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# A Systematic Literature Review on Enterprise Architecture Visualization Methodologies

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**ABSTRACT** EA (Enterprise Architecture) visualization methodologies have been explored by researchers and engineers to conduct EA modeling. The objectives of EA modeling are to clarify enterprise strategies, visualize business processes, and model information systems to manage resources, improve organization structure, adjust information strategy, and create new business value. Therefore, EA models can be broadly applied in various fields. For example, the applications include business modeling, information system architecture design, technology infrastructure configuration, software maintenance, and system security analysis. As the primary source of information, EA models are of paramount importance to researchers, architects, and developers. However, up to now, the purpose and means of these EA visualization methods have never been systematically analyzed and discussed, and a generalized EA visualization methodology with the ability to meet different demands is needed. The paper narrows this gap by conducting a systematic literature review on enterprise architecture visualization methodologies. In this study, 112 papers are retrieved by a manual search in 5 academic databases, a systematic literature review on EA visualization is explained to show a systematized category of visualization approaches, and then a general visualization approach is proposed by systematically reviewing the papers. Finally, the paper is concluded by discussing the contributions and limitations of the study.

**INDEX TERMS** Enterprise architecture, business modeling, visualization methodology, systematic literature review.

## I. INTRODUCTION

Enterprise architecture (EA) is a special field developed on the basis of the practice of information system architecture design and implementation. It is mainly used in large organizations and big projects, such as enterprise planning and government construction. Since Zachman *et al.* completed the pioneering work of EA in 1987, a lot of research and practice have been accumulated in this field. EA can be viewed as the means of optimizing enterprise structures, behaviors, and functions. In the development of EA, developers generally start from the perspective for overall optimum and then grasp the business strategies, the composition of the organization, business process of each department, inter-departmental collaboration, information systems, and other elements as a hierarchical structure. Through a comprehensive review of the organization, unnecessary costs can be reduced and comprehensive efficiency can be achieved with the whole organization. EA is a well-defined practice for

conducting enterprise analysis, planning, governance, and evaluation, with comprehensive approaches for successful development and implementation of strategies. Architects can use EA to apply architecture principles and practices to guide organizations through the business, information, process, and technology changes necessary to execute their strategies. These practices utilize the various aspects of an enterprise to identify, motivate, and achieve these changes. Although it needs a certain degree of cost in terms of time and capital, through efficiency and cost reduction, the introduction of EA often brings greater profits. Furthermore, the bigger the enterprise is, the higher the quality of EA is required.

To analyze, design, plan, and implement EA, it is usually necessary to develop EA models to realize EA visualization. Through EA modeling, the abstraction degree of the information system design can be increased, and verification at an early stage of the system development becomes possible. EA visualization enables information system designers to get a bird's-eye view for business and organization. When developing large-scale projects, EA visualization makes it easier to manage resources, strategies, risks, and business

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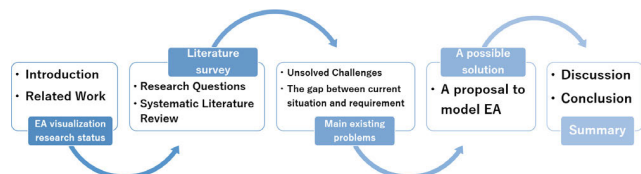


FIGURE 1. The structure of this paper.

processes. Moreover, in both academic research and practical engineering, EA modeling approaches are essential to EA visualization. As a result, many methodologies for EA implementation and deployment have been explored by researchers and engineers to conduct EA visualization. The objectives of EA modeling are to clarify enterprise strategies, visualize business processes and model information systems to manage resources, improve organization structure, adjust information strategies, and create new business value. It follows that EA models have been broadly applied in various fields.

Although there are many visualization methodologies on modeling EA, however, as of yet, the application of these theories appears to be fragmented, and the approaches are rarely systematically used in empirical studies. Therefore, it is necessary to categorize the fragmented visualization methodologies. Besides, one of the reasons for the variety of EA visualization papers is the wide scope of EA. EA involves business model, requirement engineering, governance, operation, IT infrastructure, and security analysis. For each domain, there are existing visual models. It is also necessary to integrate domain-specific visual models with EA models. In this paper, the authors propose an integrated method to develop a systematic visualization approach on EA models based on a survey of existing papers on EA visualization.

Fig.1 shows an overview of this paper. Concretely, the paper is structured as follows. In this section, the research background, the objectives of this research and the result are described as an introduction. Next, in Sect. II, research questions and research method for conducting the systematic literature review (SLR) [131] are explained. In Sect. III, literature selection and classification results are reported in chronological order. To identify the current situation and the future research directions of EA visualization research, the publication trends, technical characteristics, and quality of the selected papers are analyzed based on the information extracted from the selected studies in Sect. IV, V, and VI, respectively. After that, in Sect. VII, a general EA visualization method is proposed to narrow the gap between EA visualization methodologies and unsolved challenges in EA visualization research. In Sect. VIII, the related work is introduced to explain the motivation and necessity of our study in this paper. Finally, a discussion on the paper and the conclusion of the study are made in Sect. IX.

## II. SURVEY METHOD

This section describes the outline of this review by defining our research questions, search database, search keywords and search process.

## A. RESEARCH QUESTIONS

The research questions that we intend to answer in this study are defined as follows.

**RQ1.** What are the main purposes and motivations of EA visualization (why)? → see **Sect. III**

**RQ2.** What does the historical development trajectory of the study of EA visualization look like (when)? → see **Sect. IV(A)**

**RQ3.** In which regions do the studies of EA visualization prevail? In which venues have the selected studies on EA visualization been published (where)? → see **Sect. IV(B)**

**RQ4.** Which institutions and researchers have made outstanding contributions in the field of EA visualization (who)? → see **Sect. IV(C)**

**RQ5.** What kind of techniques are used in the study of EA visualization, and what are their strengths and weakness (what)? → see **Sect. V**

**RQ6.** How are the qualities of the selected studies (how)? → see **Sect. VI**

## B. RESEARCH METHOD

The following sources have been selected to perform the survey on EA visualization methodologies. The sources are chosen as they are generally considered to be the most important and influential academic article databases in the fields of information technology and software engineering.

- EACM Digital Library (<https://dl.acm.org/>)
- EIEEE Xplore (<https://ieeexplore.ieee.org/Xplore/>)
- ESpringer Link (<https://link.springer.com/>)
- EScience Direct (<https://www.sciencedirect.com/>)
- EGoogle Scholar (<https://scholar.google.com/>)

The following search keywords are used to find relevant studies in papers' title, abstract and index terms. "Enterprise Architecture Visualization" or "Enterprise Architecture Modeling" or "Enterprise Architecture Development" or "Enterprise Architecture Planning" or "Enterprise Architecture Implementation".

We use the following inclusion criteria for selecting the research studies by personally reading. Research articles that meet all these criteria will be selected for the SLR.

### 1) INCLUSION CRITERIA

[IC1] Studies with a clear focus on some aspects of EA visualization.

[IC2] Studies providing solutions for needs and problems of EA visualization.

[IC3] Studies subject to peer review (e.g. journal article, conference paper, workshop proceeding, and book chapters).

[IC4] Studies written in English.

[IC5] Studies available as full text.

We use the following exclusion criteria for eliminating undesirable research studies. Research articles that meet any of the following criteria will be filtered out.

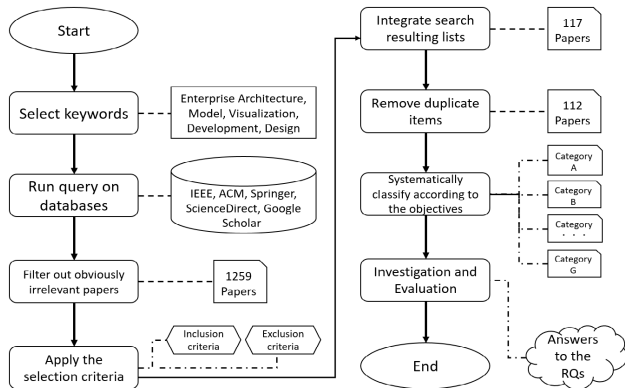


FIGURE 2. Overview of the review process.

## 2) EXCLUSION CRITERIA

[EC1] Studies not focusing on EA modeling/visualization/development/planning/.

[EC2] Studies that do not provide any conceptual, formal, or technical solution for the proposed approach to EA modeling.

[EC3] Secondary or concluding studies (e.g. systematic literature reviews, surveys).

[EC4] Studies with unclear contributions.

[EC5] Studies in the form of white papers, tutorial papers, short papers, poster papers, or manuals.

Fig.2 shows the search and screening process. The process had been completed in Oct. 2019. After identifying the articles, we analyzed them in detail. For each selected article, we recorded their bibliographical information (e.g., author affiliation, year of publication, type of publication, venue, and publisher), content-specific issues, such as the context and objective of the study, EA modeling languages, visualization tools, evaluation approach, and the number of citations. We also classified the articles according to their study operation. Last but not least, we recorded their research scope, methodology, limitations and future work.

## III. RESULTS

In this section, we aim to answer the following research questions: *RQ1. What are the main purposes and motivations of EA visualization?* More specifically, we systematically classify the selected research papers and briefly introduce them in chronological order.

The result of the literature search is reported as follows.

### A. BUSINESS MODEL

Winter *et al.* proposed a practicable structure for information management in hospitals, to support strategic planning and to reduce efforts for creating strategic plans [2]. Taylor and Palmer provided an overview of existing EA and then proposed an architecture for the embedded device domain [4]. Majedi and Osman proposed an architectural design model for implementing enterprise systems with the aid of SOA (Service-Oriented Architecture) [10]. The proposed

model can be used to address the organizational challenges in enabling cross-communication and collaboration without changing the current ICT infrastructure. Chen *et al.* presented an integrated service-oriented enterprise system development framework as well as an instantiated design process model [21], to support the engineering of enterprise-wide service-oriented systems. Antunes *et al.* explored the architecture context description and addressed the gap between the stakeholders' concerns and the resulting EA [24]. Clark *et al.* defined the LEAP framework, a lightweight framework for EA [25], and showed that it can be used to represent the key features of ArchiMate whilst containing fewer orthogonal concepts. Šaša *et al.* established and formally defined foundational EA patterns for business process support analysis [29]. Fritscher *et al.* presented an approach to connect business models to IT infrastructure [31]. Agievich *et al.* described an approach of developing and keeping relevant baseline EA description together with IT project teams using solution architecture models [35]. Perroud *et al.* proposed solutions for recurring IT-architecture problems in IT projects [61]. Jacob *et al.* propose a method to relate enterprise models specified in ArchiMate to business models [70]. Loucopoulos *et al.* presented a capability-centric modeling approach to support the design of services that meet the challenges of alignment, agility, and sustainability concerning dynamically changing enterprise requirements [78]. Jallow *et al.* presented a novel EA framework for managing information about client requirements [95]. Arriola and Markham proposed an extension of EA methods so that they can be applied to controlling the evolution of software-intensive systems across the organization [98]. Haghhighathoseini *et al.* presented an EA framework for Iranian hospitals [103].

### B. ENTERPRISE ARCHITECTURE MODEL

Barros *et al.* presented an integrated approach for modeling EA using UML, they also provided a set of process-based and role-based modeling concepts [1]. Jonkers *et al.* identified a number of principles and requirements for a language [3] for coherent enterprise descriptions. Lankhorst outlined an integrated language for EA modeling and presented the design of a workbench for EA development [6]. Le and Wegmann presented a modeling language [7] for building enterprise models to integrate business resources and IT resources, to improve an enterprise's competitiveness. Fuchs-Kittowski and Faust presented the semantic architecture tool (SemAT) for collaborative EA development [12]. Ahsan *et al.* explored a process view and modeling of healthcare using EA [17]. Li *et al.* proposed a distributed business process execution architecture, using lightweight agents to execute the business processes in a distributed environment [19]. Jonkers *et al.* proposed a method to assist ADM based on ArchiMate, an EA modeling language [23]. The ADM (Architecture Development Method) is a standardized process of TOGAF (The Open Group Architecture Framework). Bocciarelli and D'Ambrogio introduced a notation for the description of a business process in terms of both functional

and non-functional properties [28]. Meertens *et al.* proposed a mapping between ArchiMate and BMC by using BMO (Business Model Ontology) [33]. Chiprianov *et al.* proposed a model-driven approach to extend EA modeling languages with domain specificity, allowing a high degree of automation in the building of tools for the language extension [37]. Buschle *et al.* illustrated how to use a vulnerability scanner for data collection to automatically create EA models, especially covering infrastructure aspects [38]. Holm *et al.* proposed network scanning for automatic data collection and uses an existing software tool for generating EA models based on the IT infrastructure of enterprises [39]. Gómez *et al.* presented a method to avoid the confusion of linguistic conformance and ontological conformance between models and meta-models [41]. Bakhshandeh *et al.* presented a method to understand EAM (Enterprise Architecture Model) in ArchiMate by using OWL (Web Ontology Language) [46]. Hinkelmann *et al.* proposed a method to analyze information of the EA model described in ArchiMate by using EA ontology [49]. Grigoriev and Kudryavtsev presented a multi-representation approach for enterprise architecture model development and maintenance [50]. Farwick *et al.* presented an EAM (Enterprise Architecture Management) tool approach called Txture [55], that consists of a textual modeling environment and a web-application to provide enterprise-wide architecture visualizations for different stakeholder groups. Roth *et al.* proposed an approach that facilitates the analysis of arbitrary EA information models by non-technical stakeholders [58]. Bernaert *et al.* described a mobile software tool in support of the CHOOSE approach that should guide the CEO as an enterprise architect throughout the entire EA process and facilitate the implementation, management, and maintenance of the resulting EA model [59]. Antunes *et al.* proposed a method to analyze EA models described by ArchiMate as an ontology [64]. Naranjo *et al.* described an approach for EA Analysis, supported by a meta model-independent platform [68]. Desfray *et al.* described the TOGAF standard and its structure and presented EA modeling practices with examples of TOGAF [71]. Braun *et al.* proposed an extension method of the EA model by using meta-model and profile [74]. Caetano *et al.* presented an enterprise modeling method to integrate BMC, ArchiMate, and e3value by using semantic models [76]. Vålja *et al.* looked at the potential data sources, requirements that the data must meet and proposed a requirement-based EA modeling approach [79]. Cloutier *et al.* proposed a model-based system engineering approach that can be used to transform systemigrams to SysML models [81]. Azevedo *et al.* presented an ontology-based proposal for ArchiMate to analyze resources and capabilities in EA [82]. Cartero *et al.* proposed a compositional method to compose an integrated business model based on ArchiMate, e3value, and BMC (Business Model Canvas) by using meta-model [90]. They also introduced an end-user friendly wizard that lowers the barrier for the creation of EA visualizations. Uysal *et al.* proposed an EA re-engineering model and present its potential contributions [93]. Miranda *et al.* proposed an approach

that uses EA models as a basis to define use cases, named CEA (use Cases definition oriented by EA modeling) [100]. Acrețoaie *et al.* introduced the VMTL (Visual Model Transformation Language) addressing the skills and requirements of end-user modelers [101]. Rurua *et al.* presented a solution for representing variability in EA [111]. Oberhauser *et al.* contributed a VR (Virtual Reality) solution for visualizing EA models [112].

### C. REQUIREMENT ENGINEERING

Quartel *et al.* proposed an approach to integrate GORE (Goal Oriented Requirements Engineering) language with EA to specify, document, communicate and reason about goals and requirements [14]. Blobel introduced care paradigms, related requirements and an architectural approach for meeting the business objectives of the Personal health (pHealth) domain [30]. Engelsman *et al.* described a language that supports the modeling of business goals and requirements [32]. Horkoff *et al.* proposed an enterprise modeling approach to bridge the business-level understanding of the enterprise strategies with its representations in databases and data warehouses [40]. Quartel *et al.* described an architecture-based approach to IT valuation using EA and requirements modeling [44]. Teka *et al.* compared the expressive ability of TROPS and NFR (Non-Functional-Requirements) based on ARMOR [45]. Niu *et al.* proposed a framework consisting of an integrated set of activities to help tackle requirements analysis for enterprise systems [56]. ARMOR is a modeling language to describe the motivation model of EA by using goals and requirements. Boness *et al.* integrate the goal-oriented methods and EA models for requirements modeling [75]. The model-based approach can be used to rationalize EA by providing the reasoning behind the designs, in terms of selection criteria, design alternatives and more. Saddiqa *et al.* presented an EAORE (EA-Oriented Requirements Engineering) approach for open data usage as an educational resource [106].

### D. OPERATION MODEL

DePalo and Song presented an EA method that leverages existing EA models and business IT for implementing interoperability in healthcare organizations [36]. Vicente *et al.* presented a set of EA models representing the ITIL (IT Infrastructure Library) metamodel using the ArchiMate modeling language [48]. Silva *et al.* also visualized the operational processes of ITIL in ArchiMate business process models [73]. Nada *et al.* visualized ConOps (Concept of Operations) descriptions with ArchiMate [96]. Emmanuel *et al.* proposed the perspective of EEA (education enterprise architecture) business architecture to analyze the requirements of the business architecture design process [102].

### E. GOVERNANCE

Peristeras and Tarabanis proposed the GEA (Governance Enterprise Architecture) as a set of domain models that serve as a top-level enterprise architecture [5]. Niemann introduced a generalized and simplified structure for EA modeling



[8]. Buckl *et al.* showed an EAM (Enterprise Architecture Management) pattern-based approach [13] to complement TOGAF, to deliver guidance for performing EA management. Jacob *et al.* investigated and enhanced the suitability of the ArchiMate to support the modeling of business strategy concepts [34]. Närman *et al.* proposed an enterprise architecture analysis framework that can be used to assess application usage [42]. Ahlemann *et al.* discussed the value of EAM as a top management topic [43]. Monahov *et al.* outlined important design details and a prototypical implementation of a model-based query language for defining organization-specific KPIs [52]. Zhang *et al.* presented a collaborative IT governance model [57] which combines the IT governance tasks with key factors to build an evaluation index system for decision-making in architecture planning. Pourshahid *et al.* present a goal-oriented, business intelligence-supported methodology to capture stakeholders' goals, and model threats, and opportunities [66]. Veneberg *et al.* proposed a method [67] to combine operational data with enterprise architecture to better support decision-making. Hanschke *et al.* developed and evaluated the integration of agile software development techniques and EAM [72]. Luo *et al.* proposed an impact analysis method based on the business process evolution of the EA model described in ArchiMate [85]. Hinkelmann *et al.* proposed a method to ensure business-IT alignment based on EA models [86]. Gomes *et al.* presented a business continuity method by representing COBIT (Control Objectives for Information and related Technology) models in ArchiMate [92]. Hodijah proposed an e-government implementation embedded governance approach in providing trusted public services [94]. Aldea *et al.* explored how several of the most popular strategy techniques can be modeled with the help of concepts from the EA modeling language ArchiMate, in the context of the strategy process [97]. Lnenicka *et al.* proposed a government EA framework to process, publish and visualize data in different formats [109]. Wautelet proposed a model-driven IT governance process allowing to evaluate the alignment of business IT services to strategic objectives [110]. Bakelaar *et al.* propose a framework for visualization of EA changes [89].

#### F. SECURITY ANALYSIS

Bahl *et al.* introduce an Inference Graph model that can be used to localize the sources of performance problems in enterprise networks [9]. Sommestad *et al.* presented a security assessment framework using the Bayesian statistics-based extended influence diagrams to combine attack graphs with countermeasures into defense graphs [11]. Ekstedt and Sommestad presented an EA model-based approach for cybersecurity management [15]. Franke *et al.* showed how EA frameworks for dependency analysis can be extended into the realm of quantitative methods by use of the Fault Tree Analysis (FTA) and Bayesian Networks (BN) [16]. Zambon *et al.* presented the qualitative time dependency (QualTD) model and approach, to carry out the qualitative assessment of availability risks in IT architectures [27]. Grandy *et al.*

proposed a method using ArchiMate to model security analysis [47]. Gaaloul and Proper proposed an access control model-based approach [53] for managing organizational resources to ensure the security of EA. Sommestad *et al.* presented an analysis tool called the cybersecurity modeling language (CySeMoL) to support enterprise system security managers in security analysis [54]. Korman *et al.* evaluated the coverage of ArchiMate for twelve information security risk assessment approaches [65]. Abbass *et al.* developed an ISSRM (Information System Security Risk management) model described by the constructs of ArchiMate [87]. Biggs *et al.* described a SysML based approach to model the safety-related concerns of a system [88]. Mayer *et al.* visualized the security analysis of information systems by ArchiMate [91]. Pilipchuk *et al.* suggested an approach to derive access control requirements from business processes and test compliance of software designs by data flow analyses, to meet security and privacy requirements in organizations across business processes [99]. Mayer *et al.* visualized the security analysis of information systems by ArchiMate [108].

#### G. EVALUATION AND VALIDATION

Addicks and Appelrath presented a method allowing for using artifacts of enterprise architectures, to evaluate business applications [18]. Lagerström *et al.* presented instantiated architectural models for enterprise systems modifiability evaluation [20]. Becker *et al.* presented an approach that enables developers to accommodate the concerns of digital preservation in EA practice [26]. Närman *et al.* proposed a method for availability analysis based on FTA and ArchiMate [42]. Lakhrouit *et al.* presented the possibility of evaluating EA starting from the maturity model-based method of existing enterprise architecture [51]. Plataniotis reported on an empirical evaluation of the EA Anamnesis approach for architectural rationalization [60]. Florez *et al.* presented a model-based tool for analyzing EA models developed by ArchiMate [63]. Zee *et al.* formalized a set of integrity constraints, which allow guidance of decision capturing during model creation and provide means to perform consistency checks [69]. Lakhrouit *et al.* proposed a method for assessing agility achievement of different TO-BE scenarios and using different indicators based on the ArchiMate meta-models of the enterprise architecture layers [80]. Plataniotis *et al.* proposed a conceptual model for compliance checking support of enterprise architecture decisions [83]. Cohen *et al.* propose a method to formulate formal EA modeling rules [84]. Ahmadi *et al.* presented a set of novel evaluation criteria as well as a CLE (Cross-layer Evaluation) approach [105], which can consider all the EA layers from the BA (Business Architecture) layer to TA (Technology Architecture) layer. Borozanov *et al.* proposed a machine learning technique-based approach to evaluate the similarity of EA Models [107].

#### IV. PUBLICATION TRENDS

To grasp the current situation and unsolved challenges of EA visualization research, we analyze the selected papers and

discuss the publication years, publication regions, publication venues, scholar communities, research topics and issues, and technical characteristics based on the statistical data.

### A. PUBLICATION YEAR

In this section, we aim to answer the following research questions: *RQ2. What does the historical development trajectory of the study of EA visualization look like?*

Fig.3(a) presents the distribution of publications on EA visualization methodologies over time. From the selected studies, we can observe that relatively few studies were published until 2008. Before 2008, the average number of articles published on EA visualization was 1.3. Since 2009, this number has increased to 8.9. Starting in 2009, we can see a growth in the number of studies. Coincidentally, in early 2009, the Open Group published the ArchiMate 1.0 standard as a formal technical standard. ArchiMate is a common language for describing the construction and operation of business processes, organizational structures, information flows, IT systems, and technical infrastructure. From our SLR results, ArchiMate is currently the most widely used language and framework for EA visualization, which will be further analyzed in the following section. Among the selected studies, the earliest publication on EA modeling using ArchiMate is the basic concept of ArchiMate described by Jonkers *et al.* in 2004. Since then the number of research articles on EA development using ArchiMate has increased substantially. From a macro point of view, another possible reason is the impressive speed at which software systems and information technology spread in the first decade of the 21st century. People's life is becoming more and more inseparable from IT. The trend of business model innovation and IT technology innovation is unstoppable. The emphasis placed on EA by government and big companies has contributed to the popularity of EA visualization research.

However, the number of research studies on EA visualization fell off a cliff in 2014 and 2016. We have also analyzed the possible causes, but unfortunately did not find any clear reasons for explaining it. Nevertheless, given the steady rate of the number of publications (6.5 papers per year) for the past 4 years, we expect that the trend would continue in the near future. Moreover, it should be noted that the search was completed in 2019, therefore inevitably, the retrieved articles of 2019 are only part of the overall studies.

### B. PUBLICATION REGION AND VENUE

In this section, we aim to answer the following research questions: *RQ3. In which regions do the studies of EA visualization prevail? In which venues have the selected studies on EA visualization been published?*

As shown in Fig.3(b), the survey result shows that most of the authors are from the Netherlands (16.1%), followed by Germany (12.5%) and Sweden (10.7%). From the perspective of intercontinental distribution, most of the authors are from Europe, followed by North America and Asia. It should be pointed out that we have only counted the nationality of the

**TABLE 1. Venues hosting more than two selected studies.**

Venue	Number of Papers
IEEE International Enterprise Distributed Object Computing Conference (EDOC)	9
IEEE International Enterprise Distributed Object Computing Conference Workshops (EDOCW)	8
International Journal on Software and Systems Modeling (SoSyM)	7
IEEE Conference on Business Informatics (CBI)	6
ACM Symposium on Applied Computing (SAC)	5
International Conference on Advanced Information Systems Engineering (CAiSE)	4
Journal of Systems and Software (JSS)	4
Enterprise Information Systems (EIS)	3
International Journal of Medical Informatics (JMI)	3

first author of the selected papers, because if an article has ten coauthors, and they come from different countries or regions, it is meaningless to analyze all the publication regions.

Fig.3(c) shows that the majority of the selected papers are published by IEEE (45%), followed by Springer (23%), ACM (14%), and Elsevier (12%). To further analyze the publication venues of the selected papers, we classified the selected research studies to assess their distribution by the type of publication (i.e. journal article, conference paper, workshop paper or chapter of book). As shown in Fig.3(d), the most common publication type is conference (60 papers, 53.6%), followed by journal articles (32 papers, 28.6%) and workshop papers (15 papers, 13.4%). On the other hand, book chapters have only 5 occurrences (5 papers, 4.5%). Overall, conferences and journals are the most targeted publication venues, testifying that the EA visualization method has become a significant research theme.

Table 1 shows the publication venues that hosted selected more than 2 research studies. From the collected data, we can notice that while for journals, the selected studies mainly pertain to general software engineering or system modeling venues, for conferences and workshops there exists a prevalence of enterprise or business-related symposium. Besides, 3 selected contributions were published in a medical informatics related journal, which indicates that contributions about EA visualization are not only favored by venues related to software engineering or enterprise informatics but also interested in other practical application fields. Studies on EA modeling are spread across a large number of heterogeneous venues, with researchers paying attention to the specific EA visualization methodologies, as well as the benefits and effects of EA visualization.

### C. RESEARCH COMMUNITIES

In this section, we aim to answer the following research questions: *RQ4. Which institutions and researchers have made outstanding contributions in the field of EA visualization?*

This section analyzes the authors of the selected papers and their relationships to investigate the ecosystem of EA

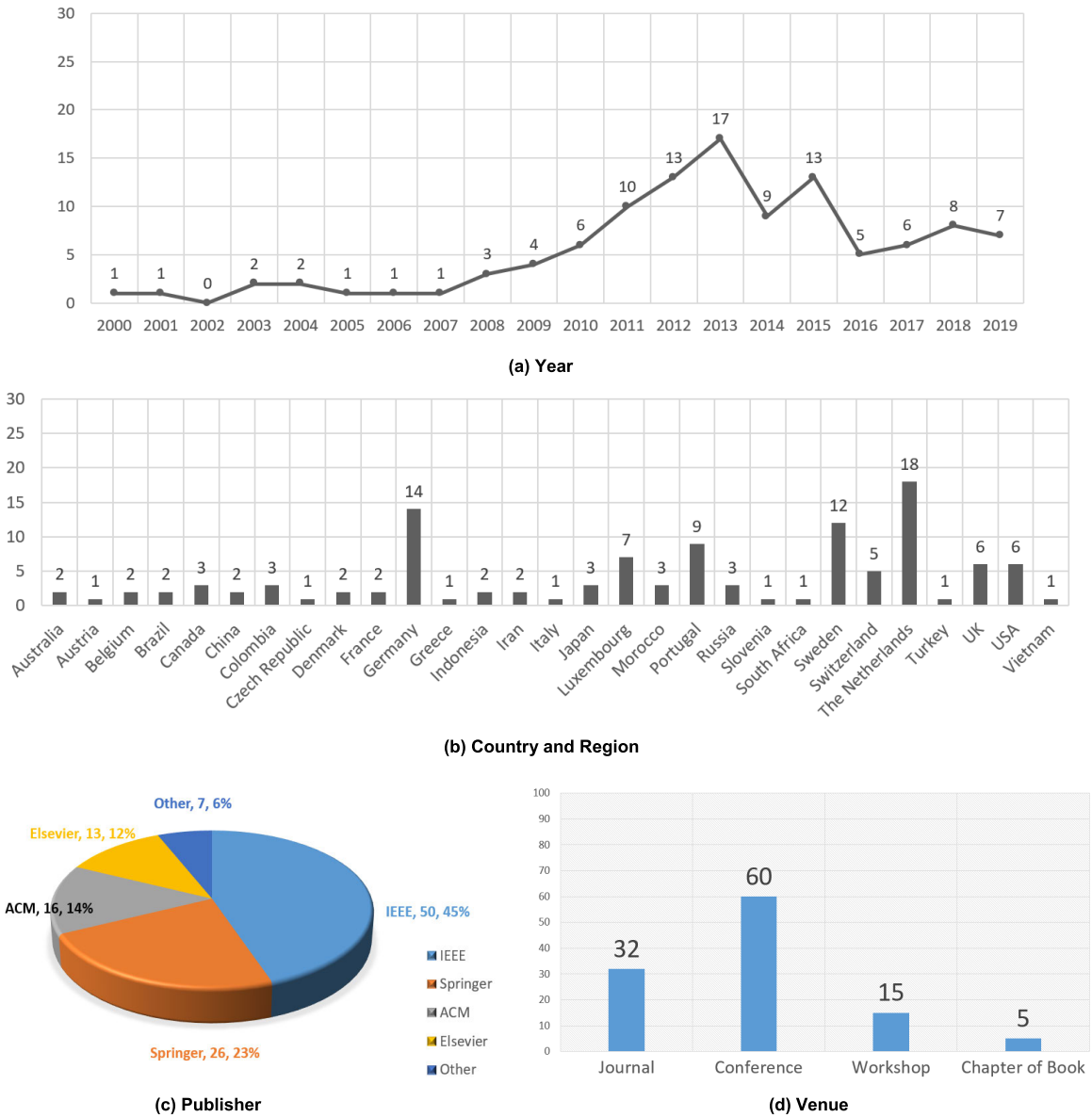


FIGURE 3. Overview of the number of included studies (a) per year, (b) by country or region, (c) by publisher, and (d) by venue.

visualization research. For the 112 selected studies, we identified the 415 authors of them. We used a free software called Gephi to plot the co-authorship network. It should be pointed out that we only focused on the condition of their joint research, did not discuss the relationship of citations. We first recorded and organized author information with a spreadsheet and imported it into the cartographic tool. Then we obtained the coauthored network diagram as shown in Fig.4, by applying the Fruchterman-Reingold (FR) force-directed network layout algorithm.

The nodes in the diagram represent the researchers, and a link exists as soon as one author worked with another author on the same publication. Although Gephi supports filtering subgraphs with fewer relationships, we had visualized the

entire network in order to grasp the overall situation of co-relationships.

Based on the coauthored network diagram, we identified that there are several small research networks for EA visualization methodologies, but not a single big one. We also found several relatively large networks, and the scholars who act as pivots in them. The scholars who got significant achievement in the study of EA visualization are H. Jonkers from Novay information technology research institute (the Netherlands), M. Iacob from the University of Twente (the Netherlands), A. Caetano from the University of Lisbon (Portugal), and M. Ekstedt from Royal Institute of Technology (Sweden). Based on our further analysis of the co-authors of the “pivot” scholars, we found that research collaboration between universities



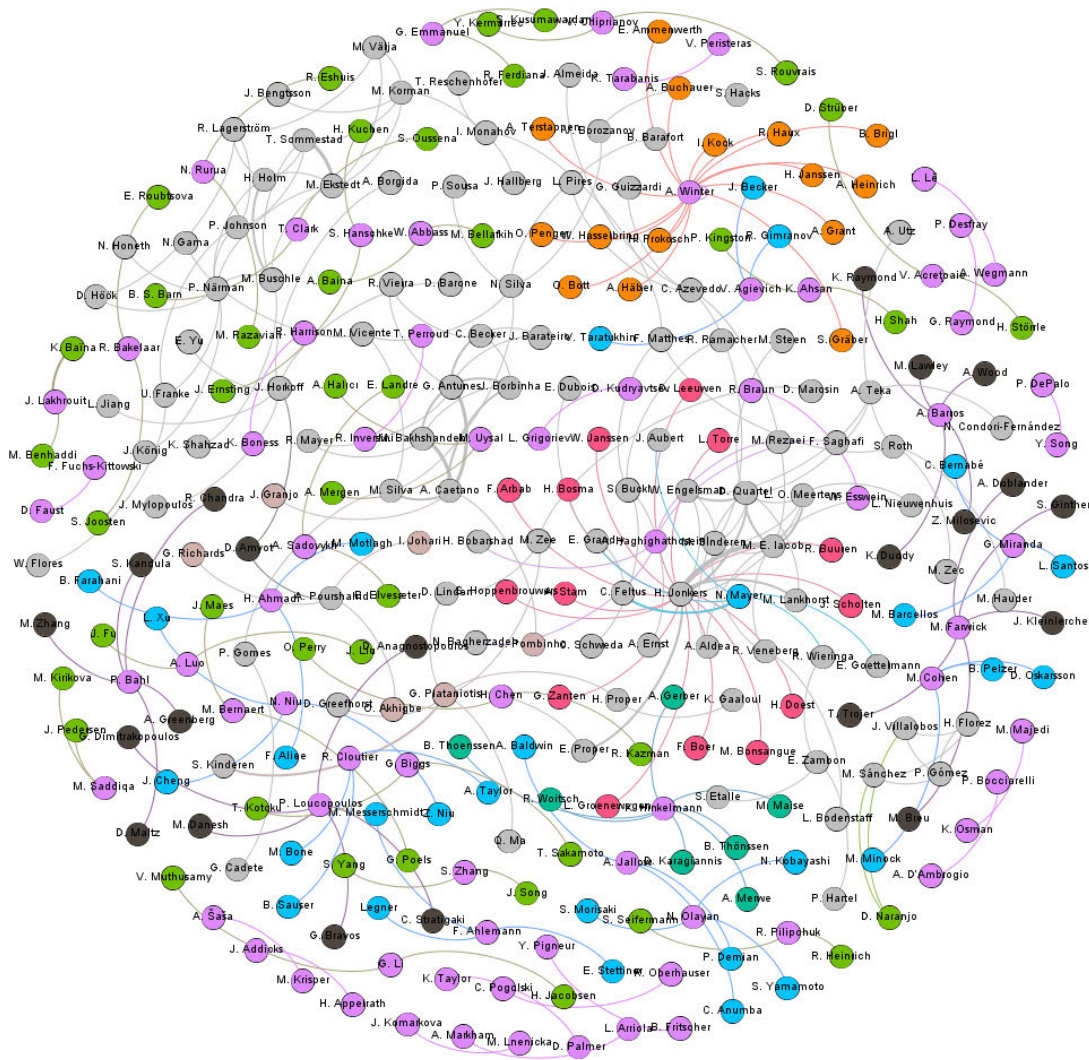


FIGURE 4. Connections between authors.

and research institutions in the same region occurs frequently. Moreover, scholars who are working in both university and company at the same time, and scholars who used to work for different organizations tend to create more collaborative research relations. In addition, it is worth noting that the scholars mentioned are all from Europe. It is reasonable to consider that the active efforts of these scholars have contributed to the prevalence of EA study in the region.

In Fig.4, there are 301 nodes and 279 edges, with a network diameter of 7, an average path length of 2.733, an average weighted degree of 2.013, a graph modularity of 0.928, and a graph density of 0.006. The indicators implied that on the whole the relationship between researchers tends to be fragmented and research activities lack cooperation. For scholars committed to EA, it is necessary to pursue further mutual understanding and research collaboration in the future, as well as consistency in research methods. In this regard, we suggest that researchers should expand their

knowledge accumulation and connections. Academic conferences, workshops or even forums on the Internet, may become good channels for this purpose.

**D. EA VISUALIZATION THEMES AND ISSUES**

To grasp the current trends and problems in EA visualization research, we analyzed the practical domains of the selected studies.

Table 2 shows the statistics based on the analysis result. EA modeling is the most addressed practice (25 papers), followed by governance (17 papers) and EA evaluation (11 papers). On the other hand, service-oriented architecture and business intelligence are the least addressed practices, there are only 2 papers in which the issues are discussed respectively. Furthermore, there are also selected studies on addressing multiple issues in one publication, such as S021, which discussed Service-oriented Architecture (SOA) and business-IT alignment simultaneously.



**TABLE 2. Primary research topics of the selected studies.**

Domain	Study ID
EA modeling	S001, S006, S007, S012, S022, S024, S033, S037, S038, S039, S046, S048, S055, S058, S059, S064, S068, S071, S074, S076, S079, S090, S104, S111, S112
Governance	S005, S008, S010, S013, S035, S042, S043, S052, S057, S061, S069, S083, S092, S094, S098, S109, S110,
EA evaluation	S016, S018, S020, S026, S051, S060, S063, S080, S084, S105, S107
Security analysis	S011, S015, S047, S053, S054, S065, S087, S091, S099, S108
Requirements engineering	S014, S032, S044, S045, S056, S075, S095, S096, S106
Business-IT alignment	S003, S021, S031, S049, S072, S078, S086
Business model	S019, S028, S029, S050, S066, S073, S102
Model-driven engineering	S023, S025, S041, S081, S100, S101
Health care	S002, S017, S030, S036, S103
Dependability assurance	S009, S027, S062, S077, S088
Business strategy	S034, S070, S082, S097
Change management	S085, S089, S093
Service oriented architecture	S010, S021
Business intelligence	S040, S067

cloud, which gives us an overview of the 50 most important keywords of the abstracts, and the frequency of their occurrence. It should be mentioned that we have filtered keywords like “paper”, “study”, “present”, “propose”, “provide”, “describe”, “existing” and other keywords that often appear in abstracts but have no real statistical value.

The most frequently occurred goal-related keywords are *model* (351 times), *process* (115 times), *requirements* (86 times), *management* (83 times), *services* (47 times), *assessment* (36 times), *alignment* (34 times), *decision* (32 times), and *security* (29 times). According to the frequency of the keywords, it can be concluded that business modeling, requirement engineering, IT management, EA evaluation, and business-IT alignment are the topics of interest. The most frequently used approach-related keywords are *language* (109 times), *framework* (73 times), *case* (49 times), and *integration* (63 times). It can be derived that the most frequently discussed technical aspects of EA visualization approaches are modeling language, EA framework, case study, and integration of EA models.

Moreover, keyword *ArchiMate* (62 times) also has been used frequently, and it is the only keyword of modeling languages that appears more than 30 times, indicating that ArchiMate is the dominant modeling language for EA visualization. The technical characteristics of the selected studies will be further elaborated in the next section.

**V. TECHNICAL CHARACTERISTICS**

In this section, we aim to answer the following research questions: *RQ5: What kind of techniques are used in the study of EA visualization, and what are their strengths and weakness?*

To study the technical characteristics of the selected literature, we first categorized the EA modeling operations performed by the authors in their research papers. It is necessary to explain the definition of the operations here for clarity. “Create” refers to EA architects creating a novel EA model or EA framework to express their propositions. “Extract” means EA architects acquiring the content they are interested in from the existing EA models. “Transform” is defined as EA architects converting an expression of EA concept into another expression according to certain principles and rules. “Integrate” means EA architects composing multiple EA models or EA approaches for a comprehensive one. “Restructure” means EA architects decomposing the existing EA model into specific ones by category, layer, or phase. “Evaluate” refers to EA architects assessing the quality of EA.

As we can see from Table 3, the most favored idea for the researchers was to “create” a new EA visualization method, with 39 papers. If the proposed method is effective and feasible, this kind of operation is the most valuable and admirable one. Next comes the “integration”, “evaluation” and “transformation”, with 19, 18, and 16 papers, respectively. The least used operation is “restructuring”, with only 7 papers. Our analysis suggests that this might have been due



**FIGURE 5. Tag cloud of keywords of the selected papers.**

In addition to the classification of the selected papers based on research domains, it is also meaningful to detect the keywords for the selected studies. With the visualization tool TagCrowd, we created a tag cloud based on all abstracts of the 112 selected papers, except for those publications that do not have abstracts, such as book chapters. Fig.5 shows this tag

**TABLE 3. Visualization operations in the selected studies.**

Operation	Study ID
Create	S002, S003, S004, S005, S013, S014, S016, S019, S025, S027, S030, S035, S037, S038, S040, S041, S043, S044, S045, S046, S048, S055, S059, S063, S068, S071, S073, S074, S077, S079, S084, S088, S092, S095, S098, S101, S103, S109, S112
Extract	S009, S026, S029, S034, S036, S039, S052, S078, S082, S089, S102, S106, S111
Transform	S017, S024, S028, S033, S047, S053, S061, S065, S070, S081, S087, S090, S091, S096, S097, S100
Integrate	S001, S006, S011, S012, S015, S021, S022, S031, S049, S050, S057, S066, S067, S072, S075, S076, S086, S099, S108
Restructure	S007, S008, S023, S032, S069, S093, S104
Evaluate	S010, S018, S020, S042, S051, S054, S056, S058, S060, S062, S064, S080, S083, S085, S094, S105, S107, S110

**TABLE 4. Mainly used modeling languages in the selected studies.**

EA model notations	Number of Papers
ArchiMate	41
UML	13
BMM (Business Motivation Model)	11
BPMN	5
CySeMoL	3
SoaML	3
SysML	2
GSN	2
CMMN	2
URN (User Requirement Notation)	2

to the difficulty of the decomposition process if there are no clear restructuring requirements and principles. In addition, it is difficult for EA architects to confirm the effectiveness of “restructuring”.

In the next step, we extracted and recorded EA visualization methods used or recommended by the researchers in these articles, including business models, EA modeling languages, and EA frameworks. Table 4 shows the EA modeling notations that have been used twice or more, in descending order of frequency.

EA models describe key elements of EA. The objective of the EA model is to capture the economic value, business process, system application, and IT infrastructure of new technology such as e-healthcare solutions. To compare the EA modeling languages, we define the key features for comparison based on the 5W1H interrogatives and the visual expressiveness levels are explained as follows.

·**Who** The interrogative “who” describes the active actors of the EA model. The active actors are the provider, partner, and customer. An example question to assess “who” feature is “*who are the key actors of the EA model*”. The “who” feature of the e-healthcare solution is as follows.

Provider: E-healthcare service provider

Partner: Doctor, Nurse, Medical receptionist

Customer: Patient

·**Why** The interrogative “why” describes the motivation elements of the EA model. The motivation elements are the concern, goal, and value chain. The concern shows the reason to achieve the stated business goal. The goal is the ideal condition that the enterprise should reach. The value chain describes the reason why the business succeeds. An example question to assess “why” feature is “*Why the information system is needed*”. The “why” feature of the e-healthcare solution is as follows.

Concern: Health, safety, efficiency

Goal: Safe, convenient and worry-free healthcare service

Value chain: Value exchange flow in key activities

·**Where** The interrogative “where” describes the context of the EA model. The context elements are the problem, cause, and channel. The problem can be resolved by analyzing the cause. The channel describes the means to provide customers with the product or service. An example question to assess “where” feature is “*In what context is the EA model developed*”. The “where” feature of the e-healthcare solution is as follows.

Problem: Timely information to support the treatment of patients is needed.

Cause: Digitization of medical information is unrealized

Channel: Service pack

·**What** The interrogative “what” describes the passive elements of the EA model. The active actors are the asset, product, and information. An example question to assess “what” feature is “*what is contained in the EA model*”. The “what” feature of the e-healthcare solution is as follows.

Asset: Operation center, database, server

Product: Smart device, e-healthcare service

Information: Medical record, personal information

·**When** The interrogative “when” describes the situation of the EA model. The situations are the event, trigger, and flow. An example question to assess “when” feature is “*when the EA model is used*”. The “when” feature of the e-healthcare solution is as follows.

Event: User information generation

Trigger: User registration

Flow: Medical record create / read / update / delete

·**How** The interrogative “who” describes the behavior of the EA model. The behavior elements are the business process, customer relationship, and cost structure. An example question to assess “how” feature is “*how does the EA model work*”. The “how” feature of the e-healthcare solution is as follows.

Business process: Treatment

Customer relationship: Employee-customer interaction

Cost structure: System development and maintenance cost, operation center expenses

·**Visual expressiveness levels of EA modeling languages**

4: The feature element is symbolized by a corresponding visual icon.

3: The feature is visualized by using a visual node.

2: The feature is identified by a special label.

TABLE 5. Key features of EA modeling languages.

Interrogatives	Who	Why	Where	What	When	How
Key Features	#1 Provider	#1 Concern	#1 Problem	#1 Asset	#1 Event	#1 Business process
	#2 Partner	#2 Goal	#2 Cause	#2 Product	#2 Trigger	#2 Customer relationship
	#3 Customer	#3 Value chain	#3 Channel	#3 Information	#3 Flow	#3 Cost structure

TABLE 6. Comparison of EA modeling languages (⊕ = applicable, – = not applicable).

Interrogatives	Who			Why			Where			What			When			How		
	#1	#2	#3	#1	#2	#3	#1	#2	#3	#1	#2	#3	#1	#2	#3	#1	#2	#3
Proportion	Visual expressiveness level																	
ArchiMate	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕
	4	4	4	4	3	3	4	4	4	4	4	4	4	4	4	4	4	3
	12 / 12			10 / 12			12 / 12			12 / 12			12 / 12			11 / 12		
UML	⊕	⊕	⊕	–	–	–	–	–	–	⊕	–	⊕	⊕	⊕	⊕	⊕	–	–
	4	4	4	0	0	0	0	0	0	3	0	3	3	4	4	3	0	0
	12 / 12			0 / 12			0 / 12			6 / 12			11 / 12			3 / 12		
BMM	–	–	–	⊕	⊕	⊕	⊕	⊕	–	⊕	⊕	⊕	–	–	–	–	⊕	⊕
	0	0	0	2	2	2	2	2	0	2	2	2	0	0	0	0	2	2
	0 / 12			6 / 12			4 / 12			6 / 12			0 / 12			4 / 12		
BPMN	⊕	⊕	⊕	–	–	–	–	–	–	–	–	⊕	⊕	⊕	⊕	⊕	–	–
	4	4	4	0	0	0	0	0	0	0	0	4	4	4	4	3	0	0
	4 / 12			0 / 12			0 / 12			4 / 12			12 / 12			3 / 12		
CySeMoL	⊕	⊕	⊕	⊕	⊕	–	⊕	⊕	–	⊕	⊕	⊕	⊕	⊕	⊕	⊕	–	–
	2	2	2	1	1	0	1	1	0	2	2	2	2	2	2	2	0	0
	6 / 12			2 / 12			2 / 12			6 / 12			6 / 12			2 / 12		
SoaML	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕
	4	4	4	1	1	1	1	1	4	4	4	4	4	4	4	4	4	1
	12 / 12			3 / 12			6 / 12			12 / 12			12 / 12			9 / 12		
SysML	⊕	⊕	⊕	⊕	⊕	–	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	–	–
	4	4	4	1	4	0	1	1	1	4	4	4	4	4	4	3	0	0
	12 / 12			5 / 12			3 / 12			12 / 12			12 / 12			3 / 12		
GSN	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	–	–	⊕	⊕	⊕	⊕	⊕	⊕
	1	1	1	1	4	1	1	1	1	1	0	0	1	1	1	1	1	1
	3 / 12			6 / 12			3 / 12			1 / 12			3 / 12			3 / 12		
CMMN	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	⊕	–	⊕	⊕	⊕	⊕	⊕	⊕	⊕
	4	4	4	1	1	1	1	1	1	1	0	3	4	1	1	4	1	1
	12 / 12			3 / 12			3 / 12			4 / 12			6 / 12			6 / 12		
URN	⊕	⊕	⊕	⊕	⊕	⊕	–	–	–	⊕	–	–	⊕	⊕	⊕	⊕	⊕	⊕
	3	3	3	1	3	1	0	0	0	3	0	0	1	1	1	1	1	1
	9 / 12			5 / 12			0 / 12			3 / 12			3 / 12			3 / 12		

1: The feature is indirectly described.

0: There is no means to represent the feature element.

Among the EA visualization notations, *ArchiMate*, *UML*, *SoaML*, and *SysML* belong to architecture-based modeling notations, *BMM*, *CySeMoL*, *GSN*, *CMMN*, and *URN* are goal-based modeling notations, and *BPMN* is a process-based modeling notation. The visual expressiveness levels of *ArchiMate*, *UML*, *BMM*, *BPMN*, *CySeMoL*, *SoaML*, *SysML*, *GSN*, *CMMN*, and *URN* are evaluated as follows.

*ArchiMate* provides the visual icons for business actor, goal, problem, cause, channel, asset, product, information, event, trigger, flow, business process, and customer

relationship. It also provides visual nodes for the concerns, cost structure, and value chain. Thus, the quantitative visual expressiveness levels of *ArchiMate* are {12, 10, 12, 12, 12, 11} (see Table 6).

*UML* provides the visual icons for business actor, trigger, and flow. It also provides visual nodes for the asset, information, event, and process. However, *UML* does not provide means for representing the concern, goal, value chain, problem, cause, channel, product, customer relationship, and cost structure. Thus, the quantitative visual expressiveness levels of *UML* are {12, 0, 0, 6, 11, 3} (see Table 6).

TABLE 7. Mainly used EA frameworks in the selected studies.

EA Frameworks	Number of Papers
TOGAF	63
DoDAF	18
BSC (Balanced Scorecard)	10
BMC (Business Model Canvas)	7
FEAF	6
MODAF	6
e3value	2
CIMOSA	2

Similarly, the other visualization notations in Table 6 can be quantitatively evaluated. Let A and B be two visualization notations. We define  $A > B$  if the sum of the key features of A is greater than those of B. Therefore, the following equation can be derived from table 6.

$$\text{ArchiMate} > \text{SoaML} > \text{SysML} > \text{CMMN} > \text{UML} > \text{BPMN} \\ = \text{URN} > \text{CySeMoL} > \text{BMM} > \text{GSN}.$$

The result illustrates that ArchiMate is the most powerful EA modeling notation in the visual expressiveness level comparison. Meanwhile, ArchiMate is the EA modeling language most frequently used by scholars as shown in Table 4, which arouses our attention and interest for it.

ArchiMate was originally designed in Netherland, it is now standardized by The Open Group since 2009. The latest version 3.1 of ArchiMate has been published in 2019. It provides a clear way to express the construction and behavior of business processes, organizational structures, information flows, software systems, and technology infrastructure based on the concepts of the IEEE 1471 standard. ArchiMate offers an integrated architectural approach that describes and visualizes different architecture domains and their underlying relations and dependencies. ArchiMate distinguishes itself from other modeling languages such as UML and SysML by its enterprise modeling scope. ArchiMate has the advantage of a wider scope, not only for software or system modeling but also for EA modeling. Specifically, it can be used to visualize business processes (this aspect covers the scope of BPMN), and conduct enterprise strategic planning.

Table 7 shows the EA visualization frameworks that have been recommended in the selected papers. To concretely evaluate the EA frameworks, we have developed a framework for comparison as shown in Table 8. Subjective evaluation items such as understandability, complexity, and usability are omitted to ensure the objectivity of comparison, because evaluation results may conflict when the items are evaluated by different analysts. We identified thirty-six feature elements using six dimensions and six interrogatives. The feature categories are layer, model, method, governance, capability, and extensibility.

Key features of EA Framework  $X$  are defined as follows.

Feature ( $X$ ) = {

Layer => (x is a layer feature of  $X$ ),

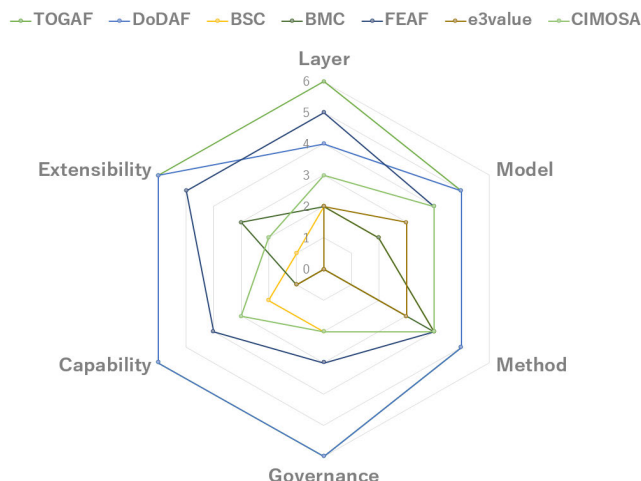


FIGURE 6. Comparison of EA frameworks.

- Model => (x is a model feature of  $X$ ),
- Method => (x is a method feature of  $X$ ),
- Governance => (x is a governance feature of  $X$ ),
- Capability => (x is a capability feature of  $X$ ),
- Extensibility => (x is an extensibility feature of  $X$ ).

For example, the key features of TOGAF can be represented as Feature (TOGAF) = {Layer => (Hierarchy, BA/DA/AA/TA, Transition, Strategy, Physical, Stakeholder), Model => (Diagram, Repository, Meta-model, Language, Reference model), Method => (Process, BLA/TGA, Iteration, Tailoring, Reuse), Governance => (EAP, Governance meeting, Compliance, Risk management, Governance log, EA board), Capability => (Maturity, Planning, Dimension, Skill framework, Increment, EA architect), Extensibility => (Method evolution, Model evolution, Evolution)}. Similarly, the other EA Frameworks in Table 7 can be evaluated.

Table 9 shows the assessment results, and we use a radar chart (see Fig.6) to represent the data. The result shows that TOGAF is the most powerful EA framework, followed by DoDAF and FEAF.

## VI. QUALITY EVALUATION

In this section, we aim to answer the following research questions: *RQ6: How are the qualities of the selected studies?*

To provide an indication of the quality of academic research on EA visualization, we quantitatively evaluate the quality of each selected research study in this section. We defined a set of criteria for evaluating the quality of research studies in an objective and unbiased manner. Each quality assessment question will be answered by assigning a numerical value. The grading standard is defined as: Yes = 1, To some extent = 0.5, No = 0.

It should be noted that the quality criteria focus more on the quality of the paper description (e.g., clarity, objectivity, completeness, essay structure) rather than the quality of the research itself. That is to say, groundbreaking or high-level research does not necessarily get high scores under



TABLE 8. Key features of EA frameworks.

Dimensions	Who	Why	Where	What	When	How
Layer	Stakeholder	Strategy	Physical	Hierarchy	Transition	BA/DA/AA/TA
Model	EA model architect	Meta-model	Repository	Diagram	Reference model	Language
Method	EA method architect	Reuse	Tailoring	Process	Iteration	BLA/TGA
Governance	EA board	Compliance	Governance log	EAP	Risk management	Governance meeting
Capability	EA architect	Skill framework	Capability dimension	Maturity	Capability-based Planning	Increment
Extensibility	Forum team	Continuum	Forum standard	Model Evolution	Forum establishment	Method Evolution

TABLE 9. Comparison of EA frameworks.

Dimensions	TOGAF	DoDAF	BSC	BMC	FEAF	e3value	CIMOSA
Layer	6	4	2	2	5	2	3
Model	5	5	2	2	4	3	4
Method	5	5	4	4	4	3	4
Governance	6	6	2	0	3	0	2
Capability	6	6	2	1	4	1	3
Extensibility	6	6	1	3	5	0	2

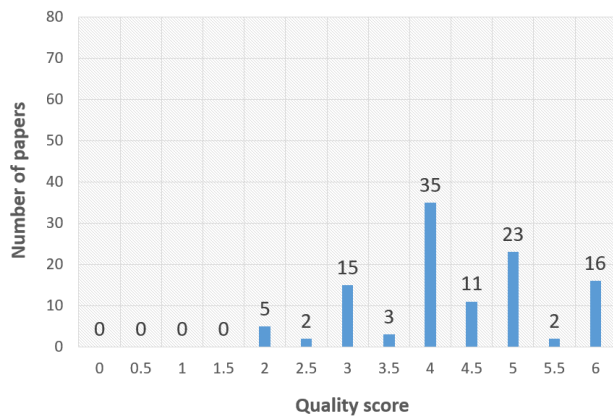


FIGURE 7. Frequency of total quality score.

this evaluation standard. The quality assessment criteria we used for the quality assessment of the selected studies are as follows.

**Quality assessment criteria**

[QC1] Is there a clear description of the context in which the research was conducted?

[QC2] Is there a statement of the objectives of the research?

[QC3] Is there a specific procedure for applying the proposed EA visualization method?

[QC4] Is the effectiveness of the proposed EA visualization method confirmed?

[QC5] Is there a critical appraisal of the research?

[QC6] Is there a discussion on the research direction for the future work of the research?

Fig.7 describes the frequency of the total quality scores for the selected 112 papers. It can be clearly seen that there are 35 studies with a score of 4. Secondly, there are 23 studies with a score of 5. The average score of the selected papers was 4.30. The highest score was 6, totaling 16 papers. The lowest score was 2, with only 5 papers. The statistical result tells us

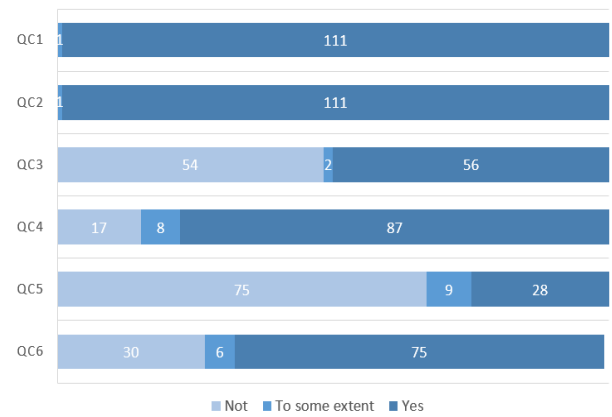


FIGURE 8. Quality assessment criteria evaluation results.

that most of the studies are of good quality. Table 10 presents the research studies with a quality score higher than 5.0.

On the other hand, we also analyzed the evaluation results of each quality assessment criterion. As shown in Fig.8, we found that the majority of the selected papers did well in the introduction of research background, purposes of the study, evaluation of the effectiveness of new findings, and future directions. However, in terms of EA visualization step description and discussion of the limitations of the proposed method, many studies still have room for improvement.

The quality and value of the papers can also be evaluated to a certain extent by their citations. Therefore, we extracted the citations of the selected studies.

Table 11 presents the citations of the 112 selected articles. The 3 most cited studies are S009, conducted by Bahl et al. in 2007, S006, conducted by Lankhorst in 2004 and S043, conducted by Ahlemann et al. in 2012, with a citation of 124, 101 and 70, respectively. The average citation of the 112 selected papers is 14.0, and 33.9% of the papers have been cited more than 10 times. There are also 21 papers

**TABLE 10. Research studies with quality score higher than 5.**

Paper ID	Year	Title	Score
S002	2001	Strategic information management plans: the basis for systematic information management in hospitals	6
S009	2007	Towards highly reliable enterprise network services via inference of multi-level dependencies	6
S020	2010	Architecture analysis of enterprise systems modifiability – Models, analysis, and validation	6
S033	2012	Mapping the business model canvas to ArchiMate	6
S042	2012	Using enterprise architecture and technology adoption models to predict application usage	6
S066	2014	A goal-oriented, business intelligence-supported decision-making methodology	5.5
S079	2015	A Requirements Based Approach for Automating Enterprise IT Architecture Modeling Using Multiple Data Sources	6
S081	2015	Transitioning Systems Thinking to Model-Based Systems Engineering: Systemigrams to SysML Models	6
S082	2015	Modeling resources and capabilities in enterprise architecture: A well-founded ontology-based proposal for ArchiMate	6
S095	2017	An enterprise architecture framework for electronic requirements information management	6
S097	2018	From Business Strategy to Enterprise Architecture and Back	6
S099	2018	Aligning Business Process Access Control Policies with Enterprise Architecture	6
S101	2018	VMTL: a language for end-user model transformation	6
S103	2018	Hospital enterprise Architecture Framework (Study of Iranian University Hospital Organization)	5.5
S108	2019	An integrated conceptual model for information system security risk management supported by enterprise architecture management	6
S109	2019	Developing a government enterprise architecture framework to support the requirements of big and open linked data with the use of cloud computing	6
S110	2019	A model-driven IT governance process based on the strategic impact evaluation of services	6
S111	2019	Representing Variability in Enterprise Architecture	6

with a citation of 0. However, we found that most (18 of 21) of the data appear in the rightmost column of Table 11. As Table 11 is arranged in chronological order, it means that most of the papers cited 0 times are published recently (2016 ~ 2019). As we all know, the citations of academic articles generally increase over time, the papers are expected to gain more citations in the future.

Since the number of citations does not depend entirely on the quality and value of the research articles, it should be pointed out that the data shown in Table 11 only gives a statistic of citation rates, and are not meant for comparison among the selected papers.

## VII. A GENERAL EA VISUALIZATION APPROACH

### A. OPEN ISSUES AND GAPS OF CURRENT RESEARCH ON EA VISUALIZATION

Among the selected papers, 37 (33.0%) studies have discussed their limitations and unresolved challenges, and 82 (73.2%) studies have clarified the directions for future work. Table 12 describes the limitations and unsolved challenges discussed in the selected papers. The most mentioned concern was the scope of the proposed EA visualization methods, with 10 studies. The authors of the 10 papers considered that they should try for extending the scope of their proposed EA visualization method. For example, the validity section of S111 admitted that the applicability of the proposed solution for representing variability in EA to other domains remains unclear. Furthermore, 8 papers claimed that more empirical evaluation should be conducted to verify the effectiveness of the proposed methods. 7 papers discussed that the proposed methods need to be improved in some aspects to improve the completeness of the proposed EA visualization methods.

Table 12 indicates that it is necessary to develop a general method for EA visualization with a wider application scope

**TABLE 11. Citation of the selected papers.**

ID	Cited	ID	Cited	ID	Cited	ID	Cited
S001	5	S029	26	S057	0	S085	1
S002	48	S030	20	S058	7	S086	49
S003	30	S031	21	S059	4	S087	6
S004	1	S032	65	S060	3	S088	16
S005	20	S033	2	S061	5	S089	0
S006	101	S034	35	S062	18	S090	7
S007	2	S035	5	S063	6	S091	3
S008	1	S036	1	S064	0	S092	2
S009	124	S037	2	S065	5	S093	0
S010	0	S038	39	S066	5	S094	0
S011	7	S039	50	S067	7	S095	10
S012	1	S040	66	S068	4	S096	0
S013	21	S041	2	S069	3	S097	0
S014	50	S042	16	S070	9	S098	0
S015	15	S043	70	S071	45	S099	0
S016	4	S044	45	S072	3	S100	0
S017	4	S045	4	S073	0	S101	3
S018	2	S046	6	S074	3	S102	0
S019	40	S047	20	S075	2	S103	6
S020	41	S048	15	S076	3	S104	0
S021	31	S049	6	S077	4	S105	0
S022	6	S050	1	S078	11	S106	0
S023	6	S051	2	S079	5	S107	0
S024	17	S052	7	S080	2	S108	0
S025	4	S053	4	S081	15	S109	2
S026	16	S054	53	S082	47	S110	0
S027	18	S055	3	S083	6	S111	0
S028	15	S056	26	S084	1	S112	0

that addresses different requirements. Because visualization methodology is the means for EA description after all, EA development is the real objectives for most EA architects.

**TABLE 12. Limitations and unsolved challenges mentioned twice or more in the selected studies.**

Concern and unsolved challenges	Study ID
Scope ( <i>of the proposed method should be extended</i> )	S004, S009, S031, S054, S065, S074, S079, S103, S104, S111
Empirical evaluation ( <i>is needed</i> )	S002, S031, S035, S077, S093, S097, S098, S101
Completeness ( <i>of the proposed method needs to be improved</i> )	S009, S031, S035, S074, S079, S097, S107
Threats to the validation ( <i>should be addressed</i> )	S020, S042, S060, S095, S108
Semantics ( <i>of the proposed method should be clearly defined</i> )	S033, S055, S081, S090, S096
Complexity and Learnability ( <i>of the proposed method need to be improved</i> )	S003, S055
Effectiveness ( <i>of the proposed method should be further confirmed</i> )	S062, S099
Constraints ( <i>for applying the proposed method need to be alleviated</i> )	S107, S110
Cost ( <i>for applying the proposed method need to be alleviated</i> )	S069, S109

If there is a comprehensive methodology or process for EA modeling, EA architects can focus on the EA development itself without spending too much energy on EA visualization approaches. However, unfortunately we did not find such a powerful EA visualization method in the selected 112 studies. In the next part of this paper, we will propose a comprehensive EA visualization method. The inspiration for the method comes from the EA visualization operations in the selected paper in Table 4. We aim to integrate these visualization operations to propose a new EA visualization method in the next section.

## B. OVERVIEW OF THE PROPOSED APPROACH

In this section, we propose a general approach to conduct EA visualization. First, we give an overview of the approach, and then we give detailed steps for application. An overview of the proposed general EA visualization approach is shown in Fig.9. The model is composed of a 6-phase process. The phases are 1) create, 2) extract, 3) translate, 4) integrate, 5) restructure, and 6) evaluate.

### 1) CREATE A VISUAL DIAGRAM FOR TARGET EA

Create the visual diagram for the EA object based on the enterprise scenario of the target system. The elements of objects and their relationships can be defined and visualized by using a specific common model. The diagram can also be decomposed into node elements and their interrelationships.

### 2) EXTRACT OBJECTS AND RELATIONS FROM THE DIAGRAM

Convert the visual diagram developed in the previous step into objects and relations by analyzing the diagram.

### 3) TRANSLATE THE DIAGRAM INTO OTHER DIAGRAMS

Transform the objects and relations extracted from the diagram into concepts of other EA visualization method for

a new diagram based on mapping rules, so that the two diagrams have the same meaning.

### 4) INTEGRATE DIAGRAMS INTO ONE DIAGRAM

Integrate different EA concepts into a composite EA concept set by merging the same concepts and retaining the different concepts.

### 5) RESTRUCTURE THE DIAGRAM INTO COMPONENT DIAGRAMS

In the integrated model developed in the previous step, the elements of different layers are mixed together, resulting in a high degree of aggregation of the EA model. For the purpose of improving the readability and maintainability of the EA model, in this step, we restructure the integrated diagram into component diagrams for different layers (Business Layer, Application Layer and Technology Layer).

### 6) EVALUATE DIAGRAMS

Assess the capability of the model according to rating criteria.

## C. DETAILED STEPS OF THE PROPOSED EA VISUALIZATION APPROACH

The proposed method consists of 6 phases. it should be noted that each phase can also be carried out separately to meet specific needs. EA models can be developed by performing the following steps in sequence.

[Phase 1] Create

(Step1-1) Analyze the enterprise scenario  $S$  of target EA  $X$

(Step1-2) Develop a specific common model  $A$  for  $X$

[End of Phase 1]

[Phase 2] Extract

(Step2-1) Classify the contents of  $A$  according to objects and relationships.

[End of Phase 2]

[Phase 3] Translate

(Step3-1) Develop a mappings  $M$  to translate the objects and relationships of  $A$  to entities of EA modeling language  $L$ .

(Step3-2) Replace objects and relationships of  $A$  into entities of  $L$  by using  $M$ .

[End of Phase 3]

[Phase 4] Integrate (if necessary)

(Step4-1) This step is necessary if multiple meta-models are developed in *phase 1*. The meta-models (e.g.,  $A$  and  $B$ ) can be integrated if the intersection of  $A$  and  $B$  is not empty, the meta-models should be integrated.

(Step4-2) Merge the same entities and retain the different entities of  $L$ .

(Step4-3) Create a new EA model  $IM$  for  $X$  using the integrated entities of  $L$ .

[End of Phase 4]

[Phase 5] Restructure (if necessary)

(Step5-1) This step is necessary if the entities of  $L$  belong to different levels. The integrated entities should be modeled into different layers.

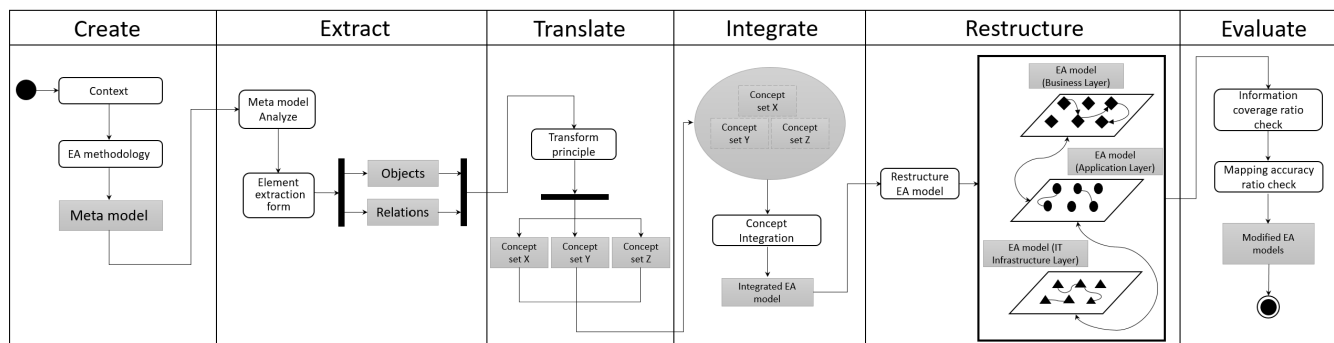


FIGURE 9. An overview of the proposed EA visualization approach.

(Step5-2) Restructure **IM** into component EA models.

[End of Phase 5]

[Phase 6] Evaluate

(Step6-1) Assess the capability of the developed EA models according to rating criteria such as information cover rate.

[End of Phase 6]

### VIII. RELATED WORK

Researchers are pushing back the frontiers and opening doors to reveal why EA happens and how it works. So far, many pieces of research have studied the current situation and problems of EA research by means of literature review.

Niemi described a study that aims to explain the benefits of EA by a comprehensive literature review and a focus group interview of practitioners in 2006 [113]. As a result, a categorization of the EA benefits has been composed and analyzed.

Jørgensen summarized experiences from years of practice, research and development in the field of enterprise modeling, and points out directions for future development in 2009 [114].

In 2010, Franke *et al.* investigated the actual application of EA, by giving a broad overview of the usage of enterprise architecture in Swedish, German, Austrian and Swiss companies [115].

In 2014, Heyl presented a systematic review on process-oriented management literature to analyze the literature in the areas of Strategic Management & Business Models (SMBM), Business Process Management (BPM), Enterprise Architecture (EA), Total Quality Management (TQM), and concluded with proposals for future research work [115]. Kakarontzas *et al.* identified important quality and functional requirements for smart cities by conducting a survey on the EA framework for smart cities [116].

In 2015, Rouhani *et al.* conducted an SLR on EAIMs, in which they assessed the current problems in EAIMs and discussed the tools used by EAIMs [117]. Rasti *et al.* analyzed the published EA related research papers from 2005 to 2014, to examine the status and progress of EA research, and to propose areas for future studies within the area [118].

In 2016, Santana *et al.* performed a literature review and create a state-of-the-art description of EA network analysis, applied measures and its main achievements [119].

In 2017, Gorkhali and Xu conducted an extensive review on 177 journal publications in the field of EA. In their paper, they have presented scholars and practitioners with a detailed overview of the available research in the field of EA [120]. Dang and Pekkola conducted an SLR to identify the major research topics and methods in studies focusing on public sector EA [121]. Their study showed that it seems that public sector EA is scattered, and there is no strong, single research stream. Moreover, there is consequently a need for more research in general, and targeted research in some specific segments. Egeten *et al.* conducted an SLR to analyze the components of an enterprise architecture framework to support business processes with the technology of an e-commerce system [122]. To propose a method to carry out the quality assessment for enterprise architecture models, Timm *et al.* suggested the EAQF (Enterprise Architecture Model Quality Framework) by analyzing related work by dint of a literature review in a design science research setting and applied it to a real-world scenario [123].

In 2018, Zhang *et al.* answered their research questions through the 5W1H analysis by carrying out a survey of BITA (business-IT alignment) research using EA [124]. These research questions aim to acquire a thorough understanding of BITA from the perspective of EA, to discover weak points in the status quo, and to identify future research directions. Nardello *et al.* developed a topic model to help structure the EA research field and enable EA to evolve coherently [125]. In this study, the authors presented about 360 identified topics in EA literature and their evolution over time. Yamamoto proposed an EA visualization method by conducting a survey on 49 publications relevant to EA [126], which is the prior research of this study. However, the number of reviewed literatures is relatively small, and the steps of the proposed method are not clearly defined.

In 2019, Gong and Janssen conducted an SLR on EA methodologies in which they revealed that EA is a broad concept that is interpreted and used in many different ways, and discussed the value of EA [127]. Zhou *et al.* integrated



several typical EA modeling methods and proposed a visual innovation methodology based on the ArchiMate framework. Nevertheless, the scope and effectiveness of the method were not fully evaluated, and there were problems in the analysis of experimental data [128]. Bork *et al.* conducted a survey on modeling language specification techniques [129]. However, the study focused on modeling specification rather than modeling methodology.

In summary, although there are a lot of existing research papers reporting literature reviews on EA to date, none of them has reviewed the existing research work about EA visualization systematically and adequately. Therefore, it is necessary to make a systematic review of EA visualization methods to systematically classify the EA visualization methodologies and summarize a general EA visualization approach to meet the requirements of different purposes.

## IX. DISCUSSION

We discuss the study presented in this paper from three aspects: the effectiveness, limitations, and contributions of the study and the proposed EA visualization approach.

### A. EFFECTIVENESS

In this section, we verify the effectiveness of our study in this paper by answering the research questions put forward by using the 5W1H method in Sect. II.

**RQ1.** What are the main purposes and motivations of EA visualization (why)?

We selected and analyzed 112 studies related to EA visualization, then categorized the selected research papers according to the objectives of EA visualization, and briefly described their characteristics and contributions in Sect. III.

On the whole, besides EA modeling, there are more researches on IT governance and system security analysis, and fewer researches on operation model, evaluation and verification. The reason may be that EA is more and more widely used in the information age, and the requirements for system security analysis are inevitably increasing. The study of the operation model requires researchers to grasp the whole situation of EA. For instance, in paper S48, the authors put forward a set of visual EA models to provide the overall process specification of business service, operation and management. It is not easy for EA architect to estimate or consider the cost of EA evaluation and verification. For example, the verification results acquired from the simulation environment are not convincing enough, and it is difficult for us to put an EA model into a real enterprise for verification. Moreover, the evaluation of EA presumably can only be carried out qualitatively.

**RQ2.** What does the historical development trajectory of the study of EA visualization look like (when)?

In Sect. IV(A), we analyzed the publishing trends of EA visualization research, including year of publication and the number of papers. We analyzed the relationship between the number of selected papers and EA modeling specification and predicted the development trend of EA visualization research

in the future. However, the analysis is not in-depth enough to discuss the development of landmark papers. To improve this disadvantage is one of our future research directions.

**RQ3.** In which regions do the studies of EA visualization prevail? In which venues have the selected studies on EA visualization been published (where)?

The survey results in Sect. IV(B) showed that most of the authors are from the Netherlands, Germany, and Sweden. From the perspective of intercontinental distribution, most of the authors are from Europe, followed by North America and Asia.

The majority of the selected papers are published by IEEE, Springer, ACM, and Elsevier. And the most common publication type is conference, followed by journal articles, workshop papers, and book chapters. Overall, conferences and journals are the most targeted publication venues, testifying that the EA visualization method has become a significant research theme in the academic community.

**RQ4.** Which institutions and researchers have made outstanding contributions in the field of EA visualization (who)?

In Sect. IV(C), we analyzed the authors of the selected papers and their relations to investigate the ecosystem of EA visualization research. The scholars and institutions that we mentioned earlier have made outstanding contributions in the field of EA visualization research with their high-quality publications. Besides, the researcher co-authorship network shows that cooperation in EA visualization research is prevalent in some small researcher communities, but most of the researchers come from the same institution or region. On the whole, there is a lack of connection and cooperation between scholars from different institutions.

**RQ5.** What kind of techniques are used in the study of EA visualization, and what are their strengths and weakness (what)?

So far, we have learned that EA visualization methods can be used for EA modeling, IT governance, EA evaluation, requirements engineering, etc. And the existing visualization operations can be summarized as “create”, “extract”, “translate”, “integrate”, “restructure”, and “evaluate”.

As mentioned in Sect. IV, we found that the most frequently used EA modeling languages (top 3) are ArchiMate, UML, and BMM, which are recommended by 41, 13, and 11 papers, respectively. Moreover, to make a detailed analysis of the EA modeling notations and frameworks, we compared the frequently used EA notations and frameworks, and we claimed that ArchiMate is most suitable for EA modeling due to its completeness and powerful visual expressiveness level for EA visualization.

Additionally, considering the current development of new technologies such as AI and 3D visualization, we believe that AI and 3D visualization will also be widely used in the research and practice of EA visualization. In fact, there have been studies using related technologies, such as paper S068.

**RQ6.** How are the qualities of the selected studies (how)?

As discussed in Sect. VI, we found that the majority of the selected papers did well in the introduction of research

background, purposes of the study, evaluation of the effectiveness of new findings and the prospect of future work. However, in terms of EA visualization step description and discussion of the limitations of the proposed method, many studies still have room for improvement.

Many scholars have expressed their concerns about the scope and completeness of their EA visualization methods. Most of them have discussed the concerns as research limitations, and hope to expand and improve their EA visualization methods in future work.

Furthermore, scholars also discussed the necessity for more empirical evidence to evaluate the effectiveness of their methods. Nevertheless, it is difficult for scholars to apply their research results to practical EA projects to obtain empirical evidence. This remains unclear and becomes an unsolved challenge that should be addressed in the study of EA visualization. This may be a difficulty in the application of EA, because persuading stakeholders to use an unfamiliar EA visualization method to model EA is not easy. Although the "university-industry" relation may solve this problem to some extent, more research must be done to illustrate the necessity and benefits of EA visualization. In addition, it is difficult to objectively evaluate the cost and risks of applying EA visualization.

Although there are many visualization approaches that have been explored to carry out EA visualization, there is no systematic visualization method to integrate the fragmented existing approaches. To narrow the gap between EA visualization approaches and the unsolved challenges in EA visualization research, we proposed a general approach to conduct EA visualization and described the detailed steps for applying the approach in Sect. VII.

## B. LIMITATIONS

The process of SLR can be divided into several steps: 1) identifying the research questions, 2) selecting data sources, 3) choosing search terms, 4) applying screening criteria, 5) doing the review, and 6) synthesizing the results. We review these steps to discuss the limitations of our study in this paper.

### 1) RESEARCH QUESTIONS

In this paper, we have chosen four questions as RQs and presented our research by answering these questions. Nevertheless, some new content can be added to enrich the completeness of the study, such as the frequently used tools or IDEs for EA visualization.

### 2) DATA SOURCES

We selected the research papers from the ACM digital library, IEEE Xplore, Springer Link, Science Direct, and Google Scholar. Although the databases are famous and high-level sources for computer science and software engineering, other databases, such as Scopus, can also be used to select the target studies on EA visualization.

In addition, the crawler script developed by programming languages such as Python seems to be useful for the literature search to improve the accuracy and efficiency of the search.

### 3) SEARCH TERMS

Although we think that we have chosen the appropriate data sources and keywords to search the target studies, there are also studies with high quality that are not in these databases, or they have not used topics, keywords, and abstracts related to EA visualization, so they cannot be selected for review. This seems to be a difficult problem that all SLRs have to face.

### 4) APPLYING SCREENING CRITERIA

A step of "consulting EA experts" can be added into the screening criteria to further screen research papers to reduce review time and improve the quality of the SLR.

### 5) THE REVIEW

Although we have extracted and recorded a large amount of data from the selected papers, some aspects of the discussion are not sufficient, we could have acquired more useful information from them. For example, the interaction between different studies has not been discussed, as a result, the research stream on EA visualization has not been formed.

### 6) THE RESULTS

The main findings for each research question can be highlighted to improve clarity. Additionally, the proposed general EA visualization approach needs a formal method for description and empirical evidence for further assessing its effectiveness. Moreover, case studies to validate the effectiveness of integrating different diagrams are needed. Although the general approach aims at solving EA modeling with different requirements, it is not applicable for all the contexts, such as the automated EA modeling mentioned in paper S038.

Resolving the challenges will become the future directions of this study.

## C. CONCLUSION

To identify, classify, analyze, and evaluate existing methods for EA visualization, we reviewed the research papers on EA visualization systematically. We selected and analyzed 112 research papers, and then we categorized them according to their purposes. The contributions of our study in this paper can be summarized as follows.

- We retrieved more than 1000 research papers about EA visualization methodologies, finally selected 112 studies and conducted a systematic literature review to investigate the current status, technical characteristics, and unsolved challenges of EA visualization research.
- We compared the most commonly used EA modeling languages and frameworks in the selected papers, and discussed the gaps and open issues in EA visualization.

TABLE 13. Selected studies in the SLR.

Paper ID	Year	Author	Title
S001	2000	Barros	Processes, Roles, and Events: UML Concepts for Enterprise Architecture
S002	2001	Winter et al.	Strategic information management plans: the basis for systematic information management in hospitals
S003	2003	Jonkers et al.	Towards a language for coherent enterprise architecture descriptions
S004	2003	Taylor et al.	Applying enterprise architectures and technology to the embedded devices domain
S005	2004	Peristeras et al.	Governance enterprise architecture (GEA): domain models for e-governance
S006	2004	Lankhorst	Enterprise architecture modelling—the issue of integration
S007	2005	Le et al.	Definition of an Object-Oriented Modeling Language for Enterprise Architecture
S008	2006	Niemann	Documentation: Structuring Enterprise Architecture
S009	2007	Bahl et al.	Towards highly reliable enterprise network services via inference of multi-level dependencies
S010	2008	Majedi et al.	A Novel Architectural Design Model for Enterprise Systems: Evaluating Enterprise Resource Planning System and Enterprise Application Integration Against Service Oriented Architecture
S011	2008	Sommestad et al.	Combining Defense Graphs and Enterprise Architecture Models for Security Analysis
S012	2008	Kittowski et al.	The Semantic Architecture Tool (SemAT) for Collaborative Enterprise Architecture Development
S013	2009	Buckl et al.	Using Enterprise Architecture Management Patterns to complement TOGAF
S014	2009	Quartel et al.	A goal-oriented requirements modelling language for enterprise architecture
S015	2009	Ekstedt et al.	Enterprise architecture models for cyber security analysis
S016	2009	Franke et al.	Enterprise Architecture Dependency Analysis using Fault Trees and Bayesian Networks
S017	2010	Ahsan et al.	Healthcare Modelling through Enterprise Architecture: A Hospital Case
S018	2010	Addicks et al.	A Method for Application Evaluations in Context of Enterprise Architecture
S019	2010	Li et al.	A distributed service-oriented architecture for business process execution
S020	2010	Lagerström et al.	Architecture analysis of enterprise systems modifiability – Models, analysis, and validation
S021	2010	Chen et al.	From Software Architecture Analysis to Service Engineering: An Empirical Study of Methodology Development for Enterprise SOA Implementation
S022	2010	Sadovykh et al.	Enterprise architecture modeling with SoaML using BMM and BPMN - MDA approach in practice
S023	2011	Jonkers et al.	ArchiMate(R) for Integrated Modelling Throughout the Architecture Development and Implementation Cycle
S024	2011	Antunes et al.	Modeling Contextual Concerns in Enterprise Architecture
S025	2011	Clark et al.	LEAP: A Precise Lightweight Framework for Enterprise
S026	2011	Becker et al.	Modeling digital preservation capabilities in enterprise architecture
S027	2011	Zambon et al.	Model-based qualitative risk assessment for availability of IT infrastructures
S028	2011	Bocciarelli et al.	A BPMN extension for modeling non functional properties of business processes
S029	2011	Šaša et al.	Enterprise architecture patterns for business process support analysis
S030	2011	Blobel	Ontology driven health information systems architectures enable pHealth for empowered patients
S031	2011	Fritscher et al.	Business IT Alignment from Business Model to Enterprise Architecture
S032	2011	Engelsman et al.	Extending enterprise architecture modelling with business goals and requirements
S033	2012	Meertens et al.	Mapping the business model canvas to ArchiMate
S034	2012	Iacob et al.	Capturing Business Strategy and Value in Enterprise Architecture to Support Portfolio Valuation
S035	2012	Agievich et al.	A new approach for collaborative Enterprise Architecture development
S036	2012	DePalo et al.	Healthcare Interoperability through Enterprise Architecture
S037	2012	Chiprianov et al.	Extending Enterprise Architecture Modeling Languages: application to telecommunications service creation
S038	2012	Buschle et al.	A Tool for Automatic Enterprise Architecture Modeling
S039	2012	Holm et al.	Automatic data collection for enterprise architecture models
S040	2012	Horkoff et al.	Strategic business modeling: representation and reasoning
S041	2012	Gómez et al.	Co-creation of models and metamodels for enterprise architecture projects
S042	2012	Närman et al.	Using enterprise architecture and technology adoption models to predict application usage
S043	2012	Ahlemann et al.	Strategic Enterprise Architecture Management
S044	2012	Quartel et al.	Application and project portfolio valuation using enterprise architecture and business requirements modelling
S045	2012	Teka et al.	Change impact analysis of indirect goal relations: Comparison of NFR and TROPOS approaches based on industrial case study
S046	2013	Bakhshandeh et al.	A Modular Ontology for the Enterprise Architecture Domain
S047	2013	Grandy et al.	Conceptual Integration of Enterprise Architecture Management and Security Risk Management
S048	2013	Vicente et al.	Using ArchiMate to Represent ITIL Metamodel
S049	2013	Hinkelmann et al.	Connecting enterprise architecture and information objects using an enterprise ontology
S050	2013	Grigoriev et al.	Non-diagrammatic Method and Multi-representation Tool for Integrated Enterprise Architecture and Business Process Engineering
S051	2013	Lakhrouit et al.	State of the art of the maturity models to an evaluation of the enterprise architecture
S052	2013	Monahov et al.	Design and prototypical implementation of a language empowering business users to define Key Performance Indicators for Enterprise Architecture Management
S053	2013	Gaaloul et al.	An Access Control Model for Organisational Management in Enterprise Architecture
S054	2013	Sommestad et al.	The Cyber Security Modeling Language: A Tool for Assessing the Vulnerability of Enterprise System Architectures
S055	2013	Farwick et al.	A Case Study on Textual Enterprise Architecture Modeling
S056	2013	Niu et al.	Analysis of Architecturally Significant Requirements for Enterprise Systems
S057	2013	Zhang et al.	Research on collaborative IT governance model oriented to business architecture
S058	2013	Roth et al.	Empowering Business Users to Analyze Enterprise Architectures: Structural Model Matching to Configure Visualizations

TABLE 13. (Continued.) Selected studies in the SLR.

Paper ID	Year	Author	Title
S059	2013	Bernaert et al.	An Android Tablet Tool for Enterprise Architecture Modeling in Small and Medium-Sized Enterprises
S060	2013	Plataniotis	An Empirical Evaluation of Design Decision Concepts in Enterprise Architecture
S061	2013	Perroud et al.	Enterprise Architecture Patterns
S062	2013	Närman et al.	Enterprise architecture availability analysis using fault trees and stakeholder interviews
S063	2014	Florez et al.	Extensible Model-Based Approach for Supporting Automatic Enterprise Analysis
S064	2014	Antunes et al.	Ontology-based enterprise architecture model analysis
S065	2014	Korman et al.	Overview of Enterprise Information Needs in Information Security Risk Assessment
S066	2014	Pourshahid et al.	A goal-oriented, business intelligence-supported decision-making methodology
S067	2014	Veneberg et al.	Enterprise Architecture Intelligence: Combining Enterprise Architecture and Operational Data
S068	2014	Naranjo et al.	Towards a Unified and Modular Approach for Visual Analysis of Enterprise Models
S069	2014	Zee et al.	Formalizing Enterprise Architecture Decision Models Using Integrity Constraints
S070	2014	Iacob et al.	From enterprise architecture to business models and back
S071	2014	Desfray et al.	Modeling Enterprise Architecture with TOGAF
S072	2015	Hanschke et al.	Integrating Agile Software Development and Enterprise Architecture Management
S073	2015	Silva et al.	Using ArchiMate to model a process assessment framework
S074	2015	Braun et al.	Designing Dialects of Enterprise Modeling Languages with the Profiling Technique
S075	2015	Boness et al.	The synergies between goal sketching and enterprise architecture
S076	2015	Caetano et al.	Analysis of Federated Business Models: An Application to the Business Model Canvas, ArchiMate, and e3value
S077	2015	Yamamoto	An Approach to Assure Dependability Through ArchiMate
S078	2015	Loucopoulos et al.	Enterprise Capability Modeling: Concepts, Method, and Application
S079	2015	Välja	A Requirements Based Approach for Automating Enterprise IT Architecture Modeling Using Multiple Data Sources
S080	2015	Lakhrouit et al.	Enterprise architecture approach for agility evaluation
S081	2015	Cloutier et al.	Transitioning Systems Thinking to Model-Based Systems Engineering: Systemigrams to SysML Models
S082	2015	Azevedo et al.	Modeling resources and capabilities in enterprise architecture: A well-founded ontology-based proposal for ArchiMate
S083	2015	Plataniotis et al.	A Conceptual Model for Compliance Checking Support of Enterprise Architecture Decisions
S084	2015	Cohen et al.	Enterprise Architecture with Executable Modelling Rules: A Case Study at the Swedish Defence Materiel Administration
S085	2016	Luo et al.	An impact analysis method of business processes evolution in enterprise architecture
S086	2016	Hinkelmann et al.	A new paradigm for the continuous alignment of business and IT: Combining enterprise architecture modelling and enterprise ontology
S087	2016	Abbass et al.	Improvement of information system security risk management
S088	2016	Biggs et al.	A profile and tool for modelling safety information with design information in SysML
S089	2016	Bakelaar et al.	A Framework for Visualization of Changes of Enterprise Architecture
S090	2017	Cartero et al.	Representation and analysis of enterprise models with semantic techniques: an application to ArchiMate, e3value and business model canvas
S091	2017	Mayer et al.	Evaluation of the risk and security overlay of archimate to model information system security risks
S092	2017	Gomes et al.	Using Enterprise Architecture to Assist Business Continuity Planning in Large Public Organizations
S093	2017	Uysal et al.	Re-Engineering Enterprise Architectures
S094	2017	Hodijah	Analysing enterprise architecture model for service based e-government towards good government governance
S095	2017	Jallow et al.	An enterprise architecture framework for electronic requirements information management
S096	2018	Nada et al.	A Proposal on a Method of ArchiMate based Concept of Operation (ConOps)
S097	2018	Aldea et al.	From Business Strategy to Enterprise Architecture and Back
S098	2018	Arriola et al.	Towards an enterprise architecture controlling framework
S099	2018	Pilipchuk et al.	Aligning Business Process Access Control Policies with Enterprise Architecture
S100	2018	Miranda et al.	Where Enterprise Architecture and Early Software Engineering Meet: An approach to use cases definition
S101	2018	Acrefoaie et al.	VMTL: a language for end-user model transformation
S102	2018	Emmanuel et al.	The Requirements Analysis of Elisa Business Architecture with Education Enterprise Architecture Perspective
S103	2018	Haghighathoseini et al.	Hospital enterprise Architecture Framework (Study of Iranian University Hospital Organization)
S104		Lê	Diagramming Multi-Level Service-Oriented Enterprise Architecture
S105	2019	Ahmadi	Cross-layer Enterprise Architecture Evaluation: An Approach to Improve the Evaluation of TO-BE Enterprise Architecture
S106	2019	Saddiqa et al.	Enterprise Architecture Oriented Requirements Engineering for Open Data Usage in Schools
S107	2019	Borozanov et al.	Using Machine Learning Techniques for Evaluating the Similarity of Enterprise Architecture Models
S108	2019	Mayer et al.	An integrated conceptual model for information system security risk management supported by enterprise architecture management
S109	2019	Lnenicka et al.	Developing a government enterprise architecture framework to support the requirements of big and open linked data with the use of cloud computing
S110	2019	Wautelet	A model-driven IT governance process based on the strategic impact evaluation of services
S111	2019	Rurua et al.	Representing Variability in Enterprise Architecture
S112	2019	Oberhauser et al.	VR-EA: Virtual Reality Visualization of Enterprise Architecture Models with ArchiMate and BPMN



- We found that the existing EA visualization methods can be categorized into 7 types according to their purposes, and there are 6 kinds of visualization operations. To provide a solution for EA visualization with different needs, we proposed a general EA modeling approach.
- we made a critical discussion on the paper based on the process of the systematic literature review.

It should be mentioned that our study in this paper is not a one-off outcome. We will continue to refine the SLR process and update our findings. In addition, we found some novel EA modeling concepts in the process of the SLR, such as EA modeling using VR (Virtual Reality), 3D EA modeling, etc. This will also broaden our research horizons, and provide directions for future research.

## APPENDIX

See Table 13.

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