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Chapter · February 2020

3 authors:

Peter Filet
Open Universiteit Nederland

Rogier van de Wetering
Open Universiteit Nederland

Stef Joosten
Open Universiteit Nederland

Chapter

ENTERPRISE ARCHITECTURE ALIGNMENT

***Peter Filet, Rogier van de Wetering*[1,*]**
***and Stef Joosten*[1]**
Department of Information Sciences,
Open University of the Netherlands,
Heerlen, Limburg[1], the Netherlands

ABSTRACT

An Enterprise Architecture (EA) is an instrument that focuses on coherence between business processes, information distribution, and technology infrastructure of an organization. In practice, we see that architects are not well equipped to manage the interrelationship between architectural business-, information- and technology-aspects in an integrated fashion. EA frameworks are mostly informal by nature, and there is a lack of knowledge and tools to support architects to check alignment formally. Due to the volume and complexity of holistic enterprise spanning architecture, it is increasingly challenging for organizations to maintain overview and coherence of architectural elements. This research enables automated, rule-based monitoring consistency and coherence between elements within an EA. It does so by

[*] Corresponding Author address. Email: Rogier.vandewetering@ou.nl.

creating an artifact that provides architects with the capability of monitoring validity within ArchiMate EA models. We validate models against formalized rules specified in Relation Algebra with which coherence can be mathematically proven. We also plot a set of applied rules onto a quality framework that calculates an overall alignment score of an EA model. Every single rule violation that influences the score is explicitly identified. Monitoring EA quality using formalized rules enables organizations to manage and control the process of EA change and thus contributes to Business/IT-alignment.

INTRODUCTION

Modern organizations are increasingly served by, and even dependent on, effective and efficient use of information systems and information technology (IS/IT). Research shows that the alignment of business and IT (also called alignment) affects organizational performance (Gerow, Grover, & Thatcher, 2015; R. Van de Wetering, Mikalef, & Pateli, 2017). Alignment between business and IT offers value to organizations and contributes to organizational success (Castellanos & Correal, 2013; Chan & Reich, 2007; Saat, Franke, Lagerstrom, & Ekstedt, 2010). Therefore, it is not surprising that within many organizations on (IT) executive-level understanding of Business/IT-alignment is evolving and the topic gains priority on the executive agenda (Gerow et al., 2015; Gerow, Thatcher, & Grover, 2014; Gregor, Hart, & Martin, 2007; Pereira & Sousa, 2005). However, scholars argue that alignment causes rigidity resulting in stagnation of maneuverability which is required in response to changes in the business environment (Gerow et al., 2014; Walraven, Van de Wetering, Helms, Versendaal, & Caniëls, 2018).

Extant literature shows that Enterprise Architecture (EA) is generally considered an important instrument to contribute to Business/IT-alignment (Alaeddini & Salekfard, 2011; Castellanos & Correal, 2013; Gregor et al., 2007; Kang, Lee, & Kim, 2010; Pereira & Sousa, 2005; Sousa, Pereira, & Marques, 2004). EA's can be considered instruments that focus on coherence between business processes, information distribution, and technology infrastructure of an organization. In practice, the proper interrelationship between these different architectural aspects is not integrally addressed (Castellanos & Correal, 2013). EAs, especially with (medium) large enterprises, therefore, quickly become large and complex. Also, the effort to maintain an EA within an organization is often carried out by a group of architects, each with their specific area of interest or specialty (Steenbergen, 2011). EA frameworks are mostly informal of nature, and widely not validated, and there is a lack of knowledge and tools to support Enterprise Architects to check this alignment formally (Castellanos & Correal, 2013; Van de Wetering, 2019a, Van de Wetering, 2019b; Wegmann, Balabko, Lê, Regev, & Rychkova, 2005).

Based on the above, this research aims to enable automated, rule-based monitoring consistency and coherence between elements within an EA, aiding architects in achieving alignment. In doing so, we specify an EA model defined in the ArchiMate modeling language. We validate this EA model against formalized rules that we define in Relation Algebra. We plot the set of applied rules on a quality framework that enables calculating the overall alignment score of an EA model. Underlying scores for quality factors like completeness and correctness determine alignment's score. Using this approach, we identify every single rule violation that influences the score. Monitoring EA quality using formalized rules makes inconsistencies and differences in interpretation visible and enables organizations to manage and control the process of EA change and thus contributes to Business/IT-alignment.

The contribution of EA to Business/IT-alignment depends on the quality of the architecture itself in general and the alignment between architectural domains, aspects, and elements in particular. Although the quality of EA is considered critical to the effectiveness and ability to realize the benefits of EA, little research to this end is available (Niemi & Pekkola, 2013). Several studies show the relevance of interrelations between aspects, domains and components within an EA (Aier & Winter, 2009; Antunes, Bakhshandeh, Mayer, Borbinha, & Caetano, 2014; Eck, Blanken, & Wieringa, 2004; Plazaola, Flores, Silva, Vargas, & Ekstedt, 2007), although be it that proposed solutions are diverse. Some studies show the notion of defining alignment heuristics as a means of managing the quality of EA, preferably supported by automated tools (Antunes et al., 2014; Pereira & Sousa, 2005; Sousa et al., 2004). Currently, there is very little research on effectively monitoring the mathematical correctness of these relationships, especially when applying changes in the EA.

Several architecture modeling languages and architecture frameworks have been developed and tested, such as ArchiMate. The extant literature argues that EA can strengthen the cohesion of business and IT. Many EA methods, frameworks, and techniques to this end are available, but an overarching approach is currently lacking in the literature. We observe this sentiment also in practice. Hence, architects argue, discuss, and suggest a lot, but provide little to none hard substantiation. If such a sound theory of architecture exists, it may be assumed that it is efficiently acted upon and communicated by professionals. So we find a lack of proper theory. A theory consists of a set of rules, hypotheses, and statements within a joint context. The context of this research is the practice of Enterprise Architects. To rise above the usual practice of 'arguing," we strive for more substantiation. We state that tooling is possible that not only aids architects in automating the manual task that architects need to perform to ensure coherence, but also provides the substantiation. To achieve this, we aim to find a set of formal rules that allows a computer to measure cohesion in EA models.

The purpose of this current research is, to demonstrate in practice that such tools are possible and useful.

THEORETICAL BACKGROUND

EA Literature

Several definitions of EA are available in the contemporary scientific literature. In the context of this research, Lankhorst (2005) describes EA as a '*coherent whole of principles, methods, and models that are used in the design and realization of an enterprise's organizational structure, business processes, information systems, and infrastructure.*' An EA is typically described using models, covering a holistic view of an organization. Due to the complexity of an EA description, many frameworks were developed to assist in this task (Hinkelmann et al., 2015). Matthes (2011) reports more than 50 EA frameworks. We focus on the widely used framework TOGAF (TOG, 2011) that is related to a modeling language and supports automated processing. It is composed of a set of closely interrelated architectures: Business Architecture, Information Systems (Application and Data) Architecture and Technology (IT) Architecture. TOGAF also includes a set of tools to enable EA teams to picture the present and future state of the architecture. TOGAF can be used in conjunction with ArchiMate (TOG, 2016).

The ArchiMate standard is based on the ISO/IEC/IEEE 42010 standard and introduces an integrated language for describing EA's. ArchiMate fits into the TOGAF framework as it provides concepts for creating a model that correlates to its three architecture layers. The ArchiMate modeling language is based on a formal foundation, which makes it fit for machine interpretation and thus offers possibilities for automated validation (Lankhorst, 2005).

Alignment Heuristics

Several studies show the relevance of interrelations between aspects, domains and components within an EA (Aier & Winter, 2009; Antunes et al., 2014; Eck et al., 2004; Plazaola et al., 2007). Some studies show the notion of defining alignment heuristics as a means of managing the quality of EA, preferably supported by automated tools (Antunes et al., 2014; Pereira & Sousa, 2005; Sousa et al., 2004). There currently is minimal scholarship on the matter of effectively monitoring the mathematical correctness of these relationships, especially when applying changes in the EA.

The internal EA alignment is described by Sousa et al. (2004) as '*the issue of alignment based on the coherency between elements of Business Architecture, elements of Information Architecture and elements of Application Architecture. The more elements each of these Architectures* *has, the richer and more complex is the concept of alignment because more rules and heuristics need to be stated to govern* the relationship between these elements. So, to build up alignment, one must first clarify the elements of each architecture'.

Achieving alignment also requires an understanding of the concept of misalignment. A Business/IT-alignment model (BITAM) defines the mappings between three layers of a business system: business models, business architectures, and IT architectures. Misalignments in BITAM are defined as improper mappings between the layers (Chen, Kazman, & Garg, 2005). El-Telbany and Elragal (2014) define misalignment as '*the continuous efforts, involving management and information systems, of consciously and coherently detecting and testing for the interrelation of all components of the business-IT relationship; where a change in one would instantly influence the other, contributing to the organization's performance over time*.' This research focuses on monitoring and managing the continuous changes in these interrelations. For this, we need a perceptible and automatically processable, thus formalized, form of modeling components and its interrelations.

The implementation of alignment heuristics in formalized rules governs the interrelation between elements within the architectural layers and aspects. This research focuses primarily on the most broadly applied ArchiMate layers (Business, Application, and Technology) and all four aspects.

The Ampersand method is designed to formalize the alignment heuristics into business rules using the language ADL ("A Description Language"), based on Relation Algebra, a part of mathematics equivalent to predicate logic, though it is easier to learn and apply (Grave, Van de Wetering, & Rutledge, 2018; S. Joosten, 2007; Stef Joosten, 2018; Michels, Joosten, van der Woude, & Joosten, 2011). Each rule stated in ADL is a formal representation of a quality aspect of architecture (either generic of business-specific). The key components for capturing rules within ADL are architecture components (called concepts) and relations between these concepts.

Quality Metrics for EA

Niemi and Pekkola (2013) investigated the EA product quality attributes and defined six quality attributes of EA product quality. That investigation does not provide proper insight as to what influence each of the quality attributes has on the overall quality of an EA. Currently, is no adequate literature available that provides a useful quality model to determine the relative impact of quality factors on the overall quality. Hence, we revert to research within the field of data models. The defined quality attributes show a similarity to the quality attributes that are proposed by Niemi and Pekkola (2013). Moody and Shanks (2003) constructed a quality model based on available literature concerning quality evaluation approaches. They provide a quality model to evaluate and improve the quality of data models. They defined a total of eight quality factors, governing both product quality and process quality. Empirical research on quality differences between novice and expert models showed that the impact of specific product quality factors on the overall quality varies. Five out of the eight quality factors are related to product quality. These quality factors with their contribution to overall quality are shown in Table 1.

Table 1. Effect of quality factors on overall quality (Moody & Shanks, 2003)

Quality factor	% contribution
Understandability	50.0%
Completeness	36.4%
Correctness	8.9%
Simplicity	3.1%
Flexibility	1.6%

Although unsupported by empirical research results, we assume that the contribution of quality factors toward data model quality can be relevant to EA model quality as well. The actual contribution is less relevant to our research goal. The constructed mechanism to calculate an overall quality is more important than the outcome itself.

Based on the similarities in definitions of the quality factors by Moody and Shanks (2003) and the EA product quality attributes by Niemi and Pekkola (2013), we have transposed the definitions of Niemi and Pekkola (2013) onto the top three quality factors of Moody & Shanks as shown in Table 2. Two out of the six quality attributes of Niemi & Pekkola were left out of scope (Availability and Usefulness) because these do not explicitly concern EA model quality and are thus less relevant for our research aim.

Table 2. Similarity mapping quality factors and attributes

Quality factor by Moody & Shanks	Quality attribute by Niemi & Pekkola
Understandability	Clarity, Holistic view (granularity), Uniformity
Completeness	Conciseness, Correctness (not being incomplete), Detailed information (granularity), Cohesion
Correctness	Correctness

We reviewed literature in search of rule candidates that could be mapped onto one of the three quality factors, as mentioned in Table 2. Although many rule candidates can be found as alignment heuristics, they are not always readily translated into Relation Algebra, which could pose a problem in the empirical part of our research. A solution to this problem is to apply meta-tagging in the EA model. Another is to discard the rule candidate.

An EA model is considered adequately aligned if the measure of alignment reaches an established threshold, as proposed by Castellanos and Correal (2013) and Aversano, Grasso, and Tortorella (2016). The applicable threshold needs to be determined for each specific situation.

Aversano et al. (2016) (p. 176 – 179) presented a method to determine the alignment degree by measuring a set of defined metrics considering business processes and software systems. A part of their method applied a semantic analysis to determine the similarity between business process activities and software components. We employ formalized rules stating the degree of alignment between the specified architecture components. With each violation of a rule, the alignment diminishes. Each violation of a rule impacts rule alignment, quality factor alignment, and overall alignment.

Methods

Design Science

Figure 1 shows our research approach. We build on the method of Doorewaard and Verschuren (2015). The key topics in this model are:

- Formalized EA model;
- Formalized rule model;
- Alignment quality model.

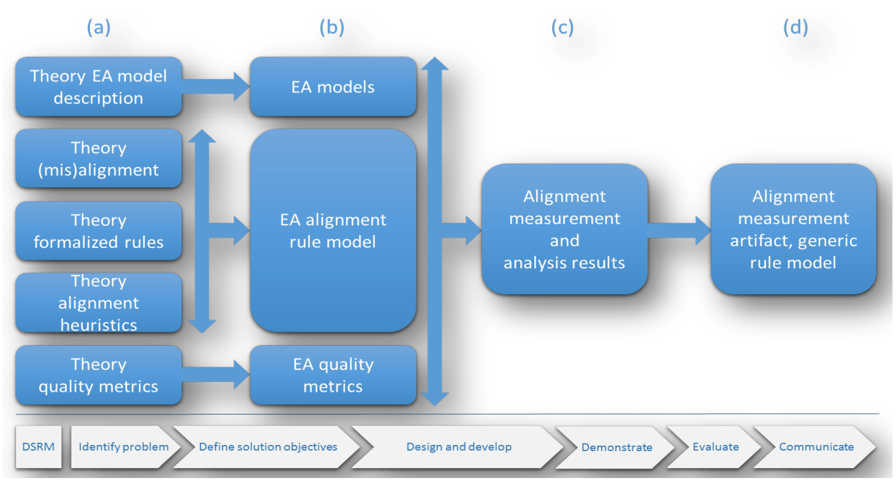

Figure 1. Research approach.

The lower part Figure 1 shows the Design Science Research Methodology process model (Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007).

This current research explores the possibility of creating a practical, applicable environment to support automated, rule-based monitoring consistency and coherence between elements within an EA model. The practical research method that supports the creation of an innovative solution to a real-world problem is the Design Science method (Gregor & Hevner, 2013; Hevner & Chatterjee, 2010).

The Design Science research method is a novel approach within the field of Information Systems because it combines focus on the creation of an IT artifact with a high priority on maintaining the relevance of IS research in the application domain (Hevner & Chatterjee, 2010). The research activities for the Design Science method are described in a conceptual framework and follow a set of guidelines to conduct and evaluate Design Science research, as mentioned in (Hevner & Chatterjee, 2010; Venable, Pries-Heje, & Baskerville, 2014). The Design Science process consists of six steps, as shown in the lower part of Figure 1.

Applied Alignment Heuristics

We found a limited number of scientific articles that unfold alignment heuristics in detail. Castellanos and Correal (2013) also referred to Pereira and Sousa (2005) and Sousa et al. (2004). Different approaches were found in the literature to define alignment heuristics, although detecting misalignment is a commonality. Pereira and Sousa (2005) and Sousa et al. (2004) used a common-sense approach to define the list of alignment heuristics. This latter approach also resulted in an overlap between the heuristics. Using a common-sense approach has the risk that heuristics cannot be applied to different businesses. This research maps the heuristics onto the quality model that we designed based on Moody and Shanks (2003) and Niemi and Pekkola (2013).

The applied rule model is constructed, based on the outcomes of the literature study (i.e., alignment heuristics from the literature transformed into formalized rules) and enriched based on interviews with EA experts that are closely involved with the researched cases. Efficacy, instead of integrality, of the set of rules that is applied to the EA models, is the primary goal that drives the selection of rules to implement.

The outcome of alignment measurement for each model is not an absolute indication of the quality of the EA model, but a precise calculation of the EA model quality to the applied set of rules.

Alignment Calculation

Based on the proposed method by Aversano et al. (2016) and the quality factor model derived from Moody and Shanks (2003) and Niemi and Pekkola (2013), rule alignment is calculated as a percentage score by dividing the number of violations of a rule onto the number of pairs in the relation that is described by the antecedent part of the rule assertion, thereby using the following metrics:

$$RuleAlignment\% = 1 - \frac{\#violations}{MaxValue\ (\#pairs\ in\ antecedent; 1)}$$

Alignment within a single quality factor (QF) is then the average RuleAlignment% of all rules applying to the same quality factor:

$$QFalignment\% = \frac{\sum RuleAlignment\%\ within\ QF}{\#rules\ within\ QF}$$

If no rules exist within a quality factor (#rules within QF equals 0), the QFalignment% for that quality factor is undefined, which implicitly increases the relative contribution of other quality factors to the overall alignment, as shown in the formula below.

We calculate the overall alignment score as the weighted average of QFalignment%. This calculation can be done for each of the quality factors:

$$Overall\ Alignment\% = \frac{\sum(QFalignment\% * QFcontribution\%)}{\sum(QFcontribution\%)}$$

If no rules exist in any of the quality factors, there is no QFalignment% for any of the quality factors, which renders the Overall Alignment% undefined. Table 1 shows the contribution of each quality factor (QFcontribution%). This calculation proposal does not incorporate the relative weight of individual rules.

Case Studies

The Design science method is focused on developing an artifact that has relevance to solving a practical problem (monitoring alignment within an EA model) while ensuring the relation to the scientific foundation such as theories and methods (Relation Algebra). The Design Science method does not provide guidelines for collecting research data, but the collected research data does influence the nature of evaluation (Venable et al., 2014). In this research, the data set consists of six EA models in ArchiMate format and alignment heuristics. The heuristics are based on the literature study.

Two out of the six EA models were provided by organizations that are active in the public sector. Four models were obtained from an open-source, i.e., are publicly available, of which one is a reference architecture. The EA models are:

1. Netherlands Tax & Customs Administration (NTCA)
   The program "Regie modernisering IV-Landschap" (Directing modernization IT landscape) aims to guide IT initiatives while maintaining cohesion. The subprogram "Overzicht & inzicht IV-landschap" (Overview & Insight IT landscape) governs the landscape of (business)process-, application- and IT-infrastructure-landscape. An EA model is provided that concerns the domain Customs and spans ArchiMate's business- and application-layer. Its metrics: 1.987 elements (of which 314 business process elements, 259 business services, 212 application components, 257 application services) with 6.148 relations. Due to confidentiality restrictions, the EA model is partially anonymized by renaming some of the

occurrences of concepts (e.g., applications, processes) without impairing the relations between the elements. The model was supplied in the ArchiMate Open Exchange File Format.

2. Ministry of Defense Netherlands (MOD-NL)
   MOD-NL provided a partial model that contains some few specific elements from both the business- and application-layer of ArchiMate. The application layer specifically covered domains GIV ("Generieke IV" or "General IT"), P&O ("Personeel & Organisatie" or "Personnel & Organization") and M&F ("Materiaal & Financiën" or "Material & Finance"). Its metrics: 2.012 elements (of which 508 business actors, 54 business roles, 1.044 application components, 406 application services) with 1.323 relations. The model was supplied from ARIS as Excel export.
3. ArchiSurance[1]
   The ArchiSurance Case Study is a (publicly available) fictitious example developed to illustrate the use of the ArchiMate modeling language. The Case Study is about an insurance company (ArchiSurance). This company was formed following a merger of three (previously) independent firms. The case provides an architecture of the company and several change scenarios. Its metrics: 129 elements with 176 relations.
4. ArchiMetal[1]
   The ArchiMetal Case Study is a (publicly available) fictitious example of a manufacturer named ArchiMetal. Through high-level architecture modeling, the ArchiMate language illuminates the coherence between an organization, and its processes, applications, and infrastructure. Its metrics: 569 elements with 760 relations
5. OpenDay[1]
   The OpenDay model is a sample model to demonstrate the functionality of the Archi modeling tool. Its metrics: 31 elements with 37 relations

[1] ArchiMate model, publicly available on https://github.com/archimatetool/ArchiModels

6. European Interoperability Reference Architecture (EIRA)[2]
   The EIRA is a reference architecture model to guide public administrations and provides interoperable European public services to other public administrations, businesses, and citizens. The EIRA defines a set of required capabilities to promote interoperability as a set of architecture building blocks (ABBs). Its metrics: 157 elements with 235 relations.

The EA model data for ArchiSurance, ArchiMetal, and OpenDay typically support the artificial formative nature of evaluation in Design Science, where the EA model data for MOD-NL, NTCA, and EIRA support the naturalistic formative nature.

Research Environment

The EA models (except the MOD-NL model) are imported into the Archi[3] tool, so they are stored in a format that can be imported into Ampersand by the compiler. The MOD-NL model was supplied in Excel format. This data is imported into Ampersand using Ampersand's Excel importer functionality.

The artifact is built with Ampersand, which itself is developed as an open-source project and uses the following toolset:

- Haskell tool stack – to compile Ampersand
- Git – to store/retrieve Ampersand source code
- XAMPP – to execute the generated artifact, contains:
  - Webserver Apache v2.4.25 (Win32) OpenSSL/1.0.2j, PHP v7.1.1
  - Database server 10.1.21-MariaDB

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[2] EU reference architecture model, publicly available on https://joinup.ec.europa.eu/node/99464.

[3] Archi is a free and open source modelling tool to create ArchiMate models and sketches. Available from https://www.archimatetool.com.

- Composer – dependency manager for PHP

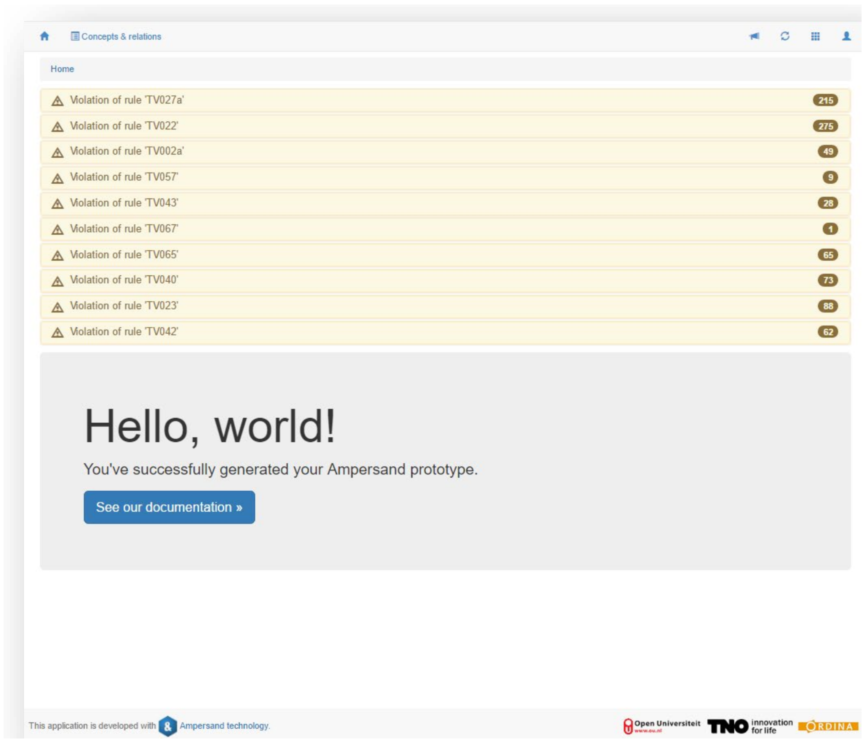

Figure 2. Ampersand output example.

For each of the EA models, the artifact consists of an Ampersand script that imports the model and the applied set of rules. Ampersand's output is a generated web-based application that can be accessed through a webserver. The web application shows violations of the applied rules. Ampersand has much more functionality to view and manipulate model content, but this functionality was not needed for the implementation of the artifact in this research. An example of Ampersand's output (based on the case for NTCA) is shown in Figure 2.

Translating Alignment Heuristics into ADL

The formal specification in Relation Algebra and Ampersand's ADL needs to be constructed to apply rules onto the EA case model. Generic rule definition is possible when EA models show similarity on the meta-model level. The ArchiMate standard is open and flexible, which leaves room for variety in application and interpretation on a semantic level. Ten rule candidates were translated generically and applied onto five case models.

Each rule is based on an alignment heuristic that is formulated in natural language. Alignment heuristic TV065 states: "*An APPLICATION REALIZES AN APPLICATION SERVICE*." A visualization in ArchiMate is shown in Figure 3.

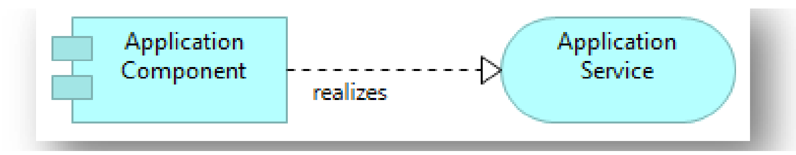

Figure 3. ArchiMate visualization of rule TV065.

For this alignment heuristic to be translated into ADL, we first need to decompose its structure and requirements. The concepts APPLICATION SERVICE and APPLICATION are assumed to be represented in an EA model by ArchiMate concepts. APPLICATION SERVICES are rendered in ArchiMate by the concept Application service. The APPLICATION is represented in ArchiMate by the concept Application Component (Application collaboration is left out of scope). REALIZES is represented by the ArchiMate relation Realization. Implicitly, the alignment heuristic requires that each application is related to an application service. The relation for this rule is submitted to the multiplicity constraint that the relationship is to be total. Graphical visualization of a total relationship is shown in Figure 4. Total relationship, where concept X represents APPLICATION, concept Y represents APPLICATION SERVICE, and relation r represents REALIZES. Relation r consists of a set of tuples that each represent the relation between an APPLICATION and an APPLICATION SERVICE.

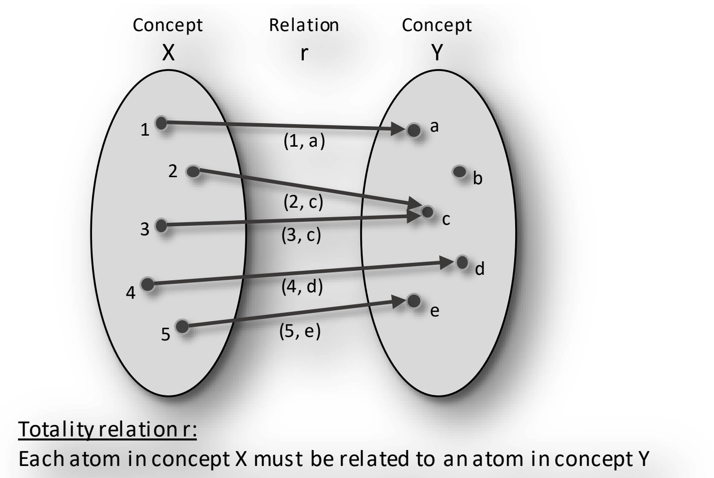

Figure 4. Total relationship.

The notation of a relation that follows multiplicity constraint total results in the following:

- in Relation Algebra $I_{[X]} \subset r; \breve{r}$
- in Ampersand ADL I[X] |- r ; r~

Violations influence overall alignment within an EA model. Each violation must be identified and used as input for the EA improvement management process. A violation of rule TV065 is described by the set difference between the antecedent and the consequent:

- in Relation Algebra $I_{[X]} \setminus (r ; \breve{r})$
- in Ampersand ADL I[X] - (r; r~)

A rule must be formulated in a way that violations identify (atoms within) the concepts that cause the violations. Since rules describe relations, violations also occur within relations, so each violation takes the form of a tuple and therefore has a source atom and a target atom.

Translating alignment heuristic TV065 into ADL leads to the following code segment:

```
RULE "TV065" : I[ApplicationComponent] |-
   realisation[ApplicationComponent*ApplicationService];
   realisation[ApplicationComponent*ApplicationService]~
VIOLATION ( TXT "Application Component \'",
       SRC naam,
       TXT "\' does not realize any Application
               Service")
```

Although the specification for rule TV065 is fairly straightforward, generic and applicable for almost any ArchiMate model, its actual validity for the EA model depends on the applied meta-model. For the MOD-NL case, this resulted in an additional case-specific translation for TV065:

```
RULE "TV065" : I[ApplicationComponent] |-
   association[ApplicationComponent*ApplicationService];
   association[ApplicationComponent*ApplicationService]~
VIOLATION ( TXT "Application Component \'",
          SRC naam,
          TXT "\'does not realize any Application
               Service")
```

All rules specified in ADL are obliged to follow ADL grammar which has its foundation in Relation Algebra. Therefore, a successful compilation of an ADL script ensures a syntactically correct specification of a rule, respecting the Design Science rigor cycle. Needless to say that for a rule to be semantically correct, verification and validation needs to be in place. For this research, rule validation is in place, as described in section 5.

For this research, the implemented rules mostly govern cardinality type rules that concern multiplicity constraints spanning one or two relation(s). In practice, EA models consist of numerous concepts and relations. Rules can easily span more than two relations, and probably concern cycles within the conceptual diagram. The need for a clear and concise meta-model is essential for describing such an efficacious rule. Examples to this end, are rule candidates TV060, TV062, and TV064 in the NTCA model.

Ampersand generates a meta-model, based on the content of the model repository. This meta-model consists of imported relations as well as several derived or generated relations that are relevant to rule specifications in ADL. A simplified meta-model, as generated by Ampersand, is shown in Figure 5.

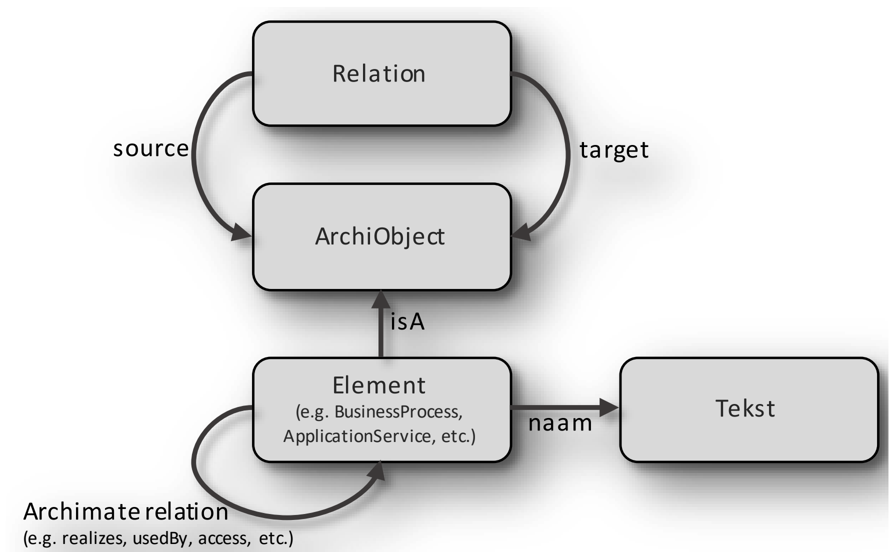

Figure 5. Simplified meta-model generated by Ampersand.

RESULTS

An overall alignment score within an EA model is calculated using the outlined method. In Ampersand, the set of rules was applied to the EA case model. At the individual rule level, Ampersand determines both the size of the antecedent part of the rule and the number of occurring violations. Because the Ampersand tool does not possess the capability to make numerical computations, calculation of the rule score, the quality factor score, and the overall score was performed in Excel conform the method above.

For the model of ArchiSurance case, the alignment calculation results are shown in Figure 6.

Quality Factor:	Completeness			
QF Contribution:	36,40%			
Rule	**Description**	**Antecedent**	**Violations**	**Score**
TV002a	Business processes should be supported by a single application	9	0	100,00%
TV002b	Business interactions should be supported by a single application	2	0	100,00%
TV008	An information entity is managed by only one application	4	0	100,00%
TV022	Processes that make no access to any entity	9	5	44,44%
TV023	Entities that are not accessed by any process	10	7	30,00%
TV027a	Each business process should be supported by at least one application system	9	8	11,11%
TV027b	Each business interaction should be supported by at least one application system	2	0	100,00%
TV040	A Business Object is realized by 1+ Data Objects	10	0	100,00%
TV042	A Business service is realized by 1+ (Business Service or Business Process or Business Function or Business Interaction)	6	1	83,33%
TV043	An Application service is realized by 1+ (Application Service or Application Process or Application Function or Application Interaction)	3	0	100,00%
TV057	A Data Object realizes 1+ Business products	4	0	100,00%
TV065	Een applicatie realiseert een applicatie service	10	7	30,00%
		Quality factor alignment		74,91%
		Weighted QF alignment		27,27%
Overall alignment				74,91%

Figure 6. Alignment measurement result ArchiSurance.

Ampersand generates a web-based application that shows detected violations. Violations for the ArchiSurance case shown in Figure 7. Rules that are not mentioned in the overview do not contain any violations and thus score 100%.

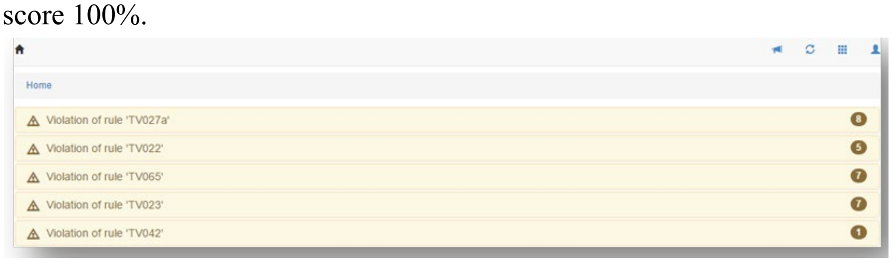

Figure 7. Overview of violations in ArchiSurance.

Each violation notification specifies precisely which tuples in the relation cause violation of a rule, as shown in Figure 8. This enables the EA management process to initiate and drive improvement actions.

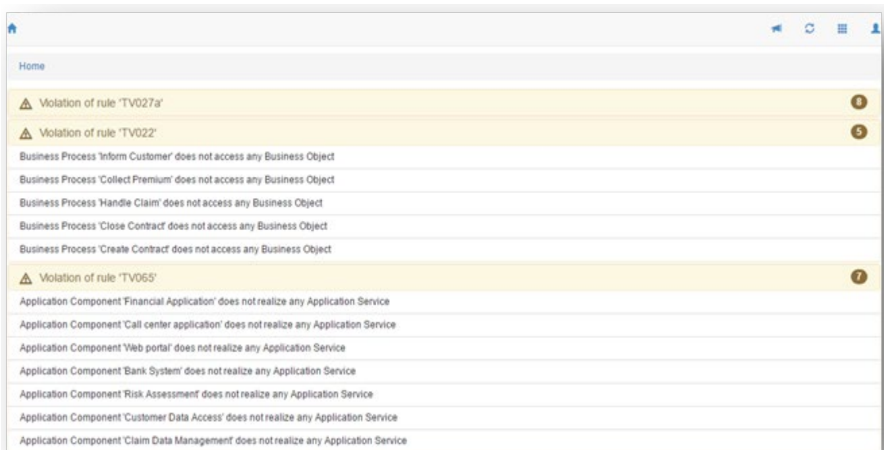

Figure 8. Detailed view of violations in ArchiSurance (partial).

The number of tuples in the antecedent part of the relationship is required to calculate the alignment metric of each rule. This number can be determined within the MySQL database by looking for the number of rows in the corresponding table. In case the expression for the antecedent spans more than a single concept, an SQL query can be defined to find the number. Alternatively, Ampersand can be used to visualize the antecedent using the INTERFACE statement.

The visualization of a rule violation for rule TV065 – AN APPLICATION COMPONENT REALIZES AN APPLICATION SERVICE is shown in Figure 9. ArchiMate view on Financial Application, by generating a view within Archi for the application component that triggers the violation, in this case, the application component FINANCIAL APPLICATION.

This particular view shows that the application component financial application realizes a business service instead of an application service. ArchiMate itself does not prohibit this type of modeling. ArchiMate allows many types of relations between components from different architecture layers; it all depends on the applied meta-model within the organization. The capability of the designed and developed artifact within this research is to detect and report anomalies concerning the used set of rules. The overall alignment calculation provides longitudinal comparison information to guide the EA management process.

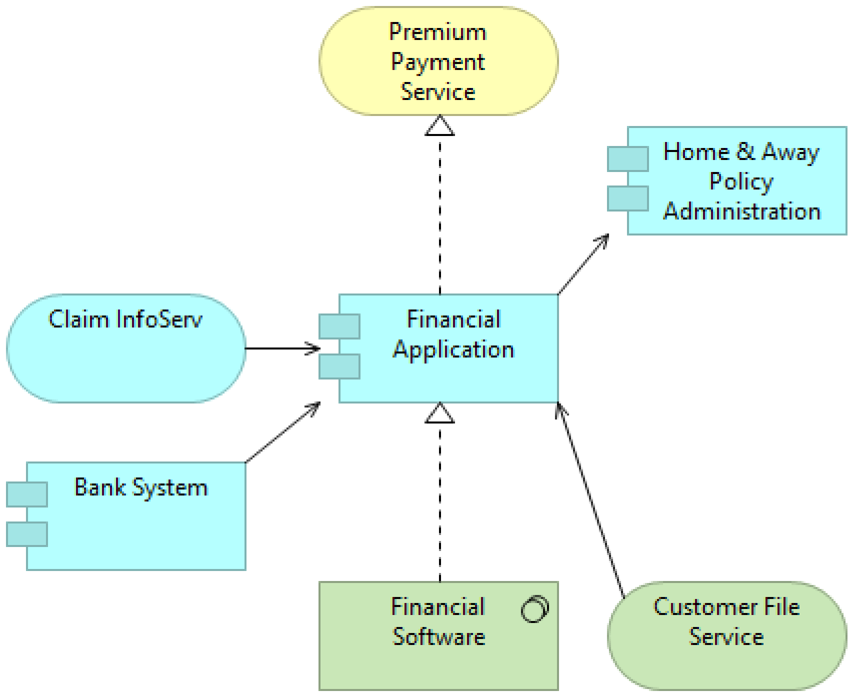

Figure 9. ArchiMate view on Financial Application.

Discussion

Model Alignment Results

Verification of Ampersand Rules

Alignment heuristics aid in monitoring alignment within an EA model. Usually, both in literature and in the business environment, alignment heuristics are formulated in natural language that makes sense to real-life people. To apply the alignment heuristics onto the EA model, they are translated into formalized rules. There are instruments to bidirectionally verify the translation process to ensure the correct application of the rule. In the direction from heuristics to rules, one could apply the structured method called RuleSpeak®[4], which consists of a set of guidelines to formulate business rules in clear and unambiguous statements in natural language that can both be understood by the business and translated into a formalized notation language like ADL. For alignment heuristic TV065, the translation into RuleSpeak® is shown in Table .

Reversely, formalized rules that are specified in ADL need to be verified to make sure the translation process is done correctly. Verification of correct translation aids the validation process with stakeholders. A rule can be translated back into the natural language using a specified procedure. The result is called a controlled natural language sentence (CNL-sentence) (Wedemeijer, Joosten, Michels, & Woude, 2014a). To adequately validate the rule translation, the CNL-sentence can be compared to the alignment heuristic in RuleSpeak® notation. For the ADL specification of rule TV065, translation to natural language is shown in Table 3.

Table 3. Rule translation validation

Type of specification	Specification
Alignment heuristic	An application realises an application service
RuleSpeak®	An application must realize an application service
ADL	**I**[ApplicationComponent] |- realisation[ApplicationComponent*ApplicationService]; realisation[ApplicationComponent*ApplicationService]~
Relation algebra	$\forall_{c \in ApplicationComponent} \rightarrow$ $\exists_{s \in ApplicationService}$ (c *realisation* s) ∧ (s *realisation*~ c)
Controlled Natural Language	For every ApplicationComponent, there exists an ApplicationService such that ApplicationComponent *realization* ApplicationService

[4] RuleSpeak® was developed in 1996 by Ronald G. Ross. Info can be found at www.rulespeak.com. It is also a topic in the Rule Based Design course that is part of the Business Process Management & IT education program by the Open University (Wedemeijer, Joosten, Michels, & Woude, 2014b).

Mutual Comparison of Model Results

Mutual comparison of alignment scores between researched cases (benchmarking) does not prove to be useful in the current scale of research. Only when both the set of rules, as well as the underlying meta-model for the compared models are equal and at a higher maturity level, benchmarking might be possible.

What we did find in the results of the various models (as shown in Appendix 27), was a difference in scores when looking from the perspective of single- or cross-layer rules. A single layer rule concerns concepts and relations that span a single ArchiMate layer (e.g., only the Business layer). A cross-layer rule crosses the boundary between the Business layer and the Application layer. What we found is that cross-layer rules show a lower average score (62%) than single layer rules (68%). Unfortunately, the number of cases used in this research is insufficient to draw substantiated conclusions from these results. Therefore, more in-depth research is needed to determine whether this observed difference is significant. Because, if it is significant, it would mean that Business/IT-alignment should be judged worse than the current results suggest.

Longitudinal Comparison

The alignment measurement for each of the EA models lacks a point of reference to be able to interpret and evaluate the absolute results. A longitudinal comparison with EA models could be beneficial; it requires EA models over time and a stable set of rules to do so. The results of this research show that objective snapshot measurements are possible.

Ampersand

Ampersand is an open-source project used in academic research projects, academic studies, and business application environments. The primary area of application is the implementation of business rules guiding the rule-driven generation of information systems. During the development and execution phase of this research, no indication is found that could diminish the reliability of the results.

Implications for Practice

Meta-Model as a Foundation under the Set of Rules

For effective modeling and monitoring, an EA model needs to follow restricted, and unambiguous modeling guidelines. Defining a meta-model for the EA model is highly recommended, if not essential, while it explicitly states the way of modeling and thus guides the definition and development of rules. The ArchiMate standard is based on a meta-model, but it leaves much room for alternatives in modeling the EA model of an organization. Without proper guidelines towards modeling EA, architects are likely to apply the individual interpretation of a situation that needs to be modeled in concepts and (types of) relations. Such a practice possibly leads to various models, which makes it more challenging to determine alignment. The time-to-implement a new rule is concise, it merely requires formalization of the rule, re-compile the Ampersand script and re-evaluation of the rules.

Violations as Input for EA Management Process

The results of this study show that monitoring based on the applied environment accurately measures the validity of the EA model to the formalized rules. It also indicates explicitly which tuple(s) in the relations cause violations of the rules. These aids architects in maintaining and enhancing the coherence within their EA model.

Limitations

Application of EA Quality Factors

Rules in the current set are barely classified to the Quality Factor ‘Understandability’. We found that most rules are repository related, while the Quality Factor ‘Understandability’ is described in the literature as relevant to views. Moreover, understandability is, by definition more a subjective concept. Hence, more research is required to create repository- or view-based understandability rules. The applied research environment Ampersand does not (yet) provide means to import and validate EA views.

The classification of rules onto EA quality factors, in general, plays a limited role in light of this current research. It influences the outcome of the alignment measurement calculation and can be used to focus on improvement actions in the EA management process.

Ampersand

Numerical computations are not (yet) possible within Ampersand. Numerical and date computations might be useful for alignment heuristics that relate to organization-specific circumstances. The Ampersand ArchiMate extension, used to import EA models in ArchiMate format, is a relatively new extension of Ampersand's functionality. Some issues arose during design and development. However, these issues were all appropriately solved. There is no indication that prior issues influence the validity of the results.

FUTURE RESEARCH

The ArchiMate standard allows many types of relations between concepts, which leads to various ways of modeling EA. A detailed meta-model is essential to develop a practical set of rules. It is worth the effort to search for or construct a best-practice or reference meta-model onto which a generic set of rules can be defined. When such a best-practice or reference meta-model exists and is applied in organizations, benchmarking of EA models and EA alignment performance can take place.

The set of EA quality factors is based on literature that originates from data modeling and is combined with EA quality attributes that are proposed in EA literature. However, no empirical findings are available to support the correct mapping of EA attributes onto quality factors, nor do we have empirical findings that support the correctness of the assumed contribution of quality factors to overall quality. Concerning the latter, further explanatory research is needed. Although in this research we chose to apply field knowledge of data models to classify rules, it is arguable that classification based on the alignment perspectives of the well-known

Strategic Alignment Model (Gerow et al., 2014; Henderson & Venkatraman, 1999) could be of value as well.

The quality factor ‘understandability’ has shown to be less practical for repository-based rules. We presume this quality factor has more relevance in rules that concern EA views, but further research to this end is needed, as well as enhancement in the Ampersand environment to support this research.

This research demonstrates the possibility of monitoring EA alignment using formalized rules, thus enhancing the quality of EA. Interesting would be to investigate the presumed relationship between EA quality and the effectiveness of EA models. As a result of this current research, we now have an instrument that provides an objective alignment indicator. Our study outcomes could open up the way to try and find a correlation between the EA quality indicator and other BITA alignment indicators, e.g., EA effectiveness, and IT performance.

Suggestions with a more practical nature concern the Ampersand environment. Loading repository content is mostly done using an ADL script. Performance-wise this should be done at runtime by preparing an adequate import file, as is the case for the MOD-NL case. This procedure considerably reduces processing time but might require additional effort for extracting the EA model from the source system.

Ampersand supports generating an application that is capable of visualizing rule violations. It currently lacks the functionality to aid alignment measurement by stating the number of pairs in the antecedent and the number of violation of a rule.

CONCLUSION

As EA models are increasingly becoming more complex, it is no longer practical to maintain consistency and coherence manually. Automated support to this end is required. Using formalized rules specified in ADL, alignment measurement is performed to initiate enhancements. This study aimed to create an efficient instrument to unambiguously monitor the correctness of coherence between elements within an EA. In practice, maintaining coherence within an EA model is a vast and tedious task of architects. Our work shows that applying an automated IT artifact to monitor coherence within an EA model, based on formalized rules, is feasible and useful to architects. Violations of rules are indicators of misalignment within an EA model on a specific point in time. Longitudinal application of rules in an iterative improvement process will aid in monitoring coherence.

Finally, to measure improvements in alignment scores, proper metrics are needed. To this end, rules are divided into quality factor categories. Violations on rules are then used to calculate the performance of the rule and the quality factor it belongs to. That provides a mechanism to distinguish between rules more accurately.

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BIOGRAPHICAL SKETCHES

Peter W. Filet

Affiliation: Open University, Netherlands

Education: MSc. Business Process Management & IT, Open University, Netherlands

Business Address:

P.O. box 20701,
2500 ES The Hague
The Netherlands

Research and Professional Experience: Business architect, CIO advisor

Rogier van de Wetering, PhD

Affiliation: Open University of the Netherlands

Business Address: Valkenburgerweg 177, 6419 AT Heerlen, the Netherlands

Research and Professional Experience: 15 years

2005-2015: Manager Strategy & Operations at Deloitte Consulting

2015-2017: Assistant Professor Information Sciences, Faculty of Management, Science, and Technology

2017-now: Associate Professor Information Sciences, Faculty of Sciences

Professional Appointments: Associate Professor Information Sciences, Faculty of Sciences

Publications from the Last 3 Years:

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Stef Joosten, PhD

Affiliation: Open University of the Netherlands

Business Address: Valkenburgerweg 177, 6419 AT Heerlen, the Netherlands

Research and Professional Experience: 30 years

Professional Appointments:

- Full Professor (part time 20%) Open University of the Netherlands (NL),
- Management Consultant, Ordina (NL),
- Vice-chair Board of Supervision, Careaz (NL).

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