CONCEPTUALIZING EA CITIES: TOWARDS VISUALIZING ENTERPRISE ARCHITECTURES AS CITIES

Research paper

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Abstract

Enterprise Architectures (EAs) are commonly visualized in the form of text, numbers, tables, graphs, models, and diagrams. These information visualization types are used to describe EAs in today's organizations, but often lack an intuitive representation. In this paper, we provide another form of EA visualization utilizing the city metaphor. This spatial metaphor is suitable for visualizing complex information structures and potentially facilitates easy understanding of EAs, especially for non-IT staff. Based on a literature review and three rounds of open card sorting, we mapped eleven classes of EA objects to city elements. Our results enabled us to develop a formal language that allows an implementable and human-readable specification of various views, which we call EA City. We created an early stage 3D EA City prototype to demonstrate its applicability. Our model provides a solid foundation for further work on the city metaphor in the context of EA visualization.

Keywords: Enterprise Architecture Management, Enterprise Architecture Visualization, City Metaphor

1 Introduction

In the digital world, in order to stay competitive, it is increasingly important for businesses to react quickly to environmental changes and new customer needs. Hence, understanding, developing and managing organizational complexity is critical to a company's success (Nightingale and Rhodes, 2004). To better understand the entire organizational landscape and its interrelations, to manage its complexity, drive transformation projects, and support innovation, a suitable approach is to apply Enterprise Architecture Management (EAM) (Lange and Mendling, 2011). EAM provides methods and tools to establish, maintain, and develop Enterprise Architectures (EAs), which are representations of time-dependent fundamental structures and relationships between business and IT components of organizations (Tamm, Seddon, Shanks and Reynolds, 2011; Aier, Gleichauf and Winter, 2011). In previous years, many researchers as well as practitioners described EAs in, e.g., the form of text documents, matrices, layers, bar charts or pie charts (Roth, Zec and Matthes, 2014), and as consisting of entities like processes, applications and computer hardware (The Open Group, 2018). Understanding complex information by employing specific visualizations is important for effective EA analysis.

Following Baker et al. (2009), there are four aspects to individual sensemaking of complex information using information visualization, namely the support of basic visual perceptual approaches, the support for Gestalt qualities, consistency with existing knowledge, and support for analogical reasoning.

Although current EA visualization types take the first three aspects into account (e.g. Roth et al., 2014), metaphors, which are facilitators of analogical reasoning (Johnson and Lakoff, 1980), are only limitedly used. This is surprising, as the use of metaphors "can make the structure of information systems easier to understand and therefore easier to use" (Dieberger and Frank, 1998). One specific type of metaphor that makes use of spatial patterns, locations and movements to transport meaning, is the spatial metaphor (Gärdenfors, 2000). Spatial metaphors are able to activate cognitive capabilities of the human mind that enable spatial orientation and a sense of bodily movement, as well as the perception and understanding of conceptual meaning (Lakoff, 1987; Johnson and Lakoff, 1999). This mode of conveying knowledge is highly efficient, as it allows for much faster and parallel cognitive processing of sensual impressions than regular language use (Humphreys and Bruce, 1989). The reason for this advantage lies in the human cognitive capability of handling movement, distance or location, which is far more fundamental to the cognitive apparatus than conceptual thinking.

A promising spatial metaphor for describing complex facts is the city metaphor with its constituting elements, well-known spatial arrangements, and its familiar concepts like city districts (Wettel and Lanza, 2007), buildings (Chiu et al., 2005) and roads (Guetat and Dakhli, 2009) which assist people in easily understanding and navigating city-like structures (Andrews, 1995; Sparacino, Wren, Azarbayejani and Pentland, 2002). Because of these advantages, the city metaphor has been applied to visualize complex information in various areas, e.g. for visualizing software code (Wettel and Lanza, 2007; Leonel Merino, Bergel and Nierstrasz, 2018), representing the Internet (Dieberger and Frank, 1998; Sparacino et al., 2002), multimedia files (Derthick et al., 2003; Chiu et al., 2005), application architectures (Soares, 2008), or Information Systems (IS) governance rules (Guetat and Dakhli, 2015). As a result, we assume that the city metaphor is also suitable for visualizing all layers of EAs by mapping EA objects to city elements. This approach has not been implemented yet, even though some authors mention its applicability (e.g. Panas, Berrigan and Grundy, 2003). Therefore, our goal is to develop a holistic description of EAs applying the city metaphor. We state the following research question: *How can Enterprise Architectures be modeled using the city metaphor?*

Our research aims to develop a formal language describing one possible mapping between specific EA objects and city elements. The idea is that EA stakeholders employ an individual EA city visualization that suits a given EA analysis scenario. To ensure a high degree of acceptance, and unlike most previous publications in this area, we will base our mapping on the existing body of knowledge about implemented EA objects in organizations and discernible city elements, as well as on empirical data. For this, we apply a card sorting exercise to explore participants' mental models in perceiving a city structure that describes complex EAs. Through three rounds of card sorting with 14 participants experienced in the area of EA, we developed a comprehensive model that mapped EA objects to city elements. Our final model contains eleven classes of EA objects and matching equivalent city elements. Based on our results, we also provide an exemplary software implementation to prove its applicability. Thus, our paper contributes to research in providing terminology for describing EAs using commonly known concepts from the city metaphor. Further, we propose a formal language as well as an example of an implementation of our EA City visualization. Our approach is not conflicting with existing EA modelling languages, such as Archimate (The Open Group, 2012), but provides another possible visualization opportunity.

This paper proceeds as follows: section 2 presents previous research about the use of metaphors in IS research and of the city metaphor in particular. In section 3, we describe our research approach in detail. Section 4 summarizes the mapping between EA objects and city elements as well as the development of a formal language. Section 5 then outlines the applicability of this approach and the development of an exemplary prototype. We conclude our paper in section 6, discussing the results and providing avenues for future research.

2 Related Work

2.1 Use of spatial metaphors for Enterprise Architecture

In general, the application of metaphors is not a new concept in Information System (IS) and management research. Morgan's (1986) well-cited book *Images of Organization* suggests various metaphors to describe organizations in terms of organism, brain, culture, political system, psychic prison, flux, transformation, and as instrument of domination. Other authors propose additional metaphors e.g. for IS development projects (Oates and Fitzgerald, 2007), organizational (IT) projects (Winter and Szczepanek, 2009), or IS development in general (Kendall and Kendall, 1993).

Most approaches share more or less similar motives in that they aim to represent a certain system in a meaningful and easily understandable way that provides direction, insight, and methods for analysis and design (Alter, 2013). The growing data volumes and consequently available information raise the need for effective visualization and data analysis techniques of complex structures that can be addressed by metaphors (Andrews, 1995). Specifically spatial metaphors, which organize objects in space, seem to address this demand well, as they allow users to understand and effectively navigate through visualized dynamic information structures by using the distinct space-related cognitive abilities of humans (Dieberger, 1997; Chiu et al., 2005). Moreover, humans easily remember spatial environments (Sparacino et al., 2002).

In the same vein, the growing complexity of today's organizations and respective supply chains effect Enterprise Architectures (EAs). EAs represent time-dependent structures and relationships containing numerous business and IT components (Tamm et al., 2011; Aier et al., 2011). Most commonly, EAs are represented in four layers: Business, Data, Application, and Technology (The Open Group, 2018). Typically, these structures are visualized using text documents, matrices, layers, bar charts or pie charts (see Roth et al., 2014 for a comprehensive overview), whereas spatial visualizations of EAs are quite rare. Exceptions are work conducted by Fittkau, Roth, and Hasselbring (2015), who utilized a 3D city model to visualize an exemplary organizational application layer, and Naranjo et al. (2014), who propose a set of EA visualizations including a spatial treemap model to represent EAs.

We will extent research in this area by applying the city metaphor to all EA layers. The city metaphor provides a rich set of familiar concepts like districts (Wettel and Lanza, 2007), various kinds of buildings (Chiu et al., 2005), and roads (Guetat and Dakhli, 2009) that can be mapped with EA objects (Chiu et al., 2005). In addition, most viewers know immediately how to navigate through a city (Andrews, 1995; Sparacino et al., 2002), so that they are enabled to engage with complex structures like EA. Further, the city metaphor eases communication and collaboration due to the concepts being known (Dieberger, 1997). In the following section, we want to take a deeper look at the application of the city metaphors in IS research.

2.2 The use of city metaphors in information visualization

We now provide a brief overview of the application and suitability of the *city planning* or *city landscape metaphor* to visualize complex information by referring to proposals of multiple authors.

Early attempts focus on the gaining complexity of the Internet. Andrew (1995) is one of the first authors who applied the city metaphor to visualize Internet content. Hence, he developed a static 3D map of the City of Graz including actually existing landmarks with embedded hyperlinks that direct a user to further information. In the same vein, Diesberger (1997) and Diesberger and Frank (1998) developed a text-based virtual city, which consists of districts that encompass buildings with floors, rooms, and doors. Their implementation is meant to support users in retrieving and re-finding information in a natural way. The ability of humans to remember spatial environments motivated Sparacino (2002) and colleagues to develop a web browser that dynamically displays content from the Internet in the form of a city, and that is controlled by body gestures. The city's districts represent topics, whereas the facades of buildings represent individualized content.

Technological advantages enhance the consumption of multimedia documents from the Internet. A conceptual work by Derthick et al. (2003) describes the application of the cityscape metaphor to show contextually similar videos. Commonly used thumbnails of videos, as well as text results of similar documents seem to be unsuitable for providing useful overviews of video libraries. Therefore, they define buildings as perspectives on topics that dynamically change depending on the interest of a user. Flying and zooming enable users to change the view on the city. Using spotlights and different colors highlights objects of interest. Chiu et al. (2005) implemented a treemap-based 3D city called MediaMetro in which the buildings are placed on a grid layout and display relevant frames from single multimedia documents on its facade, locating the most important frame on top of the building.

A popular area of applying the city metaphor comes from software code visualizations. Previous work mainly focuses on representing software packages and classes in the form of a city. Panas et al. (2003) created realistic-looking 3D cities that represent a java code package using various city elements like streets, water, clouds, trees, and street lamps. Moreover, the appearance of buildings depends on quality criteria, e.g., old or muddy buildings represent improvable code, high costs, and high risks. Moving cars show paths between origin and destination objects, and their speed and type indicate performance and priorities of method calls. The authors also mention the possibilities of adding business processes, control flows, and data-flow, or of changing the appearance of the entire city depending on analysis results. Langelier et al. (2005) propose a city visualization that supports the analysis of large-scaled software code. Boxes represent software classes and can differ in terms of color, size, and twist. Pre-defined software metrics can be selected to change the appearance of the visualization. Another well-cited visualization of software code following the city metaphor has been developed by Wettel and Lanza (2007, 2008). Their goal is to identify software design problems. For this, they map software classes to buildings and cluster buildings to districts that represent software packages (Wettel and Lanza, 2007). The height of the buildings depend on the number of functions, and their width on the number of attributes within the classes. An evaluation of the visualization revealed a statistical improvement of task correctness and a decrease in task completion time (Wettel, Lanza and Robbes, 2011). Fittkau et al. (2015) use a virtual reality (VR) head-mounted display (HMD) to visualize software code with the goal of promoting easy navigation and improved understanding. Their implementation represents software packages as boxes that can be opened and closed. In a similar manner, Capece et al. (2017) also developed a VR-based city that represents software packages in which different sizes and colors of buildings represent software classes and districts represent software packages. In the same year, Merino et al. (2017) also developed an interactive software visualization tool using VR, where buildings symbolize software classes and districts represent software packages. A subsequent evaluation with six participants revealed increased navigation by allowing users to physically walk and inspect the source code (Leonel Merino et al., 2017). In a recent work, Merino et al. (2018) implemented the same city model in an Augmented Reality (AR) environment using an HMD, and evaluated its effectiveness and emotions. In a controlled experiment with nine participants, they found that AR eases navigation and reduces occlusion. Souza et al. (2012) implemented an AR-based software evolution visualization. They used a webcam on a laptop and a piece of paper, a so-called marker, to display a city model on a monitor. Users could rotate that paper to change the perspective of the city on the monitor. Similar to existing approaches, buildings show software classes and district packages, whereas the size and color of buildings display the evolution of classes in terms of their number of changes.

The application of the city metaphor can also be recognized in other EA-relevant areas. Soares (2008) applied the city metaphor to visualize application architecture. The proposed conceptual model defines blocks as systems of applications, and buildings as single applications that contain several modules. Different positions, colors and sizes of buildings are used to present further information. Another example is provided by Guetat and Dakhli (2009) who linked EA and IS governance using the city landscape metaphor. For this, they defined a variety of districts, areas and blocks within the city, in which applications were classified. Architecture principles and rules defined the exchange between these applications and related objects, as well as prioritizing, managing, and measuring the information systems (Guetat and Dakhli, 2009).

3 Research Approach

Our goal is to create a representation of EAs by applying a city metaphor. We acknowledge that every person might perceive conceptual cities differently, hence, we propose card sorting as a suitable research method for (a) exploring people's mental models (Schaffer and Fang, 2018) of how they perceive EAs visualized as a city and (b) developing a generally acceptable representation of EA in the form of a city. To achieve this, we followed the card sorting approach described by Moore and Benbasat (1991), and utilized the description structure proposed by Schaffer and Fang (2018). Figure 1 provides an overview of our research approach.

Formative Card Sorting				Model building
1. Preparation of materials →	2. Participants →	3. Procedures →	4. Analysis and iterative revisions →	5. Description of final mapping
• Review led to 86 EA objects • Review led to 536 city elements • Synthesizing the results led to 41 EA objects and 39 city element classes	• 14 EA-experienced participants were invited • 9 researchers, 5 IS students • Recruited through network	• Introduction to topic and procedure • Conducted three rounds of formative one-to-one open card sorting sessions	• Revise cards every round • Group cards based on frequency table and interview notes • Calculate inter-rater agreement	• Final mapping of 11 classes of EA objects and equivalent city elements • Development of a formal language for machine processing

Figure 1. Research approach influenced by from Schaffer and Fang (2018)

3.1 Development of a possible EA visualization using card sorting

Preparation of materials

We conducted two broad literature reviews to identify relevant EA objects and city elements. For the former, we first derived EA objects from the commonly accepted and industry-independent EAM implementation framework TOGAF 9.2 (The Open Group, 2018). The meta model in TOGAF provides an overview of relevant but abstract entities and relationships of EAs. To ensure the development of a useful and applicable EA representation for EA stakeholders, we utilized the four layers of the meta model as an analytic framework in a subsequent literature review and mapped the entities from the meta model onto identified EA objects implemented in organizations. The layers are business architecture, application architecture, data architecture, and technology architecture. This is a necessary step as the meta model consists of abstract entities (e.g. logical technology component) that might contain concrete objects from the real world (e.g. business unit, computer, customer record, databases). In addition, we considered all sources that named and described implemented EA objects, either from case studies or from conceptual discussions informed by real-world organizational settings. This approach allowed us to identify relevant EA objects for a wide range of stakeholders. An analysis of 34 relevant articles from the basket of journals, the AISEL database, as well as IEEE published between 2009 and 2018 revealed 86 potentially relevant EA objects. We further synthesized the results to 41 unique EA objects that were then named and briefly described on single cards.

We conducted a second literature review to identify potentially relevant city elements. Following this, we based our analysis on the five well-cited generic elements of cities defined by Lynch (1960), which are paths, edges, districts, nodes, and landmarks. This helped us to structure our review and focus on the important aspects of a city. We considered all articles where aspects of cities were the subject of discussion. After analyzing 36 papers from ScienceDirect and IEEE, as well as 5 seminal books, we identified 536 (partly redundant) city elements that we grouped into 39 distinctive city element classes.

This step was needed as it reduced the number of possible elements for easier mapping. We printed cards on which all city element classes (e.g. industrial plants) were named, as well as all identified specific city elements (e.g. factory, electric power plant, and refinery). This approach ensured an abstract discussion of city elements rather than simply focusing on trivial details. The cards describing the city elements were colored differently compared to the cards listing EA objects.

Participants

Developing new forms of visualization requires creativity, but if one is to ensure applicability, also an understanding of the topic of interest. By questioning potentially appropriate candidates, we ensured that only participants with prior knowledge of EA participated. We recruited researchers, practitioners, as well as students to consider a wide range of possible perceptions of EA city visualizations. In all, 14 people participated, of whom nine were researchers and five students. We recruited all participants through the author’s professional network.

Procedure

We conducted observed open card sorting sessions for two reasons. First, we could ask further questions that helped us to understand the rationale behind the mapping. Second, we did not alternate between unobserved and observed sessions to avoid potentially incomparable results (Denford and Schobel, 2018). Before each card sorting session started, one author introduced the topic, described the rules, and briefly explained all EA objects and city elements. Further, we asked the participants to imagine a possible and general image of any EA in the form of a city. We then asked the participants individually to sort and group the prepared cards describing explicit real-world EA objects with cards describing classes of city elements where they found the best fit. Participants could create one-to-one but also many-to-many relationships. We provided sticky notes for them to add or modify EA objects or city elements if they wanted to. Cards could be assigned to a category called “I don’t know” if mapping them was not possible. All card sorting sessions were conducted individually and supervised by one author to reduce external influences. We answered participants’ questions during the card sorting; however, no hints or advices were given. Afterwards, the supervisor asked and took notes on why a participant had mapped certain cards together. This helped us to get a further understanding of how each participant perceived and built images of an EA city.

We applied three rounds of open card sorting sessions with different participants in each round. Two authors performed the first round. This round helped us to go through the process of mapping by ourselves and to refine definitions and examples where necessary. Seven researchers and one student participated in the second round, and two researchers and four students in the third and last round. The first two rounds were performed using printed cards, whereas the last round was performed using a computer-based spreadsheet. Following Denford and Schobel (2018), the different mapping methods (manual vs. computer-aided) seemed without effect on the results as it was an observed approach.

Analysis and Iterative Revisions

In order to improve the descriptions on our cards, reduce the number of EA objects, and to provide a sparse mapping table, we analyzed the results and revised all cards after each round of card sorting. Based on our notes, we rephrased names and descriptions, and used examples to improve each card and reduce ambiguous meanings. We added newly proposed EA objects and city elements to the stack of cards or linked them to existing cards to avoid redundancies. Afterwards, we analyzed the results. For the analysis, we created a matrix showing the frequency of relationships between EA objects and city elements, according to participants’ use. Pair-by-pair comparisons supported us, first, in identifying often-considered mapping relationships and, second, in grouping EA objects with similar visualization mappings. We considered grouping EA objects whenever these objects shared at least 50% of the same mapping. This is consistent with previous works, which claim that an acceptable validity level is reached when half of the judges sorted the cards in the same category, especially in early stage research projects (Nunnally, 1967; Urbach, Smolnik and Riempp, 2009; Corbett and Idrissi, 2017). Initially we had planned another closed card sorting session; however, we achieved a sufficient degree of consistency except for the two TOGAF objects Value Stream and Course of Action. We dropped both these elements as their mapping was generally inconsistent and we did not expect to identify a commonly acceptable visualization. Further, three classes of EA objects show similar mappings to city elements, but no specific and unique city element could be identified. To build a consistent representation, we then chose the most appropriate city element visualization that fitted the remaining city elements. Finally, we identified eleven groups of EA objects with similar mapping results. We described each of them briefly as shown in Table 1.

3.2 Formalizing the description of EA City visualizations

The domain analysis resulted in a set of suggested real-world EA objects and a range of suitable visualizations to represent the domain concepts. As a contribution to the design of an end-user application in which EA analysis scenarios are rendered and made accessible to human users, the definition of a formalism is required. It allows us to express the information needs of a given analysis scenario, in a way that will automatically be processed into rendering a city metaphor visualization as desired. Without such an automation, EA city visualizations could not be created efficiently with reasonable effort. EA analysis tasks in focus are, e.g., to i*dentify all the EA objects that belong to the sales unit as well as the dependencies to other units*. This natural-language statement had to be formulated in such a format that all information which is required to render EA city visualizations is given in a software processable way. This incorporates stating the objects of interest and their selected characteristics which are intended to occur in the visualization, as well as making decisions on which city element to choose when populating the EA City landscape. Formally speaking, there must be a mechanism to specify the objects of interest in an EA analysis scenario together with the visual representation by which they are to be shown as part of the EA City visualization.

At this point in the design process, we are concerned about identifying required information objects and the formal structures needed to describe EA City visualization. The aim is not to reason about a user interface, which allows for easy and efficient formation of EA cities with an ecologic interface and minimal cognitive load, yet. Therefore, the following considerations can remain abstract, without considering usability aspects.

We define a formal language that allows for the formal, yet human-readable, specification of views. Sentences in this language describe analysis scenarios and EA City visualizations in terms of a declarative language that allows us to specify all the required content and projection parameters of an EA City visualization. The language aims on the one hand to express domain objects of interest and relationships between them, and on the other hand, to articulate corresponding visual metaphors for representing the domain objects in the topology of a city with the available visual representation means we present in the following section.

4 The Development of an EA City

In this section, we present the results of the card sorting procedure and the respective formal language. In general, the EA city consists of two components: districts and city elements. *Districts* represent a pre-defined EA object that suits an individual EA analysis scenario. *City elements* are grouped by districts and represent EA objects e.g. by buildings and people. For example, *districts* might represent organizational departments and contain all EA objects, visualized as *city elements*, which are associated with each department. Streets are a special form of a *city element* and represent processes and, hence, establish a connection between EA objects within and beyond the border of districts. Vehicles are the only *city elements* that move and drive on streets. They represent data objects that are going through processes and provide data for each EA object. The mapping between EA objects and city elements is presented in detail in the following section whereas the underlying formal language is described in 4.2.

4.1 Elements of the EA City

The final eleven classes of EA objects from the card sorting and revision are presented in Table 1. Each class of EA objects is described in detail and includes the mapped city elements.

EA Objects	Description	City Elements
BUSINESS ARCHITECTURE		
Business actor, actor, role, person	Someone that communicates and interacts with others. This can be a real person (Bakar, Harihodin and Kama, 2016) or an organizational role filled by a person (Cardoso, Almeida and Guizzardi, 2010; The Open Group, 2012).	Human (e.g. pedestrian)
Laws, regulations, business rules, contracts, SLAs, control	All laws, regulations, and business rules (The Open Group, 2018), as well as arrangements like contracts and SLAs (Alwadain, Fielt, Korthaus and Rosemann, 2011), which must be obeyed.	Government building (e.g. administration, city hall, parliament)
Business function, function, business capability, business service	The provision and delivery of specific skills and know-hows (El Sawy and Pavlou, 2008) that describe the offering (Ramljak, 2017) and support the achievement of a goal (The Open Group, 2018).	Industrial building (e.g. factory, electric power plant, refinery)
Event	Internal or external occasion that causes any form of change in the organization (The Open Group, 2018). This could trigger, e.g., business processes.	Conference center (e.g. convention center)
Business goal, strategic goal, objectives, driver	The description of strategic and business goals, their milestones, driving forces, as well as their intended direction and organizational focus (Ramljak, 2017; Santana et al., 2017; The Open Group, 2018).	Monument (e.g. Eiffel Tower, Brandenburg Gate, Arc de Triomphe)
Organizational unit, business unit	A self-contained unit including internal and external stakeholders, partners, and organizations as well as further resources with individual goals, objectives, and measures (The Open Group, 2018; Rohloff, 2011).	Office building (e.g. bank, office tower, headquarters)
Business process, process	A predefined sequence of activities that creates any value to an external or internal customer (Whittle and Myrick, 2004; Quartel, Engelsman, Jonkers and Van Sinderen, 2009; The Open Group, 2018).	Street (e.g. road, highway, path)
Product	An output of a business that is likely created through the execution of business processes (The Open Group, 2012, 2018).	Shopping mall (e.g. mall, department store, shop)
Measurable indicator, KPI, service quality	Functional and non-functional measurable indication of service delivery, which allows the assessment of quality and success and eventually the performance of EAs through KPIs (Papazoglou, 2003; Ganesan and Paturi, 2009; The Open Group, 2018).	Billboard*
APPLICATION ARCHITECTURE		
Software application service, application service, software, application, business application, software application component, application component	Computer-based information system that provides functionality to end users (Riempp and Gieffers-Ankel, 2007). This can be (software) application services (Cardoso et al., 2010; The Open Group, 2012), applications (Alonso, Verdún and Caro, 2010), software (Farwick et al., 2010), or components and functions of applications (Veneberg, Iacob, Sinderen and Bodenstaff, 2014).	Residential building (e.g. apartment building, house, bungalow)
DATA ARCHITECTURE		
Business object, data object, customer record, file, document, script, records	A general, meaningful piece of information. Any business-related data objects like customer records (The Open Group, 2012), as well as all of their individual data units and values (The Open Group, 2018).	Transport vehicle (e.g. car, truck)
Database, database table	A structured or unstructured collection of data elements (The Open Group, 2012).	Parking (e.g. parking space, parking meter, off-street parking)

TECHNOLOGY ARCHITECTURE		
Platform service, infrastructural service	The composition of technical capabilities like computers, communication devices, and related software systems forming an infrastructure service (Cardoso et al., 2010), also known as platform service (Hess, Lautenbacher and Fehlner, 2013; Santana et al., 2017), that enables the delivery of applications (The Open Group, 2018).	Gas station*
Computer, server, client workstation, communication device	Necessary classes of implemented physical hardware to provide and operate infrastructural services (Cardoso et al., 2010; The Open Group, 2018).	Single fuel pump*
Network	A physical communication path between two and more devices or other networks (The Open Group, 2012).	Pipes (e.g. water supply, electricity supply)
* Self-assigned objects, as no consistent mapping could be identified		

Table 1. Description of the EA objects and the mapping to city elements

4.2 Elements of the EA City visualization language

A formal language that serves the above-described purpose must enable the expression of three main elements of knowledge that are required to render a complete EA city visualization. First, the language demands the flexibility of defining objects of interest from a discursive source domain. In this case, the identified EA objects are presented in Table 1. Second, the visual metaphors that can be used to populate an EA city scenario need to be specified, together with optional parameters that can configure their visual appearance. Finally, for each city metaphor visualization the decisions on which EA objects are to be represented by which visual metaphor have to be expressed by the language. The first set of knowledge elements describing the source domain depend on an individual EA analysis domain. The second set of knowledge elements, which specify available visual metaphors, depends on the underlying rendering engine that is configured with the language. The third component, the mapping of domain elements to visual metaphors, lead to different EA city visualizations based on individual case-based EA decision scenarios. EA analysts will create these mappings when they apply this approach.

We designed a formal textual language, which adheres to the identified requirements. In the current version of the language, there are three kinds of metaphors, which can be used in combination to form an EA city visualization. These are metaphors for spatial *areas*, spatial *relations*, and *elements* that are located in areas and optionally placed along relations. When specifying mappings for EA Cities, domain elements can be associated with metaphors of each of these kinds, and the resulting mapping definitions will be interpreted by a rendering engine to organize visual elements in a 3D projection accordingly. A grammar that describes a formal language, which allows expressing such a configuration for EA city visualizations, is shown in Listing 1.

```
Model: "Domain:" domain+=DomainElement ("," domain+=DomainElement)* "Metaphor:" metaphor=Metaphor ("City" view+=View)*;
DomainElement: name=ID;
Metaphor: ("element" elements+=MetaphorElement ("," elements+=MetaphorElement)* | "area" areas+=MetaphorArea (","
areas+=MetaphorArea)* | "relation" relations+=MetaphorRelation ("," relations+=MetaphorRelation)* )+;
MetaphorArea: MetaphorDef;
MetaphorElement: MetaphorDef;
MetaphorRelation: MetaphorDef;
MetaphorDef: name=ID ("(" parameters+=ID ("," parameters+=ID)* ")")?;
View: name=ID ":" mappings+=Mapping*;
Mapping: MappingArea | MappingElement | MappingRelation;
MappingArea: "area" (domain=[DomainElement]("(" alias=ID ")")? "as")? metaphor=[MetaphorArea]("(" parameters+=STRING (","
parameters+=STRING)* ")")? ("contains" mappings+=Mapping* "complete")? ("if" condition=STRING)?;
MappingElement: (domain=[DomainElement]("(" alias=ID ")")? "as")? metaphor=[MetaphorElement]("(" parameters+=STRING (","
parameters+=STRING)* ")")? ("if" condition=STRING)?;
MappingRelation: "relation" domainA=[DomainElement]("(" aliasA=ID ")")? "-" domainB=[DomainElement]("(" aliasB=ID ")")?
predicate=STRING "as" metaphor=[MetaphorRelation]("(" parameters+=STRING ("," parameters+=STRING)* ")")? ("if"
condition=STRING)?;
```

Listing 1. Grammar for the EA city visualization language

In the following, we will explain the use of the language concepts by a meta-model as shown in Figure 2. It will provide an overview of the EA city visualization language elements and their relationships.

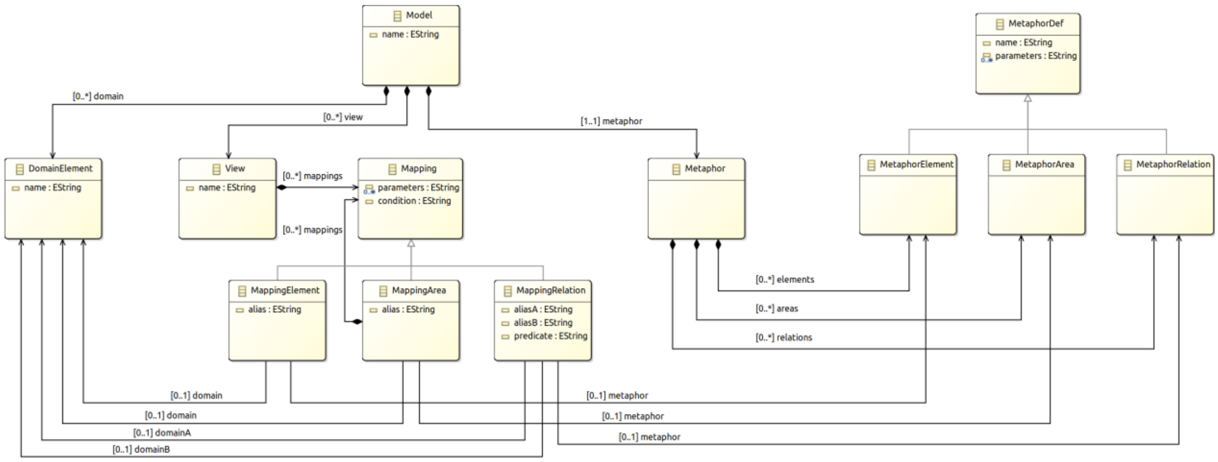

Figure 2. Meta-model of a formal description language for configuring EA city visualizations

The meta-model in Figure 2 uses the object-oriented notation of the Ecore meta-modeling language, which is part of the Eclipse Modeling Framework (Steinberg, Budinsky, Merks and Paternostro, 2008). It widely resembles the industry standard representation of class diagrams in the Unified Modeling Language (UML, 2015), with the data type "EString" representing the notion of a general string data type. For simplification, no data types other than strings are used in the model.

The central concept defined in the meta-model is the *Mapping* element. Multiple *Mappings* are contained in a *View*, which forms the description of a single EA city topology to be shown as one 3D city rendering. An overarching *Model* container can contain multiple *Views*, so several different EA city topology descriptions can be stored in a single model file. Every *Mapping* can be attached with an arbitrary number of parameters as well as a condition that specifies dynamic contexts.

The general notion of a *Mapping* gets further refined by the *MappingElement*, *MappingArea*, and *MappingRelation* concepts. *MappingElements* and *MappingAreas* each refer to one *DomainElement* and to a *MetaphorElement* or *MetaphorArea* element, respectively. By doing so, they specify that in a given *View*, the referenced *DomainElement* should be represented by the associated metaphor element. *MappingRelations* reference two *DomainElements* and own a predicate attribute which queries whether two instances of the *DomainElements* take part in the relation. A *MappingRelation* element references a *MetaphorRelation* element to choose the corresponding visual representation for a relationship. All *Mapping* elements enable alias names for their referenced *DomainElements*. These *DomainElements* can reference any external sources for interpreting their domain-specific semantics, such as the TOGAF standard. Instances of *DomainElements* are contained inside the overarching *Model* container and can be referenced from any *Mapping* in each *View*. The set of available *DomainElements* is prepared by method engineers in advance to configuring an EA city visualization. They are made available as presets that populate an initial EA city visualization configuration.

The visual metaphors for elements, areas, and relations are not overlapping; this is why *MetaphorElement*, *MetaphorArea*, and *MetaphorRelation* are distinct subclasses of *MetaphorDef*. The latter defines for all metaphor specifications a *name* attribute and an optional set of string *parameters*. Like with *DomainElements*, metaphor specifications are considered to be prepared in advance, and are made available to EA analysts as presets. As a result, they are stored in a single element called *Metaphor* that serves as a container for all available *MetaphorElement*, *MetaphorArea*, and *MetaphorRelation* descriptions and is supposed to be contained exactly once in the entire *Model*.

Instances of this meta-model are created by applying a parser generated from the grammar in Listing 1, to a textual configuration such as the example in Listing 2 in the following section.

5 Exemplary Application of an EA City

In this chapter, we propose a spatial ability-facing EA visualization based on the city metaphor that we call EA City. Figure 3 shows an exemplary three-dimensional EA City visualization based on the formal language described in chapter 4.2. This early-stage prototype is developed using the game engine Unity (version 2017.2.1f1) and written in C#. As city elements, we used modified 3D models taken for free available on the Internet. The pictured EA city was rendered in the Unity Editor on a desktop client.

For the exemplary case, we assumed a likely EA use case, where a sales unit manager wants to identify all the EA objects that belong to the sales unit, as well as their dependencies on other units. Hence, the respective EA city visualization contains rectangular city district whereas each district represents an organizational unit and all city elements associated EA objects. The name of the unit is presented in the middle of the district. City elements are connected via streets that represent processes. Connected districts are arranged next to each other and are linked by streets. We based our visualization on self-generated exemplary data and set a suitable configuration that is presented in Listing 2.

```
Domain:
BusinessActor, ControlInstance, BusinessCapability, Event, Goal, OrganizationUnit, Product, Measurement, Application, DataObject,
Database, InfrastructureService, Computer, BusinessProcess

Metaphor:
element People, GovernmentBuilding, IndustrialBuilding, ConferenceCenter, Monument, OfficeBuilding, ShoppingMall, Billboard,
ResidentialBuilding, TransportVehicle, Parking, GasStation, FuelPump
area District(name)
relation Street
```

Listing 2. Domain elements and visual metaphor specifications

Based on this configuration, we defined an appropriate formal statement. The statement provides all information required for an automatic rendering mechanism to populate the EA City landscape and selects all in Table 1 presented EA objects. Figure 3 shows a compiled and rendered model.

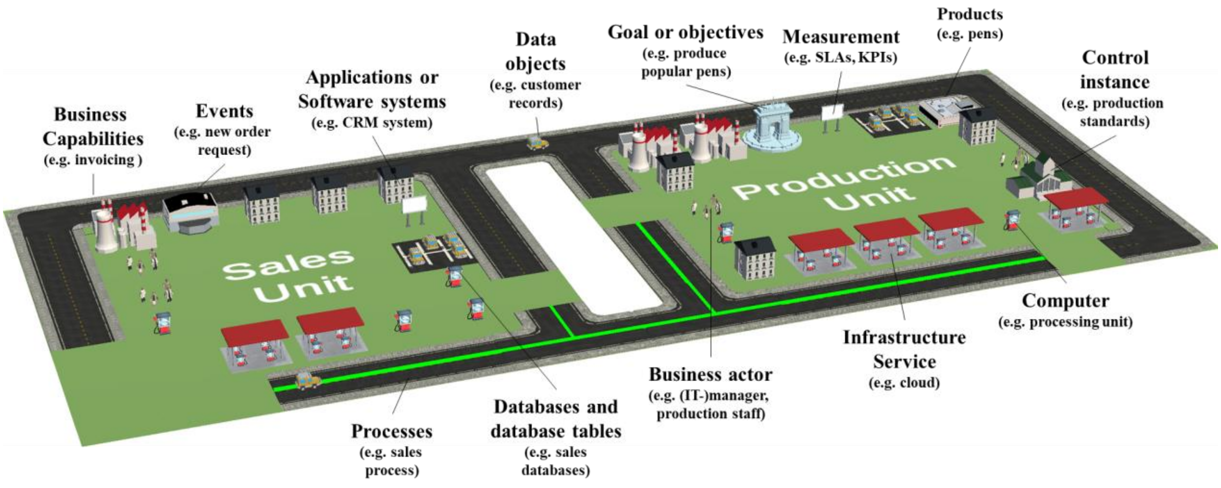

Figure 3. Three-dimensional EA City grouped by organization units

The district on the left side describes EA objects associated with a sales unit. Two business processes are linked to this unit and are presented as two separate streets. These processes are connected to EA objects in the production unit on the right side. The processes enable the transport of data objects between those EA objects. This is represented by cars driving on the streets along the corresponding EA objects represented by different buildings. Selecting a car will show a green line, which indicates the route that the car will take in the city and thus, which buildings it will pass. Three residential buildings in the sales unit district indicate three associated applications. Four fuel pumps symbolize individual servers. Application platforms, e.g. a cloud service, are visualized as two large gas stations. The parking area implies several databases. A conference center means that this unit handles events, such as order requests. The capability to process those events is represented as an industrial building in the form of a factory. A billboard shows the presence of unit-related measurable indicators. Organizational roles belonging to the sales unit are depicted as eight persons. The other district consists of a government building indicating business rules to be obeyed. Further, a monument, in the exemplary form of the Arc de Triomphe, represents goals and objectives of this organizational unit. In this case, the sales unit manager can see all sales-relevant EA objects and their dependency to objects of another business unit. Due to the three-dimensionality of the model, the EA City can be seen from different perspectives.

Another advanced example of an EA City visualization is shown in Figure 4. We assume a sales unit manager needs to know his or her supervised applications and the related EA objects. In this case, city districts are grouped by applications. Hence, we reused the configuration presented in Listing 2 but changed setting of the grouping. The resulting EA City visualization contains the same element like the first example, except for the organizational units representing blue office buildings. No residential buildings are represented since the districts are grouped by applications.

Figure 4. Three-dimensional EA City grouped by applications

6 Discussion and conclusion

This paper presents a possible visualization of EAs using the city metaphor. The goal was to propose a visualization that (a) provides a familiar environment for various viewers, (b) is based on a shared language, and (c) is able to visualize EAs. For this, we performed a broad literature review to derive real-world EA objects and city elements. Three rounds of manual card sorting sessions with 14 participants revealed eleven classes of EA objects with similar mappings to city elements. Further, we created a formal language, which was tested with an exemplary prototype. Our visualization called EA City consists of dynamic districts that are based on a selected EA object. EA objects are represented as city elements based on empirical data. The relationship between EA objects is visualized as city districts as well as streets that represent processes.

This work can foster the design of EA cities or excerpts of EA cities which researchers and practitioners can develop entire. It can also facilitate different implementations as it follows the commonly accepted meta-model of TOGAF and, hence, provides comprehensive and familiar EA objects for EA experts. In addition, EA City can be implemented using various technologies like desktop applications, 3D printing, Virtual Reality (VR), or Augmented Reality (AR) similar to existing approaches (L. Merino et al., 2017; Rehring, Greulich, Bredenfeld and Ahlemann, 2019). Those technologies might be more suitable compared to printed documents. The dynamic character of districts, which are based on EA objects or other analysis criteria, enables flexible visualizations that support multiple perspectives on the same EA.

The current body of knowledge about EA visualization can benefit from our model in several ways. It provides a consistent and familiar language, which makes it easy for viewers to identify, interpret, and talk about the same object of interest. Considering previous knowledge enhances object recognition (Sparacino et al., 2002; Baker et al., 2009). This is especially helpful when viewers with different experiences in EA or business and IT backgrounds interact with each other. Following (Baker et al., 2009), our EA City visualization suits all four aspects to individual sensemaking of complex information which might have a strong impact on effective information visualization.

However, this visualization might not be suitable for every purpose. Following the results of the card sorting sessions, we aggregated EA objects with similar mappings. As a result, EA objects in the same class, such as application components and applications, cannot be distinguished on a detailed level. On the one hand, this aggregation limits the applicability of the EA City visualization for detailed EA analyses, whereas on the other hand, it streamlines EAs to an abstract representation and, thus, enables an easily understandable visualization. To address this shortcoming, other authors propose to structure information in containers, e.g. to consider floors and rooms (Dieberger and Frank, 1998). This was not elaborated as it is not revealed in our empirical analysis. In addition, we did not consider the order of EA objects and thus, process steps or predecessors and successors cannot be represented. A solution could be that a vehicle drives a specified route and connects each city element depending on a sequence. Another opportunity might be to align city elements in order. Streets, which represent processes, also heavily influence the design of EA Cities, because all process-linked city elements must be arranged closely to each individual street. This can be challenging when single EA objects are linked with multiple processes as this might lead to big streets and complex crossings. Moreover, the grouping of EA objects to districts can lead to enhanced redundancy as the same EA objects can be visualized multiple times depending on the definition of the district. Another aspect lies in the time-dependency of EAs. The current visualization does not integrate different points in times. Hence, each EA time representation must be developed individually. Future research should derive design principles and algorithms that cope with routing and alignment challenges in order to design appealing visualizations.

Our work is not without limitations. We focus on the four commonly used layers of business, application, data, and technology architecture. The TOGAF meta-model further proposes general entities (The Open Group, 2018), which we did not consider in our paper. Even though the number and the experience of the participants seem to be sufficient, including practitioners might disclose further organizational-relevant aspects. A future evaluation of the prototype in an organizational setting can address this issue by explicitly customizing the prototype toward organizational requirements. Moreover, we tested our model using self-created data. Our prototype will benefit from the usage of real-world data, e.g. from a case study. Also, the EA City visualization language will be used as a basis for automating the renderer configuration. This will further show the applicability of the city metaphor for large-scale EA data. As the main purpose of this paper is to develop a mapping between EA objects and city elements, we did not develop a comprehensive prototype, but showed the general possibility of implementing our EA City mapping. Especially, we did not discuss how to display additional information or enable drill down in our city representation. Hence, our prototype does not provide further information, e.g. when looking at or selecting a city element. Previous work frequently implements a text box that presents more information when clicking on, or looking at an object (e.g. Wettel and Lanza, 2008; Leonel Merino et al., 2018). Another approach might be to display the name of an EA object on the respective city element. Even though we considered attributes of city objects in our formal language, we did not discuss size, color, rotation, or - most importantly - appearance of city elements, which have been shown to impact the perception of the visualization (Langelier et al., 2005). These characteristics provide another dimension for assessing the condition of EAs or enabling dynamic representation of analysis results. It is conceivable to display buildings from being new to dilapidated depending on criteria; however, this is not the scope of this paper.

Our results provide avenues for future research. Another implementation and evaluation of our model using organizational data will reveal the applicability and acceptance of EA City visualization. A comparison between different types of visualization techniques might focus on the degree of understanding, decision-making completion time, and correctness. In addition, different tasks need different visualizations (Vessey, 1991) and future research should explore a fit between our proposed visualization and specific EA analysis scenarios. As our proposed model is based on participants' mental models, compared to previous work, it potentially provides a more valid explanation of the mapping between EA objects and city elements. We hope that our approach will be used to develop further sophisticated EA representations using metaphors.

References

Aier, S., B. Gleichauf and R. Winter. (2011). "Understanding Enterprise Architecture Management Design – An Empirical Analysis." In: *Proceedings of the 10th International Conference on Wirtschaftsinformatik* (pp. 645–654). Zurich, Switzerland.

Alonso, I. A., J. C. Verdún and E. T. Caro. (2010). "The IT implicated within the enterprise architecture model: Analysis of architecture models and focus IT architecture domain." In: *2010 IEEE International Conference on Service-Oriented Computing and Applications (SOCA)* (pp. 1–5). Perth, Australia.

Alter, S. (2013). "Incorporating more system-related knowledge into systems analysis and design." In: *Proceedings of the Nineteenth Americas Conference on Information Systems*. Chicago, IL, USA.

Alwadain, A., E. Fielt, A. Korthaus and M. Rosemann. (2011). "Where Do We Find Services in Enterprise Architectures? A Comparative Approach." In: *Proceedings of the 22nd Australasian Conference on Information Systems* (pp. 1–11). Sydney, Australia.

Andrews, K. (1995). "Visualising cyberspace: information visualisation in the harmony internet browser." In: *Proceedings of 1st IEEE Symposium on Information Visualization* (pp. 97–104). Atlanta, GA, USA.

Bakar, N. A. A., S. Harihodin and N. Kama. (2016). "Enterprise architecture implementation model: Measurement from experts and practitioner perspectives." In: *2016 4th IEEE International Colloquium on Information Science and Technology (CiSt)* (pp. 1–6). Tangier, Morocco.

Baker, J., D. Jones and J. Burkman. (2009). "Using visual representations of data to enhance sensemaking in data exploration tasks." *Journal of the Association for Information Systems*, *10*(7), 533–559.

Capece, N., U. Erra, S. Romano and G. Scanniello. (2017). "Visualising a software system as a city through virtual reality." In: *4th International Conference on Augmented Reality, Virtual Reality and Computer Graphics* (pp. 319–327). Ugento, Italy.

Cardoso, E. C. S., J. P. A. Almeida and R. S. S. Guizzardi. (2010). "On the Support for the Goal Domain in Enterprise Modelling Approaches." In: *2010 14th IEEE International Enterprise Distributed Object Computing Conference Workshops* (pp. 335–344). Vitoria, Brazil.

Chiu, P., A. Girgensohn, S. Lertsithichai, W. Polak and F. Shipman. (2005). "MediaMetro: browsing multimedia document collections with a 3D city metaphor." In: *Proceedings of the 13th annual ACM international conference on Multimedia* (pp. 213–214). Singapore.

Corbett, J. and S. C. E. Idrissi. (2017). "ASSESSING THE INFLUENCE OF PERSUASIVE SYSTEMS FOR SUSTAINABILITY ACROSS WORK-HOME-COMMUNITY BOUNDARIES." In: *Proceedings of the 25th European Conference on Information Systems (ECIS)* (pp. 2874–2884). Guimarães, Portugal.

Denford, J. and K. Schobel. (2018). "Manual Versus Online Card Sorts: A Cautionary Tale for IS Researchers." In: *24th Americas Conference on Information Systems* (pp. 1–10).

Derthick, M., M. Christel, A. Hauptmann, D. Ng, S. Stevens and H. Wactlar. (2003). "A Cityscape Visualization of Video Perspectives." In: *Proceedings of the National Academy of Sciences Arthur M. Sackler Colloquium on Mapping Knowledge Domains (unpublished)* (pp. 1–2). Irvine, CA, USA.

Dieberger, A. (1997). "A city metaphor to support navigation in complex information spaces." In: *Spatial Information Theory A Theoretical Basis for GIS* (pp. 53–67). Semmering, Austria.

Dieberger, A. and A. U. Frank. (1998). "A city metaphor for supporting navigation in complex information spaces." *Journal of Visual Languages and Computing*, *9*(6), 597–622.

El Sawy, O. A. and P. A. Pavlou. (2008). "IT-enabled business capabilities for turbulent environments." *MIS Quarterly Executive*, *7*(3), 139–150.

Farwick, M., B. Agreiter, R. Breu, M. Häring, K. Voges and I. Hanschke. (2010). "Towards Living Landscape Models: Automated Integration of Infrastructure Cloud in Enterprise Architecture Management." In: *2010 IEEE 3rd International Conference on Cloud Computing* (pp. 35–42). Miami, FL, USA.

Fittkau, F., A. Krause and W. Hasselbring. (2015). "Exploring software cities in virtual reality." In: *2015 IEEE 3rd Working Conference on Software Visualization (VISSOFT)* (pp. 130–134). Bremen, Germany.

Fittkau, F., S. Roth and W. Hasselbring. (2015). "ExplorViz: Visual runtime behavior analysis of enterprise application landscapes." In: *23rd European Conference on Information Systems (ECIS 2015)*. Münster, Germany.

Ganesan, E. and R. Paturi. (2009). "Key Performance Indicators Framework - A Method to Track Business Objectives, Link Business Strategy to Processes and Detail Importance of Key Performance Indicators in Enterprise Business Architecture." In: *AMCIS 2009 Proceedings* (pp. 1–10).

Gärdenfors, P. (2000). *Conceptual spaces: the geometry of thought*. Cambridge, Mass: MIT Press.

Guetat, S. B. A. and S. B. D. Dakhli. (2015). "The Architecture Facet of Information Governance: The Case of Urbanized Information Systems." *Procedia Computer Science*, *64*, 1088–1098.

Guetat, S. and S. B. D. Dakhli. (2009). "The Information City: A Framework For Information Systems Governance." In: *MCIS 2009 Proceedings* (pp. 1377–1388).

Hess, C., F. Lautenbacher and K. Fehlner. (2013). "Business Building Blocks as Coordination Mechanism for Enterprise Transformations." In: *2013 17th IEEE International Enterprise Distributed Object Computing Conference Workshops* (pp. 194–203). Vancouver, BC, Canada.

Humphreys, G. W. and V. Bruce. (1989). *Visual Cognition: Computational, Experimental and Neuropsychological Perspectives*. Hove, UK: Lawrence Erlbaum Associates Ltd.

Johnson, M. and G. Lakoff. (1980). *Metaphors We Live By*. Chicago, IL, USA: The University of Chicago Press.

Johnson, M. and G. Lakoff. (1999). *Philosophy in the Flesh : The Embodied Mind and Its Challenge to Western Thought*. New York, USA: Basic Books.

Kendall, J. E. and K. E. Kendall. (1993). "Metaphors and methodologies: Living beyond the systems machine." *MIS Quarterly*, *17*(2), 149–171.

Lakoff, G. (1987). *Women, Fire, and Dangerous Things*. Chicago, IL, USA: University of Chicago Press.

Lange, M. and J. Mendling. (2011). "An Experts' Perspective on Enterprise Architecture Goals, Framework Adoption and Benefit Assessment." In: *2011 IEEE 15th International Enterprise Distributed Object Computing Conference Workshops* (pp. 304–313). Helsinki, Finland.

Langelier, G., H. Sahraoui and P. Poulin. (2005). "Visualization-based analysis of quality for large-scale software systems." In: *Proceedings of the 20th IEEE/ACM international Conference on Automated software engineering* (pp. 214–223). Long Beach, CA, USA.

Lynch, K. (1960). *The image of the city* (Nachdr.). Cambridge, MA, USA: MIT Press.

Merino, L., J. Fuchs, M. Blumenschein, C. Anslow, M. Ghafari, O. Nierstrasz, … D. A. Keim. (2017). "On the Impact of the Medium in the Effectiveness of 3D Software Visualizations." In: *2017 IEEE Working Conference on Software Visualization (VISSOFT)* (pp. 11–21). Shanghai, China.

Merino, Leonel, A. Bergel and O. Nierstrasz. (2018). "Overcoming issues of 3D software visualization through immersive augmented reality." In: *2018 IEEE Working Conference on Software Visualization (VISSOFT)* (pp. 54–64). Madrid, Spain.

Merino, Leonel, M. Ghafari, C. Anslow and O. Nierstrasz. (2017). "CityVR: Gameful software visualization." In: *2017 IEEE International Conference on Software Maintenance and Evolution (ICSME)* (pp. 633–637). Shanghai, China.

Moore, G. C. and I. Benbasat. (1991). "Development of an instrument to measure the perceptions of adopting an information technology innovation." *Information Systems Research*, *2*(3), 192–222.

Morgan, G. (1986). *Images of organization*. Beverly Hills, CA, USA: SAGE Publications.

Naranjo, D., M. Sanchez and J. Villalobos. (2014). "Towards a Unified and Modular Approach for Visual Analysis of Enterprise Models." In: *2014 IEEE 18th International Enterprise Distributed Object Computing Conference Workshops and Demonstrations* (pp. 77–86). Ulm, Germany: IEEE.

Nightingale, D. J. and D. H. Rhodes. (2004). "Enterprise systems architecting: Emerging art and science within engineering systems." In: *Proceedings of the ESD External Symposium Session VI* (pp. 1–13). Cambridge, MA.

Nunnally, J. C. (1967). *Psychometric theory*. New York, NY: McGraw-Hill.

Oates, B. J. and B. Fitzgerald. (2007). “Multi-metaphor method: organizational metaphors in information systems development.” *Information Systems Journal*, *17*(4), 421–449.

Panas, T., R. Berrigan and J. Grundy. (2003). “A 3D metaphor for software production visualization.” In: *Proceedings on Seventh International Conference on Information Visualization, 2003. IV 2003.* (pp. 314–319). London, UK: IEEE.

Papazoglou, M. P. (2003). “Service-oriented computing: concepts, characteristics and directions.” In: *Proceedings of the Fourth International Conference on Web Information Systems Engineering, 2003. WISE 2003.* (pp. 3–12). Rome, Italy: IEEE.

Quartel, D., W. Engelsman, H. Jonkers and M. Van Sinderen. (2009). “A goal-oriented requirements modelling language for enterprise architecture.” In: *2009 IEEE International Enterprise Distributed Object Computing Conference* (pp. 3–13). Auckland, New Zealand: IEEE.

Ramljak, D. (2017). “Business models and value oriented service design elements in ecosystem architecture.” In: *2017 25th International Conference on Software, Telecommunications and Computer Networks (SoftCOM)* (pp. 1–6). Split, Croatia: IEEE.

Rehring, K., M. Greulich, L. Bredenfeld and F. Ahlemann. (2019). “Let’s Get in Touch - Decision Making about Enterprise Architecture Using 3D Visualization in Augmented Reality.” In: *Proceedings of the 52nd Hawaii International Conference on System Sciences*.

Riempp, G. and S. Gieffers-Ankel. (2007). “Application portfolio management: a decision-oriented view of enterprise architecture.” *Information Systems and E-Business Management*, *5*(4), 359–378.

Rohloff, M. (2011). “Integrating Innovation into Enterprise Architecture Management.” In: *Proceedings of the 9th International Conference on Wirtschaftsinformatik* (pp. 776–786).

Roth, S., M. Zec and F. Matthes. (2014). *Enterprise Architecture Visualization Tool Survey 2014*. Germany: epubli GmbH.

Santana, A., A. Souza, D. Simon, K. Fischbach and H. D. Moura. (2017). “Network Science Applied to Enterprise Architecture Analysis: Towards the Foundational Concepts.” In: *2017 IEEE 21st International Enterprise Distributed Object Computing Conference (EDOC)* (pp. 10–19). Quebec City, Canada: IEEE.

Schaffer, O. and X. Fang. (2018). “What Makes Games Fun? Card Sort Reveals 34 Sources of Computer Game Enjoyment.” In: *AMCIS 2018 Proceedings* (pp. 1–10). Association for Information Systems.

Soares, L. (2008). “Using Metaphors for Visualizing Enterprise Architectures.” In: *SAC’08* (pp. 1–5). Fortaleza, Ceará, Brazil: ACM.

Souza, R., B. Silva, T. Mendes and M. Mendonça. (2012). “SkyscrapAR: An augmented reality visualization for software evolution.” In: *Proceedings of 2nd Brazilian Workshop on Software Visualization (WBVS 2012)* (pp. 17–24).

Sparacino, F., C. Wren, A. Azarbayejani and A. Pentland. (2002). “Browsing 3-D spaces with 3-D vision: body-driven navigation through the internet city.” In: *Proceedings. First International Symposium on 3D Data Processing Visualization and Transmission* (pp. 224–231). Padova, Italy: IEEE.

Steinberg, D., F. Budinsky, E. Merks and M. Paternostro. (2008). *EMF: eclipse modeling framework* (2nd Edition). Boston, MA: Addison Wesley.

Tamm, T., P. B. Seddon, G. Shanks and P. Reynolds. (2011). “How does enterprise architecture add value to organisations.” *Communications of the Association for Information Systems*, *28*(1), 141–168.

The Open Group. (2012). *ArchiMate® 2.0 Specification*. Zaltbommel: Van Haren.

The Open Group. (2018). *The TOGAF® Standard, Version 9.2* (11th ed.). van Haren Publishing.

UML, O. (2015). *Unified Modeling Language TM (UML®) Version 2.5*.

Urbach, N., S. Smolnik and G. Riempp. (2009). “Development and validation of a model for assessing the success of employee portals.” In: *ECIS 2008 Proceedings* (pp. 1699–1710).

Veneberg, R. K. M., M. E. Iacob, M. J. v Sinderen and L. Bodenstaff. (2014). “Enterprise Architecture Intelligence: Combining Enterprise Architecture and Operational Data.” In: *2014 IEEE 18th International Enterprise Distributed Object Computing Conference* (pp. 22–31). Ulm, Germany: IEEE.

Vessey, I. (1991). “Cognitive Fit: A Theory-Based Analysis of the Graps Versus Tables Literature.”

Wettel, R. and M. Lanza. (2007). "Visualizing software systems as cities." In: *2007 4th IEEE International Workshop on Visualizing Software for Understanding and Analysis* (pp. 92–99). Banff, Ont., Canada: IEEE.

Wettel, R. and M. Lanza. (2008). "Codecity: 3d visualization of large-scale software." In: *Companion of the 30th international conference on Software engineering* (pp. 921–922). Leipzig, Germany: ACM.

Wettel, R., M. Lanza and R. Robbes. (2011). "Software systems as cities: A controlled experiment." In: *2011 33rd International Conference on Software Engineering (ICSE)* (pp. 551–560). Honolulu, HI, USA: IEEE.

Whittle, R. and C. B. Myrick. (2004). *Enterprise business architecture: The formal link between strategy and results*. Boca Raton: CRC Press.

Winter, M. and T. Szczepanek. (2009). *Images of projects*. London, UK: Routledge.