Journal of Theoretical and Applied Information Technology
31st August 2023. Vol.101. No 16

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

ASSESSMENT OF THE ENTERPRISE ARCHITECTURE BASED ON THE PATTERN

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ABSTRACT

The enterprise architecture (EA) is the organizing logic for business processes and IT infrastructure, reflecting the integration and standardization requirements of the company's operating model. Enterprise architecture (EA) is an approach to managing the complexity of an organization's structures, information technology (IT), and business environment. This paper presents a complete pattern-based methodology for analyzing the complexity of enterprise architecture. The objective is to propose an evaluation methodology for guiding designers and architects in evaluating and improving the EA models. The methodology measures the mico-view and the macro-view metrics. Furthermore, our enterprise architecture patterns system will be used for automated support to manage the evaluation of enterprise architecture complexity.

Keywords: *Enterprise Architecture; EA patterns; Analysis of Enterprise Architecture; Complexity; Heterogeneity.*

1. INTRODUCTION

Enterprise Architecture (EA) provides appropriate data structures, Information Systems, and infrastructure to fulfill the business demands of an enterprise. EA enables an enterprise to achieve the intended business goals using Information Technology (IT) capabilities and also provides a competitive environment.

Complexity management has become an essential undertaking for enterprise architecture (EA). It strives for an optimal level of complexity to efficiently and effectively use the EA for its intended purposes.

In business architecture, measures are intended to control quality and better manage development projects to reduce the cost of production. They offer, on the one hand, basic clues to define quality properties such as reliability and maintenance, on the other hand, they constitute parameters for estimating and managing the effort to control the development process and control the budget.

Enterprise Architecture Management (EAM) is a multi-discipline and widely adopted in practice, surveys indicate effectivity barriers that, at least partially, appear to be a consequence of local decision makers' non-compliance with enterprise-wide architectural guidelines (Winter, 2022).

While there are efforts to develop EA frameworks, one of the major findings of the literature review conducted is that there is an evident research gap in the literature on the perception and associated factors of the EA stakeholders on having an agile enterprise architecture [24].

The literature posits that EA is of considerable value to organizations due to expected significant benefits which help organizations achieve their business and effectiveness goals by aligning IT initiatives with business objectives. The proposed papers in the literature do not cover all dimensions of complexity. They study one part while neglecting the others. The proposed methodology in this paper covers all dimensions (Analysis Time, The body of analysis, Analysis Techniques, Analysis Concerns, The EA Reference level, and Implementation) of evaluation enterprise architecture.

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The purpose of this paper is to carry out a comparative study of the existing evaluation approaches to better apply and improve them to realize an evaluation process addressing all the concepts of the enterprise architecture complexity and to present a complete pattern-based methodology for evaluating the complexity of enterprise architecture. Our objective is to propose an evaluation methodology for guiding designers and architects in evaluating and improving the EA models. Furthermore, our enterprise architecture patterns system will be used for an automated support so as to manage the evaluation of enterprise architecture complexity.

The paper is structured as follows: The second section presents the state of the art of our research, the third section presents the methodology proposed to evaluate the dimensions of complexity, the fourth section discusses fuzzy logic and applies it to complexity measures to define which measures to choose for each project, the sixth section presents a discussion to position our approach in the existing research work and the last section is to conclude.

2. STATE OF THE ART OF THE COMPLEXITY EVALUATION APPROACHES

2.1 Definition of complexity

According to Davis and LeBlanc [28] the complexity of application architecture is "The number of its components or elements, kind or type of elements and structure of the relationship between elements". On the infrastructure architecture level defined complexity as "The complexity can be defined here as the dramatic increase in the number and heterogeneity of included components, relations, and their dynamic and unexpected interactions in IT solutions"[28], another definition proposed by [7] covers all aspects of complexity "The complexity can be defined on the basis of the number and variety of components and interactions plus the rate of change of these". From the different definitions cited we can notice that the complexity is a fuzzy term, because different stakeholders have generally different views and conceptions of complexity term, as shows the figure below.

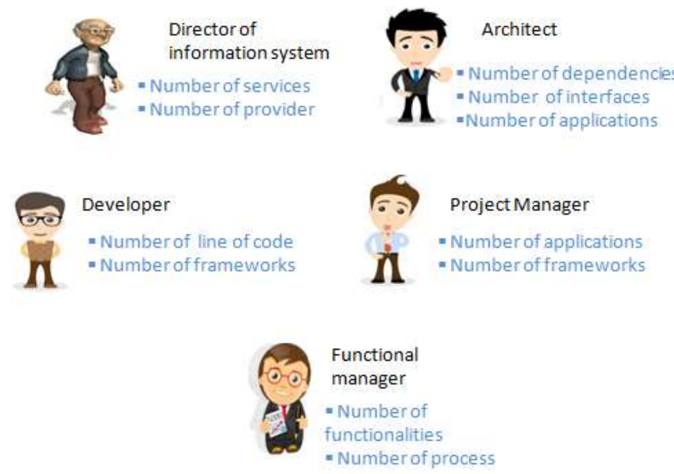

Figure 1: The Definitions Of Complexity

From these definitions, we will clarify the dimensions of complexity and propose a global definition. "The architecture's complexity is the description of its structure and quantification of the numbers and heterogeneity of components and relations between them over the time".

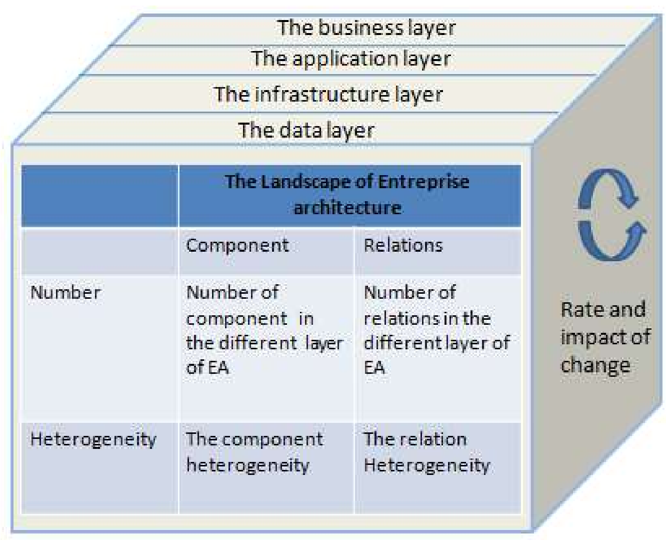

Figure 2: The Dimensions Of Complexity

The figure above shows the four dimensions of the complexity of enterprise architecture, although the number of components and relationships can be determined by simply counting the respective elements, heterogeneity, calculating change rates and the architectural structure must be calculated using formulas and measures that we must clarify.

2.2 EAM Pattern

The EAM pattern language developed by Buckl et al. [8] distinguishes between four different types of patterns:

- M-Patterns. Methodologies define steps to be taken in order to address given objectives. These objectives are addressed by procedures defined by the methodology. Others refer to them as Process Patterns [Moser et al. 2009].

- V-Patterns. Viewpoints provide the languages used by methodologies. A viewpoint proposes a way to present data stored according to one or more information model patterns.

- I-Patterns. Information models represent underlying models for the data visualized in one or more viewpoints. An information model pattern conveys an information model fragment including the definitions and descriptions of the used information objects.

- The Objective, The EAM pattern language includes a list of typical objectives. They can be used as an entry point and help to select appropriate patterns within a given context.

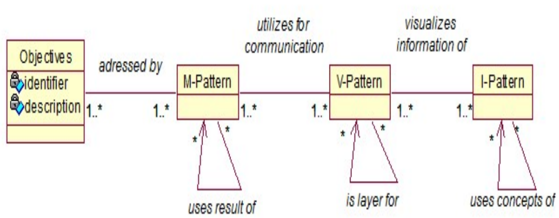

Figure 3: The Conceptual Model Underlying The EAM Pattern Language.

EAM pattern approach is based on best practices, with precise and well documented instructions, such as information model which specifies exactly what data that must be maintained to obtain specific objective. In addition, it is an approach based on the goals, which is expandable because it is based on models and can include justifications for design decisions.

In our approach we propose to design and reuse enterprise architecture management EAM patterns to create the patterns analysis of complexity. The formalism used is already discussed in the paper of Lakhrouit and Baina (Lakhrouit and Baina, 2016)

2.3 Complexity analysis approach

A systematic literature review is an important phase before conducting any research as it creates the basis for knowledge creation which helps to identify research gaps in existing research [24]. A systematic literature review is based on explicit research questions, analyzes relevant studies [26]

- **COMPLEXITY ANALYSIS APPROACHES SPECIFIC TO THE BUSINESS LAYER**

The business layer corresponds to the functional part of the application layer, which implements the logic, and describes functionalities as well as the management and control rules of the system which are implemented in the application layer.

Schmidt [13] proposed a generic approach to measure complexity and apply it to the field of enterprise architecture and specifically to the business layer. Schmidt proposed dividing the business layer into three layers: the modeling layer, the execution layer, and the motivation layer.

The approach proposed by Schmidt [13] addresses the notion of enterprise architecture but only offers measures of the business layer (A single level for the reference dimension of enterprise architecture). The particularity of this approach is the addition of the motivation layer. The method presents a measure to quantify the complexity of EA (quantitative notion). The measures proposed concern the number and heterogeneity of elements and their relationships (the notion of structure) as a dimension of complexity. The observer is not part of the model (the approach is based on indicators).

- **COMPLEXITY ANALYSIS APPROACHES SPECIFIC TO THE APPLICATION LAYER**

In this section, we will present all the approaches proposed in the literature and deal with the subject of the complexity of the application layer.

Mocker [12] identified the complexity of the application layer as being the age of applications as well as the number of functional requirements defined for each application. Based on the available literature, he identified four different measures to quantify complexity: the interdependence of applications, the diversity of technologies, the degree of standards, and the concentration of technologies (the notion of structure). The proposed approach covers only the application layer (specific to the application layer), it presents a measure to quantify the complexity of the EA (quantitative notion) and does not include the observers in its model (objective notion).

Mocker [12] was only interested in a few complexity measures while neglecting the global structure of the architecture, this concept of the structure was also studied and analyzed by Lagerström [5].

Lagerström [5] proposed a method to visualize and measure the complexity of the application architecture of the company based on the type of its typology, he divided the architectures into three types: peripheral center architecture, multi-core architecture, or hierarchical architecture.

In the case of a center-periphery architecture, the applications have the following types: kernel, control, shared, or peripheral: 1- kernel applications are the largest group of applications, 2- control applications are characterized by the high amount of outgoing information, 3- shared applications have high dependencies on incoming information and 4- applications peripherals have important dependencies on the level of the outgoing and incoming information but less important compared to the number specified in the core applications.

The multi-core architecture is composed of several important applications which have equally important input and output information and the hierarchical architecture has only a few extremely small cyclic groups.

Lagerström also proposed to calculate the propagation cost metric, He defined it as the density of the DSM visibility matrix (This matrix presents the components and the relations between the components with 0 or 1: 0 if there is no relationship between the two components and 1 if there is a relationship between them). Intuitively, the propagation cost is equal to the percentage of architecture affected when a change is made to a randomly selected element. For example, a propagation cost of 25% indicates that a quarter of the architecture can be affected when a change is made to a randomly selected software application.

This approach proposes a representation of the structure of the application architecture only, which does not cover all the layers of the enterprise architecture and is satisfied only with a representation of the application layer. This approach applies the concept of software architecture which is the design of structure matrices to reveal the structure of a landscape (structural and dynamic body). The observer is not considered in the approach (the approach is based on indicators).

Admittedly, this approach discussed a very important dimension of complexity but is not sufficient for a global analysis of the enterprise architecture because it does not cover all the layers of EA and does not discuss all dimensions of complexity.

Daniel [14] proposes a more generic application layer analysis approach than those discussed previously, he proposes to model the application landscape as a network N consisting of n nodes and m links between these nodes. The nodes designate the applications and the links represent the information flows between these applications.

To evaluate this network, the author proposes using three types of network measurements, which are: 1- centrality measurements characterizing the location of each node and their positions relative to other nodes, 2- density measurements and degree distribution as well as 3- the clustering coefficient to present the global state of the network. This approach proposes a representation of the structure of the application architecture only which does not cover all the layers of the enterprise architecture and limits the definition of the complexity to the dimension of the structure.

It proposes to use measures of the network (quantitative) by applying a transformation of the landscape into a graph with nodes and arcs (the notion of structure) and the observer is not considered in the approach (the approach is based on the indicators).

The paper of Wheling et al., [9] provides a method to identify the variability of application architectures (AAs) and an iterative decision process to determine and remove artifacts that are not required, which enables experts to reduce unnecessary IT complexity of given AAs.

- **APPROACHES SPECIFIC TO THE INFRASTRUCTURE LAYER**

In this section, we will discuss the analytical work that has addressed complexity at the level of the infrastructure layer [2][3].

The work proposed by Widjaja [2] revolves around two axes: 1- the definition of heterogeneity in a landscape as being a dimension of complexity; the measure used to quantify heterogeneity is the entropy and 2- the proposal of a generic mathematical model to quantify heterogeneity in computer landscapes. At the level of this method, the computation of complexity is restricted only to the computation of heterogeneity, it presents different types of heterogeneity in computing landscapes, for example, the heterogeneity of databases, software publishers, and hardware vendors.

This approach is limited only to the level of the infrastructure layer without taking into consideration the other layers. It presents a measure to quantify the complexity (quantitative notion), this measure concerns the heterogeneity of some elements of the infrastructure layer (the notion of structure). The model shows that if the complexity of a company's environment changes, the company must adjust to its new (dynamic) complexity. The observer is not part of the model (the approach is based on indicators).

The approach proposed by [3] proposes two axes: 1- The theoretical conceptualization of the complexity of enterprise architecture by projecting the notion of the system to the context of EA, this approach presented a holistic conceptualization of complexity and 2- The quantification measure of complexity using Shannon's entropy measure (quantitative notion) by proposing components such as different database instances and system versions operating methods used.

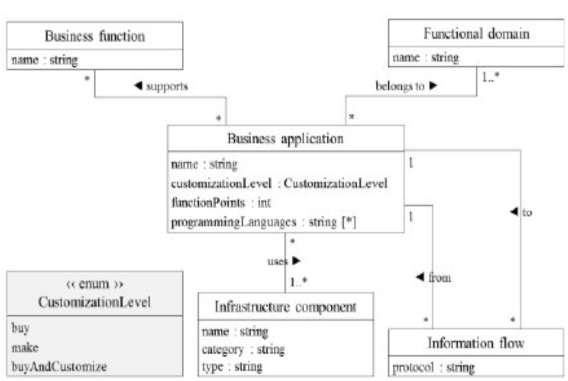

Figure 4: The Class Diagram Of The Evaluation Approach Proposed By Schutz (Schutz Et Al., 2013b)

- **HOLISTIC ANALYSIS APPROACHES**

After having presented the approaches specific to the different layers, we will present in this section the works which have proposed a generic approach for the analysis of complexity.

He et al [18] constructed a complexity measurement framework composed of twenty-eight factors, grouped into six categories: technological, organizational, objective, environmental, cultural and IT. He et al [18] conducted research that aims to develop an instrument for measuring complexity and as empirical studies related to the complexity of megaprojects are lacking, the researchers decided to use a fuzzy logic analysis to determine the importance of factors. The criteria which interest us in our comparison are those proposed in the technology category and which are: the diversity of technologies, the dependence between the processes (concept of structure), the interaction between the system and the external environment, and the risk of the use of technology, these criteria are measured in the current state of enterprise architecture (AS-IS). Admittedly, this approach covers all the layers of the enterprise architecture and presents a panoply of criteria to evaluate the complexity, nevertheless, it remains insufficient because all these results are based solely on the opinions of experts, neglecting quantitative measures.

Lankes and Schweda [19] proposed a contribution to model the enterprise architecture with the most important components such as Business processes, Business Applications, and Offered Interface, and also to measure the error propagation rate which is directly linked to the structure of the EA. The aspect they focused on is modification.

The authors also proposed a tool for the calculation and visualization of metrics. Figure 5 presents the meta-model proposed by Lankes and Schweda [19] for the analysis of the structure of EA. The dependency number attribute of a Business Process b represents the number of Business Applications, which can cause the process to fail via an Offered Interface, that the process uses. The failure Probability metric of an Offered Interface oi is calculated as the probability that the Offered Interface oi will not be operational and the failure Extent of a Business Application b calculates the deterioration of the application in case all these Offered Interfaces failed.

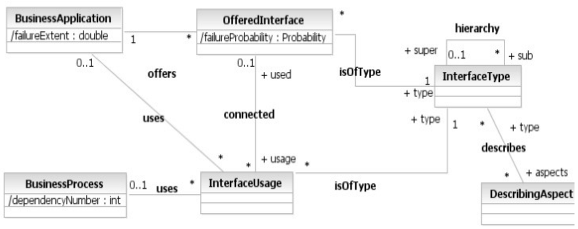

Figure 5: The Meta-Model Of Analysis Proposed By Lankes And Schweda (Lankes And Schweda, 2008)

Närman et al [20] adopted another assessment technique, they developed a framework for the analysis of the structure and maintenance of enterprise architecture. This framework is able to evaluate attributes such as cost, data accuracy, and modifiability, it is called a multi-attribute property class diagram.

Närman [20] used the metamodel to describe the components of each layer (Business Role, Business Process, Application Service and Application Function, Application Component) and the relationships between them (the notion of structure). Närman also adopted Deming's approach (Deming, 2000); Plan(Plan), do(do), and study(study) to model the change from an As-is scenario to a To-be scenario in real-time (dynamic concept). The "plan" phase presents the current configuration state, the "study" phase describes the stages of change and the "do" phase includes the final result for possible decision making.

These three phases are represented in the components of the meta-model (for example Business Process: Do, Business Process: Study, and Business Process: Plan). This meta-model addresses enough enterprise architecture concepts and also integrates the change process, certainly, these are advantages of the approach but we cannot deny that for transformation projects we will only need the components necessary to accelerate the process of analysis and the process of change, for this, we present the approaches of Lankes and Schweda [19] and Schmidt [16] which sufficiently fulfill this condition.

Schmidt [16] suggests considering architecture as a system with components and relationships. Based on an extensive review of the literature, he used a common definition of structural complexity, which is as follows: "The number of elements, the number of relations, the heterogeneity of elements and the heterogeneity of relationships".

These factors are projected into the layers of the enterprise architecture, as shown in Figure 7. The meta-model of analysis proposed by Schmidt [16] To quantify the complexity, Schmidt defined 8 measures to calculate; presented by numbers in Figure 6; such as the heterogeneity of system applications, the heterogeneity of interfaces, the heterogeneity of the implementation of business processes at the level of system applications and the heterogeneity of system applications in technology platforms. Schmidt [16] defines heterogeneity as "the diversity of elements or relationships of a system with respect to certain characteristics" and proposed to quantify it using the measure of entropy. The proposed measures only take into account the structural complexity

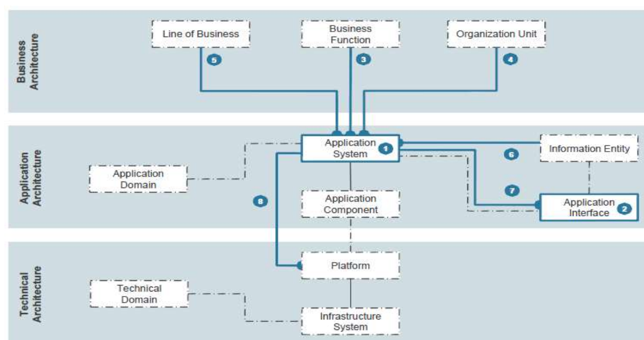

Figure 6: The Meta-Model Proposed By Schmidt [16]

The research of Maria [17] incorporates objective and subjective complexity metrics in a single EA complexity measurement model. Semi-structured interviews were used to gain insights into stakeholder perceptions and subjective complexity attributes. Based on these results, a conceptual model of EA complexity was designed. The constructs in this model have been operationalized with metrics to create a measurement instrument of EA complexity.

3. A PATTERN-BASED METHODOLOGY FOR ANALYZING ENTERPRISE ARCHITECTURE LANDSCAPE

In this section, we present a complete pattern-based methodology for evaluating the complexity of enterprise architecture. Our objective is to propose an evaluation methodology for guiding designers and architects in evaluating and improving the EA models. Furthermore, our enterprise architecture patterns system will be used for automated support to manage the evaluation of enterprise architecture complexity.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

The process begins with an initial import of the business model. This model represents the result of patterns, it can be stored, analyzed, and processed under a series of queries that operate in terms of its structure and it can also be updated by adding new information based on existing knowledge. After this processing, the analyst will be able to visualize the structure of the model in the form of a graph, in order to simplify the representation of the flows between the components of the enterprise architecture and to present the different measurement algorithms.
The analyst begins to interact with the model's visualizations, modifying and refining the visualization's parameters and queries over time. In each iteration, the hypotheses of the analysis are confirmed or rejected, and this is by associating visual patterns with EA patterns that are present from the knowledge and experience of the expert. Finally, when the analyst has acquired clear ideas about the model, he is able to communicate the results of the analysis. These stages are schematized in the Figure below.

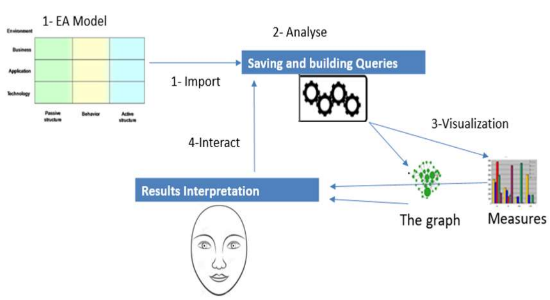

Figure 7: The Process Of The Evaluation Approach

In order to carry out this evaluation, we have defined 3 objectives:

C-102: Present Enterprise Architecture landscape and specify the dependence between the business, the application and the infrastructure layer
C-103: Measuring the heterogeneity of EA components.
C-104: Measuring the dependencies between EA components.

The figure below shows the relationship between the new objectives defined and the objectives of the EAM already defined in the EAM catalog. The aim of showing the relationships between our objectives and the objectives of the EAM catalog is to use them if they have already been achieved and to position our approach in relation to others.

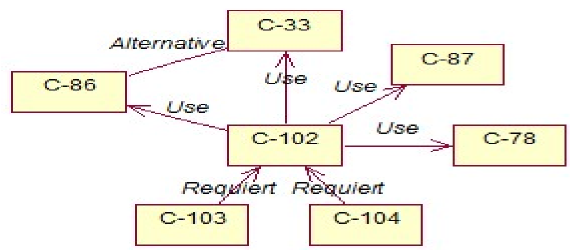

Figure 8: The Relations Between Our Objectives And The Objectives Of EAM Pattern Catalog

C-33: Which applications are used by which organizational units?
C-86: Which business applications are hosted by which organizational unit?
C-87: Which business processes are supported by which business application?
C-78: To which extent are the business processes supported by business applications? Which business processes are supported manually? Can the automated support be extended?

In this article, we will propose a methodology to satisfy the objectives C-102 and C-104/
In order to carry out this analysis, we have proposed a 7-step methodology. We will explain each step.

Step 1: Collect data and documents necessary to apply the methodology
IF we want to model each layer separately
Step 2: Apply the point of vue of Archimate
Business Process Viewpoint
Application Structure Viewpoint
Infrastructure Usage Viewpoint
Else
Step 2: Apply Step3
End IF
Step 3: Apply the I-Pattern EA landscape proposed in our approach**.**
Step 4: Apply the V-Pattern Visualization EA landscape proposed in our approach.
If we want to analyze the structure of enterprise architecture
Step 5: Apply the I-Pattern EA Structure to transform the models of Enterprise architecture on graph.
Step 6: Measure the macro-view metrics of the graph.
Step 7: Measure the micro-view metrics of the graph.
End IF

- **STEP 2: APPLY THE POINT OF VUE OF ARCHIMATE**

In this step, we map all the functionalities, applications and infrastructures of the architecture, respecting the points of view defined in the EAM pattern: Business Process Viewpoint, Application Structure Viewpoint and Infrastructure [8].

- **STEP 3: I-PATTERNS FOR ANALYZING ENTERPRISE ARCHITECTURE LANDSCAPE**

To analyze enterprise architecture. We define the pattern of information to model the EA landscape.

Overview:

Name	EA Landscape
Classification	I-Pattern
Context	Required:{I-12, I-18, I-25, I-56 } Use: {I-76}
Layer	Business, Application, Infrastructure.
Problem	This pattern allows us to present the components of the enterprise architecture, the relationship between them and the alignment between the layers. This pattern allows us to align the layers but does not present all the components of the EA but only the components necessary to realize the landscape.

Realization:

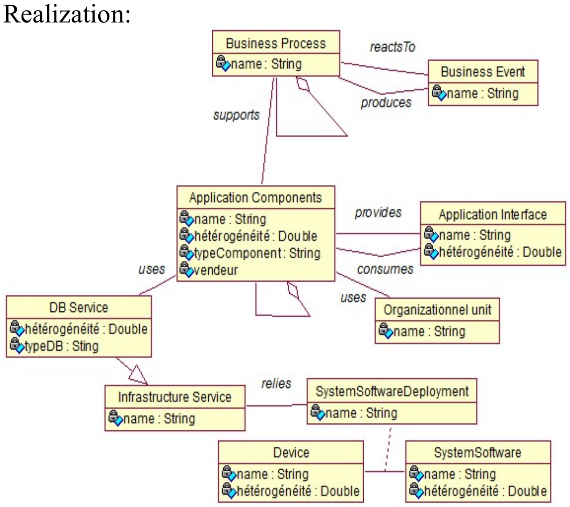

Figure 9: The I-Pattern For The Visualization Of EA Landscape

BusinessProcess: defined as a sequence of logical individual functions with connections between them, states input and output factors and a defined process objective as important characteristics of a business process. The business process should not be identified with single process steps or individual functions, but with high level processes at a level similar to the one used in value chains. BusinessEvent: something that happens and may influence a BusinessProcess. Thereby, a process can produce a BusinessEvent or can be a reaction to a BusinessEvent. ApplicationComponent: A business application is a software system, which is part of an information system of an organization. ApplicationInterface: An interface, via which an Application can expose functionality for external usage. DBServices: Describes a type of Database that provides storage functionalities.

Relation:

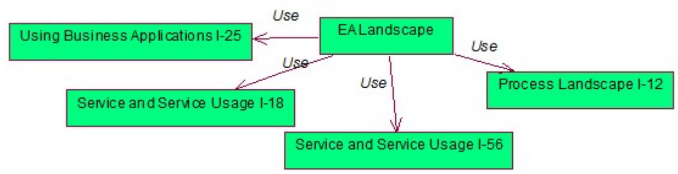

Figure 10: The relations between the I-pattern EA Landscape and the I-Pattern of EAM pattern catalogue

- **STEP 4: V-PATTERNS FOR ANALYZING ENTERPRISE ARCHITECTURE LANDSCAPE**

In the standard of ArchiMate, there are 13 views available for the different layers. In the contribution we will add new view to complement the methodology

Classification	EA landscape
Context	Use{I-25}, Use{I-18}, Use{I-56}, Use{I-12}
Layer	Business, Application, Technology
Problem	This pattern shows how to present the components which defined the enterprise architecture landscape
Force	This pattern presents the EA structure landscape

Realization:

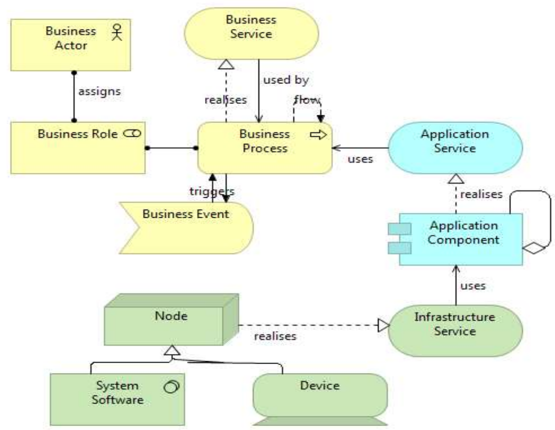

Figure 11: The Archimate Diagram Proposed To Modelise EA Landscape

Relations:

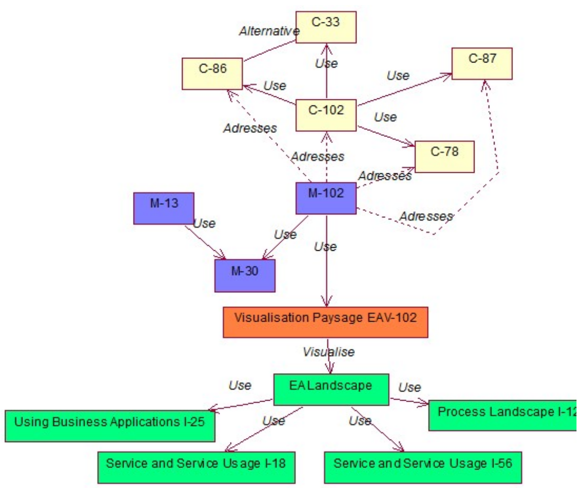

Figure 12: The Relations Between The V-Pattern EA Landscape And The Patterns Of EAM Pattern Catalogue

- **STEP 5: THE PATTERN TO TRANSFORM THE MODELS OF ENTERPRISE ARCHITECTURE ON GRAPH.**

In this pattern we describe how to present the different EA components using the network graph and how to calculate the structure using the network formula.

We propose to model EA landscape as a network G(N,M) consisting of N nodes and M links between these nodes, where links or arcs present the flow of the information. Our network is undirected because we do not consider the directions of the information flow. The network compromises several types of nodes.

Overview:

Classification	EA Structure
Context	Use {EA landscape}
Layer	Business, Application, Technology
Problem	This pattern shows how to present the components of EA but don't explain how we can analyze
Force	This pattern presents the EA structure landscape
Context	Use {EA landscape}

Realization:

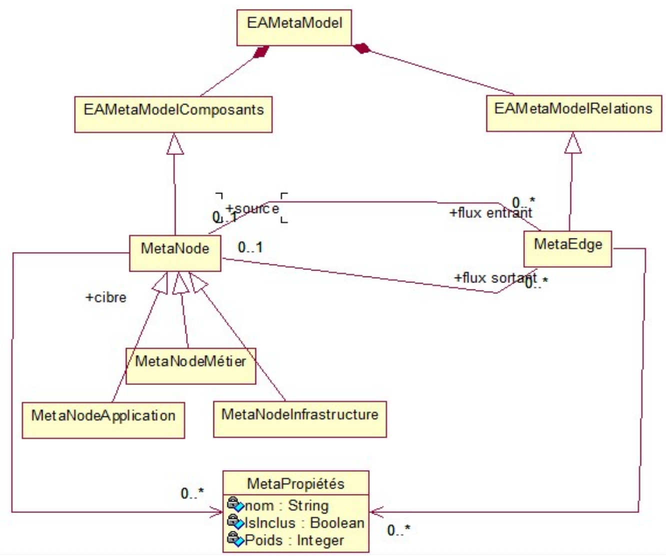

Figure 13: The Model Of Enterprise Architecture Presented As Graph

The EAMetaModel represents the enterprise architecture model which are composed of components represented by EAMetaModelComposants and relations represented EAMetaModelRelations.

In the model we can have three types of nodes: MetaNodeMetier, MetaNodeApplication and MetaNodeInfrastructure. The MetaNode and MetaEdge have properties defined in the MetaProprites

Relations:

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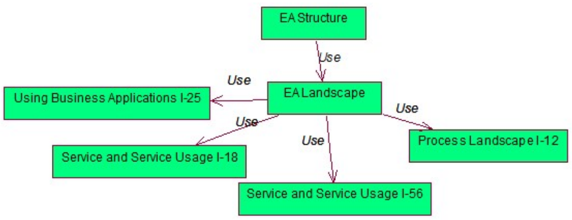

Figure 14: The Relations Between The I-Pattern EA Structure And The I-Pattern Of EAM Pattern Catalogue

- **STEP 6 AND 7 : MEASURING THE MICO-VIEW AND THE MACRO-VIEW METRICS**

Before exploring the use of networks analysis NA in enterprise architecture landscape, we here set the conceptual foundation of our work, introducing basic concepts of NA and clarifying their meaning in our context. Rooted in graph theory, NA conceptualizes and visualizes structures that emerge from any interaction or connection as networks and allows a quantitative analysis of the network nodes' relationships.
As indicated, the representation of the IT landscape as a network of nodes and edges is central to our approach. Nodes represent the EA components, which we will precise in the next section with the concept of I-Pattern; edges represent relationships and interdependencies between the components.
To analyzing enterprise architecture landscape, two visions are considered in network analysis: A "micro-view" which considers the individual structure of each node and a "macro-view" that provide complete visualization of the network and provides an assessment of the level of connectivity. The table below details the metrics considered in our approach:

Table 1: The Network Metrics Used In Our Approach

Dimension	Metric	definition
Micro-view	Degree centrality	$DC(i) = \frac{\sum x_{ij}}{n-1}$
	Closeness centrality	$CP(i) = \frac{n-1}{d(i,j)}$
	Betweenness centrality	$CI(i) = \frac{\sum g_{ijk}}{\sum g_{jk}}$
	Eigenvector centrality	$Ce(vi) = \frac{1}{\lambda}\sum_{j=1}^{n} Aj, iCe(vj)$
	Average neighbor degree	$k_{nn,i} = \frac{1}{N(i)} \sum_{j \in N(i)} k_j$
Macro-view	Density	Density= $\frac{2L}{n(n-1)}$
	Modularity	Modularity= $\sum_{C \in P} \frac{Wc}{W} - \left(\frac{Dc}{2W}\right)^2$
	Clustering	Applying the partitioning algorithm using modularity for each iteration.

Degree centrality (CD) represents the number of relations of a given node and thus indicates the degree of "activity" [30, 31, 32] of applications within the IT landscape. Formally, it can be defined as follows:

$$DC(i) = \frac{\sum x_{ij}}{n-1}$$

where xij equals 1 if there is a link between applications i and j, and xij = 0 otherwise.

Closeness centrality (CC) measures the geodesic distance of a given node to all other nodes in the network [30, 31, 32]. The node that can reach all other nodes in the fewest steps is most central. CC can be formalized as

$$CP(i) = \frac{n-1}{d(i,j)}$$

where dij is the number of links in a shortest path from application i to j ($i \neq j$).

Betweenness centrality (CB) represents the "number of shortest paths that pass through a given node" [30, 31, 32] and therefore indicates whether an application plays some kind of a gatekeeper function, controlling data exchange in the overall network. In mathematical terms, it can be written as

$$CI(i) = \frac{\sum g_{ijk}}{\sum g_{jk}}$$

where gjk denotes the number of shortest paths from component j to k ($j, k \neq i$), and gjik is the number of shortest paths from component j to k passing through application i.

The eigenvector centrality (CE), which quantifies the extent to which nodes are connected to other central nodes in the network [33]. For computing this measure for a given node, the relationships to other nodes are thus weighed based on these nodes' centralities:

$$Ce(vi) = \frac{1}{\lambda}\sum_{j=1}^{n} Aj, iCe(vj)$$

Eventually, we also consider overall graph density (as the number of edges L divided by the maximum number of edges in a full graph)

$$Density = \frac{2L}{n(n-1)}$$

Modularity is defined as the number of edges falling within groups minus the expected number in an equivalent network with edges placed at random [18].

$$Modularity = \sum_{C \in P} \frac{Wc}{W} - \left(\frac{Dc}{2W}\right)^2$$

A network N having n nodes: 1, 2, ⋯ n. P a partition of the set
of nodes in k (k≤ n) groups: C1, C2, C3, ... Ck. Wc the number of edges within the group C. Dc the sum of degrees of all nodes in the group C. W the number of the edges in the network

4. PRIORITIZING THE EA MEASURES USING FUZZY AHP

In this section, we describe and apply the different steps of the Fuzzy AHP method. First proposed by Thomas L. Saaty [29], the analytic hierarchy process (AHP) is a widely used multiple criteria decision-making tool. The analytic hierarchy process, since its invention, has been a tool at the hands of decision makers and researchers, becoming one of the most widely used multiple criteria decision-making tools.

- **Step 1: Decomposing the problem into a hierarchical structure**

We define a hierarchical tree of indicators:

1. Define the objective (level 0).
2. Define the indicators for decision or judgment (level 1). In our approach this level is the layers of enterprise architecture.(L1,L2,L3)
3. Define the sub-indicators for decision or judgment (level 1). In our approach, this level is the indicator of each layer (I11, I12, I21,…, I32).
4.

- **Step 2: Establishing a group of decision-makers**

A committee of decision-makers is formed. In order to obtain an objective decision, the background of decision-makers should be considered.
The decision-makers have to determine the relative weights of layers and indicators. The table below presents the four experts (EX1, EX2, EX3 and EX4) that we considered in the higher institute of applied engineering IGA.

Table 2: Presentation Of The Expert's Functions

Expert	The expert function
EX1	Head of IT
EX2	Network Manager
EX3	Infrastructure Manager
EX4	Computer teacher

- **Step 3 : Precising the linguistic variables**

A triangular fuzzy membership function (TFN) is used. a(li, mi, ui). Five linguistics variables are used to assess the importance of weights: very high (VH), high (H), medium (M), poor (P) and very poor (VP).

Table 3: Linguistics Variables And Fuzzy Values

Linguistic variable	Fuzzy number (li, mi, ui).	Linguistic variable	Fuzzy reciprocal number 1/(li, mi, ui).
VH	(7,9,10)	1/VH	(1/10,1/9,1/7)
H	(5,7,9)	1/H	(1/9,1/7,1/5)
M	(3,5,7)	1/M	(1/7,1/5,1/3)
P	(1,3,5)	1/P	(1/5,1/3,1)
VP	(1,1,3)	1/VP	(1/3,1,1)

Once the linguistic variables for evaluating the weights of the agility components are defined, the experts of IGA make pair-wise comparisons of the importance or preference between each pair of layers.

- **Step 4: Converting the linguistic variable to fuzzy number.**

In this step we must convert the linguistic variable of comparison matrix to fuzzy number using table 3.

Table 4: Fuzzy Comparison Matrix Of The First Expert

	Business (l,m,u)			Application (l,m,u)			Technology (l,m,u)		
Business	1	1	1	7	9	10	0,20	0,33	1
Application	0,1	0,11	0,14	1	1	1	5	7	9
Technology	1	3	5	0,11	0,14	0,20	1	1	1

- **Step 5 et 6: Precising and validate an aggregate comparison matrix**

The table below presents the aggregate comparisons matrix of components with respect to the overall objective (global indicator), In order to calculate this matrix we used the next formulation proposed by Buyukozkam and Feyzioglu [30]:

$$l_{ij} = \min_{K=1,2....K}(l_{ijk})$$
$$m_{ij} = \sqrt[K]{\prod_{K=1}^{K} m_{ijk}}$$
$$u_{ij} = \max_{K=1,2....K}(u_{ijk})$$

The end of this step is an aggregate comparison matrix.

Table 5: Aggregate comparison matrix of criteria

	Business (l,m,u)			Application (l,m,u)			Technology (l,m,u)		
Business	1	1	1	5	8,45	10	0,14	0,29	1
Application	0,1	0,13	0,2	1	1	1	5	7	9
Technology	1	3,41	7	0,11	0,14	0,2	1	1	1

- **Step 7 and 8: Summing up and normalizing each row of the fuzzy comparison matrix**

$$RS_i = \sum_{j=1}^{n} a_{ij} = (\sum_{j=1}^{n} l_{ij}, \sum_{j=1}^{n} m_{ij}, \sum_{j=1}^{n} u_{ij}). \quad i = 1, \dots, n.$$

Secondly, normalize the above row sums by

$$Si = \frac{RS_I}{\sum_{j=1}^{n} RS_j} = (\frac{\sum_{j=1}^{n} l_{ij}}{\sum_{j=1}^{n} l_{ij} + \sum_{k=1,k\neq i}^{n}\sum_{j=1}^{n} u_{kj}}, \frac{\sum_{j=1}^{n} m_{ij}}{\sum_{k=1}^{n}\sum_{j=1}^{n} m_{kj}}, \frac{\sum_{j=1}^{n} l_{ij}}{\sum_{j=1}^{n} l_{ij} + \sum_{k=1,k\neq i}^{n}\sum_{j=1}^{n} u_{kj}})$$

We determined Si values of the three components as follows:

Table 6: The Si values

	L	M	U
S1	0,25	0,43	0,59
S2	0,23	0,36	0,55
S3	0,09	0,20	0,40

- **Step 9: Compute the degree of possibility of Si = (li, mi, ui) ≥ Sj = (lj, mj, ji)**

The values of Si were individually compared and the degree of possibility of Si =(li, mi, ui) ≥ Sj =(lj, mj, ji) were then identified by the use of the equation below.

$$f(x) = \begin{cases} 1, & si\ m_i > m_j \\ \dfrac{u_i - l_j}{(u_i - m_i) + (m_j - l_j)} & si\ l_j \leq u_i\ i,j \\ 0, & sinon \end{cases} = 1, n\ et\ j \neq i$$

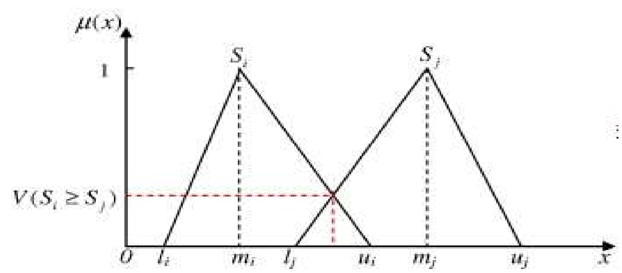

Figure 15: Definition Of The Degree Of Possibility V(Si ≥ Sj)

TABLE 7: THE DEGREE OF POSSIBILITY OF SI

V(S1>=Sj)	VALUE	V(S2>=Sj)	VALUE	V(S3>=Sj)	VALUE
V(S1>=S2)	1	V(S2>=S1)	0,81	V(S3>=S1)	0,39
V(S1>=S3)	1	V(S2>=S3)	1	V(S3>=S2)	0,51

Step 10: The weight vector W of the three layers

We determined the weight vectors using the equation below:

$$w_i = \frac{V(S_i \geq S_j \mid j = 1, \dots, n; j \neq i)}{\sum_{k=1}^{n} V(S_k \geq S_j \mid j = 1, \dots, n; j \neq k)}\ i = 1, \dots, n.$$

With
V(S ≥ S1, S2, S3,…,Sk), for i= 1,2,3,.,k = V(S≥ S1) and V(S≥ S2) and…. V(S≥ Sk) = min V(S≥ Si), for $i = 1,2, \dots, k$

Therefore, the weight vector is: (0.45, 0.37, 0.18).

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Step 3 and 4

	Degree of centrality (l,m,u)			Betweenness centrality (l,m,u)			Concentration of processes implemented by component (l,m,u)		
Degree of centrality	1	1	1	5	7	9	7	9	10
Betweenness centrality	0,11111111	0,14285714	0,2	1	1	1	5	7	9
Concentration of processes	0,1	0,11111111	0,14285714	0,11111	0,1428571	0,2	1	1	1

	Degree of centrality (l,m,u)			Betweenness centrality (l,m,u)			Concentration of processes implemented by component (l,m,u)		
Degree of centrality	1	1	1	7	9	10	7	9	10
Betweenness centrality	0,1	0,11111111	0,14285714	1	1	1	5	7	9
Concentration of processes	0,1	0,11111111	0,14285714	0,11111	0,1428571	0,2	1	1	1

	Degree of centrality (l,m,u)			Betweenness centrality (l,m,u)			Concentration of processes implemented by component (l,m,u)		
Degree of centrality	1	1	1	5	7	9	0,2	0,3333333	1
Betweenness centrality	0,11111111	0,14285714	0,2	1	1	1	5	7	9
Concentration of processes	1	3	5	0,11111	0,1428571	0,2	1	1	1

	Degree of centrality (l,m,u)			Betweenness centrality (l,m,u)			Concentration of processes implemented by component (l,m,u)		
Degree of centrality	1	1	1	7	9	10	0,1428571	0,2	0,333333333
Betweenness centrality	0,1	0,11111111	0,14285714	1	1	1	5	7	9
Concentration of processes	3	5	7	0,11111	0,1428571	0,2	1	1	1

Step 5

	Degree of centrality (l,m,u)			Betweenness centrality (l,m,u)			Concentration of processes implemented by component (l,m,u)		
Degree of centrality	1	1	1	5	7,94	10	0,14	1,52	10
Betweenness centrality	0,1	0,13	0,2	1	1	1	5	7	9
Concentration of processes	0,1	0,66	7	0,11	0,14	0,2	1	1	1

$$Si = \frac{RS_I}{\sum_{j=1}^{n} RS_j} = \left(\frac{\sum_{j=1}^{n} l_{ij}}{\sum_{j=1}^{n} l_{ij} + \sum_{k=1,k\neq i}^{n}\sum_{j=1}^{n} u_{kj}}, \frac{\sum_{j=1}^{n} m_{ij}}{\sum_{k=1}^{n}\sum_{j=1}^{n} m_{kj}}, \frac{\sum_{j=1}^{n} u_{ij}}{\sum_{j=1}^{n} u_{ij} + \sum_{k=1,k\neq i}^{n}\sum_{j=1}^{n} l_{kj}}\right)$$

Step 7 and 8

	L	M	U
S1	0,25	0,51	0,74
S2	0,17	0,40	0,58
S3	0,04	0,09	0,40

Step 6

λ(1)	0,96419
λ(2)	0,89349
λ(3)	1,68942
λmax	0,96419

Step 9

V(S1>=Sj)	VALUE	V(S2>=Sj)	VALUE	V(S3>=Sj)	VALUE
V(S1>=S2)	1	V(S2>=S1)	0,74	V(S3>=S1)	0,26
V(S1>=S3)	1	V(S2>=S3)	1	V(S3>=S2)	0,42

$$f(x) = \begin{cases} 1, & si\ m_i > m \\ \frac{u_i - l_j}{(u_i - m_i) + (m_j - l} & \\ 0, & sino \end{cases}$$

Step 10

d'(1)	d'(2)	d'(3)
1,00	0,74	0,26

$$w_i = \frac{V(S_i \geq S_j | j = 1, \ldots, n; j \neq i)}{\sum_{k=1}^{n} V(S_k \geq S_j | j = 1, \ldots, n; j \neq k)}\ i = 1, \ldots, n.$$

w(1)	w(2)	w(3)
0,50	0,37	0,13

Figure 16: The application of fuzzy AHP

5. DISCUSSION

Measurements play an important role in many scientific fields in general and in the analysis of enterprise architecture in particular. In software engineering, the measures are used to control the quality of the software product and better manage development projects to control the cost of production.

This section presents a discussion to position our approach in the existing research work.

The set of dimensions that we will adopt at the level of our classification scheme is an extension of Buckl's multidimensional framework [7] The Body of analysis, The Analysis time, The analysis technique, The Analytical concerns and The reference level)

We have studied and positioned different state-of-the-art approaches, and then we will study and discuss the values of each comparison criterion. When analyzing the works, we can observe different visions in relation to the criterion of complexity, each approach measures only one or two dimensions of complexity and neglects the others, except the papers of Lakhrouit et al.[21][10] and this paper which detailed all the dimensions of the complexity.

Regarding the criterion of the body of analysis, we can see that the dynamic notion of complexity is still under-represented in the current literature because most of the authors have focused on the structural complexity thus obtaining a total absence of a dynamic method that automatically calculates the complexity during a change except the approach of Lakhrouit et al., [10][21]which proposed a complete methodology using the observer pattern to detect the changes and to recalculate the measurements.

With regard to the exploration of the technical criterion of analysis, we find two different approaches: subjective complexity based on experts, in the field of perceived complexity; or complexity as a descriptive property of a system. Most of the models, which are developed to define, understand or measure project complexity, are in line with one of these approaches. Models related to perceived complexity (based on experts) often have levels and hierarchical aspects and turn out to be less quantifiable in terms of measurable units, such as the approach of He et al.,[18] on the other hand, models linked to a descriptive property of a system (based on indicators) are more quantifiable, as these do not include subjective elements except for a few approaches which have proposed to merge the two types[15][19]. In our approach we merge also the two techniques. we choose the dimensions based on the experience of the architects and we apply the dimensions.

These two approaches [15][19] let users enter the error rate that is predicted by experts for each component of the enterprise architecture landscape. Admittedly, the indicators allow us to have a more objective vision of the architecture, however, we cannot completely deny the role of the experts and the architects in deciding what will be the most suitable scenario or architecture for the company.

By analyzing the criterion of analysis concerns and analysis time, we notice diversity in the approaches proposed because they cover both aspects for each criterion, of the other hand, this diversity is not at all visible at the level of the reference criterion. of enterprise architecture, a few approaches [3][13] address the concepts of enterprise architecture and its components, but there is no approach that offers an analysis methodology. In our approach we propose a complete methodology with steps to evaluate EA.

From the studies carried out, we have also noticed that all the aspects of a model are often interpreted as independent[18] and emphasize the importance of assigning priorities to the measures of the models, because not all measures can be considered to have the same importance with respect to all projects. In our approach we propose to use Fuzzy logic to prioritize the dimensions of complexity.

6. CONCLUSION

Even though the interest in enterprise architecture (EA) has in recent years tremendously increased across industries, many organizations continue to encounter challenges which affect the development, implementation, and practice. As a result, different approaches have been employed to ascertain the challenges, yet they persist. Thus, the objective of this paper is to propose a complete pattern-based methodology for analyzing the complexity of enterprise architecture. The objective is to propose an evaluation methodology for guiding designers and architects in evaluating and improving the EA models.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

The purpose of this article is to propose a methodology based on the patterns of enterprise architecture. We propose 7 steps: The 2nd, 3rd and 4th step, we model the architecture using ArchiMate. The 5th step we apply an algorithm to transform the architecture into a graph. the 6th stage, we propose a set of micro and macro measures to study dependencies, density, centrality and several other dimensions. The last step we applied fuzzy logic to prioritize each dimension. Each project manager can specify the dimensions that interest him at the level of the evaluated project.

REFERENCES

[1] Lakhrouit, J., & Baïna, K. (2016). A pattern based methodology for analyzing enterprise architecture landscape. International Journal of Computer Science Issues (IJCSI), 13(6), 15.

[2] Widjaja T., Kaiser J., Tepel D., Buxmann P., 2012, “Heterogeneity in IT landscapes and monopoly power of firms: a model to quantify heterogeneity”. The international conference on information systems (ICIS), Orlando, FL.

[3] Schutz, T. Widjaja, J. Kaiser, 2013, “Complexity in enterprise architectures—conceptualization and introduction of a measure from a system theoretic perspective”. the European conference on information systems (ECIS), Utrecht, The Netherlands.

[4] Lankhorst, M.: Introduction to enterprise architecture. In: Enterprise Architecture at Work. Springer, Heidelberg (2005).

[5] Lagerstrom R., Baldwin CY., Maccormack AD., Aier S., 2013, “Visualizing and measuring enterprise application architecture: an exploratory telecom case”. School working paper 13-103. Harvard Business, Cambridge, MA.

[6] AW. Schneider, 2015, “Complexity and Diversity Management of Application Landscapes’’, Software Engineering for Business Information Systems. Department of Informatics Technische Universität München, Germany.

[7] Buckl S, Matthes F and Schweda CM. “Classifying Enterprise Architecture analysis approaches”. In Poler R, van Sinderen M and Sanchis R (eds.) Enterprise Interoperability (Lecture Notes in Business Information Processing, vol. 38). New York: Springer-Verlag, 2009,pp. 66–79.

[8] S. Buckl, A.M. Ernst, J. Lankes, K. Schneider, and C.M. Schweda. A Pattern based Approach for constructing Enterprise Architecture Management Information Models. In In Proceedings of the IEEE Enterprise Distributed Object Computing Conference, 2009. IEEE.

[9] K. Wehling, D. Wille, C. Seidl and I. Schaefer, "Decision Support for Reducing Unnecessary IT Complexity of Application Architectures," *2017 IEEE International Conference on Software Architecture Workshops (ICSAW)*, 2017, pp. 161-168, doi: 10.1109/ICSAW.2017.47.

[10] Lakhrouit, J., & Baïna, K. (2020). Analysis and implementation of the impact of change: application to heterogeneity algorithms in enterprise architecture. *International Journal of Electrical and Computer Engineering*, *10*(1), 377.

[11] Singh, P. M., & Sinderen, M. J. V. (2015, June). Lightweight metrics for enterprise architecture analysis. In *International Conference on Business Information Systems* (pp. 113-125). Springer, Cham.

[12] M. Mocker, 2009, “What is complex about 273 applications? Untangling application architecture complexity in a case of European investment banking”. In: Proceedings of the 42nd Hawaii international conference on system sciences (HICSS), IEEE Computer Society, Washington, DC.

[13] C. Schmidt, 2015,“Business Architecture Quantified: How to Measure Business Complexity”, Business Architecture Management, pp 243-268.

[14] Daniel Fürstenau, 2014, “System embeddedness and continuance inertia: an exploratory network analysis”, 7th IADIS International Conference Information Systems 2014, Madrid.

[15] Per Närman, Hannes Holm, David Höök, Nicholas Honeth, Pontus Johnson 2012, “Using enterprise architecture and technology adoption models to predict application usage”, The Journal of Systems and Software 85.

[16] Schmidt C, 2013a, How to measure enterprise architecture complexity: a generic approach, practical applications and lessons learned. Presentation at The Open Group conference, London, Oct 2013. www.scape-consulting.com/index.php/schmidt-2013d.html. Accessed 25 Oct 2014.

[17] Iacob, M. E., Monteban, J., Van Sinderen, M., Hegeman, E., & Bitaraf,K. (2018, October). Measuring enterprise architecture complexity.

In *2018 IEEE 22nd International Enterprise Distributed Object Computing Workshop (EDOCW)* (pp. 115-124). IEEE.

[18] He, Q., Luo, L., Hu, Y., & Chan, A. P. (2015).”Measuring the complexity of mega construction projects in China—A fuzzy analytic network process analysis”. International Journal of Project Management, 33(3), 549-563.

[19] J. Lankes and C.M. Schweda. Using Metrics to Evaluate Failure Propagation and Failure Impacts in Application Landscapes. In Multikonferenz Wirtschaftsinformatik, Berlin, Germany, 2008. GITO-Verlag.

[20] Per Närman, Hannes Holm, David Höök, Nicholas Honeth, Pontus Johnson 2012, “Using enterprise architecture and technology adoption models to predict application usage”, The Journal of Systems and Software 85.

[21] Lakhrouit, J., & Baïna, K. (2019). Analysis of enterprise architecture complexity: modeling and diagnosis heterogeneity.

[22] Smajevic, M., & Bork, D. (2021, October). Towards graph-based analysis of enterprise architecture models. In *International Conference on Conceptual Modeling* (pp. 199-209). Springer, Cham.

[23] Kaddoumi, T., & Watfa, M. (2021). A foundational framework for agile enterprise architecture. *International Journal of Lean Six Sigma*.

[24] Anthony Jnr, B. (2021). Managing digital transformation of smart cities through enterprise architecture–a review and research agenda. *Enterprise Information Systems*, *15*(3), 299-331.

[25] Winter, R. (2022). Designing Informal EAM Interventions–A Complementary Approach for Managing Enterprise Architecture Complexity.

[26] Sahu, A. K., R. K. Padhy, and A. Dhir. 2020. “Envisioning the Future of Behavioral Decision-making: A Systematic Literature Review of Behavioral Reasoning Theory.” *Australasian Marketing Journal (AMJ)*. doi:10.1016/j.ausmj.2020.05.001.

[27] Asmussen, C. B., and C. Møller. 2020. “Enabling Supply Chain Analytics for Enterprise Information Systems: A Topic Modelling Literature Review and Future Research Agenda.” *Enterprise Information Systems*, 1–48.

[28] LeBlanc, B. W., Davis, O. K., Boue, S., DeLucca, A., & Deeby, T. (2009). Antioxidant activity of Sonoran Desert bee pollen. *Food chemistry*, *115*(4), 1299-1305.

[29] Saaty, T. L. (2004). Decision making—the analytic hierarchy and network processes (AHP/ANP). *Journal of systems science and systems engineering*, *13*(1), 1-35.

[30] Büyüközkan, G., Ilıcak, Ö., & Feyzioğlu, O. (2022). A review of urban resilience literature. *Sustainable Cities and Society*, *77*, 103579.