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Enterprise Architecture Analysis and Network Thinking: a Literature Review

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Abstract

Previous works in enterprise architecture (EA) literature has mostly dealt with EA principles, qualitative aspects like EA value and benefits, modeling efforts like Archimate, and methodologies for EA implementation like The Open Group Architecture Framework (TOGAF) and others. Today, these are all common subjects in EA literature. In this paper, we are going in a complementary direction, aiming to contribute towards fostering a set of EA analysis methods based on network measures, considering the enterprise as a complex network. Thus, we present a central question: What is known about the application of network measures in order to analyze components and relationships in the EA context? To answer this question, we perform a broad literature review and create a state-of-the-art description of EA network analysis, applied measures and its main achievements. We also provide a research agenda for the field.

1. Introduction

In past years, we have seen an increase in the amount of research on enterprise architecture (EA) [1]. Previous works dealt with EA principles [2], qualitative aspects like values and benefits [3], modeling efforts like Archimate [4], and finally standards like The Open Group Architecture Framework (TOGAF) [5] and others. In this paper, we aim to contribute towards fostering a set of EA analysis methods. In this sense, we look at EA as a complex network, a concept that is discussed in network science [6]. In the complex network field, real world systems are modeled as networks or graphs. Thus, EA as an interwoven system of strategic goals, business processes, applications and infrastructure components (domains of the enterprise architecture), is subject to a variety of relationships and dependencies among its several components. These relationships can occur in the same domain (intra-domain relations) and/or in a different domain (inter-domains). In this sense, EA is intrinsically suitable for the network modeling approach. Once this network of relations is identified, analysis measures can be used to map important elements in terms of structures that take those inter- and intra-relations into account.

We label each attempt to analyze EA modeled as a network a *network analysis initiative*. This can be a simple well-known network measure (e.g. degree centrality, eigenvector), more sophisticated techniques or methods composed by those simple network measures (e.g. the hidden structure method [7]), or the overall analysis inspired in network models (e.g. random networks). In the view of [8], these network measures could represent more reliable and quantitative indicators to describe EA structure, helping architects guide its analysis process and evolution, allow them to go beyond their own perceptions, reducing subjectivity. Network models allow examining the effects of interdependencies between individual elements, such as applications, in contrast to aggregated patterns of occurrence as typically suggested by EA approaches (e.g. the absolute number of a technology in a company)[9].

We can cite some works that have already gone in this direction: In [7], the authors used design structure matrix to propose a hidden structure method to evaluate indirect dependencies among applications and classify them as core and peripheral components. In [10], the same method is used for visualizing and measuring software portfolio architectures to predict the costs of architectural changes. Concerned about EA evolution, the authors in [11] defined the concept of an "architectural control point" (ACP) and analyzed the influence of architectural thinking on ACPs over time. Reference [12] investigated if software portfolio architecture affects the agility of an organization to change. Reference [8] applied network measures in the information technology landscape suggesting several uses, for example, to analyze application modifiability, impacts of application failure, trace indications of cost, and perform gap analysis between scenarios.

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Since a complex network has many interconnected components [13], in our first exploratory search we identified research which also has been analyzing EA components and inter-relations under the label "EA complexity." The authors in [13] proposed three categories to classify complexity metrics in EA. Their "topology metrics" category contains studies developed under the EA complexity perspective which are aligned with the EA network model discussed in our present work. The "topology metrics" identified in Reference [13] essentially represent network methods.

With this in mind, we want to make a distinction between our work and [13]. The present work differs in aspects like the coverage of our query string and types of research objectives. We try to characterize the state-of-the-art network measures applied over EA components and relationships, not necessarily only within the EA complexity literature. We also aim to focus on structural aspects of intra- and inter-relations of EA components as in [8], while paying less attention to the properties of individual components/agents and heterogeneity aspects of [13].

Thus, in order to identify the network analysis measures that were applied in EA, it is necessary to perform a review looking at the existing body of knowledge of EA complexity (see Figure. 1, Areas 2 and 3) due to overlaps with concepts discussed. Furthermore, we identify works which dealt specifically with the network analysis of EA components, its relation to all EA subdomains, and adding these respective terms in our query string (see Figure. 1, Area 1). In Figure 1, Area 1 – our focus – represents potential network analysis works not mapped in EA complexity literature. With regard to Area 2, it depicts the overlap between EA complexity and EA network analysis. Area 3 in Figure 1 represents possible works related to EA network analysis that might not explicitly contain network-related terms, due to no standardized nomenclature in the fields.

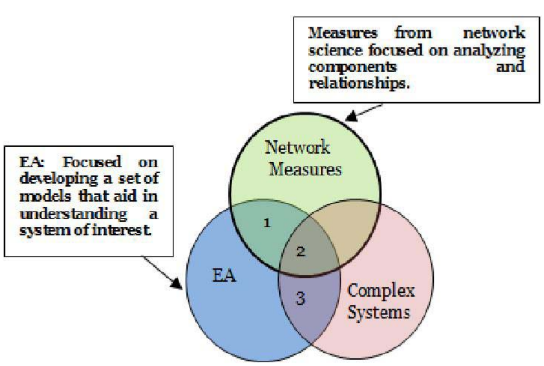

Fig. 1. Research focus and overlapping areas

To the best of our knowledge, we still do not have a state-of-the-art EA analysis with network measures. Thus, we address this gap asking: What is known about the application of network-based measures to analyze components and relationships in the EA context? To answer this question, we perform a broad literature review based on the procedures and guidelines proposed by [14].

The contributions of this research consist in a state-of-the-art review of EA network analysis, considering its components and relationships. We also describe its main achievements and limitations, tracing a research agenda for the field. We believe that our work is theory-worthy due to the lack of research mentioned, and also relevant in practice. Once measures are identified, they might be interesting for practitioners in order to foster the improvement of existing EA analysis tools as in [15] and [16]. Thus, this article is structured as follows: In Section 2, the concepts of EA as a network and as complex system are discussed. In Section 3 our research method is explained. Section 4 presents the data extracted from primary studies, and includes a discussion. Finally, we summarize our findings and talk about our next research steps.

2. Key concepts

2.1. Enterprise architecture

Due to the variety of definitions given for EA, in this paper we adopt the concept proposed by [16]: "EA as a system formed by four subsystems: business (or business architecture – BA), data-Information (or data-architecture – DA), application (or application architecture – AA) and infrastructure (or infrastructure architecture – IA)." This definition also refers to the EA domains mentioned in TOGAF [5] and is the base for the query string presented in Section 3. In general, the identified past research which analyzed EA components and inter-relationships has been modeling EA as a network (i.e. graph) or as a complex system.

2.2. Enterprise architecture as a graph or network

In the context of network theory, a graph or network is a set of components (nodes or vertices) and links (edges or relations). This representation has several interesting properties as it can encode local neighborhood relations as well as global characteristics of the data [8]. In this direction, we find the work of [6], which used measures from the social network analysis field to investigate how a component (individual) is immersed in a (social) structure, how this structure arises from micro-relations among components and how it can impact specific context variables (e.g. individual performance). In the view of [8] and [17], these network measures applied over EA modeled as a network could represent more reliable and quantitative indicators to describe EA structure, helping architects guide its analysis process and evolution. Considering this potential, References [8], [10], [11], and [12] applied network measures and algorithms [6] like degree, betweenness centrality, modularity, and others in EA analysis.

2.3. Enterprise architecture as a complex system

Although there is no generally accepted formal definition, according to [13] a complex system is a large network of relatively simple components with no central control, in which emergent complex behavior is exhibited. Complex systems theory might be utilized in architecture evaluation in order to deepen the understanding of the interactions imposed by the architecture presented in [18] and [19].

Although no agreed-upon definition of the term EA complexity exists [13], there is the work of [16], which brings a theoretical conceptualization of complexity in EA based on a literature review. In accordance with definitions of complexity in systems science, the authors in [16] say, "Complexity can be defined as a tuple of number (N) and heterogeneity (H) of the components or relations of a system." In this definition, three main concepts are central: the amount of components, their relationships, and also the heterogeneity among these relations and components.

For [20], network theory is indispensable in the study of complex systems. In his opinion, we will never understand the workings of a cell if we ignore the intricate networks through which its proteins and metabolites interact with each other.

Whether modeled as a simple network (graph) or as big network from which emergent complex behavior arises, EA analysis can benefit from network theory, analyzing static aspects through simpler questions (e.g. which is the central application in terms of information flow?) or asking questions from a dynamic or behavior perspective (e.g. does the process of network evolution involve adding new links between existing components or rewiring of existing links?)[18].

3. Research methodology

We perform a literature review following the guidelines of [14]. As the first step, we elaborate a research protocol. We are interested in studies related to quantitative measures of components and relations in the EA context which will be analyzed and consolidated in order to answer the following research questions: 1) What are the analysis goals of these studies? 2) What EA domains and respective measures have been approached? 3) What are the perceived effects/benefits of the application of measures in EA domains? 4) What are the main methods of data collection used? 5) What are the research gaps?

We derive our search terms from the definition of EA presented by [16]. In addition, we used elementary terms related to network theory like "network measures," "centrality," and "network analysis," since these terms could represent research related to relations analysis. Three research experts in the network analysis field have validated these related terms. As [8] did, we believe that querying all EA subsystems terms together with "enterprise architecture" might produce a broader coverage of research. According to [16], there are possibly various analysis approaches from other fields which might be transferrable to EA. For example, research from system of systems theory (SoS), system thinking theory, system engineering and others which did not specifically mention the expression "enterprise architecture" did cover one of the EA subsystems – application architecture – and presented some network measures/metrics. In those cases, we investigated if those measures had potential to be listed as a contribution to EA analysis research. Our query string is presented in Table 1.

Table 1- Query string for the research

Final query string
("enterprise architecture" OR "business architecture" OR "process architecture" OR "information systems architecture" OR "IT architecture" OR "IT landscape" OR "information architecture" OR "data architecture" OR "application architecture" OR "application landscape" OR "integration architecture" OR "technology architecture" OR "infrastructure architecture") AND ("complexity" OR "centrality" OR "network analysis" OR "network measures" OR "betweenness" OR "eigenvector" OR "degree" OR "network metrics" OR density OR "modularity" OR "clustering" OR "cluster")

Papers analyzed had to contain techniques, methods or any kind of network measure initiative to evaluate the infrastructure, application, information, or business process architectures (any EA subsystem) or the EA in a holistic way (EA as whole system). Different authors allude to EA complexity but are actually referring to different facets or types of EA complexity [21]. In our research, we focused on the complexity related to interdependency among EA components, which can be of two types: intra-architecture (e.g. AA) and inter-architectures (e.g. AA and BA). Our exclusion criteria are: 1) Papers containing other types of complexity like diversity or heterogeneity and deviation from standards [21] without considering any network measures; 2) papers related to product architecture or software code analysis; 3) papers in any language but English; 4) papers with files that are not recoverable in full; 5) summaries of keynotes, tutorials, white papers, book chapters, theses or dissertations; 6) incomplete papers; 7) repeat studies found in different sources or reporting similar results (e.g. reference [11] replaces a similar work in [22]); and 8) papers containing measures not related to a component's interdependency like "human resource workload at business process level," an analysis function identified by [23].

The query was executed in March 2015 for Scopus, IEEE, and Engineering Village, and executed again in August 2015 for EBSCO and AISeL. We did not limit the initial year of the publications. In phase one, we applied the query string and extracted basic information about the papers – title, keywords, and abstract. We applied inclusion/exclusion (I/E) criteria on the three screening phases described in Table 2:

Table 2 - Screening process phases

	Input papers (from all engines)	Output papers
Phase 1 – title + abstract	5739 (with duplicates)	262
Phase 2 – intro + conclusions	262	66
Phase 3 – full paper reading	66	24

We also performed in August 2015 forward and backward searches which resulted in an additional 5 papers to our dataset after applying the I/E criteria. In the last phase, we extracted the evidence from 29 (24+5) papers. We did not perform a quality assessment [14] since, based on our previous readings, we consider the field as a relatively recent and emergent area with many studies still attempting to validate their initial conclusions. We wanted to analyze papers with different hierarchies of evidence [14] and different methodological designs, therefore we relaxed our quality criteria.

4. Findings and discussion

We show the distribution of the 29 papers over time in Figure. 2:

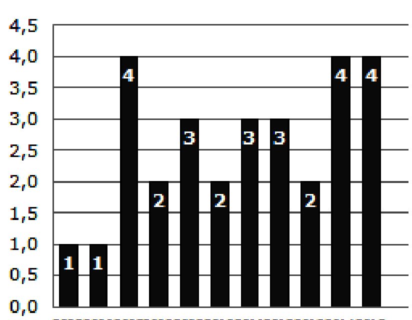

Fig. 2. Distribution of publication over time

In the EA context, analysis processes extract relevant information from the enterprise models in order to provide solid and structured information that will be valuable for making business and IT decisions [23]. We describe the common analysis goals aimed in the selected papers and create a set of 7 categories (see Table 3) for 24 analysis goals (see Table 4). Some of the categories have a clear meaning, while for the others we provide further explanation.

In the *alignment among architectures* category, we consider the initiatives of measuring to what degree a component from domain D1 is covered by/supports a component in domain D2 (e.g. analyze business coverage provided by an application). In the *EA complexity measurement* category, we grouped the papers that measured EA complexity as a whole system or any EA domains. These measures can be useful as quantitative descriptors of EA complexity and might be collected to build a time series analysis, for example. Operational and maintenance costs, allocation of EA architects according to EA segments to distribute workload, and governance structures are themes of the category *EA-related business issues*. In the *measure impacts of component dependency in overall EA* category, are papers which primarily took one component as a referential in order to investigate the impact or influence of this component for the rest of the domain (dependency analysis). Belonging to what we named the *EA dynamics* category are papers that try to investigate EA evolution over time.

Analyzing Table 3 (which is not mutually exclusive), we can highlight four main streams of analysis goals in the research: *EA complexity measurement* – 4/29 papers; *alignment among architectures* – 4/29 papers; *impact of component dependency in overall EA* – 5/29 papers; and *structural aspects of EA* – 10/29 papers.

Table 3 - Goal categories aimed by the primary studies

Goal category	Coded goal
"EA stakeholder management"	G-01
"Alignment among architectures"	G-02; G-03; G-04; G-05
"EA complexity Measurement"	G-06; G-07;G-08; G-09
"EA-related business issues"	G-12; G-13; G-14; G-15
"Structural aspects of EA"	G-16; G-17; G-18; G-19; GA-20; G-21; G-23;
"EA dynamics/evolution"	G-22; G-24
"Impacts of component dependency in the overall EA"	G-10; G-11

On the other hand, *EA stakeholder management*, appeared less as a research concern in our dataset. One can conclude that social aspects of EA – the relations among stakeholders or social roles – has not received much focus thus far. Little attention has also been given for *EA dynamics* – only 2 papers. Our data showed a diversity of analysis goals, 24 in total, without exhaustive exploration, and several measures still being proposed where authors claim validation with empirical case studies, as we will outline later.

Table 4- Analysis goals aimed by the primary studies

Analysis goals and primary studies		
Goal Analysis	***Analysis goal***	***Primary study***
G-01	Manage stakeholder concerns and influence in case of artifact changes	[24]
G-02	Measure the criticality of applications in DA	[25]
G-03	Assess the integration/alignment of application and information architectures	[26]
G-04	Analyze integration among business requirements and entities in the DA	[27]
G-05	Analyze the alignment between application and business architectures	[23]
G-06	Measure complexity in EA in terms of number of components and heterogeneity	[18]
G-07	Measure and compare EA complexity in a multi-level granularity	[28]
G-08	Measure application architecture complexity	[29]
G-09	Measure complexity of a service based on dependencies among EA components observed in service delivery steps	[30]
G-10	Identify the impact of dependencies on a component for the whole system	[7],[8], [10] [13], [31]
G-11	Analyze modifiability and change management in AA	[8], [32]
G-12	Identify the impact of application domain complexity in the operational and maintenance costs of applications	[8], [10], [21]
G-13	Identify how dependencies in AA affect an organization's ability to change their software portfolio	[12]
G-14	Allocate human resources for EA activities	[8]
G-15	Investigate the impact of IT governance structures on application and infrastructure architecture complexity	[33]
G-16	Identify key components of EA based on centrality measures	[7], [10], [34]
G-17	Identify outliers representing structural critical spots in the architecture	[8], [35]
G-18	Identify functional domains in EA, based on modularity	[8] ,[36]
G-19	Measure modularity in complex systems	[37]
G-20	Reduce dependency in the service layer in order to redesign the architecture	[38]
G-21	Analyze modularity aiming to identify improvements in design	[37]
G-22	Perform gap analysis of EA states	[11], [8], [39]
G-23	Identify business process improvements opportunities and change management	[40], [41], [42]
G-24	Analyze EA growth	[9]

4.1. Network measures found in EA analysis

We identified each EA network analysis initiative applied in empirical cases, either simulated or theoretically studied; in theoretical cases, these include only definitions and explanations of constructs.

To classify all the measures found according to the EA domains on which they were applied, we use the concepts of EA domains from TOGAF [5] and [16]. These are: business architecture (BA), data/information architecture (DA), application architecture (AA), and technology/infrastructure architecture (IA). To this set, we added three other labels: general EA (GA), holistic EA (HO), and stakeholder domain (STK). "General EA" are the measures designed by the researcher with no specific target domain of his/her analysis, meaning that the initiative is generic enough to be applied to the entire system or its subsystems as occurs in [16]. A "holistic EA" initiative is when the measure or technique focus on data from several (at least more than two) domains in its analysis process. In other words, this analysis might go through almost the entire EA, carrying elements from infrastructure to business process levels on what we consider a holistic analysis.

We identified that 22 of 29 papers have AA as the input for their analysis process. This partially corroborates [13] when they say, "EAM research focuses in application landscapes only, which does not satisfy the premise of a holistic scope of EA." Nevertheless, we did find analysis of application domains in association with others domains (e.g. references [26], [12], [25], and [36]). The majority of the measures found in Table 5 have a static lens to analyze EA since few measures were proposed to evaluate the dynamic aspects of EA (see Table 4, G-22). According to [43], such dynamic analysis is a widely-known and accepted fact in many management disciplines, but regarding EA many considerations have not yet been undertaken. We also corroborate this position here.

Several measures identified in this study were not validated with empirical data: 10 of 29 papers (around 34%) contain an illustrated application of their measures (see Table 5, label "I"); 5 of 29 papers (around 17%) proposed their measures only theoretically (see Table 5, label "T"). We also classified each measure according to the structural level on which it was applied: component level ("Co"); relation level ("Rel"); module level ("Mod"), and network level ("Net").

Table 5 - Network analysis initiatives found in primary studies

Name of initiative	EA domain targeted[a]							Structural level[b]				Val	Primary Study
	GE	*HO*	*STK*	*BA*	*DA*	*AA*	*IA*	*Co*	*Rel*	*Mod*	*Net*		
Modularity	X								X			T	[18]
Number of components	X							X				T	[18]
Degree of connectedness	X										X	T	[18]
Number of types of relations	X								X			T	[18]
Intensity of the relations (weighted relation)	X								X			T	[18]
Multiplier effect in the flows of interactions	X								X			T	[18]
G&G metric	X									X		I	[28]
Service time actual (STA)		X		X	X	X	X	X	X			I	[30]
Purity of the domain				X		X			X			E	[39]
Purity of categories						X				X		E	[39]
Data sovereignty				X	X	X		X	X			E	[39]
Correct category dependencies						X			X			E	[39]
Distance of application landscapes		X		X	X	X			X			E	[39]
Clustering algorithms and centrality measures from Netdraw tool			X	X				X	X	X		I	[24]
Centrality measures (betweenness and degree centralities)			X	X			X		X			E	[34]
Clustering index						X	X				X	E	[34]
Average path length						X	X				X	E	[34]
Girvan/Newman's clustering algorithm				X		X				X		I	[36]
McCabe's cyclomatic number				X					X			I	[35]
Activity/passivity of a business process				X					X			I	[35]
Business-application alignment				X		X			X			I	[23]
Static alignment measure (SAM)				X	X				X			I	[27]
Degree of informational dependence					X	X			X			T	[26]
Degree of functional dependence						X			X			T	[26]
Cohesion (operationalized by embeddedness)						X			X			E	[12]
Coupling (operationalized by closeness centrality)						X			X			E	[12]
Structural complexity and procedural complexity						X		X				E	[12]
Data complexity						X			X			E	[12]
Connectivity strength weighted parameter frequency (CSWPF)						X		X	X			E	[38]
"The hidden structure" method						X			X			E	[7]
"The hidden structure" method		X		X	X	X	X		X	X		E	[10]
Chidamber and Kemerer's measure of coupling operationalized by DFI/DFO		X		X	X	X	X		X	X		E	[10]
Closeness centrality		X		X	X	X	X		X			E	[10]
Business information criticality of an application (BIO)					X	X		X	X			T	[25]
Architectural control points (ACP)						X			X			I	[11]
Fitness difference between architectural control point sets						X			X			I	[11]
Small world coefficient difference between initial and final stages						X					X	I	[11]
Absolute criticality of the a services S (ACS)						X			X			T	[29]
Average service depth (ASD)						X			X			T	[29]
POU – Provided operation utilization of a service						X				X		T	[29]
ROU – Required operations utilization of a service						X				X		T	[29]
Change cost of a service						X				X		T	[29]
Instability of element – IOE (e)						X			X			T	[29]
Whitney index (WI)						X				X		E	[37]
Change cost (CC)						X			X		X	E	[37]

Name of initiative	GE	HO	STK	BA	DA	AA	IA	Co	Rel	Mod	Net	Val?	Primary Study
Centrality measures - degree, closeness and betweenness						X			X			E	[37]
Architectural relevance						X			X			E	[8]
Cross-functional application measure (operationalized by closeness centrality)						X			X			E	[8]
Degree centrality for application modifiability, risk and cost estimation						X			X			E	[8]
Clustering algorithm (not detailed) for group applications according to their relations						X					X	E	[8]
Modularity – operationalized by global modularity and clustering coefficient						X					X	E	[8]
Betweenness centrality for identify critical points in terms of risk and operational value of an application						X			X			E	[8]
Eigenvector centrality for identifying critical applications in terms of failure						X			X			E	[8]
Landscape size (number of business related IT applications)						X			X			T	[33]
Interdependency between applications						X			X			T	[33]
Redundancy – different instances of major applications for business units				X		X			X			T	[33]
Infrastructure landscape size (number of physical servers/clients)							X		X			T	[33]
Impact analysis of a component in its neighborhood	X								X			I	[31]
Number of interfaces of the application to other applications						X			X			E	[21]
Business coverage redundancy/overlap				X		X			X			E	[21]
Number of processes covered by the application (scope of the application)				X		X			X			E	[21]
Discriminant functions several network measures				X					X			E	[40]
Path dependence based network model, hub centrality, net. connectedness						X			X			E	[9]
Degree, betweenness centrality calculated with weighted qualified edges						X			X			E	[32]
Process Page Rank algorithm				X				X	X			I	[41]
"The hidden structure" method						X			X			E	[13]
Process Clustering (Hierarchical multidimensional scaling method – MDS)				X					X	X		E	[42]

[a] EA domain targeted: GE – general EA domains; HO – holistic enterprise architecture; STK – stakeholder domain; BA – business architecture; AA – application architecture; DA – data architecture; IA – infrastructure archit.

[b] Structural level on which the measure was applied: CO – component; Rel – relation; Mod – module; Net – network.

Some measures (e.g. degree centrality) appeared more than once in Table 5 because they were applied in different contexts analyzing different constructs as suggested by [8]. Most of the measures were designed for relationship level (51 of 67), and highlighting the importance of relationship modeling in EA analysis. The remaining 16 measures were applied at component, module, or network levels. To sum up, we identified 67 cases of network-related measures. It is clear that major attention was dedicated to the EA application domain while social aspects of EA and infrastructure domains still have been focused on less by researchers. Also, we must comment on some modeling issues we identified:

1) Granularity level of measure analysis: In general, most measures were applied at a single granularity level of analysis without comparing the results of measures in different levels of the system. The proper level of granularity used in the modeling is an important issue. Reference [28] finds that the degree of modularity can vary for the same system when the system is represented at the two different levels of granularity. Reference [28] also affirms that it still is not clear which level of granularity is correct in terms of making decisions about which architecture would better achieve the benefits of modularity. Although, experiences from the industry confirm that EA models need to remain on an aggregated level instead of modeling very detailed structures [44]. These questions about the "right" granularity level on EA modeling still need further understanding.

2) Indirect and direct dependencies: Reference [10] highlights the importance of indirect dependencies which were important in estimations of change cost propagation. Although, indirect dependencies do generate an additional analysis effort.

3) Symmetric and asymmetric relationships (or directed and undirected): Some studies did not distinguish between symmetric and asymmetric relationships. Studies should clarify these questions in their modeling process.

4.2. Data collection methods

In the primary studies described in Table 6, the data were collected through time-consuming approaches like interviews with IT staff and other stakeholders as well as document analysis. In a few cases, researchers have benefited from the support of an automated data collection or modeling tool. Likely as a consequence, many studies applied illustrative data.

Table 6 - Data collection methods

Method found	Primary studies
Interviews with IT staff	[9] ,[10], [11], [12], [13], [21], [24], [25] [39].
Repository/document analysis	[6], [7], [9], [10], [11], [12], [8], [13], [21], [24], [34], [39], [35], [38], [46], [42].
Automated collection	[39], [23].
Simulation/illustrative data	[9], [11], [18], [36], [29], [30], [28], [27], [25], [26], [31], [41].
No-data	[29], [33].

4.3. Benefits of the measure's application

Reference [24] applied network measures to observe changes in artifacts and its impact on specific stakeholders. At the end, the authors concluded that network measures "improved stakeholder management/governance support." Another benefit elicited was the "identification of architectural improvements to be made" pointed out by [6], [7], [30], [34], [27], [23], and [38]. "Improve communication among stakeholders" is cited as a benefit by studies from [11] and [39]. Network measures enhanced the capability of architects concerning the "identification of critical components in terms of structure and cost" as reported in studies by [7], [8], [21], [34], and [35]. Guiding emergence or helping "manage the change [42] and evolution of EA" is another perceived benefit for [6], [11], [8], [13], [36], [39], [35], [40], and [41]. Support migration planning is reported in [32]. The "identification of implicit domains in EA" was considered an important result by [36] once it was useful to match these with functional domains formally defined in enterprises. "How technologies can evolve in the landscape" is discussed by [9]. "Support EA documentation process" in specific points and improve its quality is a benefit advocated by [8]. The same authors believe that network measures can "help in the implementation phase of EA lifecycle."

4.4. Research opportunities

In this section, we provide some recommendations for the research community, listing suggestions for future works extracted from the primary studies.

1) Abstraction techniques for modeling components and relations: This topic focuses on the definition of techniques in order to reduce the complexity of the EA analysis process such as better strategies for data abstraction (e.g. how much data must be collected and at which level of granularity?) and the development of criteria for when and how systems should be modeled are worthwhile subjects for research [28], [34].

2) EA analysis at different levels of granularity: Also related to the previous topic, the inclusion of various mixed levels of granularity of system architecture representation and the sensitivity of measures to those choices would also be worthwhile future work [8], [21], [28].

3) Relationship types, weights and symmetry: A differentiation between business and infrastructure applications and its representation in separate networks is considered reasonable [8]. Analogously, the application and infrastructure architectures analyzed separately could also benefit from this approach. Centrality measures, for example, applied over bi-modal networks present different values when compared to unimodal representations. In addition, one could quantify the edges, for example, in terms of frequency of data exchange among applications [8] and explore how the analysis methods apply to symmetric and asymmetric dependency EA networks [21], [32].

4) Qualitative aspects in EA analysis measures: According to [39], research should be focused on finding and classifying more qualitative measures regarding nonfunctional aspects of application landscapes in general. Strategic value can be added to a component as an attribute, for example.

5) Validation of network measures in more cases and industries: Empirical validation of the measures is claimed explicitly in several works [7], [12], [18], [21], [36], [30], [31] and [41].

6) Correlate network measures with performance measures like cost of changes, business agility, etc. This topic was claimed covered by [7], [10] and [39].

7) Correlation among network measures: For [29], another interesting area could be to explore if and how various metrics are related to other metrics. A special case of correlation is suggested in [18] to investigate if a network measure Y1 can be expressed as a function of component measures X1, X2, ... Xn.

8) Analysis of EA evolution: Not only to perform gap analysis between AS-IS and TO-BE states of EA, for [39] long-term studies show great promise for using distance measuring for cost prediction and complexity management [13], and [32] on application landscape development. Another avenue in this direction is to examine whether an IS architecture is in a phase of expansion or consolidation [9] and [42].

9) More topological/structural analysis: Some approaches might take full advantage of the several topological properties of enterprise models seen as networks, such as discovery of paths, clusters, or graph metrics [31].

10) Tool development support for EA analysis: The need is pointed out by [10], [23], and [26]. According to [7], future work needs to be directed towards data collection support in the enterprise architecture domain. In [40], authors suggest experiments on the perception of EA components visualization as a network using the cognitive fit theory. In terms of EA analysis supported by tools, in [23] they have an extendable tool to perform analysis over EA models.

5. Conclusions

In this paper we conducted an extensive literature review and identified 67 initiatives from 29 analyzed articles with network measures applied in EA analysis. As an emergent field, we saw several research goals aimed in the papers operationalized by different measures with most of them still requiring validation. Although, we consider the present literature review as an important step for the field since it contributes towards systematizing what is known about the application of network measures in EA analysis. Finally, we hope that the identified measures list can foster a discussion among practitioners and consequently make the decision-making process of EA analysis and assessments easier. We shed light on several research gaps and hope to attract the attention of the EA research community.

Limitations and threats to validity. Based on its review's protocol, other researchers can perform an up-to-date replication of this study in the future. We did not perform a quality evaluation of the extracted evidence as explained in Section 3.

Related works. Our broader literature research is focused on network analysis. Other efforts in this direction are represented by the complexity measures identified by [13]. It is also worthy of mentioning the work of [23] as a catalog for EA analysis functions beyond the subject of complexity. EA network analysis far from replaces other approaches, for example, EA-analysis based formalisms and ontologies [45] or EA analysis with operational data [23], and instead complements EA analysis with a different and intrinsically important analysis perspective.

Future work. There are several ways to continue this study. First, we will build a unified information model for components and relations. Second, it is important to validate the measures identified assessing viability and usefulness with experts. Third, we need a conceptual model to classify the research done so far according to its analysis goals, analysis methods, data generation strategies, outputs, and building a catalog of initiatives in order to guide future research. Finally, this is part of a PhD research project which aims to apply additional EA network analysis initiatives within real-world organizations.

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