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STATE OF THE ART

Maintenance of Enterprise Architecture Models

A Systematic Review of the Scientific Literature

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Abstract Enterprise architecture (EA) models are tools of analysis, communication, and support towards enterprise transformation. These models need a suitable maintenance process to support comprehensive knowledge of the enterprise's structure and dynamics. This study aims to identify and discuss the existing approaches to EA model maintenance published in the scientific literature. A systematic literature review was employed as the research method. A keyword-based search in six databases identified a total of 4495 papers in which 31 primary studies were included. A total of nine categories of EA model maintenance approaches were identified from both information systems and enterprise engineering fields of research. The increasing amount of research in EA model maintenance suggests that the topic still presents opportunities for research contributions. This study also proposes future lines of research according to the results identified in the theoretical corpus.

Keywords Systematic literature review · Enterprise architecture · Model · Maintenance

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1 Introduction

Enterprise architecture (EA) models are analysis and communication tools that express an enterprise's organizational structure, business processes, information systems, and IT infrastructure (Lankhorst 2013) with the goal of supporting enterprise transformation (Sousa et al. 2009; Tribolet et al. 2014; Farwick et al. 2015; Silva et al. 2017a, b).

Maintaining an EA model that is up-to-date and consistent with the enterprise is an effortful task in EA management (EAM) due to both the size and complexity of EA models, frequent changes in the architecture, and the challenge of collecting and managing EA information from different stakeholders in large enterprises (Farwick et al. 2012).

Nowadays, organizations can quickly end up with several applications and information scattered across different repository silos. Due to this increase in information systems, as a manifestation of the digital transformation age, the documentation of enterprise information as an inherent part of EA model design is often regarded as time-consuming, cost-intensive, and error-prone (Kaisler et al. 2005; Farwick et al. 2011a, b).

Despite the complexity, representation, and limited tool support being the core issues of EA pointed out by literature in the past (Kaisler et al. 2005; Lucke et al. 2010), contributions towards EA model maintenance, aiming at addressing the issues above, have not yet been identified in a consolidated manner.

Different categories of approaches have been proposed in the scientific literature, ranging from maintenance processes to algorithms, viewpoints, ontologies, and tools. Nonetheless, as Farwick et al. stated, there is a need for a consolidated reference regarding such EA model maintenance contributions to assist organizations with these challenges (Farwick et al. 2013).

1.1 Paper Goals and Contributions

This study leans towards scientific literature with a focus on EA model maintenance. A first step apropos of converging new research efforts to the subject is to identify, in a consolidated manner, the different categories of approaches. Therefore, this article aims to specify a categorization for the existing EA model maintenance approaches presented in the scientific literature. The authors consider not only EA model analysis but also EA model design as two different although synergistic kinds of techniques supporting EA model maintenance. This study could extend the EA Body of Knowledge (EABOK) (Kandjani and Bernus 2012) by providing a comprehensive source of information on EA model maintenance contributions. In particular, this study aims at:

1. Exploring the increase of published scientific research contributions regarding EA model maintenance.
2. Identifying categories of approaches regarding EA model maintenance.
3. Identifying open research challenges and areas for improvement of EA model maintenance.

The target audience for this study is twofold: researchers who would benefit from a systematic overview of the subject while presenting a reference of comparison for their work, and practitioners who can incorporate the contributions from academia into their own methods and tools applicable within their organizations. The authors would like to expressly point out that this study considers only peer-reviewed scientific literature. Therefore, other types of literature, such as patents, non-scientific books, whitepapers, and analysis on EAM tools, that could provide (practice-oriented) additional insight, were disregarded, which represents both a limitation of this study and a prospect for future work.

1.2 Paper Structure

The article is structured as follows: The following section describes the research method. The two sections thereafter present the results of this study and a discussion of its findings, respectively. The following section describes related studies. Finally, the last section concludes this study.

2 Method

This research has been undertaken as a systematic literature review (SLR), using the original guidelines proposed by Webster and Watson (2002) and Kitchenham et al. (2008). According to Kitchenham and Charters (2007), an SLR method comprises three consecutive stages: planning, execution, and result analysis. Activities of each phase are illustrated in Fig. 1 and described throughout the next subsections. This section focuses on the planning stage which involves the definition of the research questions and the way the review is conducted. Execution and analysis phases are addressed in Sects. 3 and 4, respectively.

2.1 Research Questions

This study aims at answering the following questions regarding EA model maintenance:

- RQ1: Is the number of research contributions from the scientific community increasing?
- RQ2: What categories of approaches exist in the scientific literature?
- RQ3: What are the open challenges and areas of improvement in the scientific literature?

Regarding RQ1, the authors selected the published research papers on EA model maintenance from 2018 back to 2001, since no research on EA model maintenance was identified prior to 2001. Exclusion criteria were applied based on search terms and advanced search options that narrowed the scope from broader EA modelling topics to ones specific to EA model maintenance. To address RQ2, the authors applied a content analysis approach, similar to grounded theory literature (Glaser and Strauss 1967), to the selected publications, which resulted in a categorization regarding the applied techniques and theories. Finally, the authors address RQ3 by analyzing the selected contribution in detail while identifying their limitations and future efforts.

2.2 Search Process

The initial intent was to capture all relevant approaches that support EA model maintenance. Therefore, the authors performed a database-driven SLR as described by Kitchenham and Charters (2007), vom Brocke et al. (2009) and Webster and Watson (2002). The search was conducted from 2019-02-01 to 2019-03-15 using as primary set of keywords: *enterprise architecture*, *model*, and *maintenance*. The authors also considered *evolution* and *adaptation* as complementary keywords of this search.

The authors conducted this search of the following online libraries:

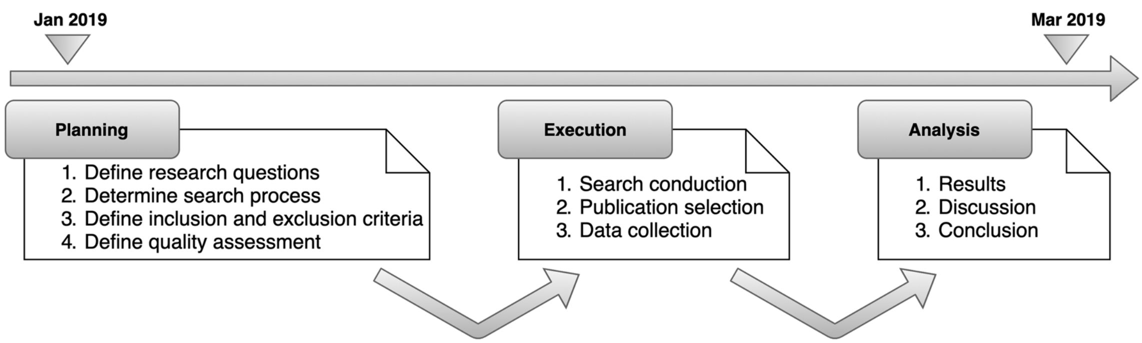

Fig. 1 Research method activities as described in Kitchenham and Charters (2007)

- IEEE Xplore (https://ieeexplore.ieee.org/Xplore/home.jsp).
- ACM digital library (https://dl.acm.org).
- AIS Electronic Library (AISel) (https://aisel.aisnet.org).
- Springer Link (https://link.springer.com).
- Tailor & Francis Online (https://www.tandfonline.com).
- Science Direct (https://www.sciencedirect.com).

The above-mentioned libraries provide adequate coverage of both scholarly and practice-oriented, peer-reviewed publications, with AISel, Springer Link, and Science Direct focusing primarily on scholarly publications and the ACM digital library and IEEE Xplore contents being more oriented towards practice.

The authors applied an advanced search to each library with the following search configuration:

- IEEE Xplore
  - Command search
  - Search: *Metadata only*
  - Query: *(((“enterprise architecture”) AND model) AND (maintenance OR evolution OR adaptation))*
  - Year: *1990–2019*
- ACM Digital Library
  - Select items from *The ACM Full-Text Collection*
  - Where: *Any field matches all* of the following phrases: *“enterprise architecture” model*
  - *Where: Any field matches any* of the following phrases: *maintenance evolution adaptation*
  - Where: Publication Year is in the range 1990–2019
- AIS Electronic Library
  - Query: *(“enterprise architecture” AND model AND maintenance) OR (“enterprise architecture” AND model AND evolution) OR (“enterprise architecture” AND model AND adaptation)*
  - Peer-reviewed only: *checked*
  - Date range: *01/01/1990–01/01/2019*
  - Limit search to: AIS Electronic Library (AISel)
- Springer Link
  - Query: *(“enterprise architecture” AND model AND maintenance) OR (“enterprise architecture” AND model AND evolution) OR (“enterprise architecture” AND model AND adaptation)*
  - Show document published between 1990 and 2019
- Taylor & Francis Online
  - Query: *(“enterprise architecture” AND model AND maintenance) OR (“enterprise architecture” AND model AND evolution) OR (“enterprise architecture” AND model AND adaptation)*
  - Date range: January *1990–January 2019*
- Science Direct
  - Query: *(“enterprise architecture” AND model AND maintenance) OR (“enterprise architecture” AND model AND evolution) OR (“enterprise architecture” AND model AND adaptation)*
  - Year: *1990–2019*
  - Article type: *Research articles* and BOOK CHAPTERS

To complement the online database search, the authors also conducted online searches of the following journals:

- Enterprise Modelling and Information Systems Architectures Journal.
- International Journal of Information Systems Modeling and Design.
- Business & Information Systems Engineering Journal.
- Information Knowledge and Systems Management Journal.

It was necessary to conduct this search as the journals are not indexed by any of the online libraries used, despite their prominence in the fields of EA and enterprise modelling.

2.3 Exclusion Criteria

This study includes peer-reviewed papers on the topic of EA model maintenance published between 1990-01-01 and 2019-01-01. To identify such papers, the authors read the title and abstract for each search result. Articles on the following topics were excluded:

- Contributions published in a language other than English.
- Non-peer-reviewed articles by the scientific community.
- Papers that did not describe approaches that support EA model maintenance.
- Papers describing EA model maintenance considering research artefacts other than models.
- Duplicate research (i.e., when the same research appears in different journals and conference proceedings, the extended version of the study was the one included in this review).

In the remainder of this article, each selected study is not addressed as stand-alone approach. Each contribution is classified into one of nine categories, thus described together with all remaining approaches that fit into the same category.

2.4 Quality Assessment

As a complementary step in the screening process, the authors conducted a quality assessment for each study to validate the quality of research regarding each filtered approach, thus selecting the most promising contributions.

From Kitchenham's guidelines (Kitchenham and Charters 2007), the authors defined three quality assessment questions to assess the quality of the research and to provide a quantitative comparison between the selected papers. The scoring procedure was also based on (Kitchenham and Charters 2007): Yes (Y) = 1, Partly (P) = 0.5 or No (N) = 0. The quality assessment questions defined were:

- QA1: How precisely do the authors state their expectations towards the established research method?
  - Yes: The authors' expectations of the applied research method are clearly explained.
  - Partially: The paper mentions their expectations in a generic manner without going into detail.
  - No: The paper does not state the authors' expectations regarding the applied method of research.
- QA2: How precisely are the contribution limitations identified?
  - Yes: The paper clearly explains the limitations of the contribution.
  - Partially: The paper mentions the limitations but lacks a rationale behind them.
  - No: The paper does not mention any limitations.
- QA3: How well has the diversity of perspective and context been explored?
  - Yes: The paper explicitly explains various perspectives on EA model maintenance.
  - Partially: The paper mentions the various perspectives on EA model maintenance but does not explain the details of each one.
  - No: The paper does not mention the various perspectives on EA model maintenance.

QA1 focuses on the authors' expectations towards the research method used while providing a thorough explanation of the research method and the motivation behind it. QA2 addresses another relevant quality attribute of research: the identification of limitations. Every study is bound to a set of constraints and impediments such as overfitting and underfitting of samples, different grade research material, as well as financial constraints, among other factors that ultimately can lead to varying results of the same research. Clear identification of all research restrictions provides a more comprehensive and at the same time accurate insight into the published research.

Finally, Q3 targets another important quality attribute of any research publication: the awareness and understanding of related contributions on a given research topic. Overall, these questions provide support for checking biases, external validation and internal validation of each contribution.

3 Results

This section presents the results of the study and the process of developing the categorization of EA model maintenance approaches.

3.1 Search Results

The search conduction and paper screening, leading to the search results described below, are illustrated in Fig. 2. As described in the Search process section, the authors used two search entry points: database keyword advanced search and journal advanced search from a set of selected journals.

The search results yielded 119 publications in IEEE Xplore, 111 in ACM Digital Library, 253 in AISel, 2840 in Springer Link, 312 in Taylor & Francis Online, and 860 in Science Direct. A total of 4495 publications matched the

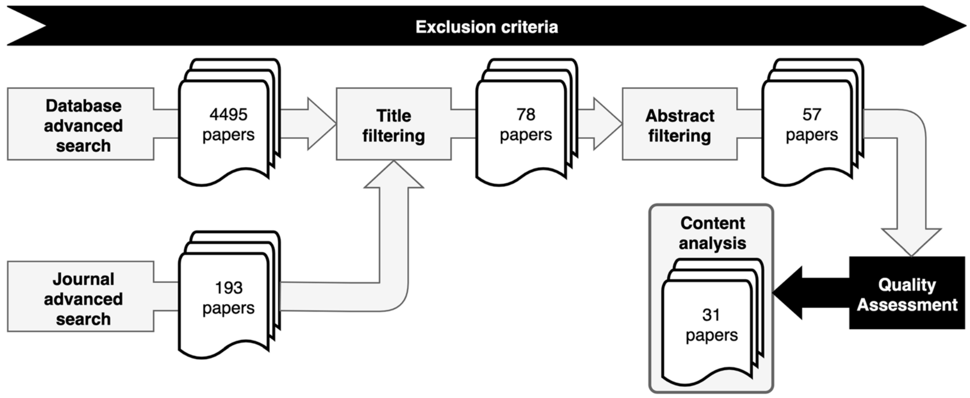

Fig. 2 Paper screening process

search criteria in this search. Advanced search in the four selected journals returned a total of 193 publications.

The screening process was based on two filtering steps, besides the exclusion criteria and the quality assessment mentioned in previous sections. Each of the steps was conducted independently by all authors to reduce mistakes. In the first screening step – title filtering – the authors excluded all articles whose title divert from the scope of this review. A total of 78 papers remained. The same rationale was applied to the filtered papers' abstracts in the second screening step – abstract filtering. This step resulted in a total of 57 papers. The selected papers from this step underwent a quality assessment, as described in the section above.

Finally, the authors applied content analysis, based on coding, to the remaining 31 papers included in this review to identify the underlying categories of approaches. More detail on the categorization process follows in the next section.

Figure 3 illustrates the number of published articles by year of publication. The chart includes the 57 selected studies prior to the quality assessment process. The trend line presented in the chart suggests a linear increase in the number of publications on the topic of EA model maintenance, with higher predominance in the last 8 years.

Figure 3 also shows a higher rate of publications on the topic during 2009, 2012, and 2013. However, the authors did not assess possible reasons behind this discrepancy compared to the trend line of the growth rate since it was out of the scope of research.

Note that this study only covers publications in the databases as well as in the considered journals and conference proceedings until January 2019. Also, no publication from the examined corpus was published prior to 2005.

3.2 Quality Assessment

As the last screening step, the authors evaluated the 57 filtered studies (see Appendix A; available online via https://link.springer.com) according to the quality assessment questions defined in the Quality assessment section. The score assigned to each paper regarding each question is shown in Table 1.

The "Total" row refers to the sum of all Y, P, and N scores concerning each QA question (as described in Sect. 2.4). The row "% total score" shows the percentage of points obtained by all the selected approaches concerning the total number of points obtained by all the selected approaches in all the Quality Assessment questions. For example, for a total score of 118.5 as the sum of all total scores of each approach and corresponding to 100% of total score percentage, QA1 has 35.5% (42/118.5) of the total score of all approaches. The last row "% max

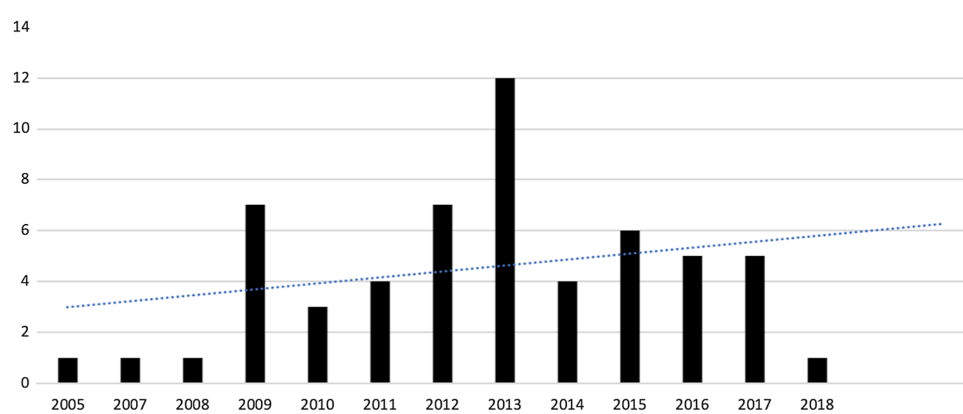

Fig. 3 Number of publications by year of publication

Table 1 Quality assessment of selected papers

ID	QA1	QA2	QA3	Total score	% by Max S
A1	P	N	Y	1.5	50
A2	Y	Y	Y	*3*	*100*
A3	N	N	N	0	0
A4	Y	N	Y	2	66.7
A5	Y	Y	N	2	66.7
A6	Y	Y	Y	*3*	*100*
A7	P	Y	Y	*2.5*	*83.3*
A8	Y	N	Y	2	66.7
A9	Y	Y	Y	*3*	*100*
A10	P	Y	Y	*2.5*	*83.3*
A11	N	N	N	0	0
A12	P	N	Y	1.5	50
A13	Y	Y	Y	*3*	*100*
A14	Y	Y	Y	*3*	*100*
A15	Y	N	Y	2	66.7
A16	P	N	Y	1.5	50
A17	Y	Y	Y	*3*	*100*
A18	P	N	N	0.5	16.7
A19	P	Y	Y	*2.5*	*83.3*
A20	Y	P	Y	*2.5*	*83.3*
A21	P	P	Y	*2*	*66.7*
A22	P	Y	Y	*2.5*	*83.3*
A23	Y	Y	Y	*3*	*100*
A24	Y	Y	Y	*3*	*100*
A25	P	Y	Y	*2.5*	*83.3*
A26	P	N	Y	1.5	50
A27	Y	P	Y	*2.5*	*83.3*
A28	Y	N	Y	2	66.7
A29	N	P	N	0.5	16.7
A30	Y	Y	Y	*3*	*100*
A31	Y	P	N	1.5	50
A32	P	N	N	0.5	16.7
A33	Y	N	P	1.5	50
A34	P	Y	Y	*2.5*	*83.3*
A35	Y	N	Y	2	66.7
A36	Y	N	Y	2	66.7
A37	Y	Y	P	*2.5*	*83.3*
A38	Y	Y	Y	*3*	*100*
A39	P	Y	Y	*2.5*	*83.3*
A40	P	N	Y	1.5	50
A41	Y	N	P	1.5	50
A42	Y	Y	Y	*3*	*100*
A43	N	P	Y	1.5	50
A44	P	P	Y	*2*	*66.7*
A45	Y	Y	Y	*3*	*100*
A46	P	N	Y	1.5	50
A47	P	N	Y	1.5	50
A48	P	N	N	0.5	16.7
A49	Y	N	Y	2	66.7
A50	P	P	Y	*2.5*	*83.3*
A51	Y	P	Y	*2.5*	*83.3*
A52	Y	N	N	1	33.3
A53	Y	Y	Y	*3*	*100*
A54	P	Y	Y	*2.5*	*83.3*
A55	Y	P	Y	*2.5*	*83.3*
A56	P	Y	Y	*2.5*	*83.3*
A57	Y	Y	Y	*3*	*100*
Total	42	30	46.5	118.5	
% Total score	35.5	25.3	39.2	100	
% Max QA	73.7	52.6	91.6		

Table rows with scores and percentages in italic refer to the selected approaches that fully (or partially) cover the defined quality assessment criteria

QA" corresponds to the percentage of points collected by the values assigned for a given Quality Assessment question over the points that would be collected should every selected study got the highest score. For instance, a total score of 42 with respect to QA1 divided by the total score of QA1, should all approaches get the highest score of 1 (Y), results in a max QA percentage of 73.7.

The authors selected the studies that either fully or partially covered all the quality assessment questions defined. Therefore, the authors chose the studies for content analysis and posterior categorization with a quality assessment score of 2.5 or higher, with the exception of A21 and A44. These two research papers cover the selection criterion despite having a score of 2. The chosen articles, as identified in Table 1, were A2, A6, A9, A13, A14, A17, A23, A24, A30, A38, A42, A45, A53, and A57 with a score of 3, representing 100% of the maximum score, followed by A7, A10, A19, A20, A22 A25, A27, A34, A37, A39, A50, A51, A54, A55, and A56 with a score of 2.5, representing 83.3% of the maximum score, and A21 and A44 with a maximum score of 66.7%.

As Table 1 demonstrates, the first question is distributed over 35.5% of the total score, the second question represents 25.3%, and finally, the third question has a distribution of 39.2%. Given these results, the authors conclude that from the 57 initial studies, a total of 31 publications present the most promising results.

3.3 Categorization

The process of developing a categorization for EA model maintenance approaches from the 31 selected publications was based on content analysis analogue to grounded theory literature (Glaser and Strauss 1967).

The authors applied an inductive coding approach using the NVivo[1] software for qualitative research coding. After loading the selected manuscripts into NVivo, each manuscript statement that explicitly described the article's approach was coded as a new node (Frameworks, Algorithms, Viewpoints, etc.), in case the approach was not yet marked as a node reference; otherwise the statement was added as a new reference of an existing node. The coding process resulted in a total of 821 codes. The number of categories was described by the number of defined nodes containing the groups of manuscripts' references that explicitly stated a given type of approach (i.e., codes referencing identical or similar descriptions, such as model/meta-model, method, and requirements).

Numbers in brackets below category names (as Fig. 4 illustrates) denote the total number of codes referring to a given category (i.e., the first number) and the total number of codes identified in all articles (i.e., the second number).

Results from the categorization process suggest nine different categories of EA model maintenance approaches. Table 2 illustrates the identified categories, the individual contribution for EA model maintenance, and the year of publication. According to the code analysis and overall comprehension of every approach, each of the nine categories of approaches is defined as follows:

- *Models/Meta-Models* Models (or meta-models at a meta-level) express an abstraction of the concepts of a specific domain of information.
- *Viewpoints* Viewpoints are specifications for constructing, interpreting, and analyzing architecture views framing specific system concerns.
- *Ontologies* An ontology is a "formal, explicit specification of a shared conceptualization" (Studer et al. 1998). An ontology specifies a set of concepts in a given domain, their properties and the existing relations between these concepts.
- *Frameworks* Frameworks, in the scope of EA, provide principles and practices for creating and using architecture descriptions of an enterprise system.
- *Algorithms* Algorithms are unambiguous specifications of how to solve a class of problems, in this specific case, EA model maintenance problems. Algorithms can perform domain-specific calculations and processing of domain data, or even automate tasks.
- *Requirements* Requirement-based approaches present a set of statements drawn from an individual or collective need that influence or contribute to a desirable outcome.
- *Processes* Processes are a collection of related, structured activities or tasks ordered and executed in a specific sequence that produces one or more outputs based on a given set of inputs.
- *Tools* A tool, in the scope of this study, is a software application composed of a set of algorithms and automated tasks that together solve one or more domain problems.
- *Methods* Methods are specific, systematic procedures for accomplishing a given goal. A method is operationalized by employing one or more techniques and artefacts suitable for achieving its purpose.

Figure 5 plots the 31 primary studies according to the year of publication and category of the approach presented in the study. This allows the reader to compare the research focus for each category throughout the last decade. As Fig. 5 shows, and according to the identified studies, approaches on EA model maintenance based on frameworks and algorithms have been prevalent in recent years. Sections 4.1 and 4.3 further discuss trends and technologies, as well as the identified challenges.

The following subsections describe each approach grouped according to the identified categories.

3.3.1 Models/Meta-Models

A17 developed an information model, grounded on temporal patterns, capable of expressing project dependencies in the EA application landscape. State of the art approaches with emphasis on explaining project- and time-dependencies, as well as a set of requirements for modelling the management evolution of the application landscape, are considered throughout the research and design process.

A30 presents GIMM (Generic Intermediate Metamodel), a meta-model-based approach that provides a solution to the limitations posed by the use of frameworks such as the EMF framework regarding meta-model and model dynamicity. GIMM realizes a basic linguistic framework for the definition of models including only the necessary elements (model, element, attribute, and relation) used in the description of a basic model.

The A56 approach – Wiki4EAM – is a meta-model that addresses the mismatch between existing unstructured information in enterprises and rigid information structures of prevalent EAM tools throughout the iterative and collaborative design of a continuously adapting EA model. A56 describes EA models as hybrid wiki models as proposed in (Matthes et al. 2011), together with a typed core expression language – MxL.

Evaluation A17 presents a case study in the field of access control models. Emphasis is placed on the

[1] https://www.qsrinternational.com/nvivo/home.

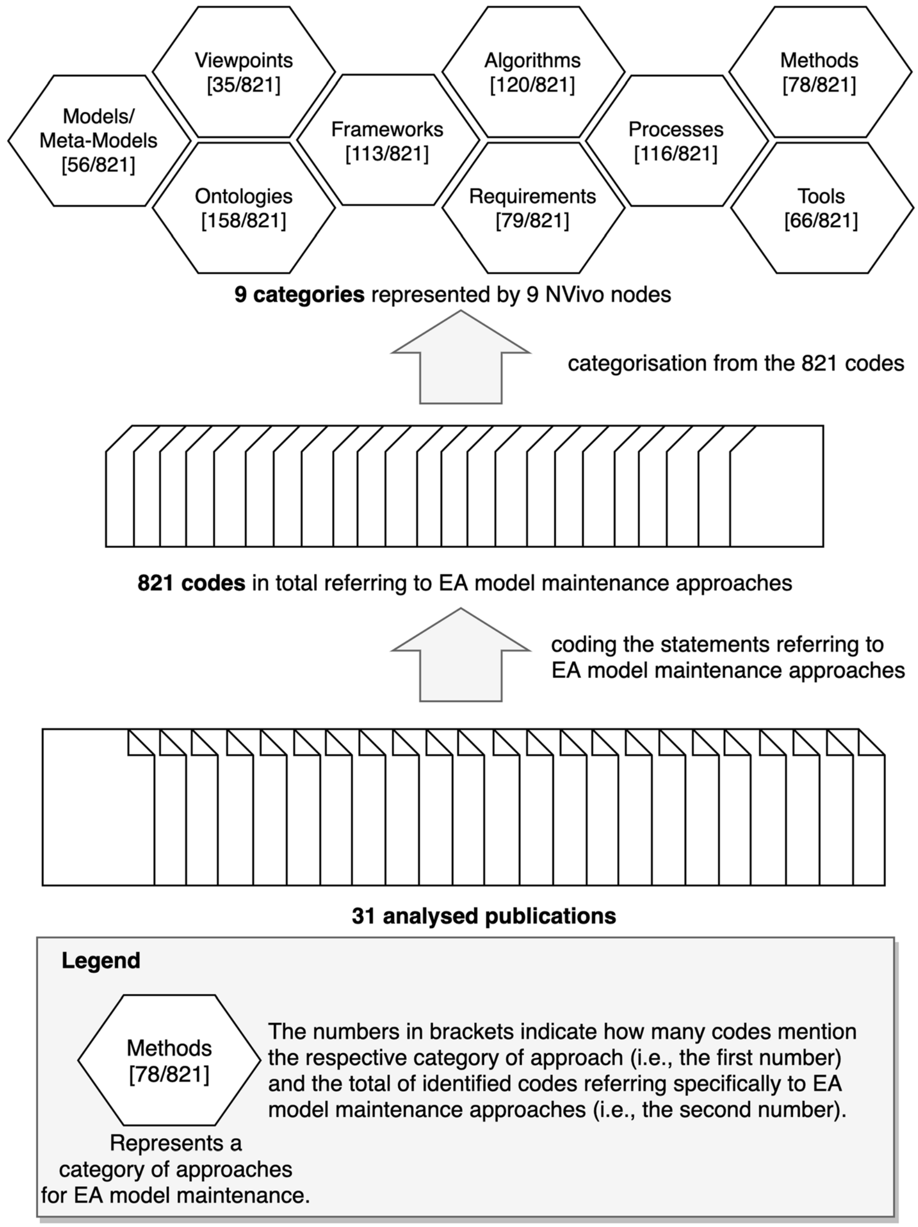

Fig. 4 Content analysis approach

organizational dynamics with the risk of a suspicious change in the depicted inventory scenario. A56 also presents a case study as means of validating its approach. The case consists of using an implementation of Wiki4EAM to analyses the application landscape complexity of four German banks.

Limitations A17 states that the model has not been validated in practice. A practical validation can present usage impediments due to the complexity of the project dependency modelling. Projects affecting the business domain of an EA are also not suitable for such an approach that solely focuses on the application landscape. A30's main limitation has to do with the editor implementing its approach. In particular, the editor components are tightly coupled, making it difficult to include their approach in other tools. As for A56, their approach lacks an in-depth study in a business environment, which could provide an empirical validation of their approach. Also, non-functional aspects, such as the usability of the prototype and ease of learning, require assessment. Finally, A56 revealed performance issues when performing complex graph algorithms.

3.3.2 Viewpoints

A13 proposes a model-based viewpoint, as an EA model extension, which expresses the evolution-specific concerns regarding EA. The A13 viewpoint frames a set of

Table 2 Summary of identified approaches that support EA model maintenance

Category	Approach	Year
Models/meta-models	A17 (Buckl et al. 2009a)	2009
	A30 (Gomez et al. 2012)	2012
	A56 (Reschenhofer et al. 2014)	2014
Viewpoints	A13 (Da Silva et al. 2017a, b)	2017
	A57 (Buckl et al. 2009b)	2009
Ontologies	A23 (Roser and Bauer 2008)	2008
	A39 (Diefenthaler and Bauer 2013)	2013
	A45 (Silva et al. 2017a, b)	2017
Frameworks	A6 (Hacks and Lichter 2018)	2018
	A21 (Binz et al. 2013)	2013
	A37 (Wolff 2016)	2016
	A42 (Dam et al. 2016)	2016
	A53 (Dam et al. 2010)	2010
Algorithms	A19 (Guerreiro et al. 2016)	2016
	A24 (Johnson et al. 2016)	2016
	A25 (Silva et al. 2016)	2016
	A34 (Franke et al. 2009)	2009
	A50 (Lautenbacher et al. 2013)	2013
Requirements	A7 (Välja et al. 2015)	2015
	A44 (Hofer 2013)	2013
	A51 (Farwick et al. 2011a)	2011
Processes	A2 (Fischer et al. 2007)	2007
	A27 (Farwick et al. 2011b)	2011
	A38 (Roth et al. 2013)	2013
Tools	A10 (Buschle et al. 2011)	2011
	A22 (Holm et al. 2014)	2014
	A54 (Grunow et al. 2013)	2013
	A55 (Farwick et al. 2010)	2010
Methods	A9 (Farwick et al. 2015)	2015
	A14 (Sousa et al. 2009)	2009
	A20 (Saat et al. 2009)	2009

evolution-specific concerns thus aiding in EA model analysis concerning EA evolution.

A57 presents a viewpoint for road mapping the development of EA over time. The approach enables the visualization of the business development supported by the application landscape over time while expressing the relevant information that needs to be gathered and maintained throughout the process.

Evaluation A13 extends ArchiSurance's application architecture: gap analysis view with the proposed viewpoint to demonstrate the evolution rationale leading to the architectural changes in the application architecture view. A57, however, states that neither a practical nor theoretical validation of their approach was made, claiming that to be one of the limitations of their work. Hence, no functional validation of the information model that supports the viewpoint was undertaken.

Limitations Concerning A13, the demonstration of their approach identified a scalability limitation which can lead to communication and performance analysis issues when applied to complex evolution scenarios. As for A57, a practical validation of the information model supporting the viewpoint is missing.

3.3.3 *Ontologies*

A23's approach – OntMT – integrates ontologies into modelling by utilizing different technological spaces to automate the generation and evolution of model transformations. OntMT was realized as a semantic-enabled modelling and development suite – Sem-X-Tool. The core components of the tool are the inference component, which consists of a knowledge base and a reasoner, and the Sem-MT-Component that implements the core part of the OntMT approach.

A39 makes use of semantic web technologies to perform a gap analysis between two high-level EA models representing the current and target state. A39 aims to provide a more detailed target state by making suggestions to a user what a detailed target state could look like, derived from the gaps identified in the high-level states and a detailed current state.

A45 presents an OWL-DL ontology as a representational basis of the underlying aspects of enterprise transformation, thus enhancing the expressiveness of EA models towards addressing evolution-specific stakeholder concerns.

Evaluation A23 identifies the support that OntMT can provide to a set of application scenarios as well as the different types of model transformations, followed by a detailed evaluation regarding the level of automation, scalability considerations in terms of memory requirements, runtime, and model transformations sizing. A45 uses the fictitious ArchiSurance case study to validate the applicability of its approach.

Limitations A23 assumes the existence of an appropriate reference ontology, which by itself is a non-trivial task. A lot of factors must be accounted for such as linguistics, probabilistic approaches, and human intervention to obtain a suitable reference ontology.

A39 does not consider the elaboration of metrics to enable a quantitative analysis of both the current and target states. Their approach also requires knowledge of the existing semantic web technologies since these technologies are not ready for use by enterprise architects.

A45's limitations have to do with the specific needs of organizations and the plethora of modelling languages, which increases the complexity of managing, integrating,

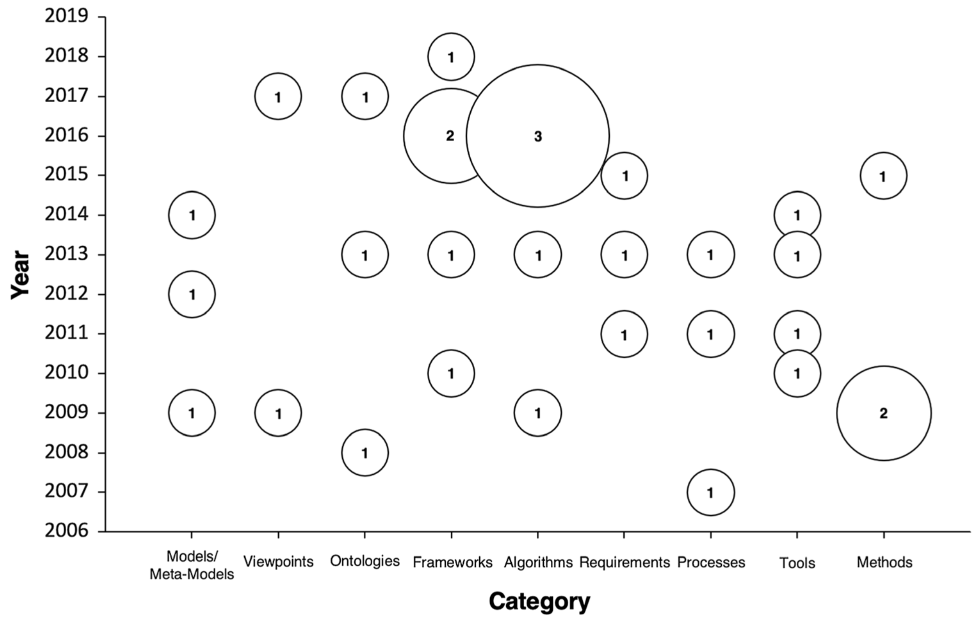

Fig. 5 Frequency of categories by primary studies between 2007 and 2018

and analyzing the different ontologies, the need for an adequate tool support that allows for the management of integrated ontologies, and the lack of an adequate integrated visualization of the different ontologies and analysis outcomes.

3.3.4 Frameworks

A6 presents a generalization of the Predictive Probabilistic Architecture Modeling Framework (P2AMF) proposed by Johnson et al. (2014), which already incorporates a way to represent uncertainty regarding the existence of modelled entities, to be applied to EA models notated in arbitrary formats like ArchiMate. A6 uses the Design Science Research (DSR) in accordance to Peffers et al. (2008) as research method.

A21 proposes an extensible framework for automated discovery and maintenance of Enterprise Topology Graphs (ETG), which represent a snapshot of the complete enterprise IT, including all its applications, processes, services, components and dependencies. In short, an ETG is another representation for an EA model. The framework's design is steered based on a set of requirements that is identified from existing literature on EA documentation, namely the quality of the EA model, or in this case the ETG, the open-world assumption, integration, update, and minimization of operational impacts. The framework's architecture is split into three layers: the graphical user interface (GUI), discovery and data. The data layer stores the ETGs as well as framework information such as available plugins, ongoing discoveries, and their configuration. The discovery layer manages the overall discovery as well as user interactions. The discovery is carried out by a set of plugins that are maintained and invoked by the plugin manager. Between the discovery and plugin manager, the scheduler object implements an algorithm deciding in which order the plugins are invoked.

A37 develops a systematic framework based on the concept of evaluation chains to support an evaluation of enterprise modelling in close cooperation with other researchers and practitioners. The framework is intended to ease the effort required for a systematic improvement and adaptation of enterprise modelling in large organizations to changing requirements and circumstances.

Since both A42 and A53 describe the same approach, according to the exclusion criteria, the authors will refer to A42, this being the most complete version. A42 presents an evolution framework for ChangeAwareHierarchicalEA models. ChangeAwareHierarchicalEA is an EA description language that aims at supporting changes in the maintenance and evolution of EAs. The evolution framework proposed in A42 has two major components: change impact analysis and change propagation. The change impact analysis identifies the potential consequences of a change and estimates what needs to be modified to accomplish a change. Change propagation determines and makes secondary changes based on a set of primary changes. In other words, changes are propagated by finding places in an EA model where consistency rules are violated and by fixing them until no inconsistency is left in the model.

Evaluation To validate the applicability of the approach, A6 implemented the aforementioned examples in the graph database using Neo4j.[2] A21 evaluated their approach in

[2] https://neo4j.com.

terms of feasibility, general applicability, extensibility, and economics as well as the fulfilment of the requirements. Regarding the feasibility and general applicability, A21 discovered four scenarios of different size from different hosting environments by using 21 different kinds of discovery plugins. Results showed that the discovery time increases linearly with the number of nodes in the ETG. As for extensibility, due to the framework's plugin architecture and ETG's extensible type system, the A21 approach is extensible and fulfils the open-world assumption requirement. As for economics, the goal of reducing IT operation costs is facilitated by automating what was formerly a manual, time-consuming and error-prone task.

A37 used the ADO*xx* metamodeling platform to evaluate applicability of its approach in practice. To validate the framework's applicability, in particular how ChangeAwareHierarchicalEA deals with changes, A42 developed a case study of a bookstore which is specified and designed, along with a number of additional requirements. These requirements provide examples of the evolution of the EA used to assess how ChangeAwareHierarchicalEA supports change propagation.

Limitations A6 identifies a lack of integration into existing EA tools and mechanisms that could handle a change of an included state or the addition of a state between two existing sates of the EA model.

Despite measurements pointing out that the linear discovery time of the A21 approach is in a range that seems to be well suited for practical applicability, 4 scenarios is not statistically significant enough to derive sound conclusions regarding the framework's practical applicability.

As for A37, a critical issue regarding the framework can be seen in the effort required for an evaluation, despite this being a fraction of the effort a company has to invest in modelling its processes and IT.

A42 only addresses the services, information processing and the organization of the modelled enterprise. The approach neither considers the aspects of strategy, goals, and vision of EA models nor the non-functional aspects such as finance, governance, quality of services, security, database, network, system interoperability and low-level software design.

3.3.5 Algorithms

A19 suggests that Markov Decision Processes can be used to calculate, based on observational data, a set of alternatives that support the enterprise architect in the evolution of EA.

A24 uses Dynamic Bayesian Networks (DBNs) as an applicable technique for EA model maintenance due to their probabilistic nature, hence capable of capturing the inherent and significant uncertainty that surrounds the knowledge of both as-is and to-be EAs.

The A25 approach consists of a set of migration rules that automate model migration when stepwise EA metamodel changes take place. Instead of destructively modifying the EA model data, each migration rule preserves the data by changing the current EA model data state (i.e., by setting the respective lifecycle dates of each changing EA model element).

A34 shows how the use of classification tree learning techniques (Mitchell 1997) can be applied to maintain and manage meta-models for EA-based decision making. Metamodels tend to become larger and more challenging to manage in time. A solution is to evaluate meta-model entities and attributes concerning the decisions that the meta-model is designed to support. A34 describes how a formal analysis method can be used to achieve greater analytical capabilities within the EA discipline.

A50 presents a four-phase algorithm supporting transformation planning of EA models. Phase one consists of linking both the current and target architectures. Phase two – segmentation analysis – consists of narrowing the scope for the following transformation path creation. Phase three, independent of the other phases, consists of the creation of the action repository, where the abstract actions that are taken into account are modelled. Finally, phase four is the creation of the transformation path, where different possible plans – sequences of concrete actions – are generated.

Evaluation A19 illustrates the need to support EA evolution decision and the benefits of doing so by presenting a case study in the field of access control models. A24 also validates the applicability of their approach by applying it to the fictitious ArchiSurance case study.

A50 provides an implementation of the approach by using model query languages and GROOVE.[3] The approach was applied to a use case consisting of the introduction of master data management in the research department of an organization. The validation of the approach was conducted by an enterprise architect and knowledge engineer with the goal of determining the differences between the expectations of the enterprise architect and the actual information provided by GROOVE.

Limitations The main weakness of the approach presented in A19 is that it has not yet been applied to a real case. A24 argues that despite the difficulty of gathering all the required information for a complete EA model being a limitation, the cost of acquiring part of that information is straightforward and inexpensive. A25 identified some shortcomings, namely that only a tool that follows an object-oriented paradigm is capable of implementing their

[3] GRaphs for Object-Oriented VErification (GROOVE). https://groove.cs.utwente.nl/.

approach. Furthermore, they do not claim that the proposed approach covers all co-evolution scenarios, despite arguing that the most common cases are covered. Finally, further testing is needed within complex organizations to provide more conclusive results regarding performance and scalability.

A34 also discusses some weaknesses of the presented approach. Regarding data completeness, A34 discusses a set of examples where uniform and complete data sets have been used, while in reality, these conditions are rarely fulfilled. As EA meta-models are maintained, old data no longer complies with the new. Nonetheless, even though such data is defective, it may have some predictive value, and classification tree techniques can be adjustable to cope with such a situation. Finally, the problem of overfitting is a prevalent one in machine learning algorithms. The learning process risks going beyond useful generalization and instead learns the peculiarities of the training set. General limitations of A50 at the time of publication do not cover other architecture layers of the EA and do not enable more abstract target architecture models to act as a starting point.

3.3.6 Requirements

A7 aims to solve the problem where a sophisticated security model needs to be maintained through data collection from several sources by presenting an approach to automate enterprise IT architecture modelling using multiple data sources. Their approach is built on the four-stage model of information processing automation (data acquisition, data analysis, decision and action selection, and action implementation) and relies on a set of collected EA and data requirements from literature to maintain data quality.

A44 derived a set of six requirements for modelling approaches for transformation projects from an application-oriented point of view that focuses on how an application landscape is used in business processes. The requirements are as follows: *Requirement 1 – The modelling approach should make the available information manageable; Requirement 2 – the modelling approach should be able to express contradictions; Requirement 3 – the modelling approach should be able to express how an application landscape supports business processes; Requirement 4 – The modelling approach should be able to express an application landscape's dependencies even for business processes that use several applications and are carried out by more than one organizational unit; Requirement 5 – The modelling approach should be able to express dependencies between applications even if they cannot be mapped to technical interfaces; Requirement 6 – The modelling approach should be able to express how an application landscape changes over time.*

A51 surveyed EA practitioners who were asked to identify how EA maintenance is executed in companies, and as a result presented a list of 23 requirements divided into six categories: (1) architectural requirements, (2) organizational requirements, (3) integration/data source requirements, (4) data quality requirements, (5) functional system requirements, and (6) non-functional requirements. Such requirements can be used in the development of tools and methods to facilitate automated EA maintenance.

Evaluation A7 describes an empirical study of a university supervisory control and data acquisition lab. The goal of this study is to empirically validate the automation effort regarding the creation of an enterprise IT architecture model using two data sources.

A44 evaluates the suitability of existing modelling approaches for addressing transformation projects based on the defined requirements. This evaluation focuses on approaches that fulfil certain criteria, such as that the approach must present a modelling notation, a methodology for creation and use of models, and tool support. Furthermore, the approach must either be capable of expressing different views of an application landscape or be open for extension so that the criteria can be fulfilled by adapting the approach. The evaluated EA modelling approaches were UML, ArchiMate, EAM-Patterns, MEMO, ADOit, and BEN. Results from the evaluation showed that some approaches provide means to fulfil some of A44 requirements, however, none of the approaches met all the requirements.

Concerning A51, its approach was grounded on a 34 questions survey answered by 43 practitioners with focus on the demand of EA automation in practice, tool support satisfaction, and on how the process of EA model maintenance is actually conducted in companies.

Limitations The A7 contribution focuses on the overall IT architecture modelling automation process, thus neglecting the implementation specific details. This limitation hinders the usage of their approach as a guideline for concrete implementations. A second limitation is that their approach only supports a specific type of models. These models have a predefined ontology and have been created more for analysis rather than documentation purposes. The third and final shortcoming is that it needs to be implemented manually without the support of data mining or computational intelligence techniques.

The A44 approach only focuses on the application landscape, thus not taking into account other layers of EA like the business and technology layers. A51 reports no specific limitations regarding requirements' identification besides claiming that this work was a starting point for the development of a method and technical solution for automated EA maintenance, hence not validated in practice.

3.3.7 Processes

A2 proposes a federated strategy to maintain EA models. One of their findings in implementing such an approach is that the integration of existing models from specialized architectures strongly influences the acceptance of EA as a management tool. For EA stakeholders in particular, this approach becomes a powerful tool as it provides valuable insights into the current and future EA that was not available before.

A27 proposes several EA model maintenance processes for semi-automated EA model maintenance. Hence it aims to reduce manual work for EA model maintenance and increase data quality attributes like consistency and actuality.

A38 presents a solution for the conflict resolution in EA models to enable automated EA documentation. The solution consists of a conflict resolution process that can be used by various end-users to resolve model conflicts.

Evaluation Regarding A2, their federated approach to EA maintenance was validated using the case of a large financial service provider, whereas A38 evaluated its approach by means of a prototype and interviews with EA domain experts.

Limitations A2 argues that despite the need for a tool extension towards supporting their process-based approach, such automation of model data updates may not be reasonable for every specialized architecture model. Additionally, they have also yet to define the criteria influencing the cost–benefit ratio of an automated approach.

A27 implicitly states a limitation of its work for the time of publication, which was not having implemented and tested the possible integration data collection interfaces that would support the (semi-)automated processes for maintaining EA models.

Finally, A38 identified some shortcomings of the interactive visualization tool supporting their process. Namely, expert feedback suggested autosuggestion features to model conflict resolution, provide touch screen support, and to include comments and annotations in the visualization.

3.3.8 Tools

Both A10 and A22 describe the same approach, thus the authors will refer to A22 as the approach's extended version. A22 illustrates NeXpose: a tool that probes a network architecture for various vulnerabilities, such as poor passwords and software backdoors. It provides information regarding the network architecture in terms of all devices communicating over TCP or UDP (computers, firewalls, and printers). NeXpose can also perform web application scans. The purpose of such a tool is to automatically create EA models based on data collection.

A54 describes how to leverage the SAP Process Integration (PI) enterprise service bus to automate EA documentation. SAP PI is a conglomerate of various dependent components: a central provider of landscape information comprising information about installed, installable software and technical details about the underlying infrastructure; a builder component responsible for designing, creating and maintaining the interactions between the applications; a mapper of runtime communication relationships between the Enterprise Service Builder elements and the actual execution environment; and an integration server responsible for processing incoming messages from sending applications, applying routing and mapping rules, and finally forwarding them to target systems.

A55's approach automatically integrates information about running infrastructure cloud instances to support maintenance of EA models. A55 extends iteraplan, an open-source EAM tool, with a web service interface to push changes that occur in the systems operation layer or in the runtime layer to an EAM view. This integration is achieved by a central model which receives model updates from various sources and pushes new, verified information to the EAM view.

Evaluation A22 uses a case study for validation purposes where NeXpose is applied on a real network. The experimental setup was designed by the Swedish Defense Research Agency, with the support of the Swedish National Defense College. The environment was set to describe a simplified critical information infrastructure at a small electrical power utility.

A54 applies surveys of 19 industry partners on 4 continents to validate the quality of data stored in SAP Process Integration systems in practice and observe the practical application of such tools regarding automated EA documentation.

A55 applies the extended version of the iteraplan tool to a change scenario related to a banking-group. The scenario consists of using the extended iteraplan's functionality as a central integration component that forwards enterprise cloud instance information to iteraplan where the information is immediately rendered to the EA stakeholders. As new cloud instances are created and started up, the central component recognizes these instances and updates iteraplan with the new instances' information, thus keeping the view up to date.

Limitations NeXpose does not deliver complete EA models, despite significantly reducing modeling effort. Also, the validity and reliability of the approach is discussed from two different viewpoints: (1) how much of the meta-model that can be captured, and (2) how accurate a vulnerability scanner is at assessing the instantiated variables. Regarding (1), most of the more modeling intensive concepts are captured with an accurate context. Regarding (2), the scanning accuracy in terms of assessing vulnerabilities is referred to in Holm et al. (2011).

As for A54, the information content of EA models is limited to elements used within the communication processes that utilize the SAP PI system. Also, orphaned data in the SAP PI system pose a problem. This includes elements which are still saved in the SAP PI system but no longer used in practice. Consequently, extracted EA information paints a misleading picture, which does not allow to make appropriate decisions.

Finally, A55 identifies, although in a generic manner, synchronization and meta-model evolution issues that are not, at the time of publication, handled by the central model.

3.3.9 Methods

A9 presents a situational method for semi-automated EA documentation, which aims at figuring out how EA documentation processes can be devised and supported by a tool that optimally supports the information demand and context of a specific organization. This method does not solely focus on automation but also accounts for manual activities and interventions where necessary.

A14 presents a method to handle the evolution over time of EA model elements and relationships that comprise an enterprise blueprint. A14 considers "projects" as the changing elements of enterprise artefacts and uses them as the enablers of automatic blueprint generation and update. The concept of time is also addressed in the approach. In particular, a state_of_existence is described for each enterprise artefact as a means of providing snapshots from past, present, and future architectural scenarios.

A20 provides an exploratory approach to EA maintenance by discussion analogies between chaos theory (CT) and the process of EA planning. In particular, A20 condenses the properties of CT that have been applied to organizational and information systems design and derive implications for EA planning, thus providing assistance in EA model maintenance approaches.

Evaluation A9 validates its method against a set of automation challenges from literature and its authors' own experience. They marked these challenges with the attributes ADDRESSED, PARTLY ADDRESSED, NOT ADDRESSED and NOT RELEVANT according to how well they deem their approach to tackle each specific challenge.

A14 presents a tool that implements the proposed method as a means of validating the applicability of the approach. The Blueprint Management System (BMS) periodically collects information from a variety of sources (project management systems, flat files, and operational systems), and for each artefact type it acts as a master or slave catalogue. When new information is collected, the system generates the blueprints that may have changed since the last generation. BMS was applied in actual companies in banking, telecommunication and retail industries.

Limitations A9 identifies the following limitations: regarding data-specific challenges, only the detection of removed elements is partially addressed. As for transformation challenges, it only partially addresses the challenge of abstraction between the EA model and the imported information from productive systems of the organization. Concerning business challenges, also only one challenge is partially addressed by their method: security vulnerability through monitoring tools in the infrastructure of the organization. Finally, as to tooling challenges, only one challenge is not addressed in A9: analyses have to be decoupled from the meta-model.

A14 argues that since the approach was tested only in the IT domain of large organizations, the usage of the same approach in the business domain or the IT domain of small organizations may pose difficulties. Namely, the approach requires artefacts to become alive and dead in the case of well-known events. With the IT of large organization, these events occur when artefacts are placed into the production environment via well-established procedures. This may not apply to small companies, where the production environment lacks such procedures, and certainly not regarding the business domain, where each employee is part of the production environment, making it almost impossible to trigger well-known events in the organization when business artefacts become alive.

The main limitation of A20 is the fact that due to being a method that has no published validation, one cannot assess the shortcomings of applying it to practical problems.

Table 3 summarizes the outcomes and limitations of the selected EA model maintenance approaches described in Sects. 3.3.1 to 3.3.9.

4 Discussion

This section discusses each research question and identifies the limitations of this study.

4.1 RQ1: Is the number of research contributions from the scientific community increasing?

Although not statistically significant, research on EA model maintenance has increased in the last eight years, as

Table 3 Summary of identified EA model maintenance approaches outcomes and limitations

Approaches	Outcomes	Limitations
Models/meta-models		
A17 (Buckl et al. 2009a)	Object-oriented modelling languages do not provide dedicated means for constructing time- and project-dependent EA models Temporal patterns enable such type of model construction These patterns could be used to augment object-oriented modelling languages to address this issue	A practical validation can present usage impediments due to the complexity of the project dependency modelling Projects affecting the business domain of an EA are not suitable to such an approach that solely focuses on the application landscape
A30 (Gomez et al. 2012)	A30 presents a meta-model strategy to address meta-model runtime load and modifiability A30 implemented their strategy in a graphical editor based on the graphical modelling framework	The editor components of A30 meta-model approach are tightly coupled, making it difficult to include in other tools
A56 (Reschenhofer et al. 2014)	A56 developed a meta-model and untyped core expression language to address the challenge of iterative and collaborative design of the EA meta-model for the static typing of a language for defining EA metrics A prototype of A30 is employed in a German bank, where it is used by enterprise architects for the holistic life-cycle management of organization-specific metrics	A56 lacks an in-depth study in a business environment Non-functional aspects, such as the usability of the prototype and ease-of-learn, require assessment A56 revealed performance issues when performing complex graph algorithms
Viewpoints		
A13 (Da Silva et al. 2017a, b)	A13 defines a viewpoint that attends to the evolution-specific concerns, framed by the underlying elements, which motivate and implement change across the EA description expressing the EA The viewpoint was applied as an extension of the ArchiSurance application architecture gap analysis view	A13 demonstration identified a scalability limitation which can lead to communication and performance analysis issues when applied to complex evolution scenarios
A57 (Buckl et al. 2009b)	A57 presents a viewpoint for road mapping the development of EA over time The viewpoint was used at a telecommunication company and in a slightly modified version at a re-insurance company The viewpoint draws from a pattern-based approach for EA management, thus are not limited to a single utilization context, but form re-usable EA management patterns, which can be integrated into a multitude of organization-specific EA management approaches	A practical validation of the information model supporting the viewpoint is missing
Ontologies		
A23 (Roser and Bauer 2008)	A23's approach of ontology-based model transformation provides technology that fosters interoperability in model exchange and the evolution of model transformations A23 automated generation of mappings offers new possibilities for the integration of domain specific languages and 'legacy' models in a plug&play manner, which makes it easier for new organizations to join collaborations OntMT also supports organizations evolving their modelling techniques and yields more efficient reuse of model transformations and the knowledge that is captured in those transformations	A23 assumes the existence of an appropriate reference ontology, which by itself is a non-trivial task. A lot of factors must be accounted for such as linguistics, probabilistic approaches, and human intervention to obtain a suitable reference ontology
A39 (Diefenthaler and Bauer 2013)	A39 shows that semantic web technologies are capable to perform the gap analysis on a current and target state in both a high level and a detail level A39 proposes how suggestions for a user can be generated from the current state to assist in the modelling of a detailed target state in detail	A39 did not consider the elaboration of metrics to enable a quantitative analysis of both the current and target states A39 requires knowledge of the existing semantic web technologies since these technologies are not ready for use by enterprise architects
A45 (Silva et al. 2017a, b)	A45 hypothesizes that the use of ontologies can be a possible and adequate approach for capturing EA model evolution A45 proposed ontology was built on architecture principles for enforcing coherence, model conformance, analysis capabilities and ontological integration of stakeholder viewpoints A45 was implemented and demonstrate in a case study that addressed the research problem by showing both the extensibility and analysis capabilities offered by the approach	A45 neither can handle nor analyze different ontologies and modelling languages A45 lacks an integrated visualization of the different ontologies and analysis outcomes

Table 3 continued

Approaches	Outcomes	Limitations
Frameworks		
A6 (Hacks and Lichter 2018)	A6 redefined the P^2AMF framework by generalizing it from a its UML/OCL notation to a graph presentation, thus enabling its application to EA models like ArchiMate A6's approach adds competing scenarios and versioning along a time series to meet the requirements of a distributed EA evolution A6 framework extension was implemented on a Neo4j graph database	A6 lacks integration with existing EA tools and mechanisms that could handle a change of an included state or the addition of a state between two existing sates of the EA model
A21 (Binz et al. 2013)	A21 proposes an approach to discover and maintain Enterprise Topology Graphs that help to adapt, analyze, and optimize the enterprise IT The framework enables the integration of existing tools into a unified model by reconciling information of different sources A21 implemented the framework and 21 discovery plugins, which were then validated and evaluated by discovering four scenarios	Four scenarios are not statistically significant enough to derive sound conclusions regarding the framework's practical applicability
A37 (Wolff 2016)	A37 presents a dedicated framework to control enterprise modelling based on the concept of evaluation chains A37 developed the evaluation chains with the ADOxx meta-modelling toolset that supports discourse and other activities in the evaluation of enterprise modelling of large organizations The framework was designed based on the collaboration of specialists who need support for numerous specific valuations and decisions on diverse characteristics of enterprise modelling processes The crucial facet of A37's approach is the adaptive partitioning of the evaluation into utilization perspectives, which is supplemented by the reference evaluation chains that can be changed and adapted for specific usages of enterprise models in an organization	A37 requires high evaluation efforts
A42 (Dam et al. 2016)	A42 proposes a framework, composed of a new enterprise architectural description language and toolkit, which provides (semi)automated support for propagating further changes across an EA model after certain initial changes have been made The underlying change propagation framework of ChangeAwareHierarchicalEA automatically generates repair plans from consistency and well-formedness rules defined in Alloy, which in turn are the drivers of propagating further changes	A42 only addresses the services, information processing and the organization of the enterprise being modelled A42 neither considers the aspects of strategy, goals, and vision of EA models nor the non-functional aspects such as finance, governance, quality of services, security, database, network, system interoperability and low-level software design
Algorithms		
A19 (Guerreiro et al. 2016)	A19 proposes a stochastic algorithm, grounded in Markov Decision Processes theory, that supports an EA-driven organizational evolution process A19 argues that the benefit of having a fully informed decision-making solution is the capability to empower the organizational decisions with tools to forecast the impacts in the near/middle/long-terms for the organization A19 remarks that a stochastic approach does not address unknown exception situations; however, it covers a significant part of the reality of how actors behave within their social and human interactions A19's solution is able to show the valuation throughout the intermediate EA evolution stages. Therefore, the organization is able to forecast not only the final valuation to be achieved, but also the value that will be returned throughout time	A19 has not been applied to a real case
A24 (Johnson et al. 2016)	A24 proposes dynamic Bayesian networks (DBNs) for automatic Enterprise Architecture modeling DBNs are probabilistic, hence able to capture the inherent and relevant uncertainty that surrounds the knowledge of both as-is and to-be architectures Bayesian Networks model causal dependencies, so that the probability of one phenomenon can be conditioned on another. These causal relationships are extremely valuable when attempting to infer the actual state of the world, as it allows intelligent use of indirect measurements DBNs are dynamic, so they are able to represent the time-dependent nature of the architecture	A24 does not gather all the required information for a complete EA model

Table 3 continued

Approaches	Outcomes	Limitations
A25 (Silva et al. 2016)	A25 specifies a set of migration rules for turning the manual task of migrating EA models into a faster, automatic process A25 contributed to an automatic migration process involving various organizational elements, affected during an EA development project, based on their respective lifecycle states (*gestating*, *alive*, *dead*, and *retired*) A25's approach was implemented in an EA vendor-specific tool to demonstrate its correctness and applicability using the EA of the ArchiSurance case study as migration subject. The migration task was completed with no errors	A25 is only implementable by tools that follow an object-oriented paradigm A25 is not complete regarding the co-evolution scenarios A25 needs further testing within complex organizations to provide more conclusive results on performance and scalability
A34 (Franke et al. 2009)	A34 shows how techniques from information theory and learning classification trees can be employed to maintain and manage metamodels for Enterprise Architecture-based decision making A34 described how these techniques can be used to achieve greater analytical capabilities within the EA discipline by applying them to a number of closely related applications, which were illustrated and validated by examples based on real data	A34 discusses a set of examples where uniform and complete data sets have been used, which in reality, these conditions are rarely fulfilled As EA meta-models are maintained, old data no longer complies with the new The problem of overfitting is a prevalent one in machine learning algorithms
A50 (Lautenbacher et al. 2013)	A50 proposes a solution of how to close the gap between a current and a target architecture by identifying the successor relationships between the architectural states and determined transformation paths in terms of sequences of concrete actions A50's approach is designed to support the enterprise architect in the task to find a way how to reach a defined target, starting with the current architecture A50 enables the consideration of the complex dependencies between the architectural elements and thus reduces changes in project plans later on because of overlooked dependencies The outcome of this solution, the transformation path, can be used to define the projects which will implement the changes	A50 does not cover other architecture layers of the EA A50 does not cover more abstract target architecture models as a starting point
Requirements		
A7 (Välja et al. 2015)	A7 presents a set of architecture and data requirements to automate enterprise IT architecture modeling using multiple data sources A7's approach builds on the four-stage model of information processing automation, namely, data acquisition, data analysis, decision and action selection, and action implementation To demonstrate the applicability of the approach, A7 presents potential data sources and includes a study using two of such sources The study shows that it is possible to use enterprise IT data to create enterprise IT architecture models from multiple sources that are timely and scalable	A7 neglects the implementation specific details, which hinders the usage of their approach as a guideline for concrete implementations A7 only supports a specific type of models. These models have a predefined ontology and have been created more for analysis rather than documentation purposes A7 needs to be implemented manually without the support of data mining or computational intelligence techniques
A44 (Hofer 2013)	A44 presents six requirements for modelling transformation from an application-oriented point of view that focuses on how an application landscape is used in business processes A44 argues that it would be beneficial for modelling approaches to meet these requirements An evaluation of existing modelling approaches showed that some approaches provide means to fulfil some of these requirements, although none of the approaches met all the requirements	A44 only focus on the application landscape, thus not taking into account other layers of EA like the business and technology layers
A51 (Farwick et al. 2011a)	A51 presents a list of requirements for a tool and a method to facilitate automated EA maintenance A51 discussed possible success evaluation criteria for such a solution A51 sees these requirements as the starting point for further development of a method and technical solution for automated EA maintenance	A51 was not validated in practice

Table 3 continued

Approaches	Outcomes	Limitations
Processes		
A2 (Fischer et al. 2007)	A2 presents a federated process to address EA model maintenance One major finding from implementing a federated approach to maintain EA models is that the integration of existing models from specialized architectures strongly influences the acceptance of EA as a management tool The integration of model data from specialized architectures into the EA repository is an ongoing process rather than a one-time effort, hence being necessary to monitor the quality of model data from source systems continuously – particularly regarding their consistency	A2 argues that despite the need for a tool extension towards supporting their process-based approach, such automation of model data updates may not be reasonable for every specialized architecture model
A27 (Farwick et al. 2011b)	A27 proposes several processes for semi(automated) enterprise architecture model maintenance These processes aim to reduce manual work for EA model maintenance and to increase data quality attributes such as consistency and actuality The basis for the processes is formed by a set of requirements gathered from a survey, interviews with EA practitioners, and from the authors own experience	A27 did not implement and test the possible integration data collection interfaces that would support the (semi-)automated processes for maintaining EA models
A38 (Roth et al. 2013)	A38 describes a conflict resolution process, supported by an interactive visualization, that can be used to resolve model conflicts A38 evaluates its approach based on a prototype and interviews with EA domain experts The proposed solution can improve existing EA documentation efforts in organizations and is one building block towards automated EA documentation A38's approach can be combined with other solutions that technically raise the level of abstraction and provide recommendations for mapping tasks to assist end-users	A38 identified some shortcomings on the interactive visualization tool supporting their process. Namely, expert feedback suggested autosuggestion features to model conflict resolution, provide touch screen support, and to include comments and annotations in the visualization
Tools		
A10 (Buschle et al. 2011)	A10 presents an extension to an existing tool that allows the automatic generation of elements for EA models A10's implementation is generic even though CySeMol, a meta-model for security analysis, was used as a running example The data gained from the vulnerability scanner can be used to instantiate any meta-model, once a mapping has been defined A10 presented a practical application based on real data of their implementation	The accuracy in terms of assessing software, operating systems and such was not examined in A10's approach
A22 (Holm et al. 2014)	A22 proposes a tool that supports a method for automatic generation of EA models with respect to the complex IT architectures of enterprises The approach mapped the meta-model of ArchiMate to the output of automatic network scanners A22 offers reliable results, especially when the scanner is given system credentials. The generated entities can represent different ArchiMate interpretations, depending on the stated requirements	A22 does not deliver complete EA models, despite significantly reducing modelling effort The validity and reliability of the approach is discussed from two different viewpoints: (1) how much of the meta-model that can be captured, and (2) how accurate a vulnerability scanner is at assessing the instantiated variables
A54 (Grunow et al. 2013)	A54 argues that SAP PI systems seem to be suitable and a reasonable starting point for an automated EA documentation endeavor Nonetheless, it cannot be generalized, and further research of productive IT environments is necessary to show the real potential of an automated EA documentation	The information content of EA models is limited to elements used within the communication processes that use the SAP PI system Orphaned data in the SAP PI system pose a problem. This includes elements which are still saved in the SAP PI system but no longer used in practice
A55 (Farwick et al. 2010)	A55 presents an approach towards automated integration of the open-source EAM tool iteraplan and private or public infrastructure cloud to support enterprise architects with EA model maintenance This integration is achieved via push and pull protocols to and from a central model, that is also synchronized with a project management tool to distinguish between planned and unplanned changes on the cloud infrastructure	A55 has synchronization and meta-model evolution issues that are not handled by the central model

Table 3 continued

Approaches	Outcomes	Limitations
Methods		
A9 (Farwick et al. 2015)	A9 presents a method to support the information demand and context of a specific organization The approach does not solely focus on automation, but also accounts for manual activities and interventions where necessary The method and its model maintenance techniques cover architecture elements on all different layers of the EA, ranging from business to IT infrastructure The presented case study showed the practical applicability of the method to create a viable, useful and tool-supported documentation process at an insurance company A9 work impacts practice from two different angles. First, EA practitioners might use the presented techniques and in particular the assembly method in order to analyze and enhance their documentation strategies. Second, tool vendors might recognize the importance of process support in order to enhance their offerings with the presented techniques	Regarding data-specific challenges, only the detection of removed elements is partially addressed As for transformation challenges, they only partially address the challenge of abstraction between the EA model and the imported information from productive systems of the organization Concerning business challenges only one challenge is partially addressed by their method: security vulnerability through monitoring tools in the infrastructure of the organization; About tooling challenges, only one challenge is not addressed in A9: analyses have to be decoupled from the meta-model
A14 (Sousa et al. 2009)	A14 presents a method for managing architectural blueprints automatically Such method changed the way IT project managers work: before, they did project budgeting and planning first and then they think about the architectural representations A14's approach was applied in actual companies from the banking, telecommunication and retail industries. In some cases, A14 aim at zero effort blueprints, since they are automatically generated based on information that flows between different communities in the organization, mostly between IT Architecture, and IT Project Management	A14 argues that since the approach was tested only in the IT domain of large organizations, the usage of the same approach in the business domain or the IT domain of small organizations may pose difficulties
A20 (Saat et al. 2009)	A20 discusses analogies between Chaos Theory (CT) and EA planning and contribute to a better understanding of the complexity of dynamics in EA planning by deriving requirements for EA planning methods A20's contribution is explanatory for the time being, and not construction oriented because no solutions to the addressed problems are implemented. Yet the findings enhance the existing knowledge base in the field of EA planning and may provide guidance for method construction Experiences from industry projects confirm that EA models need to remain on an aggregated level instead of modelling very detailed structures. It is vital to adhere to this constraint in order to preserve an acceptable cost/benefit ratio of EA A20 research does not aim at applying mathematical models from CT to EA as opposed to natural sciences. However, they hypothesize that the phenomena and characteristics described by CT support the construction of useful methods for EA planning	A20 has no validation, thus one cannot assess the shortcomings of applying such method to practical problems

shown in Fig. 3. The linear prediction trend line also supports the argument of increased research efforts towards approaches that address the challenges of EA model maintenance and evolution. This growing number of research contributions in recent years should be considered by researchers as an opportunity to further expand the EABOK on the subject.

Moreover, today's technological trends that foster digital transformation within enterprises may have the potential to impact the direction of future research regarding EA model maintenance. To further understand the way these trends may guide future research on the topic, the authors have analyzed two articles on top technology trends: 'Gartner Top 10 Strategic Technology Trends for 2019'[4] by Gartner and 'The Top Technology Trends to Watch: 2018–2020'[5] by Forester. Both articles enumerate a set of 10 technology trends mapped to two frameworks.

Gartner's framework, entitled 'intelligent digital mesh' classifies each identified trend within three interrelated domains:

[4] https://www.gartner.com/smarterwithgartner/gartner-top-10-strategic-technology-trends-for-2019/.

[5] https://go.forrester.com/blogs/top-technology-trends-2018-2020/.

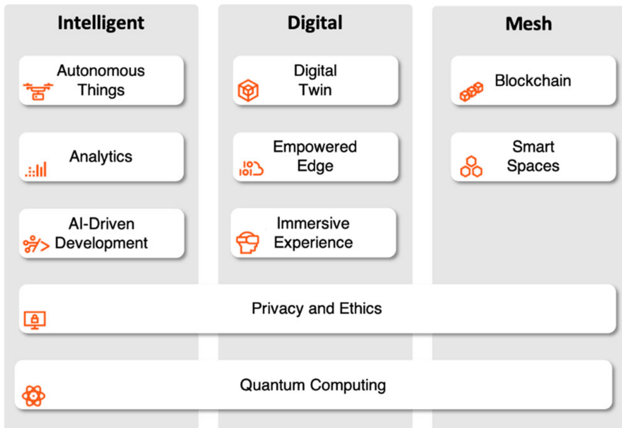

Fig. 6 Gartner's top 10 technology trends

- *Intelligent* The presence of AI in all existing technology, creating entirely new categories;
- *Digital* The blend of both the digital and physical world to create an immersive world;
- *Mesh* The exploitation of connections between expanding sets of people, businesses, devices, content and services.

Figure 6 illustrates the mapping of each trend to one of the three domains.

Forrester's framework consists of three trend phases which the identified trends are mapped to: dawning, awareness, and acceptance. Dawning trends are the ones understood by a few visionaries as having the power to disrupt and transform the business. Examples for such trends are: *Internet of Things (IoT) shifts to computing towards the edge, distributed trust systems challenge centralized authorities*, and *automated security intelligence and breach response unshackle S&R*. Trends in the awareness phase consist of trends that enterprises are aware of but are still grappling with; examples of such trends are: *software learns to learn,* and *customer experience becomes immersive*. Finally, trends in the acceptance phase are trends that most organizations are on top of; examples of these are: *Contextual privacy boosts brand value,* and *the public cloud accelerates business innovation*.

The authors conducted a comparison between both the reported trends and the identified categories of the identified EA model maintenance primary studies. The goal of this cross-correlation was to unveil which technology trends would have the biggest impact in the direction of future research category-wise. Table 3 illustrates that correlation.

By associating the information illustrated in Table 4 with the findings from Fig. 5, the authors concluded that novel algorithms and frameworks, implemented as tools that support EA model maintenance and evolution, are two of the identified categories of approaches that best synergize with the emerging technology trends.

4.2 RQ2: What categories of approaches exist in the scientific literature?

From the 31 selected approaches, the authors were able to categorize each one into nine categories. The authors argue that the categorization of these approaches allows for a better frame of comparison between the different categories. Moreover, the categorization presented in this study may be of help to academics and practitioners by identifying the limitations of the existing approaches and guidelines for future research. The authors recognize the possibility of bias throughout the content analysis due to the underlying subjectivity of the person performing the analysis. Hence, to mitigate categorization bias, each author conducted the detailed coding of each paper individually and separately.

Of the nine identified categories, four approaches were identified as *Models/Meta-Model*, two as Viewpoints, three as Ontologies, four as Frameworks, five as Algorithms, two as Requirements, three as Processes, four as Tools, and three as Methods. Notwithstanding, the authors acknowledge the possible existence of other categories of EA model maintenance approaches that, due to the limitations identified in Sect. 4.4, were not considered in this study.

4.3 RQ3: What are the open challenges and areas of improvement in the scientific literature?

Most approaches present a set of guidelines for future work that should encourage readers to extend the EABOK regarding the subject. However, it is relevant to understand which open challenges are in line with the identified technology trends that drive future research directions. Therefore, the authors selected the challenges reported by the primary studies on both the algorithm and framework categories of approaches. This choice has to do with these categories being the two that received the most attention from researchers in recent years (see Fig. 5), besides being aligned with Gartner's and Forester's technology trends (see Table 4).

Table 5 identifies the open challenges reported by each framework and algorithm-based approach. Some of these open challenges suggest a connection with the identified technology trends, thus emphasizing their importance towards future research. As an example, challenges identified by A19 go in line with augmented analytics and AI-driven development as trends supporting the new digital employee workforce and employee experience, whereas challenges such as the ones presented by A24 are aligned with AI-driven development as a means to provide

Table 4 Comparison of technology trends and identified EA model maintenance approaches

Trends (Forester)	Trends (Gartner)	EA model maintenance Approach
Internet of Things (IoT) shifts to computing towards the edge	Autonomous Things Digital Twin Smart Spaces	Tools Algorithms
Distributed trust systems challenge centralized authorities	Blockchain	Algorithms
Automated security intelligence and breach response unshackle S&R	Quantum Computing AI-Driven Development	Tools Algorithms
Employee experience redefines apps	Augmented Analytics	Algorithms
Software learns to learn	AI-Driven Development	Algorithms
Digital employees enter the white-collar workforce	Autonomous Things Digital Twin Augmented Analytics	Tools Algorithms
Insights-driven firms outpace competitors	Augmented Analytics	Algorithms
Customer experience becomes immersive	Immersive Experience	Tools
Contextual privacy boosts brand value	Privacy and Ethics	Frameworks Requirements
The public cloud accelerates business innovation	Empowered Edge	Tools Frameworks Methods

Table 5 Open challenges of the identified studies based on frameworks and algorithms

Category	Approach	Challenges
Framework	A37 (Wolff 2016)	How to enhance the proposed evaluation chains approach?
	A42 (Dam et al. 2016)	How to deal with changes in the landscape of strategic alignment?
Algorithm	A19 (Guerreiro et al. 2016)	How can business intelligence, business analytics, process mining, and event calculus be applied as an alternative support for the reported dynamic decision-making process?
	A24 (Johnson et al. 2016)	How to increase the (in)accuracies of the used sensors and the time-dependent behavior without human intervention?
		How to address active data collection in a way that the system controls parts of the data collection process as a means of improving the knowledge of the state?
		How to effectively filter relevant information from the background noise captured by the data collection tools and methods?
	A50 (Lautenbacher et al. 2013)	How to enable a more abstract target architecture to provide support for the consideration of resource constraints and value-based weighting of the transformation steps?

automated security and network intelligence and breach responses. By proposing novel algorithms and frameworks lined with these and other technology trends, both researchers and practitioners can become capable of implementing tools that automatically, dynamically, and continuously feed the organization's EA repository and as a result, its EA model.

4.4 Study Limitations

According to the guidelines from Webster and Watson (2002), Kitchenham and Charters (2007) and Kitchenham et al. (2008), the authors outline seven limitations for this study:

- The search was organized as a manual search process of specific online databases complemented with specific journals in the area of enterprise modelling. This search was conducted during the mentioned period from January 2019 to March 2019. Hence, this implies that the authors may have missed some relevant studies that were published after the period of search or published in journals or conferences which were not indexed in the selected databases.

- Since the search was carried out on the selected databases and journals, it is possible that some related resources were not included in this SLR due to the type of paper, such as own technical report, or privacy and security reasons.
- Another limitation derived from the screening process: due to filtering criteria restrictions possible articles could have been excluded. For example, the authors might have disregarded potentially applicable articles as their title and abstract was not suggestive enough regarding EA model maintenance.
- In the first screening step only the articles that were omitted by all the authors were actually excluded. Exclusion was based on the title, assuming that one or more articles would not be missed if the abstract filtering had been carried out previous to this step. This decision was due to the very large number of search results from the search string.
- The keyword selection by itself also poses potential limitations to this study. The authors could have achieved different results if more keywords related to maintenance and evolution had been chosen.
- The study only addresses peer-reviewed scientific contributions, which also poses a limitation by not covering potentially relevant approaches documented in practice-oriented forums, such as white papers or other types of documentation.
- In line with the above limitations, the authors recognize that the review may lack a complete list of categories regarding all the existing EA model maintenance approaches.
- Finally, the level of intersubjectivity of the coding for category identification is limited to the number of authors of this study. This poses the risk of increasing categorization bias, although the articles explicitly identify their approach.

Notwithstanding these limitations, the authors argue that the identified corpus of knowledge may be considered representative of the EA model maintenance approaches published in the most renowned journals and scientific forums of the area.

5 Related Work

To the best of the authors' knowledge, no literature review has yet focused on providing a comprehensive overview of the existing EA model maintenance approaches. Nonetheless, two studies need reference regarding the topic of EA documentation.

The first study conducted by Winter et al. (2010) presents empirical evidence on the scarcity of EA documentation mechanisms. Their findings show that there are different ways in which EA information can be gathered and maintained. From all the survey respondents, 29.4% state that collecting and maintaining EA data is a task done centrally and individually by the EA department. An equivalent percentage of informants affirms that these activities are conducted exclusively and locally by the respective divisions (Winter et al. 2010).

Furthermore, 45.1% of the respondents collect and maintain EA data manually, 21.6% of the respondents' enterprises employ a combination of manual and semi-automated techniques, and 5.9% of the informants' companies have established a combination of manual, semi-automated, and automated modes for collecting and maintaining EA information. These findings lead to the conclusion that a total of 72.6% of the survey participants still entirely rely on manual maintenance of their EA model (Winter et al. 2010).

The second study by Farwick et al. (2013) presents an empirical analysis of the critical problems in EA documentation as well as the appropriateness of specific EA information sources for automation concerning provided data types and data quality. The survey confirms that despite EA model maintenance standing out as one of the most significant problems in EA practice, only some enterprises benefit from automation to reduce the amount of manual data collection. This results from the fact that only a few organizations consider direct data integration between information systems and the EA tool (Farwick et al. 2013).

Farwick et al. also provide remarks on a particular issue regarding both the information sources describing the upper EA-layers and the EA tools: most of their data is manually maintained. This problem compromises the up-to-dateness, correctness, and completeness of the EA models that are heavily dependent on the maintenance process in a given enterprise. Their study reveals that "each organization needs to weigh the cost of implementing automation against the cost of manual data collection".

Both studies identify the need for approaches that are able to handle the EA documentation task and maintenance automatically, thus mitigating the propensity for error and time consumption of manually executing the task. Consistent with the rationale of both studies, the set of primary approaches presented in this study and their respective categorization provide a comprehensive reference that may be able to answer the questions posed in previous studies.

A review study on EA Implementation Methodologies (EAIM) that addresses the maintenance aspect of EAs (Rouhani et al. 2015) was also identified. In particular, problems such as keeping the EA repository up-to-date, the complexities of maintaining artefacts, and the specification and operationalization of detailed maintenance processes are yet to be adequately addressed.

6 Conclusions

The goal of this review was to investigate and identify the different categories of approaches used to provide adequate maintenance for EA models. Results reveal that each of the 31 analyzed approaches can be classified into one of nine categories.

Results were able to extend the EABOK by providing comprehensive information on the existing approaches to EA model maintenance. Moreover, the results suggest that research on this topic has been increasing over the recent years. This increasing number of contributions might present a research opportunity to design novel and practical approaches that reduce the effort of maintaining EA models. Likewise, the results provide a frame of reference to researchers who want to explore other approaches based on the identified types of EA model maintenance approaches or even contribute with novel types of approaches, with the potential to be more effective than the existing ones.

An interesting extension of this study would be to empirically verify the level of effectiveness and cost–benefit of each type of approach by defining a set of validated metrics that could address both concerns. Also, despite being out of the scope of this research, an interesting task would be to analyze possible correlations between identified categories that could promote integration or cause potential conflicts between the different approaches.

Finally, the limitations of this SLR should also be considered as future work challenges. In particular, a complementary study could be conducted focused on EA model maintenance approaches from an EA practice standpoint. This would especially be accomplished by methods and approaches proposed by leading practitioners, vendors, or standard bodies reported in terms of patents, books, white papers, and tool implementations. The findings could then be used in contrast with the academic findings of this study and enable a comparison between both lines of contributions regarding their response to real-world market and organizational needs.

To conclude, the authors would like again to stress this thought: nowadays, as EA is becoming a more established practice within enterprises, EA model maintenance must be considered as an essential aspect of EAM. Hence, it requires a proper and extensive analysis and planning, as well as the execution of the best approach (or set of approaches) to reduce the amount of effort required to keep such models up to date while maintaining the consistency and data quality of the EA models. The authors argue that an appropriate awareness and respective action towards the adequate maintenance of EA models can support a more mature and effective practice of EA within organizations.

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References

Binz T, Breitenbücher U, Kopp O, Leymann F (2013) Automated discovery and maintenance of enterprise topology graphs. In: 6th International Conference on Service-Oriented Computing and Applications. IEEE, Koloa, pp 126–134

Buckl S, Ernst AM, Matthes F, Schweda CM (2009a) An information model capturing the managed evolution of application landscapes. Springer, Heidelberg

Buckl S, Ernst AM, Matthes F, Schweda CM (2009b) Visual roadmaps for managed enterprise architecture evolution. In: 10th Conference on software engineering, artificial intelligence, networking and parallel/distributed computing. IEEE, Daegu, pp 352–357

Buschle M, Holm H, Sommestad T, Ekstedt M, Shahzad K (2011) A tool for automatic enterprise architecture modeling. In: 23rd International conference on advanced information systems engineering. Springer, Heidelberg, pp 1–15

Da Silva NMC, Da Silva MLBM, De Sousa PMVA (2017) A viewpoint for analyzing enterprise architecture evolution. In: 21st International enterprise distributed object computing conference. IEEE, Québec City, pp 20–29

Dam HK, Lê LS, Ghose A (2010) Supporting change propagation in the evolution of enterprise architectures. In: 14th International enterprise distributed object computing workshop. IEEE, Vitória, pp 24–33

Dam HK, Lê LS, Ghose A (2016) Managing changes in the enterprise architecture modelling context. Enterp Inf Syst 10:666–696

Diefenthaler P, Bauer B (2013) Gap analysis in enterprise architecture using semantic web technologies. In: 15th International conference on enterprise information systems. IEEE, Angers, pp 211–220

Farwick M, Agreiter B, Breu R, Häring M, Voges K, Hanschke I (2010) Towards living landscape models: automated integration of infrastructure cloud in enterprise architecture management. In: 3rd International conference on cloud computing. IEEE, Miami, pp 35–42

Farwick M, Agreiter B, Breu R, Ryll S, Voges K, Hanschke I (2011a) Requirements for automated enterprise architecture model maintenance. In: 13th International conference on enterprise information systems. IEEE, Beijing, pp 325–337

Farwick M, Agreiter B, Breu R, Ryll S, Voges K, Hanschke I (2011b) Automation processes for enterprise architecture management. In: 15th International enterprise distributed object computing workshop. IEEE, Helsinki, pp 340–349

Farwick M, Pasquazzo W, Breu R, Schweda CM, Voges K, Hanschke I (2012) A meta-model for automated enterprise architecture model maintenance. In: 16th International enterprise distributed object computing conference. IEEE, Beijing, pp 1–10

Farwick M, Breu R, Hauder M, Roth S, Matthes F (2013) Enterprise architecture documentation: empirical analysis of information sources for automation. In: 46th Hawaii international conference on system sciences. IEEE, Wailea, pp 3868–3877

Farwick M, Schweda CM, Breu R, Hanschke I (2015) A situational method for semi-automated enterprise architecture documentation. In: 18th International conference on model driven engineering languages and systems. ACM/IEEE, Ottawa, p 448

Fischer R, Aier S, Winter R (2007) A federated approach to enterprise architecture model maintenance. Enterp Model Inf Syst Archit 2:9–22

Franke U, Ullberg J, Sommestad T, Lagerstrom R, Johnson P (2009) Decision support oriented enterprise architecture metamodel management using classification trees. In: 13th International enterprise distributed object computing workshop. IEEE, Auckland, pp 328–335

Glaser BG, Strauss AL (1967) The discovery of grounded theory: strategies for qualitative research. Routledge, Abingdon

Gomez P, Sanchez M, Florez H, Villalobos J (2012) Co-creation of models and metamodels for enterprise architecture projects. In: Extreme modeling workshop, satellite event of the 15th international conference on model driven engineering languages and systems. ACM/IEEE, Innsbruck, pp 21–26

Grunow S, Matthes F, Roth S (2013) Towards automated enterprise architecture documentation: data quality aspects of SAP PI. In: Morzy T, Härder T, Wrembel R (eds) Advances in databases and information systems. Springer, Heidelberg, pp 103–113

Guerreiro S, Gaaloul K, Franke U (2016) Analysis of enterprise architecture evolution using Markov decision processes. In: 12th International workshop on enterprise and organizational modeling and simulation. Ljubljana, Springer, pp 37–51

Hacks S, Lichter H (2018) A probabilistic enterprise architecture model evolution. In: 22nd International enterprise distributed object computing conference. IEEE, Stockholm, pp 51–57

Hofer S (2013) Modeling the transformation of application landscapes. In: IFIP Working Conference on The Practice of Enterprise Modeling. Springer, Heidelberg, pp 101–113

Holm H, Sommestad T, Almroth J, Persson M (2011) A quantitative evaluation of vulnerability scanning. Inf Manag Comput Secur 19:231–247

Holm H, Buschle M, Lagerström R, Ekstedt M (2014) Automatic data collection for enterprise architecture models. Softw Syst Model 13:825–841

Johnson P, Ekstedt M, Lagerstrom R (2016) Automatic probabilistic enterprise IT architecture modeling: a dynamic Bayesian networks approach. In: 20th International enterprise distributed object computing workshop. IEEE, Vienna, pp 122–129

Johnson P, Ullberg J, Buschle M, Franke U, Shahzad K (2014) An architecture modeling framework for probabilistic prediction. Inf Syst E-Bus Manag 12:595–622

Kaisler SH, Armour F, Valivullah M (2005) Enterprise architecting: critical problems. In: 38th Annual Hawaii international conference on system sciences. IEEE, Big Island, p 224

Kandjani H, Bernus P (2012) The enterprise architecture body of knowledge as an evolving discipline. In: 14th International conference on enterprise information systems. Springer, Heidelberg, pp 452–470

Kitchenham B, Brereton OP, Budgen D, Turner M, Bailey J, Linkman S (2008) Systematic literature reviews in software engineering – a systematic literature review. Inf Softw Technol 51:7–15

Kitchenham B, Charters S (2007) Guidelines for performing systematic literature reviews in software engineering. EBSE Technical Report, Keele University and University of Durham

Lankhorst M (2013) Enterprise architecture at work: modelling, communication, and analysis, 3rd edn. Springer, Heidelberg

Lautenbacher F, Diefenthaler P, Langermeier M, Mykhashchuk M, Bauer B (2013) Planning support for enterprise changes. In: Working conference on the practice of enterprise modeling. Springer, Heidelberg, pp 54–68

Lucke C, Krell S, Lechner U (2010) Critical issues in enterprise architecting – a literature review. In: 16th Americas conference on information systems. AIS, Lima, pp 1–11

Matthes F, Neubert C, Steinhoff A (2011) Hybrid Wikis: empowering users to collaboratively structure information. In: 6th International conference on software and data technologies, Springer, Seville, pp 250–259

Mitchell TM (1997) Machine learning. McGraw-Hill, New York

Peffers K, Tuunanen T, Rothenberger MA, Chatterjee S (2008) A design science research methodology for information systems research. J Manag Inf Syst 24:45–77

Reschenhofer T, Monahov I, Matthes F (2014) Type-safety in EA model analysis. In: 18th International enterprise distributed object computing workshop. IEEE, Ulm, pp 87–94

Roser S, Bauer B (2008) Automatic generation and evolution of model transformations using ontology engineering space. J Data Semant XI:32–64

Roth S, Hauder M, Michel F, Münch D, Matthes F (2013) Facilitating conflict resolution of models for automated enterprise architecture documentation. In: 19th Americas conference on information systems. AIS, Chicago, pp 1662–1672

Rouhani BD, Mahrin MN, Nikpay F, Ahmad RB, Nikfard P (2015) A systematic literature review on enterprise architecture implementation methodologies. Inf Softw Technol 62:1–20

Saat J, Aier S, Gleichauf B (2009) Assessing the complexity of dynamics in enterprise architecture planning – lessons from chaos theory. In: 15th Americas conference on information systems. AIS, San Francisco, pp 1–8

Silva NMC, Mira da Silva MLB, Sousa PMMVA (2017) Modelling the evolution of enterprise architectures using ontologies. In: 19th Conference on business informatics. IEEE, Thessaloniki, pp 79–88

Silva N, Ferreira F, Sousa P, Da Silva MM (2016) Automating the migration of enterprise architecture models. Int J Inf Syst Model Des 7:72–90

Sousa P, Lima J, Sampaio A, Pereira C (2009) An approach for creating and managing enterprise blueprints: a case for IT blueprints. In: Albani A, Dietz J (eds) Advances in enterprise engineering III. Springer, Heidelberg, pp 70–84

Studer R, Benjamins V, Fensel D (1998) Knowledge engineering: principles and methods. Data Knowl Eng 25:161–197

Tribolet J, Sousa P, Caetano A (2014) The role of enterprise governance and cartography enterprise engineering. Enterp Model Inf Syst Archit 9(1):38–49

Välja M, Lagerström R, Ekstedt M, Korman M (2015) A requirements based approach for automating enterprise IT architecture modeling using multiple data sources. In: 19th International enterprise distributed object computing conference workshops and demonstrations. IEEE, Adelaide, pp 79–87

vom Brocke J, Simons A, Niehaves B, Riemer K, Plattfaut R, Cleven A (2009) Reconstructing the giant: on the importance of rigour in documenting the literature search process. In: 17th European conference on information systems. AIS, Verona, pp 2206–2217

Webster J, Watson RT (2002) Analyzing the past to prepare for the future: writing a literature review. MIS Q 26:xiii–xxiii

Winter K, Buckl S, Matthes F, Schweda C (2010) Investigating the state-of-the-art in enterprise architecture management method in literature and practice. In: 5th Mediterranean conference on information systems. AIS, Tel Aviv, pp 1–12

Wolff F (2016) Evaluation chains for controlling the evolution of enterprise models. In: Karagiannis D, Mayr H, Mylopoulos J (eds) Domain-specific conceptual modeling. Springer, Cham, pp 313–332