MASTER THESIS

Development of a method to implement the concepts of resilience in EA

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Abstract

This master thesis presents a method for implementing the concepts of resilience of Enterprise Architecture (EA). As we live in a highly technological era, we assume that the importance of resilient systems and aspect of resilience in general is increasing. Enterprise architecture is considered to be fundamental for a company. It raises the idea that combination of EA and resilience could be useful for organizations therefore this work is proposing a method that would guide designers in improving resilience. EA resilience is a relatively new field in the scientific community, therefore this topic is found to be barely covered in scientific articles. This work includes literature review where we explore what insights about Enterprise Architecture (EA) resilience are present in published literature and what could be borrowed and applied from other fields. A systematic literature review is performed using Kitchenham guidelines. As a result, 850 articles were retrieved and reviewed. Based on the selected papers for this review, we show that despite the fact of the EA resilience being poorly explored, there are some relevant findings for our topic available in other Information Systems sub-areas, i.e. strategy development. The performed literature review identifies common awareness upon Information System resilience, presenting generalized definitions, strategies used in IS resilience field, various attributes and capacities. To add more, it also explores what other types of resilience are found in the literature and what metrics are used in order to estimate resilience and its numerical expressions.

This master thesis is expected to support organizations in improving their decisions regarding EA modelling. The research proposes a developed method that serves organizations as a guideline for implementing the concepts of resilience EA and is likely to increase it as well. As a result, five-steps method “Implementation of the concepts of resilience in EA“was created. This approach is expected to enrich the overall understanding of resilience. Furthermore, it is likely to provide a better understanding of EA between stakeholders as well as supports decision making.

All five steps of the method were applied as a solution for a case study at one of the largest manufacturing companies in Lithuania. Then designed solution was validated with a questionnaire based on UTAUT (Unified Theory of Acceptance and Use of Technology) by the panel of expert. Overall, the method resulted in positive evaluation and is believed to contribute to the scientific community.

This research was limited in several ways. First of all, EA resilience is barely discovered among scientific community. Second, resilient EA and industry of manufacturing is not a common topic in articles either, therefore it also limits the result. Finally, mindset of authors limits the method by the knowledge and way of thinking. It is believed that novel approach could be proposed as the scope of this field has not been covered yet.

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1 Introduction

During the last century, the industry has encountered several industrial revolutions contributing to it evolving dramatically. Threats of various disasters have increased and caused a demand for enhanced resilience among the company's strategies, systems and overall infrastructure. Recent events revealed that not purely technological change has an impact on the economy and industry in general but also global events such as the COVID-19 pandemic which disrupted every aspect of companies and our lives. On one hand, it caused an economic and industrial crisis, on the other hand, it forced everyone to implement technologies in every area: from education to the work industry. Pandemic hit all the world unexpectedly and required fast decision making and digitalising what is possible. Organisations were compelled to think how to change processes and adapt to the current situation and, as it is generally known, decisions which are made under pressure tend to be imperfect. Threats of various disasters have increased and raised a need for enhanced resilience among the company's strategies, systems and overall infrastructure. Developing a resilient entity is recognized to be a consistent and precision requiring process.

Assessing resilience is part of such a process. As the name of this paper indicates, one can make the assumption that resilience can be implemented in enterprise architecture (EA) and be estimated too. It is believed that the property of resilience is becoming one of the most important characteristics for a system, therefore it should be managed, explored and induced rather than dampened (Righi, Saurin, & Wachs, 2015).

Aspects of resilience have been explored for quite some time. The first accepted and most known definition of "resilience" was presented by C.S. Holling et al. in 1973 in their work about stability and resilience in ecological systems (Holling, 1973). Several papers mention this date to be the start of research studies on resilience. The word 'resilience' comes from the Latin word 'resilire' meaning to spring back or to rebound. Various papers have been published with a focus on resilience in different domains, extending knowledge on characteristics, metrics, formulas, cases, etc. Despite the increasing need of resilient systems, as we will see, this work reveals that an area of Information System (IS) resilience is relatively young, therefore, studies providing a full overview, definitions, metrics and numerical expressions to estimate resilience of this field are scarce. The first clear definition of IS resilience is formulated by Sarkar et al. in their work, where the authors also argued IS resilience falls under Organisational resilience (Sarkar, Wingreen, & Ascroft, 2016a).

Enterprise Architecture (EA) is a field focused on the architecture domain in line with business strategy. It is covered by Information System field therefore presented findings about IS resilience also cover another field EA resilience. This study zooms in this specific aspect of EA resilience, namely its assessment. It aims to examine, what is found in the scientific literature on the topic of EA resilience and come up with an answer regarding the question “How to implement the concepts of resilience in EA?”. Answering this question is important for several reasons: First, to our best knowledge, little has been done so far to provide metrics for estimating EA resilience whereas other fields of resilience already provide various numerical expressions. Exploring possible ways of adapting concepts of resilience in EA is important as it is valuable information, contributing to modelling of resilient EA at the company. It can give an insight of the current state at the company and indicate weaknesses. Furthermore, this work provides a structured summary of what is already done in concern of resilience in the past 5 years therefore this work could serve as a source of information for future studies. Finally, as the method has been evaluated neutral towards positive, it is believed, that the usage of the method improves the resilience and helps in decision making.

1.1 Problem Identification and Motivation

Various failures, disruptions are an understandable and common situation in the industrial world. When one machine crashes, it has usually an impact on the rest of the production chain. Such situations require decisions which are based on the particular situation and offer the best possible solution. When a disruption happens, architectural models and knowledge of the overall system become a necessity. Models which do not reflect resilience are not as helpful as they should be, even though a sequence of events might include resilient decisions (i.e. OR junction). Nevertheless, such models do not include any quantitative expressions, therefore the decisions taken might lead to more losses than benefits due to unexpected costs. Hence, we are raising the question, what could help to evaluate the situation and lead to the best applicable decision? In our opinion if enterprise architecture is modelled correctly and proper metrics are applied, it can be of great benefit.

For the past 40 years, scholars in multiple fields have explored various facets of resilience. The first accepted and best-known definition of ’resilience’ stems from the work of Holling on stability and resilience in ecological systems (Holling, 1973). Since then, resilience was studied in other domains and disciplines, including engineering, psychology, sociology, and subject to structured literature reviews (Bhamra, Dani, & Burnard, 2011). Additional systematic reviews are conducted to study resilience both from the perspective of the organization and supply chain (Kamalahmadi & Parast, 2016). Most recently, Morisse et al. (Morisse & Prigge, 2017a) explored resilience for industry 4.0 manufacturers and reflected on it by using the metaphor of building a house. Comprehension of the environment and understanding of an organization’s systems forms the foundation of a building. Four pillars stand on it: people, process, technologies and information. The rooftop of this house is made up of the main characteristics of resilience. This combined structure forming a house as per (Morisse & Prigge, 2017a), results in the resilience of an Industry 4.0 organization.

In the field of IS, the first definition of IS resilience is formulated by Sarkar et al. who also argue that IS resilience falls under organizational resilience (Sarkar, Wingreen, & Ascroft, 2016a). Based on the current body of knowledge, research and literature, we can observe that the concept of resilience is studied in multiple domains and disciplines at different aggregation levels. Given its complex nature, we argue that IS resilience is related to organization resilience but has a much wider scope and application domain. Thus, it should be approached from a multidisciplinary perspective. This motivated us to conduct research about resilience in EA, its position in IS and interconnections with other scientific disciplines and domains.

1.2 Research Objective

The primary objective of this research is to develop a method that explored the model of EA and supports in the assessment of resilience. This approach is believed to enhance the resilience of a system, help in decision making, enrich the collaboration between stakeholders within an organization and provide a better view of the situation while facing various disruptions.

The following steps are taken in order to achieve our stated objectives:

- Conduct a literature review regarding EA resilience
- Decide on what information will be used for this research in order to extend the EA model
- Develop guidelines for implementing EA resilience
- Evaluate the proposed method
- Discuss the limitation, further research, recommendations and the results

1.3 Research Question

The research question that is raised and answered in this study is:

How to implement the concepts of resilience in EA?

In order to answer this question, the following sub-questions were derived from the main question:

- RQ1: What is known in the scientific literature about resilience in Enterprise Architecture or Information Systems?
- RQ2: What are the different types of resilience found in the literature?

- RQ3: What metrics are used to assess systems resilience and on what calculation models are these metrics based on? Focus on the field of manufacturing.
- RQ4: How to design a method which can help with modelling and assessing the resilience of Enterprise Architecture?
- RQ5: Is the proposed method in RQ4 useful in practice?

The motivation for RQ1 is to have a deep look at what research efforts have already achieved towards resilience in the field of IS and how it is defined in various papers. It helps to identify a gap in the field and allows us to uncover further research questions worthwhile exploring. The motivation for RQ2 was to find what kind of other types of resilience exist. It is believed that several types of resilience could be covered by EA resilience as they might be closely related. RQ1 and RQ2 logically lead to RQ3 which is focused on the metrics. As the aim of this research is to develop a method for improving the resilience of EA, metrics and numerical expressions play an important role because it could be used in the quantitative assessment of resilience of EA. Even though this study does not cover numerical assessment, we believe that it could serve for the future studies. Nevertheless, answering RQ3 broadens our knowledge and serves in modelling the method with a focus on resilience which is also an answer to RQ4. RQ4 is answered by considering all the information which was found while answering to the first three questions therefore the proposed method is based on gained knowledge. Finally, RQ5 aims to discover whether the method is found to be useful in practice. The motivation for it is to assure that the proposed method is suitable for organizations and might be used in the future.

1.4 Research Methodology

A literature study will be conducted for answering the research questions so the primary knowledge would be built. Defining a problem requires guidelines. For this research, we chose Design Science Methodology (DSM) proposed by Wieringa (Wieringa, 2014). The author describes in DSM, that in order to present the problem-solving process, first a problem itself should be presented, then a treatment designed and validated (Figure 1).

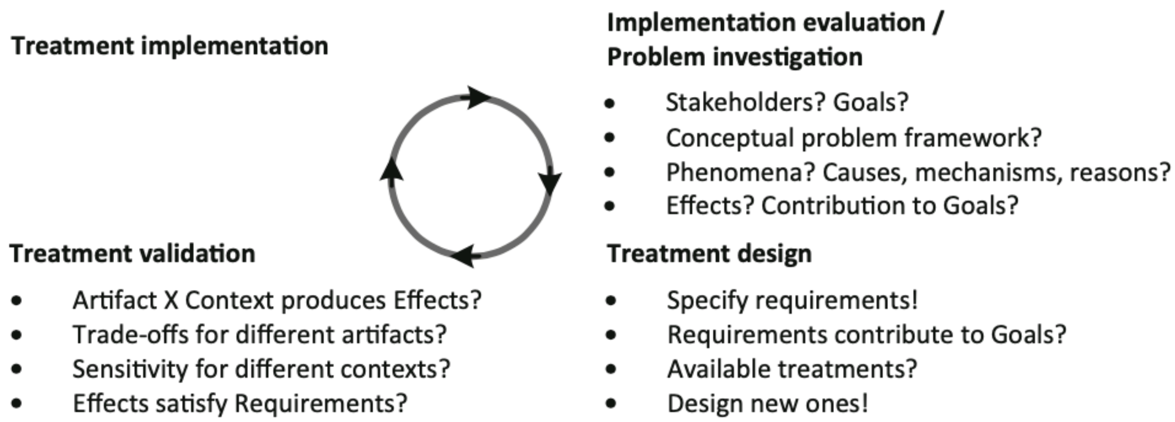


Figure 1 The engineering cycle (Wieringa)

In his work, Wieringa proposes the template for formulating the design problem which, according to the author, helps to identify missing pieces of information. The template is presented below:

- Improve <a problem context>
- by <(re)designing an artifact>
- that satisfies <some requirements>
- in order to <help stakeholders achieve some goals>.

Following these guidelines, the following design problem is formulated:

- Improve the modelling of EA in organizations
- by designing a method for implementing the concepts of resilience in EA
- that falls under system requirements
- in order to help organizations achieve higher performance.

1.5 Structure of the thesis

This study is structured following the DSM framework. First, the systematic literature review is performed and presented in Chapter 2 with the goal to introduce the audience to the field of resilience. Chapter 3 presents the design and development of the method which is demonstrated with a case study in chapter 4. Chapter 5 presents the validation by a panel of expert and finally the paper concludes with the discussion about the contribution of this study and recommendations for further research (Chapter 6).

2 Literature Review

2.1 Research Methodology

As a research methodology for this study, the systematic literature review (SLR) method proposed by Kitchenham and Charters (Kitchenham & Charters, 2007) has been chosen. Following their guidelines, our SLR was conducted in three stages: planning, conducting and documentation. The first stage of planning includes formulating research questions and developing a review protocol. The second stage, conducting, is about performing research: deciding on exclusion and inclusion criteria, relevant databases, year range and performing the search. The third stage, documentation, is a study selection part, where the list of included and excluded studies is developed, and the quality of primary studies is assessed (Figure 2).

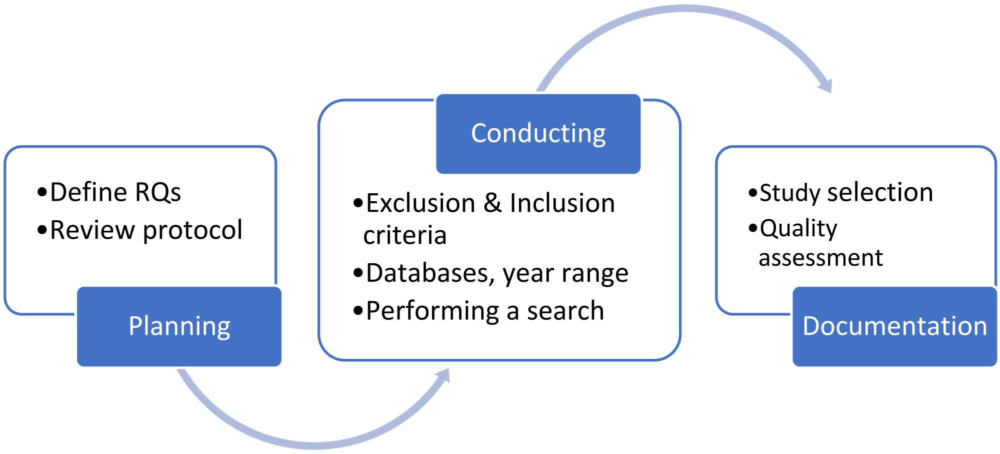


Figure 2 SLR method process

2.2 Research Questions

IS resilience being a relatively new field has barely been explored. To find more about this field and provide an overview, the following research questions are raised:

> RQ1: What is found in the literature about resilience in Enterprise Architecture or Information Systems?
> RQ2: What are the different types of resilience found in the literature?
> RQ3: What metrics are used to estimate systems resilience and on what calculation models are these metrics based on? Focus on manufacturing field.

The motivation for RQ1 is to have a deep look at what research efforts have already achieved towards resilience in the field of IS and how it is defined in various papers. It helps to explore a gap in the field and allows us to uncover further research questions worthwhile exploring. The motivation for RQ2 was to find what other types of resilience exist. It is believed that several types of resilience could be covered by EA resilience as they might be closely connected. RQ1 and RQ2 logically lead to RQ3 which is focused on the metrics. With this paper we are aiming to find a way how to assess EA resilience, therefore metrics and numerical expressions play an important role as without it, the possibility to estimate resilience quantitatively drops to the bottom.

2.3 Search process

This literature review concentrates on searching scientific articles available through a scientific database rather than books. Six databases were chosen for performing the SLR:

- ACM Digital Library (http://portal.acm.org).
- IEEE Xplore (http://www.ieee.org/web/publications/xplore/).
- Science Direct – Elsevier (http://www.elsevier.com).
- Taylor and Francis (http://www.tandfonline.com).
- Scopus (https://www.scopus.com)
- Sage (http://www.sage.com)

These databases are chosen on purpose, namely, to provide a wide variety of highly relevant articles, conference papers and journals where the focus is on EA or IS. As each of the research questions answers slightly different questions, different search queries were used for every database.

In order to find the right keywords, first, it was checked what Scopus would return as a result if a search ‘ALL ("resilience of enterprise architecture") or ALL (("enterprise architecture resilience")’ is performed. It returned ‘0’. Therefore, a different approach was taken. The following search commands were used to retrieve relevant articles:

- RQ1: TITLE-ABS-KEY ("enterprise architecture " OR "Business architecture" OR "information architecture" OR "Technology Architecture" OR "information system") AND KEY (resilience) DOCTYPE (ar OR cp) AND PUBYEAR > 2014 AND (LIMIT-TO (LANGUAGE, "English"))
- RQ2: (TITLE-ABS-KEY (resilience W/1 type) OR TITLE-ABS-KEY ("classification of resilience") OR TITLE-ABS-KEY (resilience W/1 classified) OR TITLE-ABS-KEY (resilience W/1 kind) AND PUBYEAR > 2014

- RQ3: TITLE-ABS-KEY (("information system*" OR "enterprise architecture" OR enterprise) AND (metrics OR measure* OR indica tor OR calculations OR formula OR estimat* OR "numerical analysis") AND (resilien*) AND (manufactur* OR produc*))

2.4 Inclusion & exclusion criteria

A set of criteria, as it is proposed by Kitchenham et al. (Kitchenham & Charters, 2007), is defined for picking the relevant sources. For this study, any paper directly or indirectly discussing resilience, is considered to be relevant. In order to narrow results, restrictions such as KEY (resilience) or W/n[1] resilience in search command were included. Also, the exclusion criteria were applied. First of all, it was limited to papers written in English only. Second of all, the year range for the date of publication was applied. Only articles published from 2015 or later are included in this research. This limit was set due to fast changes and growth in technologies and related areas, therefore it is assumed that papers which were published before 2015 are not that relevant as it used to be.

2.4.1 Study Selection

Numerous results were retrieved from different databases. To find papers, answering the research questions, results were sorted out. For each of the questions, three groups were created: Yes, Maybe, No. By reading the title and abstract it was decided, whether a paper is really discussing resilience or just mentioning it on the side. If the paper contains important views, it is put to the 'Yes' folder. If there are doubts about the importance, then it is sorted to 'Maybe'. If the abstract did not mention any aspect worth looking into the article, the paper is moved to the 'No' folder. When the first phase of sorting to 'Yes', 'No' or 'Maybe' is finished, articles in 'Yes' and 'Maybe' folders are evaluated based on a full text read. Irrelevant papers are excluded from the research. The applied selection criteria (SC) are presented below:

SC1: Does the paper answer RQs?

Y (yes): source provides complete, explicit definitions, answering RQ
M (maybe): paper is discussing to RQ somehow related aspects
N (no): paper offers an only narrow and shallow explanation to RQ or does not provide any answer

[1] W/n stands for "Within n words". For example, searching for Information System resilience, "System W/2 resilience" could be used and that would bring the results where "resilience" is within two words from "System".

SC2: Is an assessment of resilience the main target?

> Y: findings on resilience are the main purpose of the paper, different academic sources contributed to the same explanations
> M: resilience is somehow mentioned in the paper but does not provide any new inquiry
> N: resilience was not mentioned at all or a paper had no resilience focus

SC3: Does the paper contribute to IS?

> Y: source aims to provide relevant findings for the information systems, the discussed topic is covered by information system field
> M: findings are related to the IS but not further explained
> N: IS resilience or topics covered by Information Systems is neither explained nor mentioned

SC4: Does the paper provide new insights?

> Y: the paper provides new finding relevant to this research
> M: paper is based on previous research but provides new or relevant insights
> N: paper is based on a previous search bus does not provide any relevant

2.4.2 Executing the steps

Table 1 shows the number of papers found per source based on the search commands (Section 2.3, Search process) in selected databases. The initial search was performed in six databases resulting in 850 papers in total from which only 59 were selected as providing relevant information. Most papers were retrieved from Scopus, probably since the first search was performed in Scopus. Due to the user-friendliness of Scopus, almost half of the papers, 325 to be exact, were retrieved from it while a bit more than a fifth of all selected studies were retrieved from IEEE (187). The smallest amount of sources was found in ACM Digital Library (25) and Sage (45) where a search for all three questions resulted in 70 articles. Apart from the mentioned databases, 170 papers were found in ScienceDirect and 98 in Taylor & Francis.

Some of the papers for RQ2 were selected manually while analysing papers for other research questions therefore the result of selected papers (23) compared to studied papers (155) seems to be quite high. While working on research question 2, we realised that the results of the search analysis were already satisfying, therefore a search on ScienceDirect was not performed.

After the selection procedure, only a small percentage was left of all papers (Table 1). 6 % of all 405 papers were chosen for RQ1. Sources for RQ2 were selected more precise and resulted in 15 % out of 155. In order to answer RQ3, 9 % out of 290 papers were selected and used. Due to the fact that some papers are used in several questions, the total number of selected papers is 59 instead of 72 (Table 1).

Table 1 Papers found in databases and selected for RQs

Source	**RQ1**	**RQ2**	**RQ3**	**Total**
ACM Digital Library	7	5	13	25
IEEE	63	13	111	187
Sage	5	19	21	45
Scopus	196	73	56	325
Science Direct	86	-	84	170
Taylor & Francis	48	45	5	98
Total Papers found:	**405**	**155**	**290**	**850**
Total Papers selected:	**24**	**23**	**25**	**58**

2.5 Results

The following sections present the selected papers and the findings aiming to answer each of the research questions.

2.5.1 Findings on results

2.5.1.1 Demographic description of the selected papers

The pie chart in Figure 3 presents the distribution of selected studies per year for this SLR. At first glance, it is obvious that the majority of publications are published in 2016. The proportions of studies of the year 2017 and 2019 can be stated to be contributing more or less equally to this systematic literature review, at 18 % and 20 % respectively. 2015 and 2018 result in similar proportion too, 14% and 12% subsequently. Although only 4 % of selected articles are published in 2020, it cannot be judged whether 2020 contributes a lot to the topic of EA resilience or not as it is the ongoing year.

The bar chart in Figure 4 illustrates the selected studies per venue. A majority (67 %) of publications are contributions from journals followed by conference proceedings with 28 %. Only 3 % of studies are serials. Thesis contributes to this search just slightly, resulting in 2 % This indicates that the majority of selected papers provide important insights and are accepted by the scientific community.

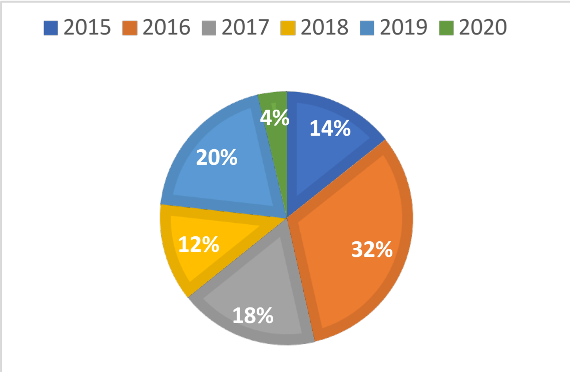


Figure 3 Distribution of selected studies per year

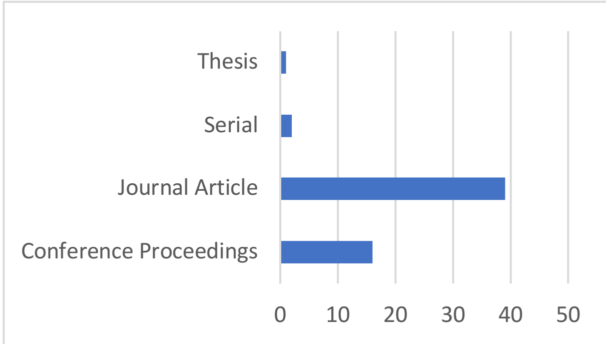


Figure 4 Distribution of selected studies per venue

The following diagram, Figure 5, indicates the countries of the affiliations of the authors. As can be seen from the figure, the majority are in the USA. Portugal, UK, Iran and Australia are contributing to these studies more or less equally – around 10 % each respectively. It is surprising to find out that the number of authors from Iran and the UK is almost the same. Italy and the Czech Republic showed to be providing interesting insights for this research as well, 5 % of the authors origin from these countries.

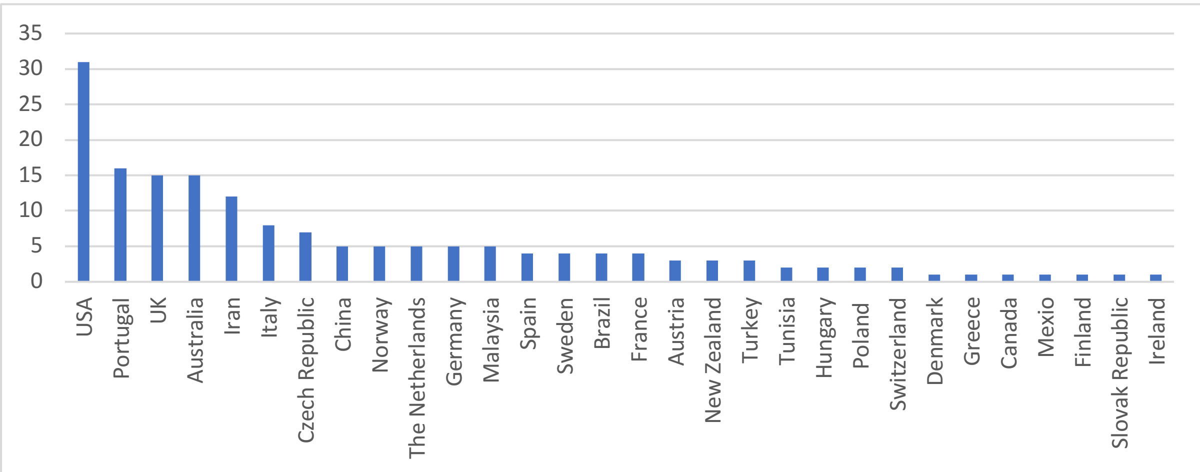


Figure 5 Countries of the authors of the included papers in this review.

2.5.1.2 RQ1: What is found in the literature about resilience in Enterprise Architecture? And in Information Systems?

Our search for RQ1 in total produced 405 results. Half of those outcomes were recovered from the Scopus database. Sage and ACM Digital Library search retrieved the least - up to 10 papers. Out of 405 papers only 24 were somehow related to IS resilience and only 9 out of 24 had a clear focus on Information System resilience.

In order to answer this question, data were collected and analysed. It was realised that various databases to this day offer only a narrow and shallow understanding of resilience focusing on Enterprise Architecture.

Table 3 presents the topics related to resilience, the findings related to each topic and the respective literature sources.

Table 2 Findings on IS resilience

Topic	**Findings**	**Source**
Definition	IS resilience is the ability of a system to work under predicted or unforeseen disruptions and to return to equilibrium or recover to an acceptable level of performance as soon as possible. It aims to mitigate the likelihood of failures and losses and requires constant adaptation to new known or unknown threats.	(Amaral, Fernandes, & Varajão, 2015; Sarkar et al., 2016a; Sarkar, Wingreen, & Ascroft, 2016b) (Buchanan et al., 2018) (Goudalo & Kolski, 2016; Gu, Jin, Ni, & Koren, 2015) (Heeks & Ospina, 2019) (Pirinen, 2017; Sakurai, Watson, & Kokuryo, 2016) (Almeida, Neto, & Madeira, 2017; Rehak, Senovsky, Hromada, & Lovecek, 2019; Slivkova, Rehak, Nesporova, & Dopaterova, 2017; Urbanczyk & Werewka, 2019) (Pasquini, Ragosta, Herrera, & Vennesland, 2015; Velu, Al Mamun, Kanesan, Hayat, & Gopinathan, 2019)
Strategy	The strategy of IS resilience should be aligned with organisational resilience and aiming to provide solutions which would be independent of a specific scenario or event. It should also provide alignment between IT and business strategies. IS resilience planning differs from other fields since the ideal time to implement is during the crisis or adverse circumstances when uncertainty is greater than normal.	(Marrella, Mecella, Pernici, & Plebani, 2019; Sarkar et al., 2016b)
Factors (Attributes)	Factors contributing to resilience: diversity, efficiency, adaptability, cohesion, self – organisation, robustness, learning, redundancy, rapidity, flexibility, equality, agility, vulnerability to risk, responsiveness	(Heeks & Ospina, 2019) (Barn & Barn, 2015) (Seyedmohsen Hosseini, Barker, & Ramirez-Marquez, 2016; Platt, Brown, & Hughes, 2016; Ramezani & Camarinha-Matos, 2020; Slivkova et al., 2017) (Sarkar et al., 2016b)
Capacities	Avoidance (Resistance), Absorptive, Adaptive, Recovery (Restorative),	(Goudalo & Kolski, 2016; S. Hosseini, Al Khaled, & Sarder, 2016) (Barn & Barn, 2015)((Seyedmohsen Hosseini et al., 2016; Sarkar et al., 2016a, 2016b) (Platt et al., 2016; Ramezani & Camarinha-Matos, 2020; Velu et al., 2019) (Elleuch, Dafaoui, El Mhamedi, & Chabchoub, 2016; Heeks & Ospina, 2019; Labaka, Hernantes, & Sarriegi, 2015; Slivkova et al., 2017) (Pasquini et al., 2015)

Following the definition of EA given by Gomes (T. Gomes et al., 2016), enterprise architecture provides a common view on how enterprise resources (product, process, technology, information and application architecture) are integrated and associated to each other to provide the primary drivers of the enterprise. Hosseini et. al (Seyedmohsen Hosseini et al., 2016) share one of the ways to estimate EA resilience by providing a numerical expression:

$$R = \max \sum_{i=1}^{m} z_{i\frac{d_i}{c_i}}$$

Here R stands for resilience,

m – number of operations in the enterprise IS,

i – time of recover of operation,

z – importance weight of operation *i*,

d – the demand time for the recovery of operation,

c – the completion time of operation *i.*

Papers with no focus on IS but covering product resilience, process resilience, technology resilience and organisational resilience are assumed to be part of IS resilience field and are also used for answering RQ1.

Information extracted from retrieved sources was classified in four groups*:* definition, strategy, attributes and capacity. All selected papers had a definition of resilience but only three had defined IS resilience (Pirinen, 2017) (Sarkar et al., 2016a, 2016b). Discussion on strategy and IS resilience planning was not popular among papers and just one paper (Sarkar et al., 2016b) shares insights. Characteristics of resilience is a more common topic: 7 papers mentioned and explained it. Finally, the last group of papers discuss capacity, which defines the functions of IS resilience. 13 out of 24 articles complements to it.

2.5.1.3 RQ2: What are the different types of resilience found in literature?

The review of different kinds of resilience indicated that there is not one clear opinion, nonetheless, several similarities can be observed.

We found that there is a growing body of literature about different types of resilience, thus the review indicated that a wide range of types is emerging over time. First, it was thought that there are only two main forms of resilience: engineering and ecological, as it is indicated in Gomes studies (T. Gomes et al., 2016), but, contrary to our expectations, further studies demonstrated that resilience can be grouped by various aspects:

- Domains
- Expression of the measure – whether it is a qualitative or quantitative measure
- Source of disruption – whether it is internal or external
- Longevity - whether it is long-term or short-term resilience.

However, a limited number of papers contribute to resilience categorised by other aspects than domain.

Such term as Internal or External resilience are found only in work of Labaka and Hosseini (Labaka et al., 2015; Labaka, Hernantes, & Sarriegi, 2016) (Seyedmohsen Hosseini et al., 2016)). This type of resilience depends on the source of disruption: whether it is internal or external. 'External' stress can be caused by government, society, other external stakeholders, while internal refers to the level of critical infrastructure (Labaka et al., 2016). We note that short-term resilience and long-term resilience were barely used in selected papers. Only two papers referred to it. Freeman supports in his job that short-term durability is utilized when regular services and financial activity return to normal condition after confronting short-term consequences (Freeman, McMahon, & Godfrey, 2016) while Kahnamouei explains short-term resilience as an ability to cope with altering conditions or a capacity to reduce the consequences of disruption (Kahnamouei, Bolandi, & Haghifam, 2017). Long-term resilience is described as constantly evolving and changing and providing a response to a range of long-term stressor (Freeman et al., 2016). As none of the presented types of resilience was assigned to long-term resilience, this property (long-term resilience) is deleted from the table. Kahnamouei proposed a framework for long-term resilience in his work which consists of a cycle of four functions and four different states (Kahnamouei et al., 2017).

As four out five indicate the behaviour of resilience, we could combine resilience grouped by domain with other types. Main groups for resilience are determined by the amount of research representing it.

Table 3 Types of resilience

Domain	**Explanation**	**Qualitative**	**Quantitative**	**External**	**Internal**	**Short-term**	**References**
Community	The ability of a community to respond, withstand and recover from a crisis by taking collective actions and using available resources.						(Seyedmohsen Hosseini et al., 2016) (Comes, 2016) (Ostadtaghizadeh, Ardalan, Paton, Jabbari, & Khankeh, 2015) (Van Trijp, Boersma, & Groenewegen, 2018)
Critical Infrastructure	the ability of sectors, subsectors and elements to mitigate the intensity of impacts caused by a disruptive event and to reduce the duration of their failure or disruption						(Rehak et al., 2019) (Seyedmohsen Hosseini et al., 2016) (Labaka et al., 2016)
Cyber	Process ensuring the protection of core functionality and defining straightforward and practical ways to restore any lower priority functions R=DS/TS						(Conklin & Shoemaker, 2017) (Hua, Chen, & Luo, 2018) (Babiceanu & Seker, 2017)
Ecological	The behaviour of natural systems in response to a disaster	X				X	(Van Trijp et al., 2018) (Davidson et al., 2016) (Rocchetta & Mina, 2019; Sabatino, 2016)
Economic	The ability to avoid or reduce both direct and indirect losses caused by disasters.			X	X		(Seyedmohsen Hosseini et al., 2016) (Labaka et al., 2015) (Pashapour, Bozorgi-Amiri, Azadeh, Ghaderi, & Keramati, 2019) (Sabatino, 2016; Zobel & Baghersad, 2020)
Engineering	Often defined as safety management, it is a system capability to handle disruption and		X			X	(Seyedmohsen Hosseini et al., 2016) (Righi, Saurin, & Wachs, 2015) (Van Trijp et

	build knowledge for future shocks;						al., 2018) (Davidson et al., 2016; Sabatino, 2016)
Organisational	Company's ability to recognize threats, evaluate current and future risk and rebound from adverse and unexpected situations	X		X	X		(Amaral et al., 2015; Sahebjamnia, Torabi, & Mansouri, 2018) (Seyedmohsen Hosseini et al., 2016) (Wang, Nistor, & Pickl, 2017) (Labaka et al., 2015) (Sarkar et al., 2016b) (Andersson, Cäker, Tengblad, & Wickelgren, 2019) (Rehak et al., 2019) (Velu et al., 2019) (Zobel & Baghersad, 2020) (Van Trijp et al., 2018) (Davidson et al., 2016) (Morisse & Prigge, 2017b)
Social	Capability of groups or communities to face crisis, cope with and overcome it by making social, political and environmental changes.			X			(Seyedmohsen Hosseini et al., 2016) (Labaka et al., 2015; Platt et al., 2016)
Social-ecological	The ability to respond, withstand and recover from a socio-ecological disturbance without shifting to a new regime with a different set of processes and structures					X	(Sabatino, 2016; Sanchez, Osmond, & Van Der Heijden, 2017)
System	Ability to reduce effectively both the size and duration of the deviation from concentrated system performance levels	X					(Wang et al., 2017) (Seyedmohsen Hosseini et al., 2016)
Technical	Systems capability to maintain functionality when subject to a crisis			X	X		(Labaka et al., 2015) (Rehak et al., 2019) (Zobel & Baghersad, 2020)
Urban	Refers to community resilience with focus on cities. Cities and community can cope with severe natural, economic, biomedical, social, technological or political hazards.						(Van Trijp et al., 2018) (Mehmood, 2016)

2.5.1.4 RQ3: What metrics are used to estimate systems resilience and on what calculations are these metrics based on? Focus on the field of manufacturing.

In order to answer this question, results from databases using a particular search command were analysed (Section 3.3). From 290 articles only 25, which is 8 % of all papers, were assumed to be relevant for this research question. Metrics with numerical expression referred by most papers were Recovery time (Gu et al., 2015; Jin & Gu, 2016; Wei & Ji, 2010) and Performance loss (Jin & Gu, 2016; Nan & Sansavini, 2017; Wei & Ji, 2010). Table with formulas and references indicate that there have already been relevant studies, based on various cases, and revealing interesting findings (Table 4). Studies demonstrated that there are metrics that have synonyms and therefore are known differently in various sources, for example, robustness and rapidity both signify the same - how quickly a system recovers to the first degree of functionality. Flexibility and adaptability are also found to be used equally as both discuss an ability of a system to change status (Morisse & Prigge, 2017b) (Govindan, Azevedo, Carvalho, & Cruz-Machado, 2015) (Heeks & Ospina, 2019). Diversity and knowledge are discussed in four papers therefore it is assumed to have the highest significance.

For one of the papers, the snowballing principle is applied since it appeared to be applicable for this particular search and giving significant insights (Wei & Ji, 2010). The paper is not focused on IS, it rather discusses an industrial control system. Nevertheless, it shares important findings as it introduces the audience to metrics for the resilience of the control system and also provides formulas for estimation purposes. It is assumed that those formulas could be also applied in the IS field, therefore it is included in this search.

Table 4 Metrics for resilience

Metric	Definition	Formula	References
Capability Drop Ratio (CDR)	Defines capacity of degradation by the influence of disturbances	$RC_d = \frac{C_0 - C_{min}}{C_0}$	(Luo, Kou, Liu, & Chen, 2018)
Capability Recovery Degree (CRD)	Defines the margin of recovery when capability restores from the lowest level to a new dynamic steady state.	$\Delta C_r = C_r - C_{min}$	(Luo et al., 2018)
Capability Recovery Ratio (CRR)	describes the percentage of capability restore after the influence of disturbances.	$RC_r = \frac{C_r - C_{min}}{C_0 - C_{min}}$	(Luo et al., 2018)
Collaboration	Organizations ability to work together and share knowledge in between.		(Morisse & Prigge, 2017b)
Connectivity	Connection in all levels, from process to product.		(Morisse & Prigge, 2017b)
Degrading time	Time that takes for a system to reach its bottom in case of attack	$T_i^d = t_i^m - t_i^0$	(Wei & Ji, 2010)
Diversity	Option to choose from a variety of different assets, institutions, etc.		(Morisse & Prigge, 2017b) (Kusiak, 2019) (Heeks & Ospina, 2019)
Flexibility	Systems property to change to new status easily		(Morisse & Prigge, 2017b) (Govindan et al., 2015) (Heeks & Ospina, 2019) (Macdonald, Zobel, Melnyk, & Griffis, 2018)
Knowledge	Ability to reach and share common knowledge effectively among members		(Morisse & Prigge, 2017b) (Govindan et al., 2015) (Heeks & Ospina, 2019)
Performance degradation	Maximal performance degradation due to incident	$P_i^d = P_0 - P_i$ $\Delta C_d = C_0 - C_{min}$ $\Delta Max\_C_d = C_0 - C_t$	(Wei & Ji, 2010) (Luo et al., 2018)
Performance loss	Indicates system performance degradation during the transients of a disruptive event	$P_i^l = P_0 \times \left(t_i^r - t_i^0\right) - \int_{t_i^0}^{t_i^r} P(t)$ $PL_{DP} = \int_{t_d}^{t_r} \left(MOP(t_0) - MOP(t)\right) dt$	(Wei & Ji, 2010) (Nan & Sansavini, 2017) (Jin & Gu, 2016)
Production loss	Production loss caused by disruption, during and after the disruption	$PL^P = \frac{t_D}{T_I^0(0)} PR^S - \sum_{k=t^P+1}^{t_D - t^P} PR^P(k) +$	(Gu et al., 2015)

		$\sum_{k=\frac{t_D}{T_I^0(0)}+1}^{\infty}\left(PR^S - PR^P\left(kT_I^0(0)\right)\right)$	
Protection time	Defines time that a system managed to absorb incident	$T_i^p = t_i^d - t_i^0$	(Wei & Ji, 2010)
Recovery time (Throughput settling time)	The time that system takes to recover after the disruption	$T_i^r = t_i^r - t_i^s$ $TST_\varepsilon^P = \max\left\{k \middle\| k \geq \frac{t_D}{T_I^O(0)}, PR^P(kT_I^O(0)) < (1-\varepsilon)PR^S\right\}T_I^O(0) + T_I^O(0) - t_D$	(Wei & Ji, 2010) (Jin & Gu, 2016) (Gu et al., 2015)
Redundancy	Defines the extent to which components within a system are substitutable for		(Heeks & Ospina, 2019)
Robustness	Amount of time to recover to an acceptable level of functionality	$RAPI_{DP} = \frac{MOP(t_d) - MOP(t_r)}{t_r - t_d}$	(Nan & Sansavini, 2017) (Heeks & Ospina, 2019)
Total loss	Total financial loss experienced by a company due to disruption	$L_i = f(P_i^l, R_i^c)$	(Wei & Ji, 2010)
Total underproduction time	Total time when system production rate was lower than its steady-state value	$TUT_\varepsilon^P = t_D + \sum_{k=\frac{t_D}{T_I^O(0)}+1}^{\infty} \mathbf{I}\{PR^P(kT_I^O(0)) < (1-\varepsilon)PR^S\}T_I^O(0) - \sum_{k=1}^{\left\lfloor \frac{t_D - 2t^P}{T_I^P(t^P)} \right\rfloor} \mathbf{I}\{PR^P(t^P + kT_I^P(t^P)) \geq (1-\varepsilon)PR^S \cdot \frac{T_I^P(t^P)}{T_I^O(0)}\}T_I^P(t^P)$	(Gu et al., 2015) (Jin & Gu, 2016)
Vulnerability	Probability of occurrence of unforeseen disruptions	$V_x = P(x) \cdot D_x = P(x) \cdot (\int_0^d (Lb - x)dt + \int_0^d (x - Ub)dt)$	(Man, 2019)

2.5.2 Discussion

2.5.2.1 General discussion

This systematic literature review revealed that resilience has been increasingly recognised as an indispensable property in various domains. Nonetheless, it was expected, that our search would provide more models and that the field of IS resilience was explored much more. In our set of selected papers, we found that the majority of papers are published in journals which tells us that the topic of resilience in Information Systems is getting mature. We also found that the year 2016 is the one in which one third of our included papers were published. Moreover, we found that the US is the country with the most active researchers on the topic of resilience. One might think that our understanding of the topic might be skewed as we used a sizeable number of sources authored by US-based researchers. However, we believe that this does not necessarily mean a threat to validity, as our included set of papers cover publications of authors from 29 countries. This means that the interest in the topic of resilience is growing in general, regardless of regional differences. We consider this as a positive development towards the generation of more generalizable knowledge covering a very broad variety of countries and contexts.

2.5.2.2 Definition

"Information Systems resilience" is a relatively young area. A search on Scopus has shown the very first publication mentioning "Information Systems resilience" could be traced back to 2013. The controversial question is whether IS resilience is covered by organisational resilience or the opposite – organisational resilience is covered by the IS resilience. Organisational resilience is explored scientifically more and was addressed as a means to work reliably in many different adverse conditions whereas IS resilience is more concentrated to a continuance of secure and dependable IS solutions, such as alignment between IT and business plans, averting potential business risks and capitalising on present and potential business opportunities. Research uncovered that organisational resilience is a broader field and it is understood that when disturbance happens on IS facet it is an effect on the whole organisational ecosystem, so it is said that data systems resilience is coated by organisational resilience (Sarkar et al., 2016a).

Explored papers from 2015 revealed that only a few definitions for IS resilience were proposed. This result highlights that little is known about the IS resilience and mostly nothing is known about Enterprise Architecture resilience. Nevertheless, the term ‘Information systems resilience” is found in several papers among which a precise definition of IS resilience has been proposed only once (Sarkar et al., 2016b). All of the other discovered descriptions were based on the general meaning of resilience: the ability to recover quickly from a disruption. Sarkar in his work with a focus on the governance shares a definition for IS resilience: Information Systems resilience is a function of an organisation's overall situation awareness related to Information Systems, management of Information Systems "vulnerabilities, and adaptive capacity, risk intelligence, flexibility and agility of Information Systems in a complex, dynamic, and interconnected environment." (Sarkar et al., 2016a). Multiple properties are covered by it: system awareness, vulnerability, adaptability, flexibility and agility. Though system characteristics are discussed, different phases that are faced by the system are not mentioned. A slightly different approach is taken by Goudalo where four capacities (anticipation, absorption, reconfiguration, restoration) are covered and all of it is presented: "the capacity to prepare and adapt facing perpetuating evolutionary conditions and to restore full capability after an accident or an attack."(Goudalo & Kolski, 2016). Pirinen (Pirinen, 2017) outlines that the system should recover, rebound or jump back to the primary or addressed system state. Relatively recent Heeks work (Heeks & Ospina, 2019) concludes that this system property is mostly understood in sense of recovery and continuity and still lacks investigation in "bounce forward" adaptive role, which is found in the basic definition of resilience. Therefore, after studying various papers a definition for this study is proposed (Table 2):

IS resilience is the ability of a system to work under predicted or unforeseen disruptions and to return to equilibrium or recover to an acceptable level of performance as soon as possible. It aims to mitigate the likelihood of failures and losses and requires constant adaptation to new known or unknown threats.

2.5.2.3 Capacity

The next distinguished group among results is named as “capacity”. It defines functions of resilience. All papers relate to four capacities: Avoidance (also known as resistance) absorptive, adaptive and recovery, in some papers called as restorative. These four capacities could be also called as a sequence for reaction and are commonly used to name phases to which resilience belongs. When a disturbance occurs, the very first thing a resilient system ought to be available to perform would be to withstand the disturbance and fight back without any consequences. If a system is not capable to do so, the phase of absorption is started. System performance is not capable to keep up with disruptions and starts decreasing. At this stage, the system is aiming to keep its efficiency high, what might result in a change of process, applying maintenance if it is a technical issue, change of a product, etc. If the system fails at this part the bottom might be hit and the process would stop. If it keeps up to battle back, the system moves to the next phase of recovery. Following the definition of resilience engineering, three elements that should be estimated can be distinguished: entity of changes and disruptions, the optimal performance and deviation from it as well as expanses due to adjustments (Pasquini et al., 2015). Pasquini et al. present resilience as a sum of four main abilities: anticipation, monitoring, learning and response. Another field, Critical Infrastructure (CI) stands for various systems, networks and assets which are ensuring security, economy and public health. In this field resilience is defined as:

$$R = \sum_{s=1}^{N} \omega_s \cdot (P_s - E[I_s]) \ ,$$

Here R stands for resilience,
s – indicates scenario
ω_s – the likelihood of occurence of particular scenario,
P_s – stands for the preparedness
$E[I_s]$ – the expected impact on the CI in case scenario happens (König, 2019).

Thus, we assume that the principles of CI are similar to the principles of Information Systems resilience. Rehak et al. (Rehak et al., 2019) present components and variables determining the resilience of critical infrastructure elements. The following diagram presents the three different phases: disruption, recovery, adaptation (Figure 6).

The first phase, disruption, starts when an unforeseen interruption happens. A system, using its capacity of avoidance detects the new shock. If the level of disruption keeps increasing, it hits the boundary of absorption. This line indicates the change in system behaviour. The aim now is to absorb stress to maintain the original level of resilience. In case the intensity of disruption aggregates and reaches a limit of absorption, that is when the level of resilience starts falling and the system starts reacting with appropriate actions. If IS succeeds in fighting back and intensity of disturbance falls, the process of recovery is started. The target of the recovery process is to reach a primary level of performance or the acceptable one. Next phase is adaptation when the system learns from the recent event and reconfigures itself to be prepared for unknown threats. This adaptive capacity indicates how important it is to acquire, disseminate and retain information and knowledge (Van Trijp et al., 2018).

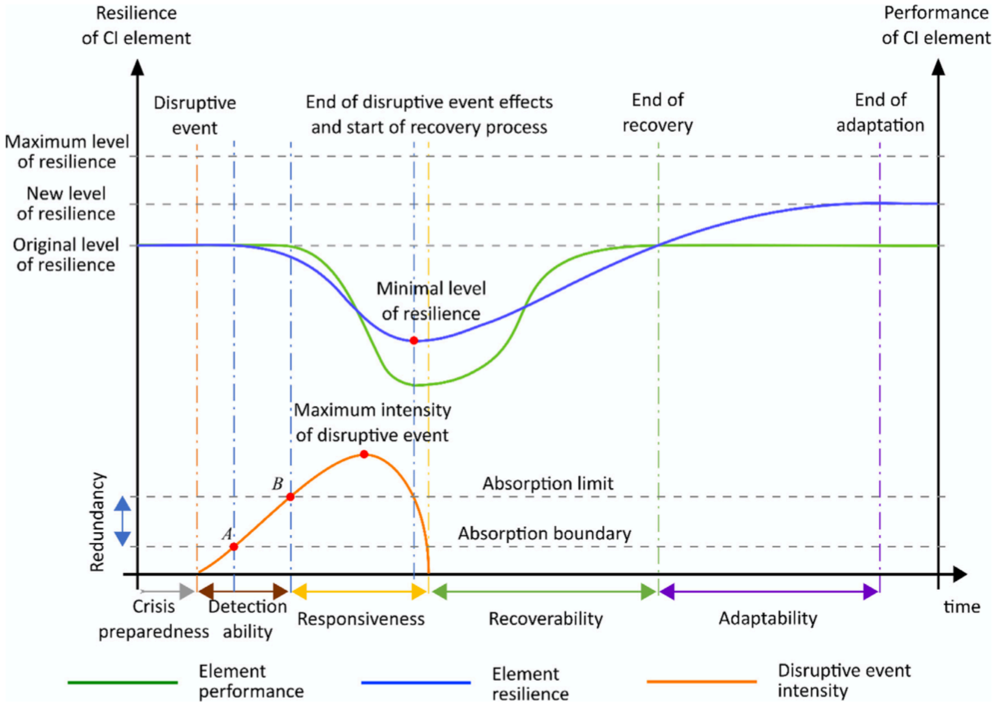


Figure 6 Lifetime of Critical Infrastructure resilience. (Rehak et al., 2019)

2.5.2.4 Strategy

In the reviewed literature, the concept of 'strategy' is linked to the understanding of a disaster. Following the proposed lifetime of a disaster, three phases can be generalized: readiness, responsiveness and recovery (Figure 6). Various strategies can be applied to each of the phases to reach better results. The first phase, readiness, takes place while the planned level of operations is maintained. Several strategies are proposed for this stage. Inventory control, investing in training and education, learning from the experience of others, predicting the likelihood of an event and warning, identifying threats and building common knowledge should be also playing a role. The next phase is response. The system falls into this phase when it failed in the first phase and a disaster occurred. During this phase, the system has one aim, to withstand the attack and keep the performance as high as possible. At this point, strategies which include risk and information sharing, utilizes the plans created during the stage of readiness, reorganizes resources and involves multi-sourcing, are commonly used. The third phase is recovery. It starts when a disturbance is fought back and finishes when the system is back to a pre-disruption or normal operational state. At this stage repairing, restoring and rebuilding tasks are performed, identifying lessons learned and best practices. (Ramezani & Camarinha-Matos, 2020) presents a list of various strategies which could be applied during different phases (Table 5).

Table 5 Resilience strategies during a different phase

Strategy	Readiness	Response	Recovery
Acceptance		X	
Barbell	X		
Buffering	X		
Collaboration	X	X	X
Cost Minimization	X		
Customer Service			X
Creating Disruption Management Culture	X		
Crisis Management	X	X	X
Demand Managing		X	
Forecasting	X		
Fault Injection	X		
Government Lobbying		X	
Graceful Degradation		X	
Insurance	X		
Infrastructure Investments	X		
Inventory Management	X		
Knowledge Management			X
Mapping	X		
Network Structure Planning	X		X
Postponement		X	
Performance measurement			X
Policy management	X	X	
Real-time monitoring	X		
Reengineering	X		
Risk Assessment	X		
Risk-hedging	X		
Revision		X	X
Sensemaking		X	X
System Analysis/Evaluation	X		
Supplier Selection	X		
Sourcing	X	X	
Weak links		X	

Resilience strategy is addressed by several papers. As it was mentioned before, IS resilience falls under organisational resilience, thus both strategies should be aligned with each other (Sarkar et al., 2016a). Business has an important role in IS, too, therefore, four relevant aspects in planning are distinguished: IT and business strategies should be placed in a line, IT investment on strategic priorities should receive more attention, discussion on ways to avoid potential business risks and capitalization on current business opportunities (Sarkar et al., 2016a). Four main parts of the strategy can be outlined: 1) structured evaluation and exploration of disruption risks as well as continues search on possible improvements on warning systems, general awareness of the underlying causes 2) raising awareness of responsibility and acceptance of it 3) long-term strategy, usage of preventive measure 4) cooperation within partners in advanced planning and quick response, assessments of risk factors (Tarhan, Aydin, & Tecim, 2016). Following the proposed four stages could work as a starting point in the implementation of more resilient decisions in EA.

2.5.2.5 Attributes of resilience

IS resilience as a property can be seen from three different perspectives: resilience as a property of IS input system, resilience as property information system itself and resilience as property IS output system (Heeks & Ospina, 2019). Various characteristics are mentioned in multiple papers (Table 2). Factors contributing to resilience are diversity, efficiency, adaptability, cohesion, self – organisation, robustness, learning, redundancy, rapidity, flexibility, equality, agility, vulnerability to risk and responsiveness. People, organisations and communities have an impact on IS resilience, too. As it is expected from a system to be flexible and building the knowledge from past events, it is also expected that personnel has to be flexible, motivated, optimistic and consistent (Barn & Barn, 2015).

The list of collective characteristics and explanations is provided in Table 6.

Table 6 IS resilience attributes

Name	Definition
Adaptability	Capability of a system to act in a flexible way and change in response to new pressure
Agility	Capability of a system
Cohesion	Indicates whether variables of a system have relationships together
Diversity	Indicates whether equipment (?) varies
Efficiency	Indicates the performance of a system
Equality	Equal disruption of access and roles among system
Flexibility	Capability of a system to adapt to changes
Learning	Capability of a system to obtain new skills and expand knowledge
Rapidity	Capability of a system to react to external disturbances quickly
Redundancy	The extent to which components within a system are substitutable
Responsiveness	Capability of a system to react to various disruptions
Robustness	Capability of a system to withstand external disruptions with the lowest possible fluctuation in performance
Self-organisation	Capability of a system to rearrange its functions and processes in case of external disruptions
Vulnerability to risk	Indicates the likelihood of occurrence of unforeseen disruption

2.5.2.6 Types and Metrics

With the second research question, various types of resilience were gathered. Search showed that resilience types can be categorized not only by domain where methods for enhancing resilience are applied but also by the lifetime (short-term, long-term), source of disruption (internal or external) and whether it is possible to quantify or only qualify. Types of resilience are explored due to the prediction that various types share common models and formulas, therefore, discovered numerical expressions and other information, taken from different domains, might be applied for EA resilience, too. One of such examples is cyber resilience which could be stated to fall under EA resilience because enterprise architecture covers not only technological but also product, process, information and application architectures (R. Gomes, 2016). Conklin et al. in his work present the seven main steps of ensuring cyber resilience which are as follows (Conklin & Shoemaker, 2017):

1. Classification – classifying threats.
2. Risk assessment – providing a detail description of every threat and possible harm.
3. Ranking – all threats are ranked thus it would be assured that assets ranked as “critical” would be maintained and assigned to supervise.

4. Design and deployment – identify controls objectives, design an infrastructure to ensure its stated mission, goals and objectives and deploys it.
5. Test – checking the critical control performance against stated mission goals.
6. Recovery – a creation of a complete and consistent recovery process.
7. Evolvement – deploying process and technology improvements.

These six steps could be easily applied to the resilience of EA, too.

A list of different types of resilience is presented in Table 3. Freeman affirms in his work that short-term resilience is used when normal services and economic activity are back to normal state after facing short-term shocks (Freeman et al., 2016), while Kahnamouei describes short-term resilience as an ability to cope with altering conditions or a capacity to reduce the consequences of disruption (Kahnamouei et al., 2017). Long-term resilience is described as constantly evolving and changing and providing a response to a range of long-term stressors which is built up over months or years (Freeman et al., 2016). Long-term disturbances are the ones, coming at regional, national or global levels such as industrial accidents, climate change, scarcity of resources, etc. Long-term resilience aims to ensure good conditions for citizens, air quality, etc. Example practices are reducing CO2 emissions, increasing the economic sustainability through innovation and reduce dependence on global supply network (Freeman et al., 2016). None of the selected types of resilience has been assigned to long-term resilience. It can only be presumed that all of the levels could be counted for long-term resilience as it mostly depends on the chosen strategy and situation. Controversially, short-term resilience is about recovering quickly and establishing normal activities soon after short shocks that disturb public services or supply networks. Types assigned to short-term resilience were found to be: ecological, engineering and socio-ecological. What was surprising is that pandemics are counted for a short-term resilience (Freeman et al., 2016), though looking back to 2020 it could be discussed more whether a pandemic should be counted as a short-term or long term disturbance because COVID-19 had an impact globally on all economies and this shock lasted for months. Other possible short-term resilience strategies requiring stressors are changes in business ownership, extreme climate change, technology disruption, etc.

Another categorization is based on the source of resilience, whether the stress comes due to unforeseen situations in a company or external stakeholders (i.e. government, society, etc.). External situation is impacted by social, political or environmental change whereas internal situations depend totally on critical infrastructure. Risks raising internal disruption could be anything from lack of maintenance of infrastructure to lack of clear crisis management (Labaka et al., 2016).

Diversity is one of the metrics that could be discussed from both sides: on one hand, diversity seems to be a good approach facing cascading failures – if the equipment is diverse, maintenance would be required for less facility. Additionally, diversity provides an ability to react to spontaneously changing customer demands (Morisse & Prigge, 2017b). However, if there is a low level of diversity and something fails, it is less expensive because repair, maintenance and replacements costs would be lower. Furthermore, it is possible to discuss and achieve lower costs for equipment and its maintenance because stocking up on an alternate part would be more cost-effective as well as there is a higher probability that a process could be continued (Morisse & Prigge, 2017b).

Metrics for estimating resilience has been collected from various areas. Part of the retrieved metrics can be quantified but it is assumed that there could be more formulas than the ones included in this research. The aspect of whether the metrics are quantified depends highly on what is the area and field and whether there is enough information to apply the formula. The most common formula found in the literature was on 'time to response' and 'performance degradation' (Table 4). Reliability and restoration are the main attributes of the system performance therefore when the performance degrades, it also means that the system loses the trustworthiness (Yodo, Wang, & Rafi, 2018). Some of the metrics that were found could also be applied for assessing Enterprise Architecture resilience. Vulnerability, property defining how easily systems are at risk from being exposed and subsequently causing disturbances. It is related closely to the abilities to learn, anticipate and monitor. The extent and duration of the disruption are taking the place of the product of the probability of the occurrence of disruption and the level of its consequences. Both these metrics (the product of the probability of the occurrence of disruption and the level of its consequences) are used for measuring the vulnerability of risk. The formula of vulnerability, presented by Man et al.(Man, 2019), is a good example of how metrics from other domains can be applied in enterprise architecture: the formula of vulnerability is taken from systems' theory and adapted for the resilience of enterprise architecture (Table 4). Most of the presented metrics are based on the field of engineering resilience. It focuses on change, training, risks assessment, safety management tools, analysis of accidents and each of these are also important for EA resilience (Righi et al., 2015). The faster a system can recover and use the least resources, as a result, the more resilient it is.

To sum up, the collected data contributes to a clearer understanding of IS resilience. As Enterprise Architecture is covered by Information Systems field, it can be also stated that this work contributes relevant findings for Enterprise Architecture.

3 Design

This chapter aims to answer the question how a method, helping in modelling and assessing Enterprise Architecture (EA) resilience, can be designed. The knowledge gained from performing a literature review is considered as a basis for the design and development part. The design part is performed following the guidelines of Design Science Methodology, proposed by Wieringa (Wieringa).

No guidelines on how resilience could be reflected in the EA model have been found in the scientific literature, therefore we assume that it is a relatively young field which has been barely studied in sufficient depth. Nevertheless, the literature review provided information which we found important for designing an approach for modelling and assessing EA resilience. As it is mentioned in the section before (section 2.5.2.2), the definition for this study is proposed:

IS resilience is the ability of a system to work under predicted or unforeseen disruptions and to return to equilibrium or recover to an acceptable level of performance as soon as possible. It aims to mitigate the likelihood of failures and losses and requires constant adaptation to new known or unknown threats.

It could be stated that the concept of resilience enhances traditional risk management strategies as it focuses on unpredictable situations and their consequences. Several authors relate to disaster management and resilience in general. According to Ramezani (Ramezani & Camarinha-Matos, 2020), there are three phases of disaster management: readiness, response and recovery. Similar steps were found in the work of Wei et al. (Wei & Ji, 2010) work, where they present the resilience enhancement circle, comprising three parts: risk assessment, resilience engineering and resilience operation. Also, Conklin et al. (Conklin & Shoemaker, 2017) discuss in their work the seven steps for creating a cyber-resilient architecture: classify, risk, rank, design/deploy, test, recover and evolve. From what is known about the resilience, we can generalize that the resilient system is improved when the probability of failure has been decreased, disruption has resulted in lower consequences and recovery time has been reduced.

We discovered Marrella et al. (Marrella et al., 2019) work being significant for our studies too. The authors presented five levels of resilience awareness for process models: no resilience awareness, failure awareness, data resilience, milestone resilience and process resilience. It was found to be extremely useful for the construction of our method as it helps to understand better the concept of resilience better and as it brings significant insights.

Our approach in this work is to combine the ideas from the scientific literature and to provide a method which could help in modelling and assessing the resilience of

Enterprise Architecture. Business Process Modelling Notation (BPMN) is used as a representation language.

The proposed method contains five steps (Figure 7). The first is performed when the business processes are designed as they are, without taking into an account possible failure. The result of the first step is an EA model where everything is executed, and data is transferred as it is expected. This step delivers background information for the designer and also provides insights in the current system. The same approach is found in the paper of Marrella (Marrella et al., 2019) and is called to be the “null level of resilience awareness maturity”.

The next step of our method in order to assess EA resilience is to consider possible risks. Thus, the second step of the method is the risk analysis. Similar tactics are found in literature: Ramezani (Ramezani & Camarinha-Matos, 2020) in their work speak about the readiness as well as Wei et al. (Wei & Ji, 2010) where risk assessment is covered. Besides these authors, Conklin et al. (Conklin & Shoemaker, 2017) who present steps for creating a cyber-resilient architecture with their work, also include the risk assessment and threat ranking. Furthermore, Marrella (Marrella et al., 2019) claims that the first move towards resilience is raising the awareness that there are possible failures. It leads us to the conclusion that the identification of risks is essential for the assessment of EA resilience.

Consequently, the third step of our proposed method is the discussion of alternatives. We are aiming to raise the awareness that sources, whether it is data, electricity or any other source, should be available all the time: if the primary source is not available than the secondary source should be used instead. Having alternatives in mind and being prepared to use it raises a common awareness.

The next step in our model is focused on defining secondary milestones. The idea of the secondary milestones is borrowed from Marrella’s (Marrella et al., 2019) maturity level “Milestone resilience”. According to the authors, the initial expectations of the process to achieve a given milestone should be revised and possible ways of mitigation declared. It seemed for us as an important aspect which has not been met in any other strategies while performing a literature review. The practice has shown that situations vary and sometimes it is not possible to reach the target. Having alternative milestones would help in decision-making: if the first goal is not reached, the compromise can be found and alternative target achieved. It must be noted that a resilient system does not mean that the performance must be restored to the full performance. The importance lays on the recovery to the sufficient level in order to perform its functions therefore the alternative target does not have to be the same quality level as the primary one.

The final step of the method “Implementation of the concepts of resilience in EA” (Figure 7) is the application of attributes of resilience which were identified while performing the literature review. With our method, we are aiming to improve EA resilience through the model and to propose to apply attributes. This approach has not been found in any scientific studies, but we believe that considering attributes and aiming to implement it in the model can enhance resilience too.

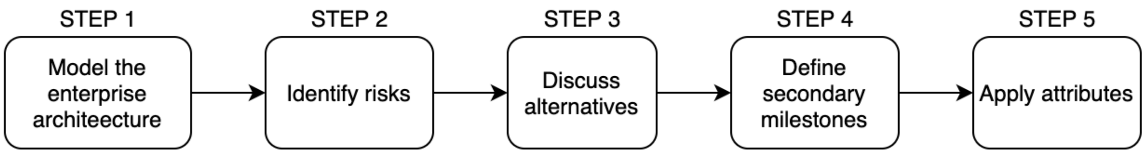


Figure 7 Implementation of the concepts of resilience in EA

The method itself has several goals. First, it has the intention to raise the awareness for resilience. Second, it seeks to decrease the threat level and improve decision making. Finally, the method aims to prove that the concept of resilience can be implemented and reflected via enterprise architecture. We believe this solution will assist future designers to model a more resilient EA.

The question might be raised, how the proposed method differs from risk management method. We can outline several differences. First of all, this method is focused on the concept of resilience as the proposed steps are based on the scientific literature, discussing resilience. Second of all, this method covers more aspects than the risk management only. As for an example, risk management proposed by TOGAF consists of five activities: risk classification, risk identification, initial risk assessment, risk mitigation and residual risk assessment, risk monitoring. Meanwhile in our proposed method, risk identification and assessment are stated only for one step. To add more, to our best knowledge, none of the risk management methods propose the idea of applying attributes (step 5) and enhancing resilience via EA model.

The following subsections provide a more detailed explanation for every step.

3.1 Step 1 – Model the enterprise architecture

In the first part of the method, the focus is mainly on the analysis of the current EA at the organization. It could be assumed that company has an up-to-date EA model therefore the existing one is used. However, the practise has shown that organizations barely update the documented EA, that is why this step endorses to update the model or design a new one. In a case where the model has been designed from the beginning, it is important to take into account that enterprise architecture should be presented the way it is right now, without considering any possible failures. In other words, the wishful perfect scenario must be reflected where everything is executed correctly (Marrella et al., 2019).

Modelling an enterprise architecture of the organization is the most important input for this step because it lays the foundation for the following analysis. This creates the need to acknowledge the structure of the organization and the way company functions. Past studies have shown that IT landscape are common to be insufficiently managed and documented as well as the communication between operational technology and information systems, therefore it all is recognized to be the core problems, according to the experts (Nowakowski et al., 2018). Bringing together the two halves of an organization, namely the business IT and the operational side, results in a comprehensive architecture for a manufacturing company. Thus, at this work we also recommend extending EA to the plant floor. As the Industry 4.0 is already approaching, we foresee the importance of covering EA at the plant floor level. There is a threat for a business to overspend for functionality when not all levels are covered. Each department might end up with several systems for the same functionality and that would result in overspending.

Discussing with stakeholders the current situation would help to understand better how the system works at the company. In this scenario, the most important part is to comprehend the overall picture of the system and gain some insights in what could be improved. Thus, the input for this step is gathered through interviews, organizational documents and visiting the plant if it is manufacturing company. Modelling and performed analysis really depend on the industry. It must be kept in mind that the aim of this method is not to model the perfect EA but to find the weak points and enhance it with concepts of resilience therefore it is important that the model reflect the reality as it is.

It is our recommendation for modelling to use Archimate notations. There are four different layers which identify four areas: business, application, technology, physical. Business layer (yellow) contains elements regarding companies, processes, products, location and data sources that support businesses value-add. The application layer (blue) aims to model software functionality in terms of applications and data relevant to the business. The technology layer (green) is for describing system software application and infrastructure. Finally, physical layer is used for modelling physical assets, such as equipment, warehouse, material and another physical environment. Modelling with Archimate provides consistency across all architecture models. The architecture can be visualized on separate layer or on cross-layer model.

Table 7 Summary of step 1

Step 1: Analyse the enterprise	
Objective	To gain the overview of the current EA
Input	Description of the structure
Activities	Identify the stakeholders Describe the processes Model EA
Techniques	Discussions with stakeholders and local experts EA modelling
Output	Enterprise architecture model

3.2 Step 2 – Identify risks

At this stage, possible risks are being analysed. In this case risk stands for a problem which demands further attention and cause disruption. Organizations face various types of risks such as operational, financial, personnel, strategic and other. By the analysis of the risks we attempt to prevent system failures and aim to reduce the impact or the probability of a negative risk. The process starts with identifying threats and weak points of the architecture. Eight techniques of risk identification are proposed (Yembi Renault, Agumba, & Ansary, 2016):

- Brainstorming – this is one of the most common used techniques. All important people who are somehow related to the project gather together at one place and note down the risks that they foresee.
- Interviews/expert opinion – interviewing experts or the relevant people at the project can help to identify risks and solve or mitigate the frequent problems.
- Questionnaires – this is used in order to identify possible risks in a project. The list of questions is structured will and handed out to the people working on the project. The main drawback of this technique is that at the end final results are based on the individuals, the advantage is the consistency and short responses.
- Delphi technique – this technique is similar to brainstorming just the main difference is that people do not know each other, and the factors are identified without consulting any other project participant. This technique is more suitable to be used for identifying the potential impact of the risk and the possibility of occurrence than recognizing them.
- Expert systems - This strategy utilizes the previous encounters of specialists to distinguish expected risks in a development venture. The weakness of this procedure is that it depends on provided information therefore it might overlook the threat which was lately excluded.

- Past experience checklists – risks that were experienced in the past or in the similar projects and can be applied at the current one.
- Documentation review - it is recommended to have planned and documented detail review of the ongoing project, taking into consideration all the assumptions, plans and previous project files, as it might reveal entrenched risks.

Every change, whether it is on the operational, governmental or any other level, might raise new risks. Since it is difficult to enumerate all unexpected events and quantify its probabilities, a risk assessment should be carried out more than once, updating the list after a while.

The stakeholders play an important role here, because they are the main source of information. Their participation has a major impact as they are the only ones who can provide insights into the system which cannot be seen from the model. The model is reviewed and places, which seem weak are acknowledged – all possible undesirable incidents are enumerated. Every possible failure is analysed separately, tracking to the source of disruption. This also lays the foundation for the rest of the risk analysis and is often referred to as ”risk assessment” (Wei & Ji, 2010).

The analysis is based on the identification and quantification of the threats as well as possible consequences. Every identified risk must at least have a short description, area where it might occur or have an impact on and foreseen consequences. Then the probability of occurrence and impact for the rest of the system must be estimated. The probability of the occurrence can be estimated by the events from the past or by comparison with similar case. As for an example, if the risks under discussion is a failure of a device, the probability of it to fail can be estimated by same or similar device failing at another place or a company. What related to physical world, it is common for manufacturers to know the weak places of their products and they can inform you for how long you will not face any problems and when the probability for failure to occur increase.

Then risks can be ranked by two dimensions: occurrence probability and severity of consequences. Such a ranking would help to identify the weakest parts of the architecture and the main risks. There are no strict instructions on how to measure likelihood and the impact of risks, thus it is left for the designer to decide how many levels of frequency and effect he wants to indicate.

TOGAF standard, also covering risk assessment, assess effects by following four criteria: catastrophic, critical, marginal, negligible. Frequency according to TOGAF is indicated as follows: frequent, likely, occasional, seldom, unlikely. If the list of risks is relatively short, a simplified version could be used where likelihood is estimated as likely, possible or unlikely, and impact as low, moderate or high. The combination of likelihood and effect classifies risks by four levels: extremely high, high, moderate, low.

If the simplified version is used, then only three levels are used: high, moderate, low. One of the tools recommended by professionals to assess risks is a risk matrix. This matrix is a table which contains severity and hazard's probability for every risk. The levels can vary depending on designer because there are no strict rules set up. TOGAF proposed to use 4 levels for risks: extremely high, high, moderate and low. Extremely high risks are the ones which are not acceptable, and service cannot be used until it is eliminated or at least mitigated. High risk level means that work activities cannot proceed until the hazard has been moderated. Additional resources might be used in order to mitigate the risk. Where the risk includes work in progress, urgent actions must be taken. Moderate risk indicates the situation when disruption happen, but the process can be continued and additional reasonable practical controls must be applied. Low risk is largely acceptable. Improvements can be offered but it should not result in high additional costs. The risks can be visualised in the matrix and be coloured accordingly to the risk level. It is common to work with 3x3 or 5x5 matrix. It is recommended to use 3x3 matrix when the list of risks is a relatively short one. The following two matrix present the classification scheme used in TOGAF (Table 8) and the simplified version of the risk matrix (Table 9), when so detailed categorization is not necessary. The colours used at the heat risk matrix tend to be from green to red, applying if from the lowest to the highest risk accordingly.

Table 8 TOGAF Risk Impact Assessment

Effect	Frequency				
	Frequent	Likely	Occasional	Seldom	Unlikely
Catastrophic	E	E	H	H	M
Critical	E	H	H	M	L
Marginal	H	M	M	L	L
Negligible	M	L	L	L	L

Table 9 Risk heat map

Likelihood	**Impact**		
	Low	**Medium**	**High**
High	L	M	H
Medium	L	M	M
Low	L	L	L

To sum up, this step aims to identify risks. It is also important to mention that the step is not standalone activity and includes contribution of all the team. Several techniques for risk identification are presented. It is also explained how risks can be ranked and risk matrix is offered as well. However, it must be admitted that no risk identification technique is sufficient to cover all possible risks. The table below illustrate the summary of this step (Table 10).

Table 10 Summary of step 2

Step 2: Identify risks	
Objective	Identify risks and rank them
Input	EA model
Activities	Identify the risks Rank the risks
Techniques	Risk identification techniques Risk matrix
Output	List of ranked risks

3.3 Step 3 – Discuss alternatives

In this phase, failures and threats of the EA are already analysed. Here we focus on possible sources of failure that are discussed in the previous steps. If the disruption happens due to the shortage of a source, another alternative source is desired to be found. For example, if the network is unavailable, the question will be raised what the company can do to keep the business running when all the knowledge, which is necessary to keep the same level of performance, becomes unreachable? What about the situation when the hardware goes down and the source of information becomes inaccessible - how can the company continue to perform? Our recommendations are that the discussed sources should be documented and, if it is possible, included in the EA, so that anyone who faces similar problems could consider the alternatives or at least get a general idea of how to deal with the respective situation.

None of the covered articles in the literature review have proposed an instructed way how to find all the sources and provide the alternatives therefore here we propose our solution. First of all, part of elements in EA model needs some kind of source: whether it is only data or technical source or maybe it is human knowledge. Therefore, we recommend listing out the possible sources for the elements which might seem critical to the organisation. If it is not clear which elements are critical, every element should be listed out. As for an example, for servers to work properly and provide the service it needs to have the internet connection and electricity. Similarly, if manufacturing is covered, there is need for electricity, but it might also require the Internet, if Industry 4.0 company is being discussed. When the list of elements is noted down, sources can be grouped. Grouping by the source provides a better overview and a clear structure. The last task is to consult with the stakeholders and, if necessary, specialists of that area, what alternatives of a source are so the process could be continued. We provide a list of the questions which could help identifying alternative sources:

- What sources are necessary for the system to operate?
- Are there any alternative sources that are already available? If yes, note it down
- If no alternative sources are already available, what are the options for the process to be continued?

Table 11 Summary of step 3

Step 3: Discuss alternatives	
Objective	Identify alternatives of source
Input	EA model
Activities	List down sources needed for each element Group the list by the source Discuss what available alternatives are provided Brainstorm other possible alternatives
Techniques	Answering the questions Discussion with the stakeholders
Output	List of alternatives

3.4 Step 4 – define secondary milestones

This step represents the analysis of the targets. The secondary milestones are necessary to be determined so that a process can be terminated reasonably, in other words, terminated when the secondary milestone is reached.

If the initial objective indicated by a primary milestone can not be accomplished, accepting a weaker target could be the best solution. According to the definition of a milestone with alternatives found in research of Marrella (Marrella et al., 2019), a milestone can be associated to tasks or stages that establish on its entry condition or can be linked to the exit conditions of tasks or stages. For instance, if the target of the task is to create a report, realizing that the input data contains errors can lead to a faulty result or the termination of a process. In case of the corrupted data the alternative milestone could be "low - quality report". Furthermore, it is not possible to reach the primary milestone sometimes because the alternative source is used. Thus, having alternative targets enable the completion of the process at acceptable level and contributes to the maturity of the EA model.

According to Marrella, a new milestone, representing status that can terminate a process, must be designed by the designer. We argue them by believing that it is not up to designer to decide the secondary milestone. Insights can be shared but more of it results from the discussion with the stakeholders. It is not within the competence of an enterprise architect to decide what result of the process is acceptable and whether the process should be terminated or not. Nevertheless, the EA can include the milestones, usually reflected in by an element of a product or a service - it depends on the type of a company, what is the primary target of the EA. The concept of ‘‘milestone’’ does not only mean the final product. It is also used to cover the completion of a major deliverable event necessary to make progress toward the objectives inferred by a successful execution of a model (Marrella et al., 2019).

Here we target a few things. First of all, defining how the process can be terminated, provides the knowledge what to do in case the circumstances change, and the primary target cannot be reached. Second, it enhances readiness for the disruption: as the secondary milestone is defined, it provides more control and less confusion.

We have not found any recommendations on how to identify the alternative milestones therefore we came up with our own approach. We recommend listing out the processes and primary milestones. Then raise the question: what might happen that would have an impact on the primary aim and would prevent from succeeding. This will raise the awareness of possible reasons for termination. As the termination has been defined, it becomes easier to identify, what the willing secondary milestone could be.

Table 12 Summary of step 4

Step 4: Define secondary milestones	
Objective	Identify alternative milestones
Input	EA model List of ranked risks List of alternatives
Activities	Indicate primary milestones Decide on alternative milestones
Techniques	Listing out process, primary milestone, termination reason and secondary milestone
Output	Secondary milestones

3.5 Step 5 – apply attributes

This step aims to assure that all operations are performed smoothly with as less disruption or uncertainty as possible. At this point, threats and weak points of a system have been declared, metrics defined, alternative sources discussed, and secondary milestones determined. All previous steps lead to this part where the updated EA model is proposed with identified necessary changes and all the previously acknowledged improvements. The next step is to consider attributes of resilience which could be included in the model. The analysis of scientific literature provided us with a list of attributes (Table 13). We believe that part of these attributes could be reflected in enterprise architecture and would enrich the model itself and serve as explanation for the change of the process. Six attributes have been selected as the ones that can be included in enterprise architecture.

3.5.1 Adaptability

The first one to discuss is adaptability. Sometimes adaptability is confused with sustainability or stability. Though both of them are aspects of equilibrium and share similar concepts, it differs from adaptability. Sustainability aims to ensure long-term survival, keeping the same quality level whereas stability defines a steady-state system with none or minimal fluctuations. Adaptability is a capability to respond flexibly to new changes. It enables a system to maintain equilibrium while expecting for a disaster or to return to an equilibrium state after experiencing unexpected adversity. When the surprise and other challenges occur, the system must be able to adapt to new circumstances and continue functioning in a certain level of performance. It can be performed in various ways, i.e. re-routing and substituting requirements, using alternative resources, learning from the past, adjusting the process as a response to the new circumstances, etc.

As an adaptability reflects the change, we propose the idea that this attribute of EA resilience can be reflected in EA by junctions “OR” or “Plateau” element where the cause of change would be stated on the relation.

3.5.2 Diversity

The property of diversity contributes to resistance by providing sufficient resources to rely on. Diversity is about having a choice whether it is the variety of assets, institutions, system processes, adaptable decision making, resources, etc. Diversity is a relatively broad field which is implemented in various field, as for an example, supply management. Here the attribute is applied by having more than one supplier. Different data sources and algorithms also reflect the reality. As the enterprise architecture consists of four architectures, namely business, application, information and technology, it leads to the conclusions that the aspect of diversity can be reflected in EA model not only by a property, but also by multiple elements related to one element. As for an example, having multiple suppliers for raw materials, role-based coordination within the company expressed in business layer, noting down different devices in technology layer, etc. We propose to reflect this attribute of resilience, diversity, by using relationships and noting down important information in a property.

3.5.3 Efficiency

The next presented attribute is efficiency which can also be reflected in a model through the metrics. Efficiency measure the useful work performed by a machine or people. It can be estimated following the parameters given by the manufacturer or manually by measuring the produced amount per time. In the context of resilience, efficiency depends on the response to the change. As for an example, if unexpected failure occurs, what affect would it have on efficiency? By modelling EA with Enterprise Studio, we can use metrics for setting up the values for efficiency. The values can be also aggregated and be used as a background for the decision making.

3.5.4 Redundancy

The following feature for discussion is redundancy. It reflects the extent to which components within a system are substitutable. Redundancy is realised by the system having parallel machines, buffer capacity or resources which would help and mitigate the loss. It is the concept which allows a system to be changed by another system. One of the widely known examples of redundancy is redundant databases. This type of databases is immediately available in case the main database fails. Applying redundancy at the company might be costly but it becomes worthwhile in unpredicted events. It provides continuity to the process and enhances the speed in production.

We propose to reflect redundancy in the EA by presenting backup copies, depicted by two-sided relationship between two elements and visualising extra capacity by an element.

3.5.5 Responsiveness

Subsequently responsiveness, whether the EA element is capable of reacting to various disruptions, follows. We state that responsiveness goes together with all the other attributes therefore we do not state that it should be visualised in EA. As it was stated before, adaptability can be expressed by using Plateau with relations on which the triggering reason would be stated. Responsiveness is about responding to a disruption, to any new changes therefore it could be stated as being a part of adaptability. Nevertheless, the responsiveness can be excluded as an additional metric in EA model which would be indicated whether the element is capable of responding to a change without human interaction.

3.5.6 Self-organization

The last discussed attribute is self-organization, which means that a system is capable of rearranging its processes in case of disruption in a way it stabilizes a structure or a function. Self-organization is noticed in various forms: physical, biological, ecological, social and even economic. High level of autonomy, strong relations between actors, strong value system are the key characteristics of self-organization. Diving into more details, high level of autonomy enhances communication and collaboration among group members and leads to more creative and innovative solutions as well as increase in intrinsic motivation. Strong relations (interactions) between business actors means having effective communication. It builds trust and collaborative behaviour therefore the information sharing is also engaged. This could be modelled by the relationship between the business actors. The less relationships a business actor have, the more dependent it is from the business actor with which it is related. Strong value system within the organizational setup is about openness, trust, confidence, collaboration, cooperation, independence, experimentation, authenticity, confrontation, and pro-action within the team (Alhassan & SÖZEN, 2018). These are listed out as a key values in ensuring in promoting the processes of self-organization. We believe that in EA self-organization can be reflected with business layer and relation within actors which would present the structure of the governance. On the other hand, self-organization can be called as an attribute in reducing the information and achieving a task or a goal be self-reorganizing the entities, i.e. by applying self-organization context, a disorganized system quickly becomes organized. Adaptability, the attribute that has been discussed before, serves self-organization by adapting to a desirable state prior to the self-organization can begin therefore we propose the idea that both attributes are tightly connected and reflected in EA model.

Our proposal is to reflect it by using a relationship between the related elements.

Table 13 Attributes that can be reflected in Enterprise Architecture

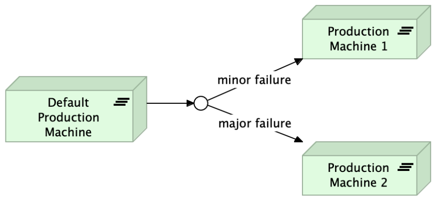
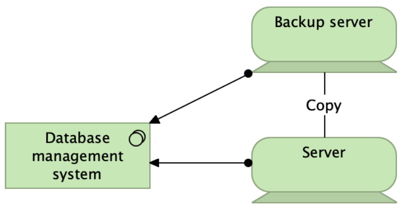
Attribute	Definition	Usage in EA
Adaptability	The capability of a system to act in a flexible way and change to perform its basic work within a response to new pressure	OR junction, Plateau, as for an example: 
Diversity	Possibility to choose from a variety of assets, system processes, adaptable decision making, resources, etc.	Property of an element
Efficiency	The amount of useful work performed by a machine or a people.	Property of an element
Redundancy	The extent to which components within a system are substitutable.	Having backup copies, being up to date, i.e.: 
Responsiveness	The capability of a system to react to various disruptions	Property of an element
Self-organization	The capability of a system to rearrange its functions and processes in case of external disruptions	Relationship between business processes or between business actors

Table 14 Summary of step 5

Step 5: Apply attributes	
Objective	Enhancing resilience by applying its attributes
Input	EA model List of risks
Activities	Discuss with stakeholders Apply attributes
Techniques	Brainstorming
Output	Updated EA model

4 Case Study

In this chapter a case study is presented for which the method "Implementation of the concepts of resilience in EA" (Figure 7) is applied. This case serves as the background for the application of the methodology described in Chapter 3.

4.1 Case Description

In the face of globalization and rapid alteration in the economy, competition becomes more and more significant. Producing a high-quality product or staying innovative is not sufficient anymore in order to stay in the market. Companies must weigh the importance of digital technologies and their impact on production efficiency in order to survive in the modern competitive world. Therefore, a continuous analysis of changes and possible failures must be performed. By investing into digital technologies, companies aim to become more competitive. On the other hand, innovative solutions raise a problem of luddite people who resist to any new technological approach. Finding qualified employee is one of the biggest tasks which the industry faces, therefore digitalisation of the processes is still an open question. Nevertheless, the upcoming Industry 4.0 revolution will have a huge impact on manufacturing companies as it will require changes of the processes of manufacturing, systems, service and products.

This case study involves the company Nematekas, one of the largest meat production companies in Lithuania. The company was founded in 1994 and has been one of the leading organizations in producing high quality meat products ever since. It could be stated that the company is relatively young but if we consider the fact that Lithuania has been independent for the last 30 years only, Nematekas can be called a mature company. In the last century, the movement towards innovation was a random process, now it is a goal-oriented managed activity. An organization that is not striving for innovations, is quickly pushed out of the market, therefore keeping processes modern and being innovative plays an important part in the company's life.

4.2 The problem

Daily challenges and the future Industry 4.0 raise awareness for the upcoming changes and the importance of resilience. Therefore, company at this time should pay more attention to the resilience because it relies on it a lot. To begin with, the production depends highly on the demand and machinery. Sometimes the demand increases two or even three times and that results in production 24/7. Such situation means that there is no time left for any failures and every minute is important. Therefore, it could be stated that probability of disruption is correlated with resilience: failure is more likely to occur when system is less resilient. However, knowledge of the equipment supporting the processes and actions taken in case of a disaster, is not documented anywhere and is fragmented between the stakeholders in the company. This means that if failure happens, psychological pressure increases because it is unclear what to do so the production would continue, and product would be produced. Every unfulfilled order result in losses such as fines, reputation damage, harm of trust and loss of income money. In order to increase the resilience of the system and keep the performance stable, Nematekas was offered to apply the proposed method.

4.3 The Approach

This section outlines the application of the method proposed in chapter 3 to the case study described in section 4.1. The following sections are divided into the steps of the method. With the following process, we are aiming to validate whether the method can be easily applied and if it is suitable for the context. The case has been limited to the production of one product category for the purpose of simplicity.

4.3.1 Step 1 - Analyse the enterprise

This section presents the current technological landscape of the company. For modelling the current architecture Enterprise Studio is being used.

As described before, Nematekas is a meat processing company. The production includes complex processes, covering various scenarios. Therefore, for the sake of better demonstration, it was decided to focus on the production of one product group which is parboiled sausages. The manufacturing process of the product is required to follow multiple requirements and standards set by the EU and State Food and Veterinary Service regulations. One of those is traceability which means that the organization is able to trace any product back to the raw material processed. In order to reach this requirement, the company took a technological approach and decided to implement MS Dynamics NAV component for manufacturing companies - terminals. A terminal is a computer suitable for factories and directly connected to industrial weight scales. Together it forms the system responsible for the tracking processes. Via terminals and MS Dynamics NAV application interfaces, the factory workers can perform the processes of picking up and putting away technical material. Every step starts with picking up a product and ends when the put-away process is performed. During the put-away procedure, the semi-product is being weighted and weight is recorded in production order. Figure 8 presents the enterprise architecture of the production of parboiled sausages. The production of only one product category and related entities are presented in the model due to several reasons: First of all, the model of all structures, processes and other entities participating in a full production would result in a huge model which would not fit in one page and would not give any clarity to the audience. Secondly, with the use case scenario, we aim to validate the method and share our insights with the audience, therefore a larger model does not specifically mean a higher quality of work.

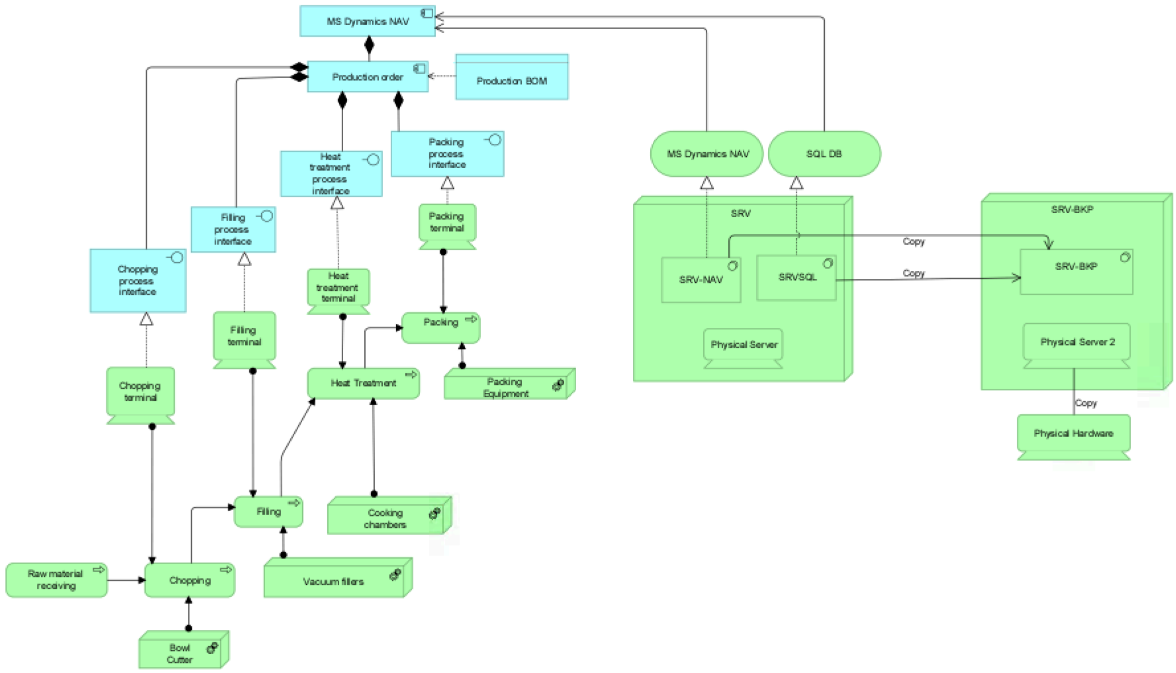


Figure 8 Production of parboiled sausages

The model does not represent the full architecture of the system, but it shows the most significant part for the production of parboiled sausages. MS Dynamics NAV is playing an important role for the production, because the information about the past and future orders can be accessed here, all forecasting is handled in MS Dynamics NAV. Furthermore, the production orders which contain all necessary information for the manufacturing process are also stored there. The manufacture starts when the production order is generated. Whether the production order is going to be generated depends on sales orders that were received and the forecast of demand. As soon as the production order is created, it can be accessed via terminals in the warehouses. This means that at every terminal a new task appears (one production order has many production tasks; one production task is assigned to one terminal; one terminal can have many production tasks). The task contains an information on what product is being manufactured, the quantity that is necessary in order to perform the task, task number and location code. Every process has the terminal assigned to it as well as equipment. All the processes are listed in a queue, ordered by the priority. It means that the factory worker needs to execute the tasks from the top to the bottom.

It is not surprising that all IT-related data is based on servers. The main servers used for MS Dynamics NAV are SRV-NAV and SRVSQL. SRVSQL is a virtual server where SQL Database is running. SRV-NAV is a virtual server where MS Dynamics NAV is based. Snapshots of both servers are made every night to SRV-BKP, so if the disaster happens and the SQL database gets corrupted, there is always a copy which can be recovered. Therefore, we claim that the original EA model representing this part of the overall system (Figure 8) already includes some principles of resilience – redundancy to be specific. The company is aware of possible failures and disasters, therefore the server SRV-BKP contains snapshots of the server SRV and, if SRVSQL is affected, SRV-BKP is always ready to take over the process. In other words, SRV-BKP would take the role of SRVSQL so the interruption would not be felt. Additionally, copies of SRV_BKP are also recorded in the external hardware in case of servers SRV and SRV_BKP get corrupted.

In order to reflect the most important parts, the model is slightly simplified and some details are left out, so it would be easier for the audience to analyse (Figure 9).

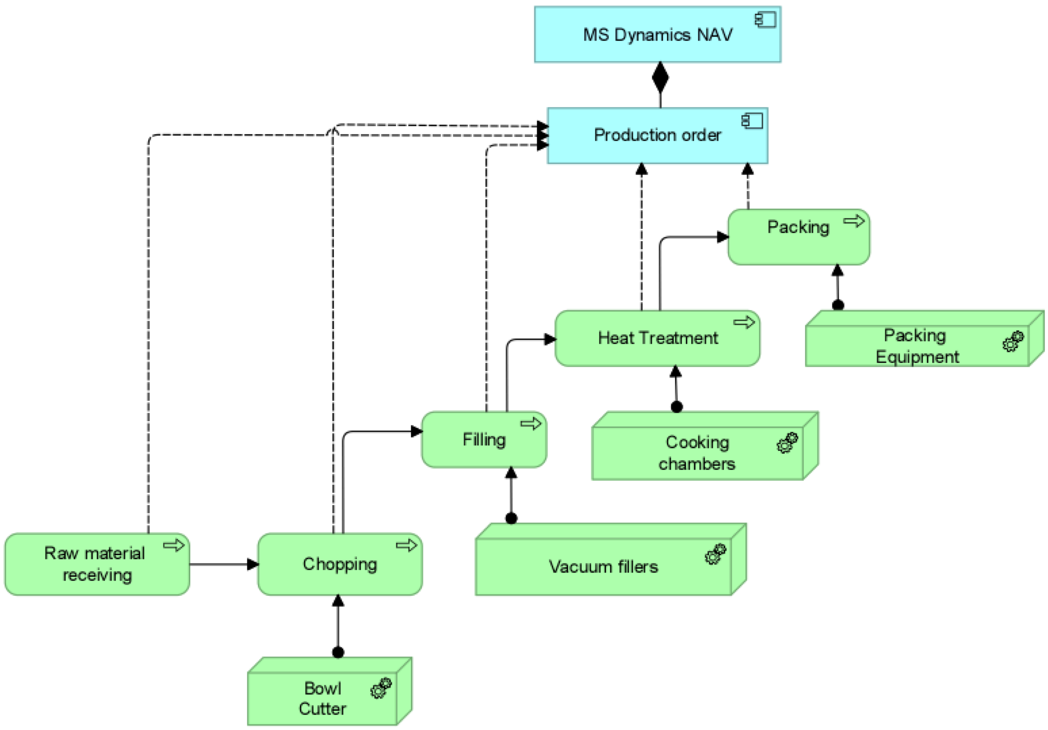


Figure 9 Simplified version of production of parboiled sausages

To begin with, manufacture of any product is initiated when the raw material is received: meat and other ingredients are being weighted and prepared for the following process. When the raw materials are received, the chopping process starts: the mass for the product is made - materials are put into a cutter bowl where everything is chopped, emulsified and mixed. Nematekas has four cutter bowls from which three are used daily (Figure 10) and the fourth plays more a role of a backup bowl cutter as it is used only when one of the daily used bowl cutters fails or when the amount of order extremely increases. Various aspects have an impact on a technological process such as the amount of product, speed of knives or running smoothness, therefore the process cannot be speeded up and has to follow the instructions. Otherwise, it might result in a low-quality product which would not be suitable for sales. This leads to the conclusion that all cutters are equal in between by the meaning that all are suitable for all products and even if the orders increase and production is failing to fulfil the plan, the performance of the chopping process cannot be increased.

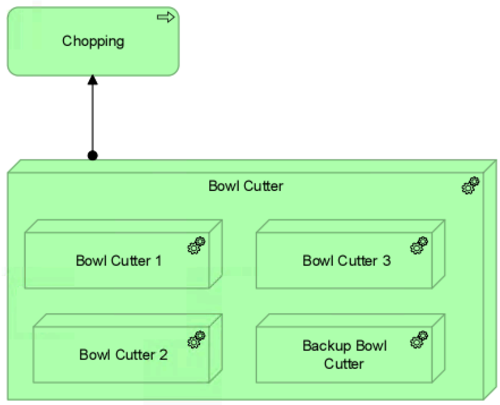


Figure 10 Physical view of bowl cutters

The next step is filling where the sausage is formed and linked or clipped (depends on the product). Nematekas has five Handtmann vacuum fillers of which three are for linking and two are only for clipping (Figure 11). After the product has been formed, it is hanged on the frames which are moved to the cooking chambers for the further treatment.

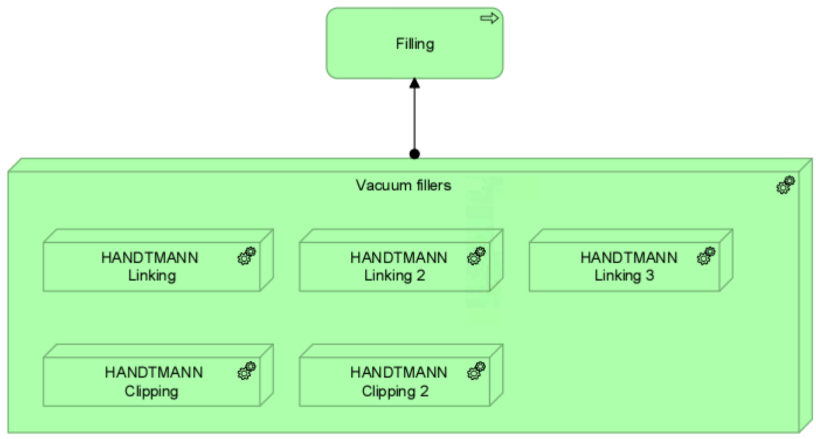


Figure 11 Physical view of vacuum fillers

The next process is heat treatment. There are eleven cooking chambers: four Stein and seven Schroter (Figure 12). There is no major difference between Stein and Schroter apart the fact that heat treatment programs might vary. The performed thermal process is a fully automated one. Processes such as steaming, smoking, drying, baking and cooling are adjusted via computer control for each product individually. Heat treatment ends up with the cooling part - water spraying. Cooling can be performed in the same chamber or moved to another place, where water is sprayed to reduce the temperature of a product sharply, for increasing its shelf life. When the process is finished, frames are moved from the cooking chambers to the place where the product will be packed.

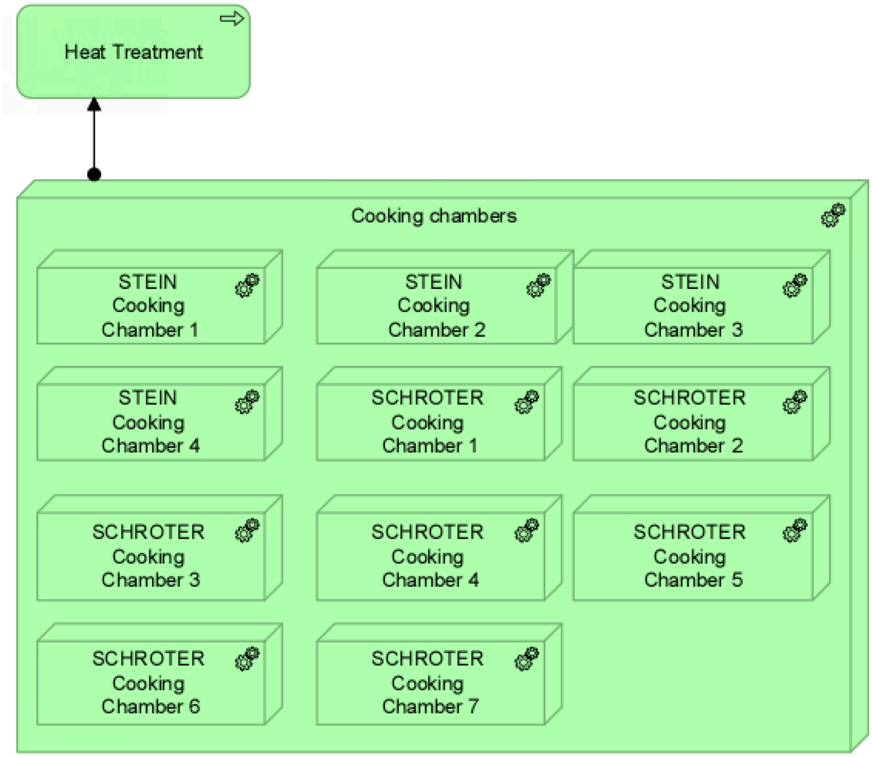


Figure 12 Physical view of cooking chambers

The last step of production is packing. There are five packing machines, each varying by the packing form and used for different product groups. For sausages vacuumed in small packs Tiromat is being used, for the ones in big form – VC999, Veripack or Comet and lastly, for short ones packed in bags, Etna is used. Labelling takes part in the packing process and can be executed manually or automatically. With this step the production is finished and can be transferred to the warehouse where the full order for a customer is being collected.

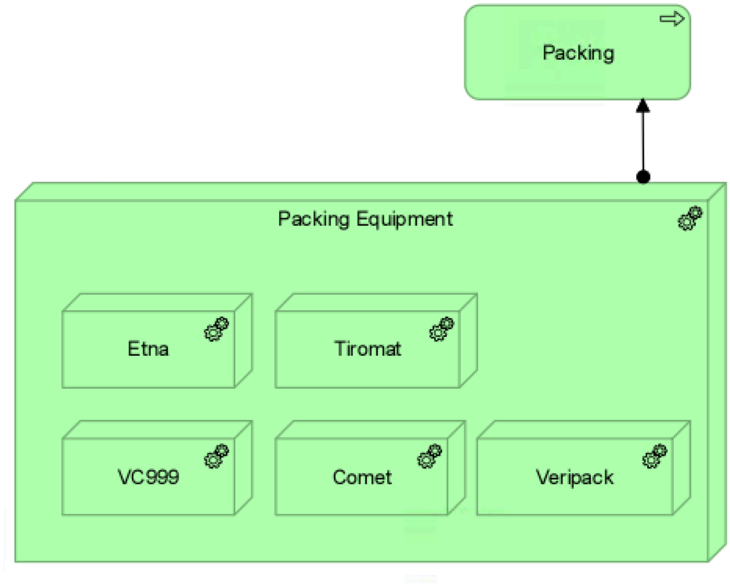


Figure 13 Physical view of packing equipment

4.3.2 Step 2 – identify risks

The second step of the proposed method is focused on failure awareness. During this stage, the possible threats are being discussed and failures explored. Our risk identification is based on the analysis of the model as well as discussions with the stakeholders about possible risks. In the method (section 3.2) it is mentioned that the risk assessment should be carried out once again after some time pass and new changes occur. However, due to the time limit and absence of the new changes, the risk assessment is carried only once.

In this case, Figure 9 is going to be reviewed. From the model, it can be seen that the relationships are very strong here. One process trigger another. There is no possibility to skip a step. It indicates, that if one process stops, production cannot be continued, therefore disruptions at every process are expected to be avoided or at least to last as short as possible.

The production of every product is initiated when raw materials are received and continued with chopping. A machine used for cutting is called a bowl cutter. As it was mentioned before, Nematekas has four bowl cutters, but only three can be used permanently as it was noticed, that the fourth is used to break down after running longer. If one bowl cutter out of those three breaks down, it means that the load for the other two increases significantly. There can be two solutions for this situation. First, engineers should have spare parts for the most unstable parts which are common to break. Second, the fourth cutter should be always prepared and ready for usage (Figure 15).

The next process is filling. Nematekas owns five vacuum fillers of which three are for linking and the other two are for clipping. If one linking machine breaks down, it is not a major problem as there are two other fillers which can be used for the same process. Contrarily, if a disruption source is a clipping machine, the production is affected more when there is only one machine which can overtake a process. In case both clipping vacuum fillers fail, the company has nothing else to do but to wait till one of those gets fixed. In the case of a permanent failure, the company experiences even more loss as the prepared mass can be used only for a particular number of hours, therefore long-lasting disruption means a waste of material, too. We propose several outcomes for this situation. The first suggestion is to have periodical check-ups during which the weak places would be identified and fixed. The second suggestion is to have spare parts which tend to fail for a clipping or linking machine. Such approach would save the time in case the machine stops running. The third tip is to analyse whether one of the machines are adaptable for both processes (chopping and linking). This would help a lot in the case of permanent failure. One of the machines could be switched to linking or clipping, according to the needs, what would help to keep the same performance as always and stabilising the production.

The following process is heat treatment for which cooking chambers are used. Nematekas owns eleven cooking chambers in total: four Stein and seven Schroter. All Stein cooking chambers have the same specifications and it all differs from Schroter with their programs for products. Additionally, two out of four Stein cooking chambers have a four times bigger capacity: instead of two frames, it can fit eight. Luckily, according to the head of the mechanics department at the company, it rarely happens that all chambers would be full at the same time therefore if one stops working properly, there is another chamber which can be used. As the technological process is the same no matter which chamber is used, no higher performance can be reached. It leads to the conclusion that even in case of a disruption, the company is already well prepared and would not suffer too much.

The last technological process where machines are used is packing. Different machines are used for different products in this process. During this process, there is a probability that one of the equipment as any other can break down. What makes this situation different, is the fact that not all machines are suitable for every product. According to the senior food technologist of the company, VC999, Veripack and Comet can be switched with each other in case of a disruption, but the efficiency might be lower as VC999 produces two times more than Veripack or Comet at the same time. If Etna breaks down, VC999 is the only one suitable for packing the same products. In the case of disruptions where the source is Tiromat, it is possible to use Veripack, but the efficiency would suffer. Overall, there are three machines which can support the production of the same kind product, then there is Tiromat which can be changed with

Veripack and lastly, there is Etna, which is the only machine packing in bags, therefore it can be changed with VC999.

The most of discussed failures could be called minor as there are solutions for how it could be resolved in a short amount of time. On the contrary, major failures are stated to be the ones which require more than just a simple fix and last longer than a few hours. Additionally, another category worth discussion is a so-called *force majeure* situation (unavoidable circumstances). Power outage, internet outage, water being cut off, pandemic and similar circumstances fall under this category. What could be done in this case? According to the responsible people at the company, the probability for a power outage is relatively low because there are two power inputs: if one stops providing electricity, the switch happens automatically, and the power is provided from the other source. An internet outage is not a common issue either, but if such a situation occurs, the company is prepared for such situation and can switch to another connection. If the switch fails, nothing too much extreme happens: terminals stop synchronizing, but the production can be continued unless it lasts longer. In such a case when the Internet is not provided for more than two hours, the production would be impacted and the control of what, when and how should be produced would be based on the knowledge of the technologist rather than on MS Dynamics NAV. Nematekas has also considered the possibility of water being cut off. If such situation occurs, the company would need to stop the production, because water is used not only for producing a product but also for cleaning. In order to be prepared for such a situation, an organization decided to dig a well. Therefore, if the water is cut off, the company could proceed the production by pumping up the water from the alternative well. The year 2020 had hit a company differently: Nematekas faced a lack of employees when the production increased twice due to Covid-19. During this time the main target was to keep efficiency as high as possible and manage staff in a way, that the scarcity would be the lowest. The situation turned to be even more complicated as people could easily take sick-leave due to Covid-19. Additionally, the government offered subsidies for unemployed people. Such governmental support created a scarcity of blue-collar workers because people, receiving subsidies, do not find the reason why to work at the company and receive payment equal or a bit higher than received subsidies, as they can additionally work in the land and receive money by selling their products[2] or just work unofficially. The pandemic showed that having a resilient system does not solely ensure the success in fulfilling the plan and that employees are playing an essential role anyway. This situation forced the company to look for processes which could be automated. The higher the level of automation is, the less

[2] It must be noted, that Covid-19 started approximately in March 2020. That is the time when people usually start harvesting and working on the land.

employees are necessary for a manual production. Such changes would likely improve the overall system resilience as well as improve the performance.

Following the proposed method, potential risks must be assessed. For this assessment, we exclude aspects where we are unable to change anything, as for example, the lack of staff or a power outage when both chains have been cut off. After the discussion about the threats with the senior food technologist and the head of the mechanics' department, a list of risks was defined (Table 15). Every equipment has the probability of failure which is based on past events. The impact of the risk is based on the usage (whether the load is high or low), the efficiency and the number of employees involved. The packing process is the one where the threat of a bottleneck and the impact of failure varies depending on the machine. Out of the equipment that is used there, Etna, seems like the most vulnerable machine, because even if the process is going to be moved to VC999, the efficiency would drop down and at least one more person would be needed. A similar situation can be expected when Tiromat needs to be exchanged by Veripack: the efficiency goes down and more staff is required. The filling process requires two machines for clipping and three for linking, in case of a disruption, the production can be switched on another machine. A parallel situation occurs in terms of chopping and heat treatment: in case one equipment fails, other resources can be used. An internet outage is also ranked as a risk because it would lead to the termination of the entire production. After all, the significant knowledge is based on MS Dynamics NAV or the cloud software and becomes unavailable. We propose that in companies, where the production takes place, the information, such as recipes, the production order and other relative data required for the manufacturing process, would be saved locally on computers and printed out, too. This would not only help in case that the network becomes unavailable but also in case when disaster happens and all data becomes corrupted.

The risks identified above have been presented to the stakeholders and asked whether they have any comments to add or if there any corrections are needed. The probability and possible impact for the rest of the system has been discussed and evaluated by low, medium or high. The probability and impact are based on the past events and on the analysis of EA. To be more precise, the probability is based on the records of machine failures from the last year. We have listed out 9 risks out of which four has a major impact for the rest of the system. The table below (Table 15) illustrates the results of the risk assessment. Risks related to the packing process has been listed out one by one because only equipment for packing differs and is not suitable for all products. Though likelihood and impact vary, the solution for all the risks of packing process are familiar: it is based on the fixing the machine and changing the equipment. R4 and R5 have a lower impact for the rest of the system because they are not used as much as, for an example, Tiromat, and the performance of this machine is lower. R6 is identified for filling process. As it has been discussed before, filling is slightly complicated as there are three machines for linking and two for clipping. According to the head of the mechanics department, it rarely happens that the failure occurs. The records of broken-down equipment for packing from the last year compared to the rest of the equipment proved that the likelihood is medium. The impact has been estimated as low because if a vacuum filler fails to continue production, there are several outcomes: the machine can be fixed, another clipping machine could be used or the linking machine could be modified. The next risk is R7 for chopping process. The company has three fully performing bowl cutters and one which tends to crash if is in use for a longer time. Therefore, the impact for this risk is estimated to be low as there are several solutions: using the backup bowl cutter and fixing the machine. Risks related to heat treatment are also stated to have low impact. The stakeholders where asked how frequently it happens that they do not have a spare cooking chamber which would be free to use in a case a failure occurs and they have responded such situation barely occurs due to planned production. Nevertheless, the fact that there is sufficient number of cooking chambers, does not mean that it does not fail. The number of failures from the past years show that the likelihood for a cooking chamber to face a disruption is medium. The last but not least, the risk R9 is identified as the Internet outage. It happens almost never therefore the likelihood is low. On the other hand, the company without the internet faces lots of inconvenience that is why the impact for this risk is said to be high. Nonetheless, as it was mentioned before, if the main source of the Internet gets disrupts, the switch can be performed, and the Internet would be provided from the other source. If the alternative source fails, then the company must note down the important information and input it later when the system is up. If it lasts for a longer time, the printed recipes must be used for the production.

Table 15 Risk assessment

Risk ID	Process	Equipment	Risk	Solution	Likelihood	Impact
R1	Packing	Etna	Failure	Fixing the machine Moving the process to VC999	Low	High
R2	Packing	Tiromat	Failure	Fixing the machine Moving the process to Veripack	Medium	High
R3	Packing	VC999	Failure	Fixing the machine Moving the process to Comet and Veripack	High	High
R4	Packing	Comet	Failure	Fixing the machine	High	Low
R5	Packing	Veripack	Failure	Fixing the machine	High	Medium
R6	Filling	Vacuum filler for clipping	Failure	Fixing the machine Moving the process to another clipping Modifying linking machine to be suitable for clipping and continuing production on it	Medium	Low
R7	Chopping	Bowl Cutter	Failure	Using another bowl cutter Fixing the machine	Medium	Low
R8	Heat Treatment	Cooking Chambers	Failure	Moving production to another cooking chambers Fixing the cooking chamber	Medium	Low
R9	All	All	Internet outage	Fix the weight on the paper Use printed out recipes	Low	High

A risk heatmap (Table 16) is used to show the results of the risk assessment. The colours follow the definition of consistent colouring which is as follows:

- Green – risks where a combination of likelihood and impact are the lowest
- Red – a critical zone where the probability of occurrence as well as the impact are high

- Yellow – risks between green and red, where the probability and impact together result in a higher value as the ones in green and not as high as the ones in red.

The risk heat map allows us to gain a better view on the situation. According to the map, R3 is the risk where occurrence and disruption impact are the highest. R2 and R5 are in the same category, yellow, which means that the likelihood and impact of appearance are higher than risks from the green category but lower than the red. Lastly, we have a green category which indicates risks where the combination of likelihood and impact are the lowest.

Table 16 Risk heat map

	Impact		
Likelihood	**Low**	**Medium**	**High**
High	R4	R5	R3
Medium	R6, R7, R8	-	R2
Low	-	-	R1, R9

4.3.3 Step 3 – discuss alternatives

This step aims to suggest an alternative solution, when the disruption occurs due to an inaccessible source. Following the proposed method, at list of the sources must be identified first. The response to the listed out questions in section 3.3 are illustrated in the table (Table 17).

Table 17 List of alternatives

EA element	Source	Alternative	Can the process be continued without alternatives?
Bowl Cutter	Water Electricity	Water dwell Alternative power line Power generator	No
Vacuum fillers	Electricity	Alternative power line Power generator	No
Cooking Chambers	Water Electricity	Water dwell Alternative power line Power generator	No
Packing equipment	Electricity	Alternative power line Power generator	No
Physical Server	Electricity The Internet	Alternative power line Alternative Internet provider Electric generator	Yes
MS Dynamics NAV	Electricity The Internet	Alternative power line Power generator Alternative Internet provider Keeping product recipes printed	No

As it can be seen from the table above (Table 17), there are three types of sources: water, electricity and the Internet. We do not include in the list sources to which we have no impact, as for an example, personnel or supply of material. The possible alternatives have been figured out while speaking with the stakeholders. It was found out, that the company has fought about the possible need of alternatives. In case the supply of water is cut off, the company has a ready-to-use water dwell. Electricity plays an important role too as the production is directly dependent on it: if there is no electricity, production cannot run. Such circumstances can also lead to the variations of the temperature at the warehouse and decrease the quality of a product and materials. Luckily, there are two lines of power which supply electricity to the company, therefore, if a disaster happens and the first line is cut off, the switch happens and the second power line initiates the supply of electricity. We have also suggested the idea of building a power generator if both chains fail to supply the electricity. However, the idea of a power generator has been rejected due to financial reasons. It does not pay off to build a power generator as there is a second line and a situation, when both lines are cut off, happens once at most per a year and last only for a few hours. Slightly a different situation concerns the Internet. If the Internet becomes inaccessible, MS Dynamics NAV is interrupted, including production orders, which become unavailable. It can lead to the termination of all processes, because employees are no longer receiving instructions of what and how to proceed. It could be said, that the production could be continued due to the human knowledge. Nevertheless, having the necessary content (i.e. product recipe) printed out would mitigate the risks a lot while facing such circumstances (Figure 14). On the other hand, IT department has also thought of a possible interruption of the Internet. In order to forestall a possible outage, there are two independent lines to the Internet. In case one line fails, the switch happens automatically, and second line starts providing the Internet. Nevertheless, if the source of the problem is the Internet provider, the 3G can be connected to the switch and that would be sufficient for sending out the invoices and receiving the orders.

Figure 14 Implementation of an alternative source in EA

4.3.4 Step 4 – define secondary milestones

Secondary milestones are necessary to be defined, so that the process could be terminated in case something starts to fail. The use case scenario, that is explored here, is a production of parboiled sausages. As the scenario is covering the production of food, we can state that a process has to be terminated due to a drop of quality during the production (i.e. machine fails in the middle of the process, the produced product is too salty, etc.). Additionally, if it is noticed that the product information on MS Dynamics NAV is faulty, the production process should be terminated as well, until the food technologist corrects the information and gives the instruction to proceed. It depends on the process, what a secondary target could be. After analysing the process and the overall structure as well as discussing the alternatives with the senior food technologist, it was realised that enhancing the resilience through the EA model requires more people to involve than only the designer himself. It is not up to enterprise architects to decide what could be the alternative milestones as it is not in their competences anymore.

Table 18 Secondary milestones

Process	Milestone	Termination reason	Secondary milestone
Chopping	High-quality meat mass	Food spoilage	Animal by-product
Filling	Clipped or linked sausages	Food spoilage	Animal by-product
Heat treatment	Heat treated product	Food spoilage	Animal by-product
Packing	Packed product	Equipment failure Lack of packaging material	Product in different packaging
Packing	Packed product	Food spoilage	Animal by-product
All	High-quality product	Faulty recipe	Animal by-product

The milestones have been discussed with the stakeholders and the result of the discussion are illustrated in the table above (Table 18). As it is recommended in the method, the milestones for every process have been defined. There are four processes which together lead to the main target which is a production of a high-quality product. However, the scenario might not always be perfect. One of the identified reasons for termination, affecting all the processes, is a faulty recipe on MS Dynamics NAV. As the production is based on the product order, the faulty recipe on MS Dynamics NAV has a direct impact on all the processes. If such situation occurs and the production has been started, the target of a product changed from the particular sausage to an animal by-product. Animal by-product is defined as materials from animals that people do not consume. Such products can be sold to the companies which grow animals therefore even though Nematekas experience a huge loss, by selling the food spoilage it might gain some money. Similarly, the secondary milestone for all the other processes which are terminated due to the food spoilage is also chosen to be production of an animal by-product. The only process that differ from the rest is packing. There are a few more reasons for termination which is a failure of equipment and lack of packing material. There might occur a situation, when a packing equipment breaks down. In such situations there are two outcomes: wait for the machine to be fixed or move the process to another machine. The trick part is that not every machine is suitable for producing the same form product. As for an example, there are machine which has a functionality of thermal forming and there are others which do not. Packing a product with another machine might result in a different packing form. similarly, if there is a lack of material, as for an example, labels, the company can proceed manufacturing by labelling the product with different labels. All in all, two alternatives in sausage manufacturing are proposed: the animal by-product or the product in different packing.

4.3.5 Step 5 – apply attributes

The fifth step aims to apply the attributes of resilience to the enterprise architecture model. To begin with, six attributes could be reflected in the EA model: adaptability, diversity, efficiency, redundancy, responsiveness and self-organization (Table 13). Two of them can be modelled, one comes from the relationship and the other three can be reflected in the model by properties. It can be seen from the original model that equipment groups could be modelled by applying the concept of adaptability. We have four equipment groups: bowl cutter, vacuum filters, cooking chambers and packing equipment. With this chapter we aim to implement the attributes of resilience in every group therefore the following sections present the processes and our proposal. It must be mentioned, that efficiency is not discussed in any of the processes because, as it was revealed in section 4.1, it is a quantitative metric and stakeholders did not see the reason to share this information. it is understandable and it does not have impact on the validation of the method because it would not impact a decision. It can be explained by the fact that the machinery used at the production is specific and due to high demand, efficiency does not have an impact because decisions is one from one

4.3.5.1 Chopping

Bowl cutter consists of four bowl cutters. Three of these are working properly and on full capacity, but there is the fourth which has the same capacity but stops working after a certain time. It leads to the conclusion that instead of using four bowl cutters all the time, the company should use three permanently and keep the backup one for extra situations as that backup bowl cutter is not fully reliable (Figure 15). We assume that this would be a more efficient and less cost-effective approach as it would also improve decision-making because it would provide some clarity: in case one of permanently functioning bowl cutter fails, the process can be moved to the backup bowl cutter immediately. According to the past events, the bowl cutters do not fail that frequently, therefore it does not seem a rational decision to buy a new one instead of the Backup Bowl Cutter. Having the spare part and managing to fix it in a short time would already create a favourable situation. In addition, taking preventive measures such as a regular check-up would decrease the probability of failures, too. Overall, our proposal is to adapt adaptability and redundancy. Adaptability is illustrated by OR junction therefore if a failure happens and one of properly working bowl cutters fail (Bowl Cutter 1, Bowl Cutter 2, Bowl Cutter 3), the process is moved to Backup Bowl Cutter. This solution (Figure 15) also covers redundancy which is illustrated with a Backup Bowl Cutter – it plays a role of a buffer equipment.

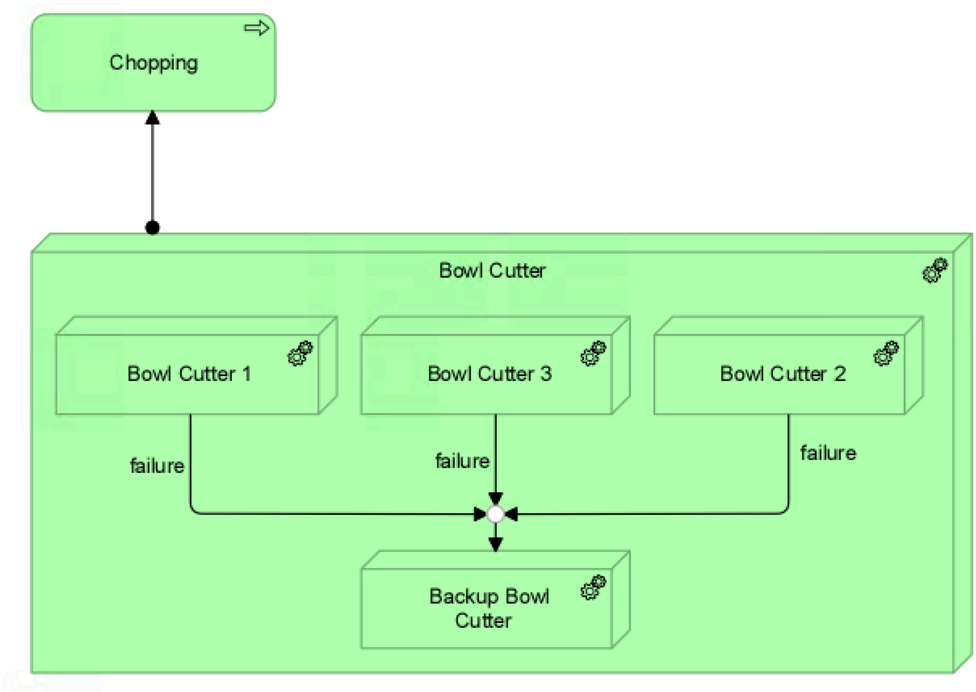


Figure 15 Enhanced resilience for chopping process

4.3.5.2 Filling

The next grouped equipment are vacuum fillers (Figure 16). The company used to have a vacuum filler which could perform both processes, clipping and linking, but after some time the company realised that the performance is higher when the machine has one function to perform only. Nevertheless, it is still possible to revert the equipment to the previous functionality if needed. We propose to reflect adaptability at the model by using an OR-junction for the different functions of the machines, thus it would reflect that when the failure happens, another machine of the same type is used (Figure 16). There is no flexibility in changing the process, therefore the only way to enhance resilience is to have regular check-ups and diagnostics. One more solution found in the literature is keeping track of the failures. It can provide important insights and help to foresee the upcoming disruption as there is a tendency for the same failures to occur again after some time. A spare part enhances resilience, but it is left for the discussion what attribute it reflects as it is part

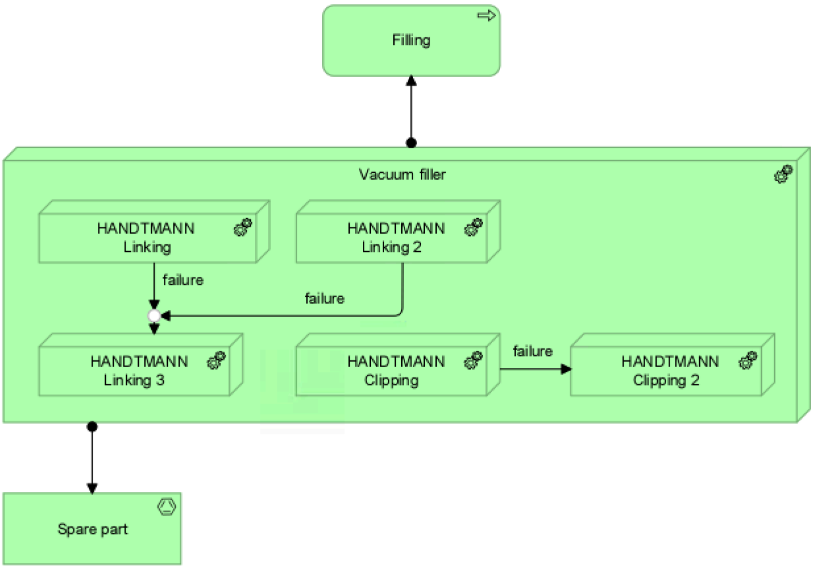


Figure 16 Enhanced resilience for filling process

4.3.5.3 Heat treatment

The third equipment group is cooking chambers. According to the food technologist and the head of the mechanics' department, the usual demand is not requiring full capacity therefore only a part of all cooking chambers is used at the same time. It leads to the conclusion that there is always at least one cooking chamber that can be used in case one fails. However, there are still space for improving the resilience. The practice has shown that the equipment is directly dependent on the amount it processes so if one machine is used more than the rest, there is a higher probability that the first one is going to fail earlier than the rest. This aspect is considered and it leads to the conclusions that the machines should be used according to their capacity. As for an example, if there are eight frames which must be processed, then using Cooking Chamber 1 or Cooking Chamber 2 instead of several Schroter cooking chambers would be a more resilient choice. It must be also noted that different products require a different program for the heat treatment which means that products in one cooking chamber cannot be mixed up.

Even though according to the head of the mechanics' department and senior food technologist, a situation in which all chambers would be used at once rarely happens, our approach is to include in the model how the process would be managed when one of the bigger or smaller cooking chambers fails. In this case, as all chambers have the same parameters, it does not matter which chamber is used instead of the one that breaks down. Here we use an OR-junction to reflect the adaptability when the failure occurs. It can be seen from the model (Figure 17) that most of the problems are caused when one of the cooking chambers, having eight frames capacity, fails. If such a situation arises, it might result in a higher need for smaller capacity cooking chambers and longer waiting time. Once again, with OR-junctions we illustrate the attribute of adaptability. The fact that company has cooking chambers of two different brands falls under the attribute of diversity. In case the software of one brand gets corrupted or experience any other software related problem, it does not affect all the equipment for the heat treatment. As for an example, if Stein software fails to proceed, Schroter could be still used due to different programs.

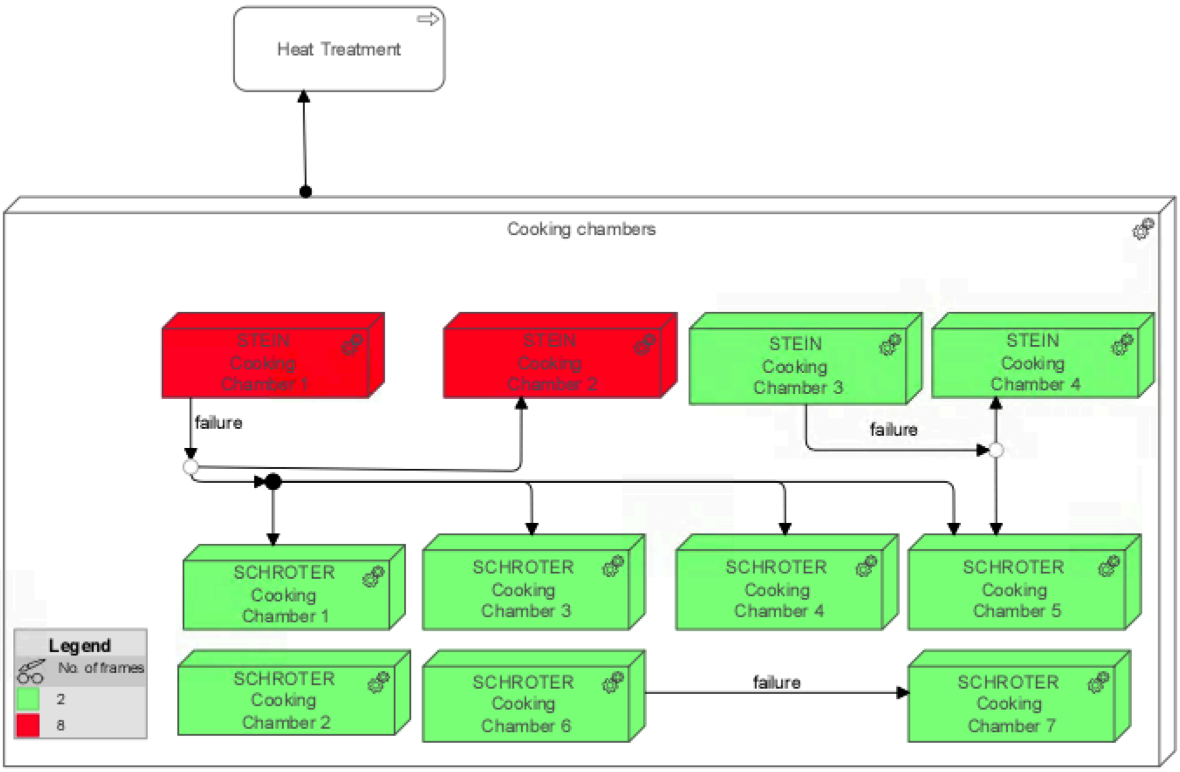


Figure 17 Updated model of cooking chambers

4.3.5.4 Packing

The last process to discuss is packing. A different approach is chosen for modelling the packing equipment (Figure 18). Instead of grouping all machines, the composition relation is used for visualizing the way the packing equipment are organized. It allows us to reflect clearly which machinery can process particular products and which actions should be taken in case of a disruption. Based on the risk assessment table (Table 15) it can be stated that while the failure is minor (the one which requires quick fix, not lasting more than two or three hours), it is better to try fixing the machinery than continuing production with a different machine. However, if a failure is major and machine cannot be fixed quick, the process should be moved to another equipment. Such assumptions are made because switching machines result in additional waste of material due to necessary preparation process and it is also time consuming. As it was mentioned in the analysis of EA (section 4.3.1), machines used for packing differ not only by properties but also by the functionality. Therefore, if a machine breaks down, it is a must to know what other equipment can process the same product. Thus, the composition relation is used in order to illustrate the packing equipment processing diverse products (Figure 18). There are three main machines (Etna, VC999, Tiromat) which pack products in bags, big forms and small forms accordingly. If Etna fails, VC999 can be used though it must be noted that it would not reach the same quality and the packaging would differ. If VC999 breaks down, the process could be moved to Veripack and Comet. If Tiromat fails, Veripack is used. The proposed model also includes metrics to show how the equipment differs from each other and which has the highest performance (expressed in packs per minute). Overall, with this approach we implement the concept of adaptability and efficiency. The attribute of diversity can be also noticed in this process, however, there is still a need for a discussion whether the company gains or lose by using the equipment of different manufacturers. It is not a secret that manufacturing companies aim to produce different products by using same parts as much as possible because it is cost effective. This leads to the assumption, that if a company would use the products of two or three brands, then it could stock parts which are common to fail and are suitable for more than one equipment what would likely result in shorter lasting disruption.

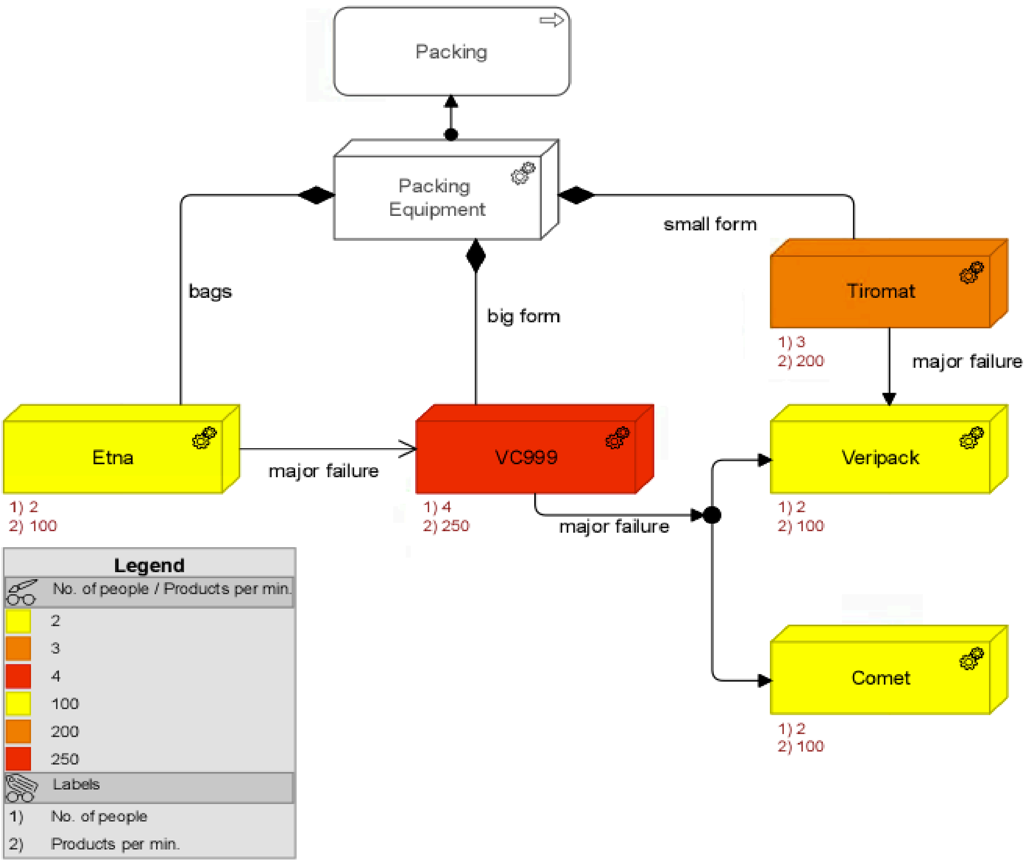


Figure 18 Updated model of packing equipment

4.4 Reflection

The proposed method has been validated through the use case scenario at the company Nematekas – the production of parboiled sausages. First, the original enterprise architecture was modelled because the company did not have one. The knowledge for the modelling was gathered by communicating mainly with the head of the mechanics' department, senior food technologist and head of the IT department. The enterprise architecture has been analysed and insights documented in step 1. The following step represented the risk analysis. Some risks where identified but the most attention was paid to the packing process. A risk heat map is presented as well as the risk assessment. Consequently, the following step is a discussion about the possible alternatives in case the primary source is unavailable. The fourth step analysis the secondary milestones. All these four steps lead to the fifth where attributes of resiliency have been implemented in the EA model, providing new insights.

With the use case scenario, it was revealed, that the method requires the participation of all the stakeholders. In the beginning, there were doubts whether the method is going to be suitable for the manufacturing company, because the steps of the method (Figure 7) seem to be more suitable for an IT company, i.e. looking for alternatives. Nevertheless, the method was successfully applied and validated with the given use case scenario. It leads to the conclusion that the implementation of the proposed method can still provide improvements even if an organization has not moved to Industry 4.0 where technologies and IT play a very important role.

The proposed method can also be applied to other meat industry companies in Lithuania. We come to this conclusion for several reasons. First of all, Lithuania as a country is pretty young (only 30 years of freedom) and the industry of meat manufacturing has been there for the last 26 years. With these numbers, we want to say that as the industry is young, changes do not happen quickly and even though the movement leading to the industry 4.0 can be already seen, there is no such company for now. This leads to the conclusion that all meat industry companies in Lithuania use the same principles and similar or even the same equipment. The second reason is that the IT architecture and business processes are alike therefore the method can be easily adapted to another organization by the following example with the use case. Slightly a different situation can happen with other meat industry companies in Europe or even worldwide. Thus, we believe that the approach should be applicable anyway, but new improvements or even changes might be proposed as we cannot assure that every organization in the meat industry is following the same processes.

We suppose that a large-sized company would benefit more from the implementation of the method than a small one, because bigger amounts are produced, which includes more employees, a higher variety of equipment, diverse processes and altogether it leads to a greater probability of various disruptions. Nevertheless, we believe that companies of any size would benefit from applying this method as a new approach.

The method is based on the knowledge gained from the scientific literature review therefore it cannot assure that all important aspects for all industries are gathered, thus the case study has not revealed it. Nonetheless, the approach seems solid and pretty flexible in the meaning that there is left space for improvisation, hence any company could find a way to use this approach. The most significant part and the success of the method lies in the EA analysis which requires knowledge from different business units. The designer has to understand how the company functions, the structure and all the principles to be able to adopt the method. Additionally, the ability to see a bigger picture and being able to provide insights on how the concept of resilience can be adapted, has a significant impact on the success. Of course, it depends a lot on the architecture of the company whether this method will support the company. One or another way, even if the resilience was not improved, the common knowledge would be shared among the stakeholders what is always beneficial for an organization.

5 Validation

Following the Design Science methodology, the designed solution must be validated prior to its implementation (Wieringa, 2014). In order to do so, a panel of experts in the field of EA is assembled and introduced to a model, as described in the following sections. They were asked to fill in the questionnaire which is based on the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh, Morris, Davis, & Davis, 2003). UTAUT consists of four constructs, which comprise direct determinants of user acceptance and usage behaviour (performance expectancy, effort expectancy, social influence, and facilitating conditions), and the indirect determinant factors which are attitude toward using technology, self-efficacy and anxiety. The model includes also key moderators, namely gender, age, experience, and voluntariness of use. However, this study does not include the construct of social influence as it does not seem to be relevant, because it is defined as the degree to which an individual perceives that important others believe he or she should use the new method. We do not seem this construct being suitable for this work for several reasons: First of all, only one respondent out of five is from the company where the method is applied and the other four are from universities, therefore it would be misleading to ask all the respondents for the statements of the social influence construct. To add more, we do not include the key moderators as they are not determinant variables of user acceptance and behaviour.

The following table (Table 19) explains the constructs which were used in the questionnaire.

Table 19 Constructs used in the questionnaire

Construct name	Definition	Root Constructs
Direct determinant		
Performance expectancy (PE)	The degree to which an individual believes that using the system will help him or her to attain gains in job performance	Perceived usefulness Extrinsic motivation Job-fit Relative advantage Outcome expectations
Effort expectancy (EE)	The degree of ease associated with the use of the system	Perceived ease of use Complexity Ease of use
Facilitating conditions (FC)	The degree to which an individual believes that an organizational and technical infrastructure exists to support the use of the system	Perceived behavioural control Facilitating Conditions Compatibility
Indirect determinant		
Attitude toward using the method (ATUT)	An individual's overall affective reaction to using a system	Attitude toward behaviour Intrinsic motivation Affect toward use Affect
Behavioural intention to use the method (BI)	An individual‘s perceived likelihood or subjective probability to use the system	

5.1 Participants

The experts that agreed to take part in the validation process are five:

- A professor of a Lithuanian technical university, with ten years of experience in EA research and ten years of experience in EA implementation and/or consulting
- A professor of a Dutch technical university, with two years of experience in EA research and two years of experience in EA implementation and/or consulting
- A professor of a Dutch technical university, with 17 years of experience in EA research and 15 years of experience in EA implementation and/or consulting
- The head of the IT department at one of the leading manufacturing companies in Lithuania, with five years of experience in EA research field and 15 years of experience in EA implementation and/or consulting

- A professor of a Dutch technical university, with three years of experience in EA research and five years of experience in EA implementation and/or consulting

Each expert was provided with the information about the method and asked to fill in the questionnaire, which can be seen in Appendix D: Questionnaire. The questionnaire is based on Likert scale (lowest score – strongly disagree, highest score – strongly agree), therefore the respondents answer the questionnaire by giving their preference for each statement from 1 to 5. The following section introduces the obtained results.

5.2 Results

This part discusses the results of the questionnaire. The table below (Table 20) illustrates the evaluation of the method by each respondent. It allows comparisons between the different constructs of UTAUT and shows how every member of the expert panel responded. The table is structured as follows: statement ID, the number of participants, the response of each participant, the minimum score given by the participant for the related statement in the questionnaire, the maximum score given by the participant for the related statement in the questionnaire, 'Sum' is the total score given by the participant for the related statement in the questionnaire, 'Mean' is the average score given by the participant of the related statement in the questionnaire, 'STDEV' is the standard deviation of the scores given by the participant. The standard deviation measures the amount of dispersion of a set of data values. The higher the value of the standard deviation is, the more the opinions among respondent differ. On the contrary, the lower STDEV is, the more the opinions coincide.

Overall, it can be seen that the proposed method is evaluated positively. The construct measuring FC (facilitating conditions) results with the highest average score per construct, 4.20, while the lowest average point per construct is 3.07 for the construct of behavioural intention (BC). The opinions between the experts differed the most for construct PE (performance expectancy) and the least for the EE (effort expectancy).

Figure 19 illustrates the summary of the results concerning the mean and standard deviation per statement. From this chart, 17 out of 18 statements have a mean value equal or above 3. This shows that the participants tend to have a positive response about the proposed method. The standard deviation indicates how spread out the data is: a relatively high variation is said to be when the standard deviation is higher than 1. Lower than 1 can be considered as a low variation. From the graph below, 8 out of 18 statements have the standard deviation higher than 1. The mean of all standard deviations is 0.89. This indicates that there are statements where participant disagree with each other but most of the time participants share same or similar opinion. The following sections discuss every construct separately.

Table 20 Questionnaire results

Statement	N	N1	N2	N3	N4	N5	Min	Max	Sum	Mean	STDEV
PE1	5	3	2	4	5	4	2	5	18	3.60	1.10
PE2	5	3	2	2	5	4	2	5	16	3.20	1.30
PE3	5	3	2	1	5	4	1	5	15	3.00	1.60
EE1	5	3	2	4	4	3	2	4	16	3.20	0.80
EE2	5	4	5	4	3	4	3	5	20	4.00	0.70
EE3	5	4	3	4	3	4	3	4	18	3.60	0.50
EE4	5	4	5	4	4	4	4	5	21	4.20	0.40
EE5	5	3	3	3	5	4	3	5	18	3.60	0.90
ATUT1	5	4	3	4	5	4	3	5	20	4.00	0.70
ATUT2	5	2	3	1	4	3	1	4	13	2.60	1.10
ATUT3	5	3	4	3	3	3	3	4	16	3.20	0.40
ATUT4	5	3	4	3	4	3	3	4	17	3.40	0.50
FC1	5	4	5	5	2	4	2	5	20	4.00	1.20
FC2	5	4	5	5	4	4	4	5	22	4.40	0.50
FC3	5	4	4	4	5	4	4	5	21	4.20	0.40
BI1	5	3	2	2	5	3	2	5	15	3.00	1.20
BI2	5	3	2	2	5	3	2	5	15	3.00	1.20
BI3	5	3	2	3	5	3	2	5	16	3.20	1.10
PE										3.27	1.28
EE										3.72	0.74
ATUT										3.30	0.86
FC										4.20	0.77
BI										3.07	1.10

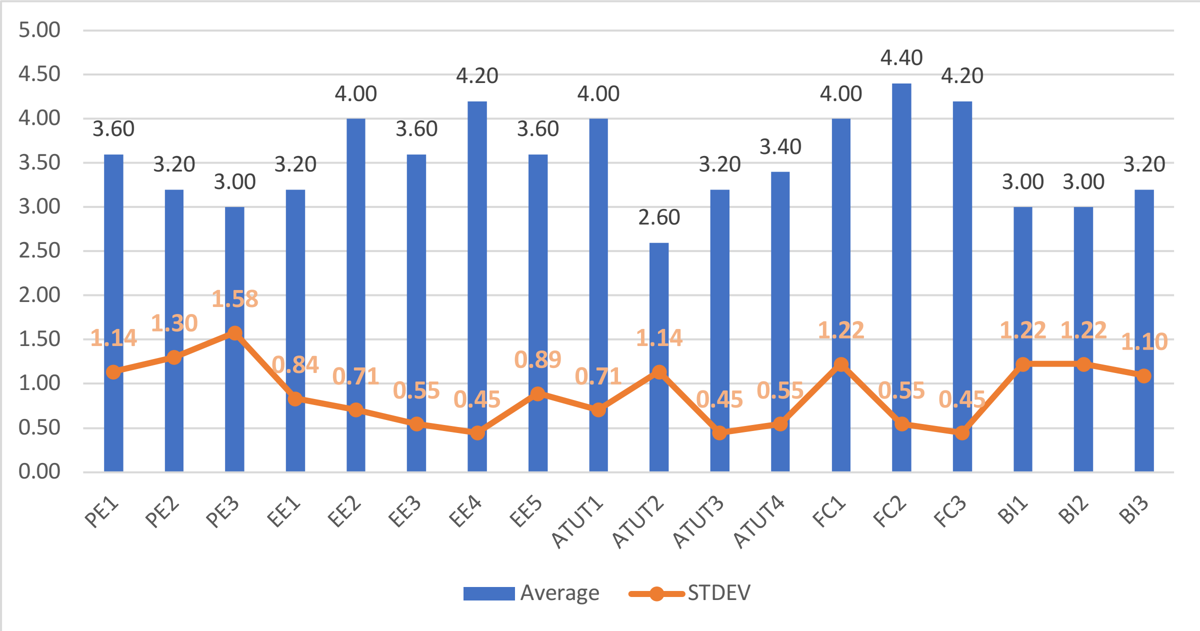


Figure 19 Average and standard deviation per statement

5.2.1 Performance expectancy (PE)

The construct 'performance expectancy' represents whether an individual using the proposed method would improve his or her performance in work area (Venkatesh et al., 2003). The table below (Table 21) exposes how the respondents evaluated statements focused on performance expectancy. The highest score per statement is 5. The mean per each statement is not lower than 3 and that leads to the average of all statements resulting in 3.26. The PE3, which states that "using the method increases my productivity" has resulted in the highest standard deviation. The results vary a lot, therefore the standard deviation turns out to be 1.6. These numbers lead us to the conclusions, that even though the performance expectancy of the method reached a score higher than the average, the results of the third statement shows that it could be argued whether the method could increase the productivity or not as it has been evaluated as very positive and very negative, too. We realise that PE3 statement is quite subjective therefore as the positions and type of work differs among experts, the opinions vary as well. On the contrary, the first statement, which claims that the method is useful, has received the positive ratings. Overall, even though the total score of performance expectancy is slightly higher than the average (3.26 out of 5), the method is found to be beneficial according to the evaluation of the majority of the participants. Nevertheless, it can be also assumed that with different expert panel, construct of 'performance expectancy' might be evaluated in more negative or positive manner.

Table 21 Performance Expectancy survey results

Statement		N1	N2	N3	N4	N5
PE1	I would find the method useful in my job.	3	2	4	5	4
PE2	Using the method enables me to accomplish tasks more quickly.	3	2	2	5	4
PE3	Using the method increases my productivity.	3	2	1	5	4

5.2.2 Effort expectancy (EE)

The construct of 'effort expectancy' defines the degree of ease associated with the use of the system (Venkatesh et al., 2003). The mean of all statements equals to 3.72, while for every statement separately the average value is higher than 3.5, except for the EE1, where the mean is 3.2. This leads to the conclusions that participants are neutral towards positive about the ease of use of the method. The standard deviation of every statement is below 1.0, thus it can be stated that all the experts share more or less the same opinion. The most positive result is obtained by EE4 statement "learning to operate the method is easy for me". The expert panel agreed that it is not difficult to learn how to use the method. On the other hand, the fifth statement EE5 has received mostly a neutral evaluation. This means that the users of the method do not see the benefits that this method brings and if it is beneficial at all. We believe that the fact of EA resilience being a new field has an impact on such an evaluation, as it is hard to foresee the benefits when nothing similar has been proposed before. In our view the personal motivation plays an important role here as well. Overall, we state that the effort expectancy of the method has been rated positively and that the expert panel agreed on the method being easy to apply.

Table 22 Effort Expectancy survey results

Statement		N1	N2	N3	N4	N5
EE1	My interaction with the method would be clear and understandable.	3	2	4	4	3
EE2	It would be easy for me to become skilful at using the method.	4	5	4	3	4
EE3	I would find the method easy to use.	4	3	4	3	4
EE4	Learning to operate the method is easy for me.	4	5	4	4	4
EE5	The rewards for implementing the method is worth the time.	3	3	3	5	4

5.2.3 Attitude toward using technology (ATUT)

The construct 'attitude toward using technology' defines an individual's overall affective reaction to using a system (Venkatesh et al., 2003).The average value of all statements for ATUT resulted in 3.3, which means that the respondents evaluated the method as being sufficiently interesting. The first statement obtains the most positive result in this construct, presumably because the approach is new, and the experts believe that the method delivers important insights in EA and that the organization could benefit from it. However, the second statement, which questions whether applying the method is engaging, has received a variety of rates: from 1 to 4. We find the results understandable because the method needs a lot of documentation and teamwork and, as it is generally known, teamwork demands the effort. On the other hand, the method requires a lot of communication and collaboration among stakeholders and that could be seen as a more engaging activity. The third (AUT3) and fourth (ATUT4) statements result in neutral score what leads to the assumption that from the first look, the method does not make a work more entertaining. On the other hand, changes at work usually face resistance therefore it is not a surprise that the method is not evaluated as activity for fun. Overall, we believe that the second statement (ATUT2) depends on the experience of the experts and how the application of the method is being seen.

Table 23 Attitude toward using technology survey results

Statement		N1	N2	N3	N4	N5
ATUT1	Using the method is a good idea.	4	3	4	5	4
ATUT2	The method makes work more interesting.	2	3	1	4	3
ATUT3	Working with the method is fun.	3	4	3	3	3
ATUT4	I like working with the method.	3	4	3	4	3

5.2.4 Facilitating conditions (FC)

'Facilitating conditions' represents a construct that describes the degree to which an individual believes that an organizational and technical infrastructure exists to support the use of the system (Venkatesh et al., 2003). The average value of this construct is 4.2 and it is the highest result among all the groups. The fourth expert (N4) rated the first statement of facilitating condition construct (FC1) with two points out of five. Contrarily, all the other experts evaluated the method with four or five points out of five. The assumption behind this situation is that all the respondents except the fourth one understood that the resource for the usage of the method was provided together with the questionnaire, while the fourth expert probably thought that the question is raised about the previous background. Nevertheless, the second statement and its results reveal that all participants have adequate prerequisite to use the proposed method. This could be explained by the many years of experience in the EA field.

All participants are convinced that they have the fundamental knowledge to use the proposed method, because they understand the concept of text mining and machine learning. For other lecturers who do not have any knowledge about these concepts might have a different response. In conclusion, all participants believe that they have adequate qualifications to use the proposed method. Contrarily, the second respondent from the export panel has only two years of experience and still rated the method with five points. Therefore, it can be stated that even though the person is relatively new to the field of EA, the proposed approach is suitable for people of a diverse range of related experiences as well as it is compatible with different systems.

Overall, it can be stated that the method is suitable for most of the systems and that it does not require any specific resources or knowledge in order to use it.

Table 24 Facilitating Condition survey results

	Statement	N1	N2	N3	N4	N5
FC1	I have the resources necessary to use the method.	4	5	5	2	4
FC2	I have the knowledge necessary to use the method.	4	5	5	4	4
FC3	The method is compatible with other systems I use.	4	4	4	5	4

5.2.5 Behavioural intention to use the method (BI)

The construct of 'behavioural intention to use' is a person's perceived likelihood or subjective probability that he or she will engage in a given behaviour (Venkatesh et al., 2003). The average value of this construct is slightly higher than 3, with a result of 3.07 to be precise, and the mean for each statement is equal or more than 3. The standard deviation is higher than 1, what indicates that the opinion of experts varies. The table below presents the responses per participant. The fourth expert (N4) provided the most positive response toward his intention to use the method for assessing resilience in the enterprise architecture. On the contrary, the second and fifth respondents do not show the motivation and willingness to use the method, whereas the other two choose neutral position. However, an interesting aspect is that the willingness to use the method is expressed by the third participant: even though he or she does not intend or predict to use the method in the upcoming twelve months. The opinions for this construct vary a lot therefore we assume that the intention might depend on the type of work and current or future tasks. to add more, it also depends on the type of work if he or she will have the opportunity to use the method. Therefore, we cannot be totally certain and state that method is likely no to be used in the near future.

Table 25 Behavioural intention to use survey results

	Statement	N1	N2	N3	N4	N5
BI1	I intend to use the method in the next 12 months.	3	2	2	5	3
BI2	I predict I would use the method in the next 12 months.	3	2	2	5	3
BI3	I plan to use the method in the next 12 months.	3	2	3	5	3

5.2.6 General discussion

Overall the results of the questionnaire are positive. The construct of 'facilitating conditions' (FC) has received the highest points, resulting in an average of 4.2. It indicates the strong side of the method being compatible with organizational and technical infrastructure in various environments. In a manner inverse to FC, the most negative feedback was gained for the construct of 'behavioural intention'. This construct shows that the expert panel chooses a neutral position and does not have any motivation in using the method in the upcoming year. On the other hand, the standard deviation is relatively high what means that opinions among experts vary.

The participants were also asked to share any additional feedback. One of the new insights is that the approach focuses on the concepts related to risks, therefore it is proposed to be broadened. It has also been noticed that adaptability seems to be part of redundancy to some extent. We agree with this statement, because redundancy and adaptability are closely related, therefore some principles overlap. It was also noticed by another expert that redundant components might seem interesting and beneficial but there are some drawbacks which should be considered, as for example, costs, additional relationship and dependencies. Furthermore, one of the experts has mentioned that it is not clear how this method differs from any other risk management method. Regarding the response to this comment, we complement Chapter 3 with a short explanation about the distinction between the risk management method and EA assessment method. In short, the main difference is that the focus is on resilience and, to our best knowledge, we are the only ones who propose the idea of applying attributes of resilience.

The participants shared positive feedback as well. It was noted, that the research is interesting and seems promising as well as that the method by itself is seen to be powerful if implemented correctly. One of the experts shared the insight that the real challenge of this method is competence on site. He reasons that success of implementation is correlated to deep knowledge of the whole picture, involving processes and overall infrastructure. The expert claimed that the human resources, which are involved in the whole analysis of an enterprise, impacts the success of the project too. More people means more opinions and likely higher resistance to new changes. The same respondent shared that the application of the method becomes even more complicated in the organization with matrix management as it depends a lot on the communication and teamwork between the stakeholders. To conclude, the evaluation of the method was overall positive. The discussed constructs lead to the assumption, that the proposed method is found to be suitable for various environments and might be used in the practice. Communication between stakeholders and the designer plays a major role as success of the method depends on it. Overall, the approach is found to be promising and useful.

6 Conclusions

In this chapter the results of this study are discussed, in regard to the main research question as well as the sub-questions defined. It is followed by the final conclusion of the thesis. The next subsection presents the limitations, detected during this study which is followed by the contribution to the practice and theory. Lastly, future work and the recommendations for practitioners are presented.

6.1 Discussion

The objective of this research is to articulate a method for implementing the concepts of resilience in EA. This objective is defined in the context of this research from the main research question in Chapter 1.3*:*

How to implement the concepts of resilience in EA?

To assist in answering the main question, sub-questions were raised:

- RQ1: What is known in scientific literature about resilience in Enterprise Architecture or Information Systems?
- RQ2: What are the different types of resilience found in the literature?
- RQ3: What metrics are used to assess systems resilience and on what calculation models are these metrics based on? Focus on manufacturing field.
- RQ4: How to design a method which can help with modelling and assessing the resilience of Enterprise Architecture?
- RQ5: Is the proposed method in RQ4 is useful in practice?

The performed literature review in Chapter 2 was necessary in order to collect the knowledge from the literature. The findings of the literature review answer the first three sub-questions, regarding EA, IS and other types of resilience and ways to measure it. Our expectations were that resilience in Enterprise Architecture has been explored for a while and sufficient amount of information is going to be retrieved by using the main keywords. Unfortunately, search showed that EA resilience is in its infancy, however, sufficient information was found in related fields. As a result of it, 850 papers were reviewed out of which 58 were selected. Findings have been categorised in 4 topics: definition, strategy, attributes and capacities. It was found that the strategy of IS resilience should go together with organisational resilience and provide the alignment between IT and business strategies as well. The list of attributes provided important information for performing the research and contributed to it significantly. Furthermore, resilience has been grouped by domains, expression of the measure, source of disruption and longevity. This categorization helped to broaden the knowledge in resilience in a structured way. As a result, twelve types of resilience are presented and each categorized whether it is qualitative, quantitative, external, internal or short-term resilience. In addition, various metrics to assess resilience have been collected from different areas. Unfortunately, only a part of metrics is listed out together with the formula to estimate it. Nevertheless, we assume that part of the collected and presented metrics could be used for assessing enterprise architecture (EA) resilience. All together it contributes a clearer understanding of information system resilience and bring relevant findings for EA.

Chapter 3 provides an answer for RQ4, which questions whether a method could be designed which would guide on how to implement the concepts of resilience in EA. Therefore, in Chapter 3 the method has been developed, following the design method by Wieringa. The method consists of five steps that need to be performed in sequential order. First, the enterprise architecture should be modelled. As the Industry 4.0 is approaching, we recommend for the manufacturing companies extend EA to the plant floor. Modelling EA is based on gaining the information from the interviews, organizational documents and visits of the plant. All these activities help to understand better the structure and processes of the company and provide the foundation for the following work. The next step is the identification of the risks. Various risks are identified and ranked by the probability of occurrence and impact for the rest of the system. Then the risk heat map is created which is based on the rank list. This helps to visualize which risks might cause higher consequences and therefore require more attention. The third step is aiming to identify alternative sources. Alternative sources are useful when the primary one becomes unreachable and it also helps to mitigate the possible threat. The following step discusses and states secondary milestones which help to terminate the process in a reasonable way and provide an acceptable outcome. Finally, the fifth step of the method aims to apply the attributes of resilience to the EA. The proposed attributes have been specified while performing the literature review. Furthermore, concerning the attributes of EA resilience and its realisation in the model is a totally new approach which was not found in any of the papers while performing the scientific literature. We believe that it lays the background for the future research which could extend the list of the attributes of EA resilience and think of more ways how to visualise it in the model as well as how to quantify.

A detailed view of every step is presented, providing a better understanding of how to follow the method and what is expected to be done. With this method we aim to apply the concepts of resilience, which were found while performing the literature review. We believe that our proposed approach is useful for the designers to model a more resilient

EA which would likely lead to better readiness for various disruptions and threats at the organization.

The following question of this research (RQ5) is aiming to reveal whether the approach is useful in practice. Therefore, the case study (Chapter 3) is presented as well as the opinion of the experts' panel. The case study revealed that the approach improves the understanding of the overall system and helps in finding the critical places. It also provides a different view of the risks as it raises the question about the secondary milestones and alternatives. Finally, the attributes of resilience are being discussed and implemented. It is assumed that the chosen approach of visualising attributes of resilience such as redundancy and adaptability, clarifies how the disruption should be handled. To add more, following the proposed guidelines, leads to the documentation of the knowledge which is usually spread between the stakeholders and this is also seen as a positive result of the approach. In order to improve the answer to the fifth sub-question, the expert panel has been asked to fill in the questionnaire (Appendix D: Questionnaire). The opinion of the experts varies but, nevertheless, the overall evaluation is positive. It has been identified, that the method is seen to be compatible with organizational and technical infrastructure in various environments. Furthermore, the opinions about the increased performance and likelihood to use the method varies a lot, nevertheless, it results in neutral towards a positive attitude.

6.2 Contributions

6.2.1 Contributions to practice

There are several contributions to practice. The performed review of the scientific literature results in the identified strategies, attributes, types and metrics of resilience. It offers companies today a classified list, based on scientific literature, of what they can implement to be more sustainable. It could also serve the EA practitioners as the background for their studies as well as for the development of the quantitative way to assess the different levels of EA resilience. Furthermore, the proposed lists enable organization to include the aspects of EA resilience in its EA practice. The method aiming to implement the concepts of resilience of EA is proposed. The artefact has been thoroughly applied, validated at the company and evaluated by the expert panel. This method serves organizations with simple steps to follow to implement the concepts of resilience in EA. Furthermore, it can be adapted by other companies without much effort. It can also serve as a guideline for an overview of the weak places of the organization as well as the plan for response to the disruption and improve decision making.

6.2.2 Contributions to theory

The findings of this research contribute to communities of academic research on EA and IS. The contribution to the theory of this research paper lies in the fact that IS resilience has been explored and valuable information provided in a clear structured way. The definition for Enterprise Architecture resilience is developed based on the systematic literature review. It was revealed that resilience can be categorized by domain, lifetime, expression (quantify or qualify) and source of disruption. Various types of resilience with explanations are shortly discussed and presented. Based on all covered scientific literature, we have proposed several metrics and strategies that could be applied to improving Enterprise Architecture resilience. Several strategies characteristics, quantitative and qualitative measures have been identified. The collected information can serve as a starting point for further research in EA resilience. We believe that the proposed definition could serve as a starting point of an ongoing conversation on EA resilience in the EA community. Furthermore, as the information is mostly collected about the IS resilience field due to limited number of papers on EA resilience, the researchers could use it for the further development of EA resilience. There are more open questions such as how EA resilience is related to sub-fields, i.e. crisis management, decisions making, etc. As EA resilience is said to be in it is infancy, we believe that this work contributes with its literature review to the theory, therefore forms a line for future research.

6.3 Limitations and Future Research

6.3.1 Limitations

There are several limitations to the research which can be divided into the different research questions. It is plausible that a number of limitations may have influenced the results obtained in Chapter 2. To begin with, retrieving articles focused on resilience is rather complicated due to the fact that most papers refer to resilience but barely discuss it. EA resilience is a new field and is concluded to be still in its infancy. As the focus of the study was on EA and IS resilience there is some possibility that more information would have been revealed if the field was not that new. As expected, most papers were not focusing on resilience as a field but rather as a property (resilient systems, resilient community, etc.) which had also resulted in findings. Furthermore, The current study only searches literature from six digital libraries. Some relevant studies might be missed from the search results. Lastly, the keywords used in the search process might not capture all relevant studies.

Regarding Chapter 3 and Chapter 4, the lack of scientific literature discussing guidelines and strategies for EA resilience limits the development of the method. The method was developed by combining various ideas from several sources and coming up with five steps therefore the results are limited by selected sources and authors mindset. In addition to this, the validation itself is limited because the method has been validated with only one case. One of the possible improvements could have been discovered if the method is applied to companies from different areas. In addition, the in-between relations in the enterprise architecture model from the case scenario are rather strong. Having less directly dependent relations and bigger EA model could reveal more about the method, but it would also take more effort. However, due to the limited time, we only validated this work with one case scenario and did not do too much to validate it more and did not go for the quantitative analysis.

6.3.2 Future research

For future research, it is recommended to validate a method with different case scenario and also where in-between relations are not that strong. Similarly, a bigger case with more complex enterprise architecture would bring more insights. These works could also reveal the weak points of the method and propose ways to improve it. The aspect that can be looked into further, is the usage of the model. Is the model suitable and sufficient for different types of company? Could metrics be involved and result in the quantitative assessment? To what extent does this model of EA resilience assessment help the decision-maker? Could this method be extended and adapted for Industry 4.0 automated decisions? Another suggestion is to implement quantitative analysis. This research proposed quantitative metrics which could be used in further studies and bring more results. There is a number of open questions on the validity of the model as it is now. Furthermore, in this model, the in-between relation is really strong, and it does not show the overall picture of the assessment when processes are not fully dependent on each other therefore the method should be validated with different case scenario where processes are independent or somewhat related. To add more, a case, where all equipment is fully functioning and used all the time, would bring different results too and reveal weak points of the method.

6.4 Final Conclusion

To conclude, five research sub-questions have been raised in order to answer to the main question of this research:

How to implement the concepts of resilience in EA?

The review of scientific literature was performed. The limited number of papers with a focus on EA resilience has been found thus the scope was extended to include IS resilience. The literature review introduces a reader in a structured way to the definition, strategies, characteristics and roles of IS resilience. The field has been also categorized by domain, lifetime, measure and source of disruption. The quantitative and qualitative metrics of IS resilience have been presented as well. We believe that it provides a reasonable background which could serve for future research in developing a quantitative method for estimating EA resilience. The performed review of the scientific literature laid the foundation for to the development of the method. We came up with the five-steps method for implementing the concepts of resilience in EA. Every step is explained in detail thus it could be simply understood and applied. The case study is illustrating how the method is used in practice – the approach has been applied at a manufacturing company. It showed that EA resilience includes stakeholders, processes and functions, applications and data, products and services as well as technology and physical elements. As the application of the method includes the plant floor, we believe that the approach could be applied to the future Industry 4.0 companies as well. In the field of EA, it is not common to meet and discuss resilience, thus including them into practice was not straightforward. Nevertheless, it is believed that the method provides sufficient guideline on enhancing resilience of EA and could serve the EA designers. The method was also validated with a questionnaire by the expert panel. Though the field of resilience of EA is relatively new, we believe that the proposed approach and provided information is found to be useful and could be applied as well as improved. The validation revealed that the overall evaluation is neutral towards positive. This leads to the conclusions that the method is likely to be accepted and that it could be useful for the future work. However, a step further would be to design a method for quantitative analysis. Though the field of EA resilience is in its infancy, we believe that this field is relative and the importance of it is increasing.

To conclude, the proposed approach has its limitations and drawbacks but, nevertheless, it is seen to be useful. The review provides a strong overview of the scientific literature. The developed method, aiming to implement the concepts of resilience of EA, contributes to the practice and theory and could serve for the designers and researchers.

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Appendix

Appendix A: Strategies of resilience

Strategy	Definition
Acceptance	Accepting the disruption risk, and the related cost; typically, favoured when (1) the cost of dealing with disruptions outweighs the losses from accepting them(2) disturbance hazard is low; or (3) reduction costs are very large.
Barbell	Eliminating the vulnerability to losses due to disruptions by investing the majority of the assets in safe tools while taking risks together with the in areas with large- scale favourable results.
Buffering	Trying to acquire equilibrium through setting safeguards that protect companies.
Collaboration	Ability to operate effectively in achieving objectives that are compatible or common, which would help to handle disruptions. Collaboration contributes to uncertainty and boost system's response capacity.
Cost Minimization	Focus on cost reduction via constant removal of waste (effective utilization of source) or actions that do not include value and can in some instances, be the cause of disruptions. Such as buffering this strategy might be in conflict with other people.
Customer Servicing	Engaging customers in a collaborative conversation at a business atmosphere.
Creating Disruption Management Culture	Establishing a culture which addresses a number of perspectives of members of a company on decision making about vulnerability management and disruptions and associated topics like reimbursement, managing strategy, responsibilities.
Crisis Management	Process by which a company copes with disruptive events (before, during, and following occurrence).
Demand Managing	Responding to need changes through incentives and approaches of cost promotions
Forecasting	Forecasting market demand, etc., to prevent damaging consequences and enhance the chances for success.
Fault Injection	Assessing the dependability of a system by injecting flaws through the design stages, prototype, operational steps.
Government Lobbying	Trying to influence decisions made by the authorities, e.g. to mitigate the effect of risks that may have a long-term impact.
Graceful Degradation	Keeping as limited functionality as much as possible in case of disruption to prevent a catastrophic failure
Insurance	Financial risk sharing strategy, transferring the risk of compensable loss to an insurer.
Infrastructure Investments	Building foundation information technology upgrades infrastructures and systems integration, and boost degree of automation.
Inventory Management	Ordering and stocking decisions such as stock investment and stock optimization.
Knowledge Management	Aimed at generating knowledge about company ecosystem dangers and construction (informational and physical) with the ability to learn from previous

	disruptions to strengthen endurance through development of its versatility, visibility, pace and cooperation capabilities.
Mapping	Macro-graphical representation of the company network and its current state and future condition. Mapping tools will help companies understand the community in and become aware of its vulnerabilities.
Network Structure Planning	Choosing business tasks, and procedures of the ecosystem's structure, quantity, location, and ability, to restrict its vulnerability through strategy accountable for failures
Postponement	Moving ahead actions or operations to the latest stage in time to comprehend and meet requirement.
Performance measurement	Attempt to reduce lead times.
Policy management	Policies, processes, and guidelines included in organizations to make decisions that lead to endurance and to mitigate risk systems.
Real-time monitoring	To watch and sign an alert on the internal and outside conditions of its elements and the machine. It contributes to comprehension of the way the system works as it fails, easing discovery of their flaws.
Reengineering	Knowing the company ecosystem structure and decrease in sophistication through business process re-engineering initiatives.
Risk Assessment	Interpreting and evaluating severity and the likelihood of events that occur infrequently based on expertise
Risk-hedging	Actions targeted at eliminating the vulnerability to losses that were possible without restricting this system's benefits. Hedging involves creating possibilities.
Revision	Considering some substitution and revising the strategy of sourcing, operations, and centre (redesign, re-routing,...) in response to disruptions.
Sensemaking	Procedure of producing consciousness in cases of doubt or high complexity so as to expect or make conclusions.
System Analysis/Evaluation	Inspection preventative maintenance plans to make sure that processes are strong to misestimation of disturbance parameters or programs.
Supplier Selection	Increasing resilience degree of the provider accountable for disruptions by selecting suppliers based on different criteria (e.g. flexibility, responsiveness)
Sourcing	Planning, constructing and designing a competitive and trusted supplier base which could be responsive to a lack. It can incorporate emergency backup sourcing and provider diversification.
Weak links	To rapidly discover an error condition and also break up a "weak link" stop dispersing failures.

Appendix B: Metrics for resilience

Metric	Formula	Abbreviations	References
Capability Drop Ratio (CDR)	$RC_d = \frac{C_0 - C_{min}}{C_0}$	RC_d = capability drop ratio C_0 = capability before disruption C_{min} = capability after disruption	(Luo et al., 2018)
Capability Recovery Degree (CRD)	$\Delta C_r = C_r - C_{min}$	C_r = capability recovery degree C_{min} = capability after disruption ΔC_r = capability recovery degree	(Luo et al., 2018)
Capability Recovery Ratio (CRR)	$RC_r = \frac{C_r - C_{min}}{C_0 - C_{min}}$	RC_r = capability recovery ratio C_0 = capability before disruption C_{min} = capability after disruption C_r = capability recovery degree	(Luo et al., 2018)
Degrading time	$T_i^d = t_i^m - t_i^0$	T_i^d – degrading time t_i^m –the moment that system performance reaches the bottom due to incident i t_i^0 – the moment that incident i occurs	(Wei & Ji, 2010)
Performance degradation	$P_i^d = P_0 - P_i$ $\Delta C_d = C_0 - C_{min}$ $\Delta Max\_C_d = C_0 - C_t$	P_i^d = maximal performance degradation of system due to incident i P_0 = the original system performance when incident i occurs P_i = the minimum performance due to incident i C_0 = capability before disruption C_{min} = capability after disruption ΔC_d = capability drop degree C_t= capability of a system to complete a task	(Wei & Ji, 2010) (Luo et al., 2018)
Performance loss	$P_i^l = P_0 \times (t_i^r - t_i^0) - \int_{t_i^0}^{t_i^r} P(t)$ $PL_{DP} = \int_{t_d}^{t_r} \big(MOP(t_0) - MOP(t)\big)dt$	P_i^l= total loss of performance of system due to incident i P_0 = the original system performance when incident i occurs t_i^r=the moment that the system completely recovers from incident i occurs t_i^0 = the moment that incident i occurs	(Wei & Ji, 2010) (Nan & Sansavini, 2017) (Jin & Gu, 2016)
Production loss	$PL^P = \frac{t_D}{T_l^0(0)} PR^S - \sum_{k=t^P+1}^{t_D - t^P} PR^P(k) + \sum_{k=\frac{t_D}{T_l^0(0)}+1}^{\infty} \Big(PR^S - PR^P\big(kT_l^0(0)\big)\Big)$	PL^P = production loss t_D = duration of disruption PR = production rate $PR^P(k)$= production rate at time k T = cycle time t_R =duration of reconfiguration to take B = one of policies $t^P = t_R$ I{P=B}	(Gu et al., 2015)
Protection time	$T_i^p = t_i^d - t_i^0$	T_i^p = the time that system can withstand incident i without performance degradation t_i^d= the moment that system performance starts to degrade	(Wei & Ji, 2010)

		t_i^0 = the moment that incident i occurs	
Recovery time (Throughput settling time)	$T_i^r = t_i^r - t_i^s$ $TST_\varepsilon^P = \max\left\{k \middle\| k \geq \frac{t_D}{T_I^O(0)}, PR^P(kT_I^O(0)) < (1-\varepsilon)PR^S\right\} T_I^O(0) + T_I^O(0) - t_D$	T_i^r= the time that system needs to recover to normal operation from incident i t_i^r=the moment that the system completely recovers from incident i occurs t_i^s = the moment that the system starts to recover TST_ε^P = throughput settling time $PR^P(k)$= production rate at time k t_D = duration of disruption T = cycle time	(Wei & Ji, 2010) (Jin & Gu, 2016) (Gu et al., 2015)
Robustness	$RAPI_{DP} = \frac{MOP(t_d) - MOP(t_r)}{t_r - t_d}$	MOP(X) – measurement of performance during phase X t_d = beginning of disruptive phase t_r = end of disruptive phase, beginning of recovery phase	(Nan & Sansavini, 2017) (Heeks & Ospina, 2019)
Total loss	$L_i = f(P_i^l, R_i^c)$	L_i = total financial loss due to incident i P_i^l= total loss of performance of system due to incident i R_i^c= recovery cost	(Wei & Ji, 2010)
Total underproduction time	$TUT_\varepsilon^P = t_D + \sum_{k=\frac{t_D}{T_I^O(0)}+1}^{\infty} \mathbf{I}\{PR^P(kT_I^O(0)) < (1-\varepsilon)PR^S\} T_I^O(0) - \sum_{k=1}^{\left\lfloor \frac{t_D - 2t^P}{T_I^P(t^P)} \right\rfloor} \mathbf{I}\{PR^P(t^P + kT_I^P(t^P)) \geq (1-\varepsilon)PR^S \cdot \frac{T_I^P(t^P)}{T_I^O(0)}\} T_I^P(t^P)$	TUT_ε^P= total underproduction time $PR^P(k)$= production rate at time k I{X} = an indicator function, representing the true(1)/false(0) value of the statement X.	(Gu et al., 2015) (Jin & Gu, 2016)
Vulnerability	$V_x = P(x) \cdot D_x = P(x) \cdot (\int_0^d (Lb - x)dt + \int_0^d (x - Ub)dt)$	V_x = vulnerability to risk x (lower is bett $P(x)$ = chance of occurrence of risk x D_x = disruption d = duration of the disruption Lb = lower boundary of normal range Ub = upper boundary of normal range	(Man, 2019)

Appendix C: Quality Assessment

Author	Title	Year	QA1	QA2	QA3	QA4
C. S. Holling	Resilience and Stability of Ecological Systems	1973	Y	Y	N	P
D. Wei; K. Ji	Resilient industrial control system (RICS): Concepts, formulation, metrics, and insights	2010	Y	Y	P	P
A. Amaral; G. Fernandes; J. Varajão	Identifying Useful Actions to Improve Team Resilience in Information Systems Projects	2015	P	Y	P	Y
B. Barn; R. Barn	Resilience and values: Antecedents for effective co-design of information systems	2015	P	Y	N	P
K. Govindan; S. G. Azevedo; H. Carvalho; V. Cruz-Machado	Lean, green and resilient practices influence on supply chain performance: interpretive structural modeling approach	2015	Y	P	N	Y
X. Gu; X. Jin; J. Ni; Y. Koren	Manufacturing system design for resilience	2015	Y	P	Y	N
L. Labaka; J. Hernantes; J. M. Sarriegi	Resilience framework for critical infrastructures: An empirical study in a nuclear plant	2015	Y	Y	Y	P
A. Ostadtaghizadeh; A. Ardalan; D. Paton; H. Jabbari; H. R. Khankeh	Community disaster resilience: A systematic review on assessment models and tools	2015	P	Y	N	Y
A. Pasquini; M. Ragosta; I. A. Herrera; A. Vennesland	Towards a measure of Resilience	2015	N	Y	Y	N
A. W. Righi; T. A. Saurin; P. Wachs	A systematic literature review of resilience engineering: Research areas and a research agenda proposal	2015	Y	Y	N	Y
D. Woods	Four concepts for resilience and the implications for the future of resilience engineering	2015	P	Y	N	Y
R. Gomes	Resilience and enterprise architecture in SMEs	2016	N	P	Y	Y

T. Gomes; J. Tapolcai; C. Esposito; D. Hutchison; F. Kuipers; J. Rak; A. De Sousa; A. Iossifides; R. Travanca; J. Andre; L. Jorge; L. Martins; P. O. Ugalde; A. Pasic; D. Pezaros; S. Jouet; S. Secci; M. Tornatore	A survey of strategies for communication networks to protect against large-scale natural disasters	2016	P	P	Y	Y
A. Mehmood	Of resilient places: planning for urban resilience	2016	P	Y	N	Y
T. Comes	Designing for Networked Community Resilience	2016	P	Y	N	Y
J. L. Davidson; C. Jacobson; A. Lyth; A. Dedekorkut-Howes; C. L. Baldwin; J. C. Ellison; N. J. Holbrook; M. J. Howes; S. Serrao-Neumann; L. Singh-Peterson; T. F. Smith	Interrogating resilience: Toward a typology to improve its operationalization	2016	Y	Y	N	P
H. Elleuch; E. Dafaoui; A. El Mhamedi; H. Chabchoub	A Quality Function Deployment approach for Production Resilience improvement in Supply Chain: Case of Agrifood Industry	2016	Y	P	P	P
R. Freeman; C. McMahon; P. Godfrey	Design of an integrated assessment of re-distributed manufacturing for the sustainable, resilient city	2016	N	Y	Y	P
W. Goudalo; C. Kolski	Towards advanced enterprise information systems engineering: Solving resilience, security and usability issues within the paradigms of socio-technical systems	2016	P	P	Y	Y

S. Hosseini; A. Al Khaled; M. D. Sarder	A general framework for assessing system resilience using Bayesian networks: A case study of sulfuric acid manufacturer	2016	P	P	Y	Y
X. Jin; X. Gu	Option-Based Design for Resilient Manufacturing Systems	2016	N	P	Y	P
L. Labaka; J. Hernantes; J. M. Sarriegi	A holistic framework for building critical infrastructure resilience	2016	P	Y	P	Y
S. Platt; D. Brown; M. Hughes	Measuring resilience and recovery	2016	P	P	P	P
M. Sabatino	Economic crisis and resilience: Resilient capacity and competitiveness of the enterprises	2016	Y	Y	N	P
M. Sakurai; R. T. Watson; J. Kokuryo	How do organizational processes recover following a disaster? a capital resiliency model for disaster preparedness	2016	N	P	Y	N
A. Sarkar; S. Wingreen; J. Ascroft	Top management team decision priorities to drive IS resilience: Lessons from Jade Software Corporation	2016	P	Y	P	P
A. Sarkar; S. Wingreen; J. Ascroft	Governing information systems resilience: A case study	2016	P	P	P	P
C. Tarhan; C. Aydin; V. Tecim	How can be Disaster Resilience Built with Using Sustainable Development?	2016	N	P	Y	P
R. Almeida; A. A. Neto; H. Madeira	Resilience benchmarking of transactional systems: Experimental study of alternative metrics	2017	Y	P	P	P
R. F. Babiceanu; R. Seker	Trustworthiness Requirements for Manufacturing Cyber-physical Systems	2017	P	P	P	P
W. A. Conklin; D. Shoemaker	Cyber-Resilience: Seven Steps for Institutional Survival	2017	N	P	Y	N
A. S. Kahnamouei; T. G. Bolandi; M. Haghifam	The conceptual framework of resilience and its measurement approaches in electrical power systems	2017	N	Y	N	P

M. Morisse; C. Prigge	Design of a business resilience model for industry 4.0 manufacturers C3 - AMCIS 2017 - America's Conference on Information Systems: A Tradition of Innovation	2017	N	Y	N	P
C. Nan; G. Sansavini	A quantitative method for assessing resilience of interdependent infrastructures	2017	P	P	Y	P
R. Pirinen	Towards common information systems maturity validation Resilience Readiness Levels (ResRL)	2017	Y	P	Y	Y
A. X. Sanchez; P. Osmond; J. Van Der Heijden	Are Some Forms of Resilience More Sustainable than Others?	2017	Y	Y	N	P
S. Slivkova; D. Rehak; V. Nesporova; M. Dopaterova	Correlation of Core Areas Determining the Resilience of Critical Infrastructure	2017	N	Y	N	P
Z. Wang; M. S. Nistor; S. W. Pickl	Analysis of the Definitions of Resilience	2017	Y	Y	N	Y
R. K. Buchanan; S. R. Goerger; C. H. Rinaudo; G. Parnell; A. Ross; V. Sitterle	Resilience in engineered resilient systems	2018	P	Y	P	P
J. Hua; Y. Chen; X. Luo	Are we ready for cyberterrorist attacks?—Examining the role of individual resilience	2018	Y	P	Y	Y
A. Luo; Y. Kou; J. Liu; T. Chen	The resilience measure method to information systems	2018	P	Y	P	P
J. R. Macdonald; C. W. Zobel; S. A. Melnyk; S. E. Griffis	Supply chain risk and resilience: theory building through structured experiments and simulation	2018	Y	Y	P	P
N. Sahebjamnia; S. A. Torabi; S. A. Mansouri	Building organizational resilience in the face of multiple disruptions	2018	Y	P	P	P
J. Van Trijp; K. Boersma; P. Groenewegen	Resilience from the real world towards specific organisational resilience in emergency response organisations	2018	Y	Y	Y	Y

N. Yodo; P. Wang; M. Rafi	Enabling Resilience of Complex Engineered Systems Using Control Theory	2018	P	P	P	P
T. Man	Measuring and Analysing Resilience of Enterprise Architectures	2019	Y	Y	N	Y
T. Andersson; M. Cäker; S. Tengblad; M. Wickelgren	Building traits for organizational resilience through balancing organizational structures	2019	Y	Y	P	P
R. Heeks; A. V. Ospina	Conceptualising the link between information systems and resilience: A developing country field study	2019	Y	Y	N	Y
S. König	Choosing optimal ways to increase resilience of critical infrastructures	2019	P	Y	N	P
A. Kusiak	Fundamentals of smart manufacturing: A multi-thread perspective	2019	N	N	P	P
A. Marrella; M. Mecella; B. Pernici; P. Plebani	A design-time data-centric maturity model for assessing resilience in multi-party business processes	2019	P	P	Y	Y
S. Pashapour; A. Bozorgi-Amiri; A. Azadeh; S. F. Ghaderi; A. Keramati	Performance optimization of organizations considering economic resilience factors under uncertainty: A case study of a petrochemical plant	2019	P	Y	P	P
D. Rehak; P. Senovsky; M. Hromada; T. Lovecek	Complex approach to assessing resilience of critical infrastructure elements	2019	P	P	Y	P
S. Rocchetta; A. Mina	Technological coherence and the adaptive resilience of regional economies	2019	Y	P	Y	Y
W. Urbanczyk; J. Werewka	Contribution title enterprise architecture approach to resilience of government data centre infrastructure	2019	Y	Y	Y	N
S. R. Velu; A. Al Mamun; T. Kanesan; N. Hayat; S. Gopinathan	Effect of information system artifacts on organizational resilience: A study among Malaysian SMEs	2019	N	P	P	P

J. Ramezani; L. M. Camarinha-Matos	Approaches for resilience and antifragility in collaborative business ecosystems	2020	Y	Y	N	Y
C. W. Zobel; M. Baghersad	Analytically comparing disaster resilience across multiple dimensions	2020	N	N	Y	Y
TOTAL:	Y		23	32	21	22
	P		22	24	18	31
	N		13	2	19	5
	Average result		0.59	0.76	0.52	0.65

Appendix D: Questionnaire

The following questions were used to validate the method. The questions are based on the items used in estimating UTAUT (Venkatesh et al., 2003) and adapted to evaluate the method.

Performance expectancy (PE)

PE1. I would find the method useful in my job.
PE2. Using the method enables me to accomplish tasks more quickly.
PE3. Using the method increases my productivity.

Effort expectancy (EE)

EE1. My interaction with the method would be clear and understandable.
EE2. It would be easy for me to become skilful at using the method.
EE3. I would find the method easy to use.
EE4. Learning to operate the method is easy for me.
EE5. The rewards for implementing the method is worth the time.

Attitude toward using the method (ATUT)

ATUT1. Using the method is a good idea.
ATUT2. The method makes work more interesting.
ATUT3. Working with the method is fun.
ATUT4. I like working with the method.

Facilitating conditions (FC)

FC1. I have the resources necessary to use the method.
FC2. I have the knowledge necessary to use the method.
FC3. The method is compatible with other systems I use.

Behavioural intention to use the method (BI)

BI1. I intend to use the method in the next 12 months.
BI2. I predict I would use the method in the next 12 months.
BI3. I plan to use the method in the next 12 months.

Please state any additional feedback regarding the proposed approach