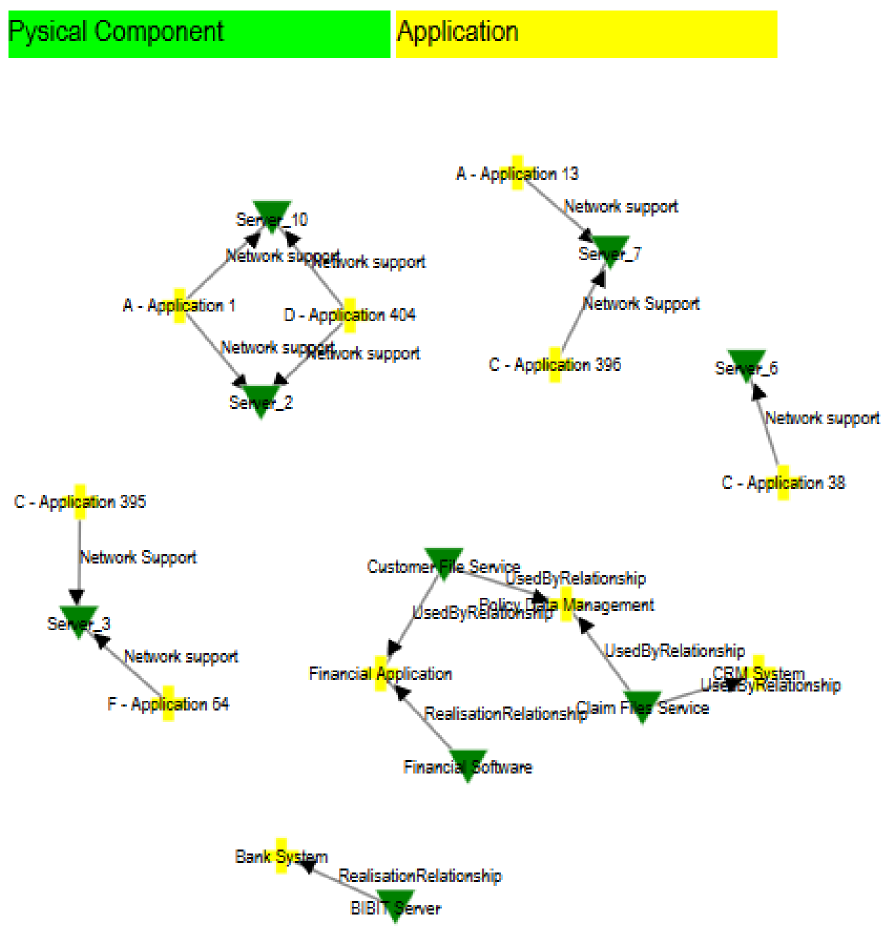


Figure 24. V-109 Transparency about used physical components for business applications.

Show IT-Infrastructure | Show Archi | Show All

Business capability Business application	Insurance Policy Data	Insurance Request Data	Customer File Data	Damage Claim Data	Policy Creation Service	Claim InfoServ	CIS
Legal aid Insurance Policy	X						
Insurance Request		X					
Liability Insurance Policy	X						
Customer File			X				
Damage Claim				X			

Figure 25. V-111.1 Use of business applications.

Show IT-Infrastructure | Show Archi | Show All

Business capability Business application	Y - Application 722	W - Application 528	U - Application 321	T - Application 225	S - Application 129	R - Application 914	Q - Application 818	I - Application 978
Ability to Succeed in Our Industry	X	X	X	X	X	X	X	X
Ability to Sell Our Products to Public Sector								
Ability to Market Our Products to Public Sector			X			X		X
Ability to Design Services								

Figure 26. V-111.2 Relation between business capability and business application.

Low Complexity | Medium Complexity | High Complexity

Show IT-Infrastructure | Show ArchiMate | Show All

Business Application	Instance	Number of relations ▲
Policy Data Management	ApplicationComponent	7
Insurance Policy Data	DataObject	7
Financial Application	ApplicationComponent	6
Customer Data Access	ApplicationComponent	4
CRM System	ApplicationComponent	4
LAN	Network	4
Home and Away Policy Administration	ApplicationComponent	4
Mainframe	Node	3
Claim InfoServ	ApplicationService	3
Customer File Service	InfrastructureService	3
CIS	ApplicationService	3
Firewall2	Node	3

Figure 27. V-113.1 Complexity of business applications.

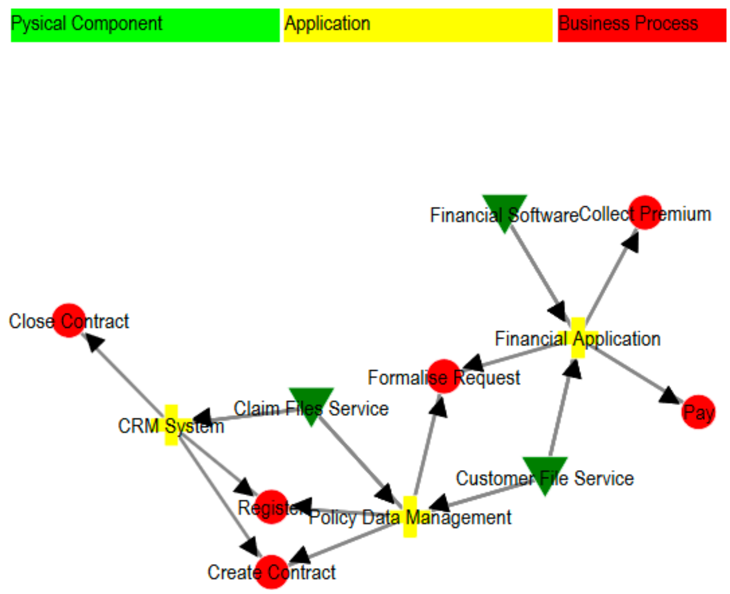


Figure 28. V-114 Layer diagram to visualize IT landscape status.

Show IT-Infrastructure | Show Archi | Show All

ID	Number of relations
Bank System	1
Financial Application	2
Policy Data Management	2
CRM System	1
D - Application 404	2
A - Application 1	2
C - Application 395	1
F - Application 64	1
C - Application 38	1
C - Application 396	1
A - Application 13	1

Figure 29. V-119 Number of infrastructure components used by business application.

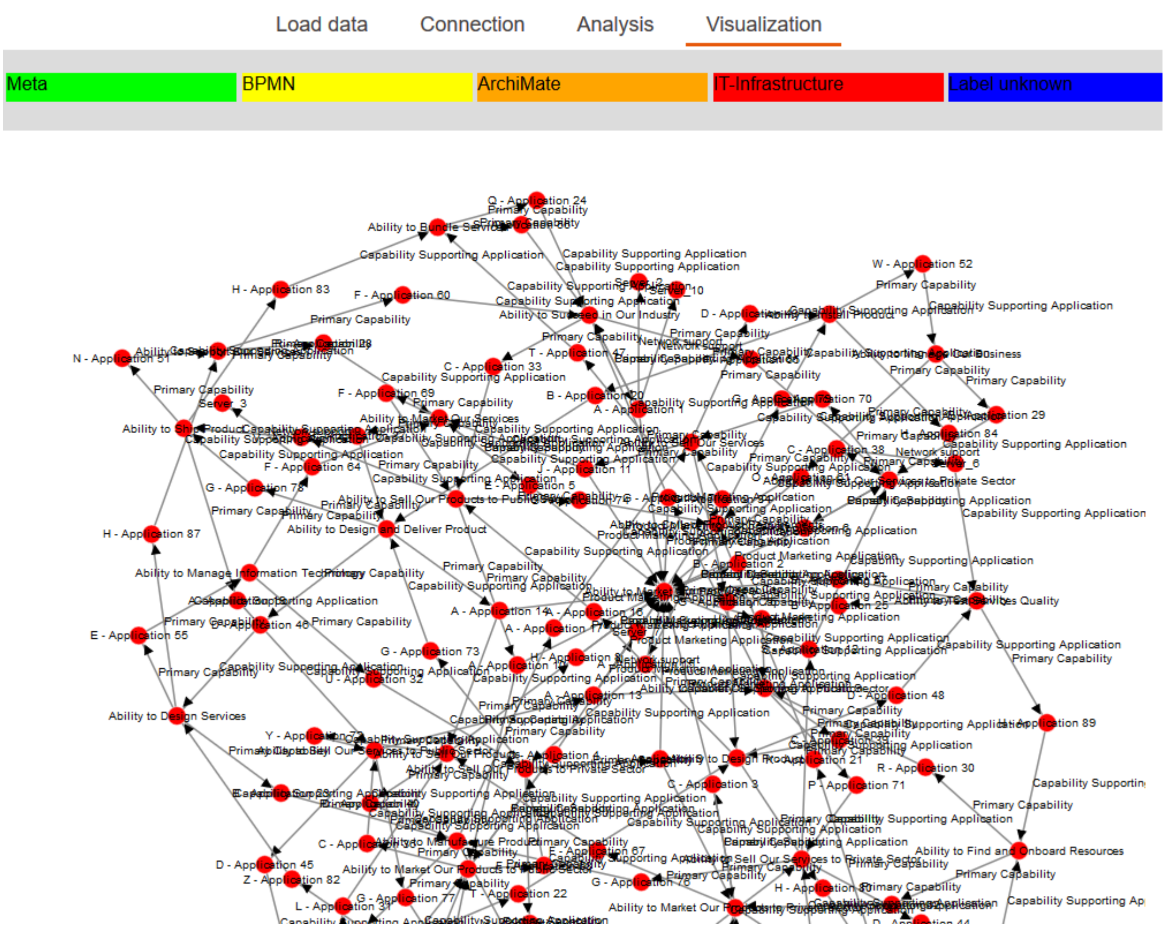


Figure 30. Visualization tab.

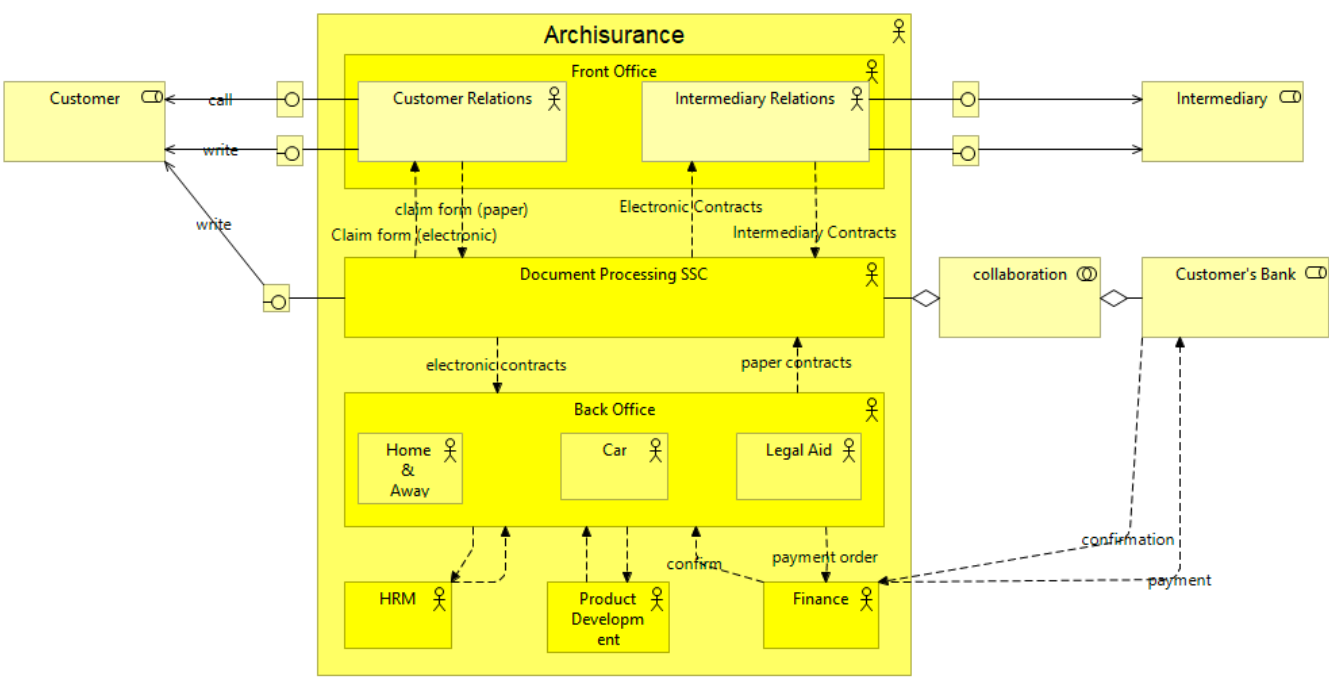


Figure 31. ArchiSurance Actor Cooperation View.

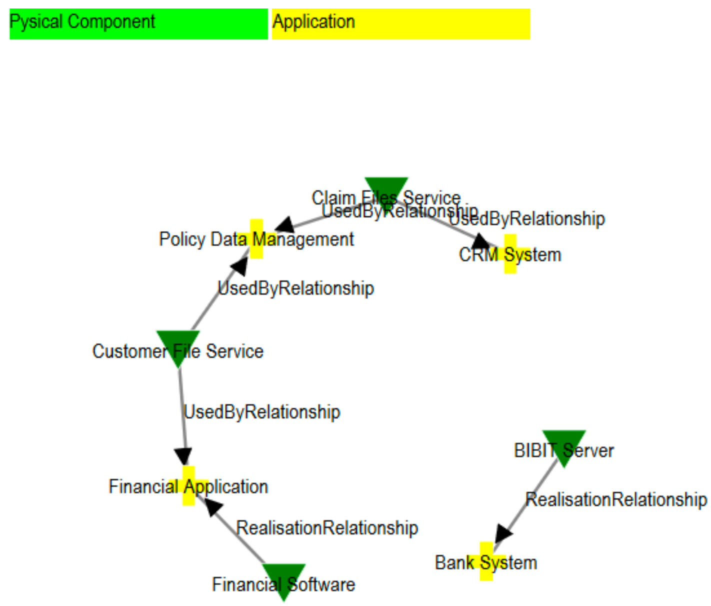


Figure 32. V-109 with ArchiSurance data.

Business capability **Business application**	Legal aid Insurance Policy	Insurance Request	Liability Insurance Policy	Customer File	Damage Claim	Travel Insurance Policy	Car Insurance Policy	Home Insurance Policy	Check and Sign Contract
Insurance Policy Data	X		X			X	X	X	
Insurance Request Data		X							
Customer File Data				X					
Damage Claim Data					X				
Policy Creation Service									X
Claim InfoServ									
CIS									
Financial Application									
CRM System									
Policy Data Management									

Figure 33. V-111 with ArchiSurance data.

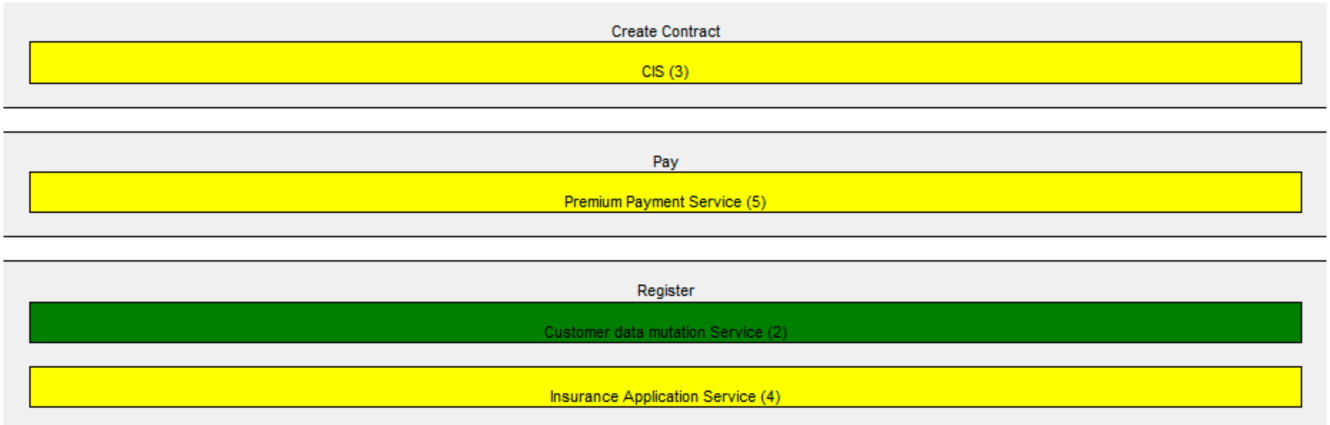


Figure 34. V-107.1 with ArchiSurance data.

Business Application	Instance ▾	Number of relations
Call center application	ApplicationComponent	2
CRM System	ApplicationComponent	4
Customer Data Access	ApplicationComponent	4
Home and Away Policy Administration	ApplicationComponent	4
Claim Data Management	ApplicationComponent	1
Financial Application	ApplicationComponent	6
Bank System	ApplicationComponent	2
Policy Data Management	ApplicationComponent	7
Risk Assessment	ApplicationComponent	2
Web portal	ApplicationComponent	3
Calculate Premium	ApplicationFunction	2

Figure 35. V-111 with ArchiSurance data.

ID	Number of relations
Bank System	1
Financial Application	2
Policy Data Management	2
CRM System	1

Figure 36. V-119 with ArchiSurance data.

Acknowledgment

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