Enterprise Architecture Resilience by Design: A Method and Case Study Demonstration

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***Abstract*—In the past decades, a broad range of technological innovations have helped organizations reach new levels of performance and have shaped the economies of the world and societies of the future. However, unexpected events, such as the COVID-19 pandemic and the blocking of the Suez Canal, have shown that many organizations are unprepared to deal with the impact of the disturbances that can occur. Thus, organizations are challenged to include resilience in the design of their Information Systems and Enterprise Architectures (EAs). We respond to this challange and propose a five-step method aimed to help organizations design resilient enterprise architectures to be able to better deal with (un-) expected disturbances. Our method builds upon the 'EA resilience by design' paradigm, combines knowledge from several domains, namely resilience, risk analysis, and EA, and leverages the ArchiMate 3.1 language to model several resilience characteristics. Using a case study at a leading manufacturing organization in the agri-food sector in Lithuania, we demonstrate the applicability of our method and draw some early lessons learned based on our very first evaluation with experts.**

Keywords—Resilience by design, Enterprise Architecture Resilience, ArchiMate, Risk management, Industry 4.0, COVID-19 pandemic, Society 5.0.

I. INTRODUCTION

Since the 18th century, several industrial revolutions have reshaped the way in which traditional industries operate and have opened up opportunities for new inventions. From the mechanization brought on by the first industrial revolution to the emergence of electricity, mass production, and methods of communication in the second industrial revolution, to the rise of electronics, telecommunication equipment, computers, and automation in the third industrial revolution. Finally, the fourth industrial revolution (Industry 4.0) brought the usage of cyber-physical systems and internet of things integrating physical objects with the processing of virtual data [1]. While these four industrial revolutions did affect industries differently, they all shaped the economies of the world and provided a foundation for developing future societies that utilized technology not only for economic development, but also for solving societal problems from a human-centric perspective (Society 5.0).

However, not only technological changes can have a significant impact on the economy and industry. Global disruptions, such as the COVID-19 pandemic, the blocking of the Suez Canal which disrupted the global supply chains, have shown that despite having the latest technologies and capabilities, many organizations are unprepared to deal with such acute disruptions [2]. While many companies adopted thebackbone for technological progress, it is important for them to consider how to cope with unexpected events and minimize their impact, as disruptions are inevitable and resources are limited [2].

In the case of the COVID-19 pandemic, many organizations were forced to make significant transformations by redesigning key processes and adopting technological solutions to maintain their operations while dealing with a rapidly changing environment [3]. However, the long-term impact of this rapid digital transformationon the economy and society is not yet known. Thus, instead of reactively responding to disruptions, organizations should consider designing resilience measures in their processes and infrastructure in order to anticipate and adapt to disturbances by reorganizing, changing, and learning from past events [4].

Generally, scholars trace the origine of resilience research to Holling [5] who refers to resilience in ecological systems. Over the past decades, resilience as a concept and a phenomenon has been explored in various domains, such as ecology, critical infrastructure, engineering, organizational science, among others [6]. These collective research efforts have resulted in the definition of characteristics, metrics, and strategies allowing us to understand resilience from different perspectives [7]. However, it is worthwhile noting that certain domains have limited research on resilience. For example, in Information Systems (IS), resilience has only been explored in the past decade, with the first official definition being provided by Sarkar et al. [8]. Similarly, Enterprise Architecture (EA) resilience has only recently been investigated, with our previous study [7] being the first to coin the term and provide a definition for it. Both sources [7, 8] indicate an important need for more research on resilience in both IS and EA contexts. In addition, considering the rapid and sometimes chaotic digital transformations that organizations embraced due to COVID-19 [9], we think that this need aggravates even further. If organizations want to ensure that, in case of disruptions, the impact is minimal or avoidable [2], they need to include resilience in the processes of designing their Information Systems (IS) and EA.

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To fill this gap, in the present paper we focus on resilience as a critical attribute of EA and set out to propose a method that helps organizations design resilient EA and IS. More specifically, building upon our previous research [7], this method provides guidance on how to incorporate resilience characteristics into EA models. Thus, our research follows the 'resilience by design' paradigm which states that systems must be designed to recover their functions on their own in case of disruptions over a certain period of time [2].

Our research aims to make several contributions. From a theoretical perspective, we make a first step towards makingresilience an integral part of EA and and a first proposal for a method implementing the novel paradigm, namely 'EA resilience by design'. Furthermore, we design a five-step method that uses complementarily knowledge from several domains – resilience, risk analysis, and EA. Moreover, we leveragethe ArchiMate 3.1 language for the purpose of modelling several resilience characteristics. From a practitioner's perspective, our method offers guidance in the design of resilient EAs. As such it could be considered for inclusion in the toolbox that enterprise architects would use if they want to achieve to used to an increased level of organizational preparedness for coping with expected and unexpected disturbances.

For planning and executing our research process, we used the Design Science Research Methodology of Peffers et al. [10], which also shaped the structure of this paper. In what follows, Section II introduces the background and related work on resilience definitions and types, IS resilience strategies and characteristics, EA resilience by design, and several resilience methods from related domains. Section III presents our EA resilience method. Section IV demonstrates the use of the method in a real-world case study, and Section V presents the results of our very first evaluation. Section VI concludes with our critical reflection on limitations and future work.

II. Background and Related work

Our design science research process was informed by our previous systematic review of literature on the state of the art on resilience in IS and EA [7]. The sources included in this section are drawn among those that were already evaluated in the published review [7]. It should be noted that in this paper, we will not present the full results of the systematic literature review, but rather only those parts that are relevant to the method design research that we reported here. In the next sections, we will introduce the most important terms and the sources that we used as the foundation for our proposal for the EA Resilience by Design method.

A. Resilience

As already indicated, the first known definition of resilience was provided in [5] and treated resilience as the capacity of a system to adapt to change and deal with surprise while retaining the system's basic functions. Next, Labaka et al. [11] look at resilience from two perspectives, namely internal and external, based on the source of the disruption. External disruption may originate from the government, society, natural disasters, and other external stakeholders and factors, while internal disruptions are often caused by issues within the organization's internal processes, systems, and infrastructure. Another view provided by scholars (e.g. [12,13]) categorizes resilience into short-term and long-term resilience. Short-term resilience refers to the recovery to normal operating conditions after being confronted with short-term consequences [12], or to an ability to cope with altering conditions or capacity to reduce the consequences of a disruption [13]. In contrast, long-term resilience is seen as constantly evolving and changing to respond to a range of long-term disturbances [12]. Kahnamouei et al. [13] proposed a framework for long-term resilience which consists of a cycle of four functions and four different states.

For our research, we consider it important to address both internal and external resilience, and short-term and long-term resilience. The main reason for this is that these types of resilience can be interrelated. If we look at the COVID-19 pandemic, we can consider this as an external disruption that has a short-term impact [12]. Why short-term? Because for most organizations, after the pandemic ends, the stress on their operations will also end. Alternatively, a pandemic can evolve into an endemic and become part of the new status quo. Thus, the consequences of this pandemic on organizations are both internal, due to the changes in the processes, systems, and infrastructure that had to be made, and long-term, due to organizations choosing to implement solutions that will also be used after the pandemic ends. As such, EA practitioners need to look at the design of specific IS as well as the larger environment modelled in an EA.

B. IS Resilience

As said introduction, the research on IS resilience is relatively new, with Sarkar et al. proposing the first definition: *"IS resilience is a function of an organization'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"* [8].

Other authors [14, 15] take a slightly different conceptualization of IS resilience which focuses on the notion of recovery. For example, Pirinen [14] outlines that the system should recover, rebound or jump back to the primary or addressed system state. In the same vein, Heek et al. [15] argue that IS resilience should be understood in the sense of recovery and continuity. These authors indicate that the topic still lacks investigation into the "bounce forward" adaptive role, which is found in the basic definition of resilience.

Furthermore, scholars (e.g. [16,17]) reasoned about IS resilience also from a process perspective. In line with this, they focused their work on the definitions of phases that organizations should go through to achieve a satisfactory level of IS resilience. E.g., Guodalo and Kolski [16] define the four phases of IS resilience, namely anticipation, absorption, reconfiguration, and restoration. A different perspective is provided in [17], where three phases of IS resilience (readiness, response, recovery) are proposed based on the strategies that organizations can apply. For each of these phases, the authors describe several strategies that organizations can use, such as collaboration, forecasting, and risk assessment (for the readiness phase), acceptance, crisis management and revision (for the response phase), and knowledge management, performance measurement, and sensemaking (for the recovery phase). In this context, the concept of strategy means a particular way to understand a disaster [17].

Finally, our systematic literature review [7] presents a list of IS resilience characteristics gathered from multiple papers, such as diversity, efficiency, adaptability, cohesion, self-organization, robustness, learning, redundancy, rapidity, flexibility, equality, agility, vulnerability to risk and responsiveness. This extends the properties of IS resilience mentioned by Sarkar et al.[8], namely situation awareness, management of vulnerabilities, adaptive capacity, risk intelligence, flexibility, and agility. In the present research, we use these strategies [17] and characteristics [7] as our starting point for defining EA resilience.

C. EA Resilience

Several scholars attempted to define EA resilience. First, in our systematic review [7], we proposed the following definition *"EA resilience is the ability of an organization to identify and assess the vulnerabilities of enterprise resources in its integrated architecture and prepare for disruptions, by designing specific measures in an EA to increase its capabilities to adapt to new or changing circumstances and restore full capability after an unexpected disruption." Second,* Bemthuis et al.[4] studied it from the perspective of cyber-physical systems of systems and emergent behaviors. In contrast to these publications [7, 4], in this paper, we also coin the term *enterprise resilience* to represent the type of resilience enabled by designing EA models. This is similar to what is understood in literature as 'resilience by design'. For EA, this means that an organization should design its EA with resilience in mind.

According to our previous study [7], research on EA resilience is very limited. While knowledge from existing areas of research can be very useful for defining EA resilience, there is not much knowledge on the resilience strategies, metrics, and characteristics that would be suitable for inclusion in a method for EA resilience. Thus, in the present work, we adopt the reasoning of our previous study [7] which suggests that all these aspects that are defined for IS resilience would also apply to EA resilience.

D. Related Work

As a basis for designing our method, we draw on two frameworks: the resilience awareness framework of Marella et al.[18] and the cyber resilience assurance framework of Conklin and Schumacher [19]. The first defines five levels of resilience awareness for process models, as follows: no resilience awareness, failure awareness, data resilience, milestone resilience, and process resilience [18]. The second framework [19] proposes seven steps for ensuring cyber resilience, namely classifying threats, risk assessment, ranking threats, design and deployment of a solution, testing the solution, creating a recovery process, and evolving the solution. We chose these sources as the basis for our work because of their suitability to our context and the possibility to use them complementarily.

III. Method for EA Resilience by Design

To design our method, we have used the knowledge presented in Section II. However, we acknowledge that this knowledge is insufficient as there is no research currently available on *how resilience can be modeled* in an EA. Since we want to provide a method to support EA resilience by design, we propose several guidelines for how this can be done with the help of the ArchiMate modeling language. ArchiMate is chosen because (i) it is a popular modeling language for EA [20], and (ii) with the addition of the Physical layer it is highly suitable for modeling organizations representative of Industry 4.0 [21] and Society 5.0.

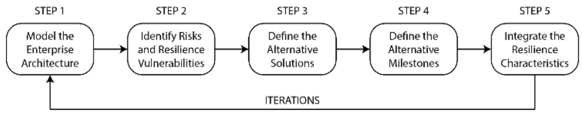

Fig. 1. The five steps of the EA Resilience by Design Method.

Our proposed EA Resilience by Design method contains five steps, which can be performed iteratively, as shown in Fig. 1. Iterations are recommended since the needs of organizations and their environment change over time. Plus, organizations usually learn from past events and, in turn, adapt their EA to better address certain disturbances. Thus, as the process of designing an EA requires iterations, so does improving the resilience of the architecture. In the following subsections, the steps of the methods are explained in more detail.

A. Step 1 – Model the Enterprise Architecture

The first step is about modeling the current situation of the EA. In many cases, this EA model would already be available if the organization uses the ArchiMate language. The purpose of this model is to provide insights into the current state of the processes, systems, data, and infrastructure of the organization. Additionally, we assume that organizations follow a certain strategy and are motivated to design resilience in their IS/EA. Hoowever, we make the note that at this step, it is expected that in the organization there is *no awareness* of the failures that might occur. This expectation is suggested by Marella et al.[18] who define the so-called"null level of resilience awareness maturity".

We note that in our proposed method, the presence of an up-to-date version of the EA model is important for any organization committed to resilience, just because the model ensures the assessments that are done in the following steps.. This also contributes to having a more complete overview of the risks. However, it is not necessary to model the whole EA if this is not feasible for the organization due to time and other resource constraints. Rather, an up-to-date model, using resilience-focused viewpoints, of the critical business processes, their related systems, data, and infrastructure would be sufficient. This type of modeling follows the principle of agile EA [22], where only the information necessary for decision-making is modeled. For this task, we recommend using the ArchiMate modeling language, with a focus on the business, application, technology, and physical layers.

B. Step 2 – Identify Risks and Resilience Vulnerabilities

The second step focuses on assessing the possible risks related to the EA. We choose to include risk assessment in our method because of its importance emphasized by other authors [18, 19] in relation to resilience. In [19] the cyber resilience framework includes risk assessment and threats ranking as separate steps in its application process. Similarly, the authors of the resilience awareness model [18] claim that the first step towards resilience is raising awareness that there are possible failures. Drawing on these authors [18, 19], in Step 2, we acknowledge that (i) organizations can face various types of risks, such as operational, financial, personnel, and strategic and that (ii) by analyzing those risks, organizations would gain insights into the probability of each risk occurring and the impact it might have. In turn, organizations would be able to identify some specific vulnerabilities in their EA.

It is worth mentioning that the main purpose of this step is not the identify every risk. Since risks and resilience vulnerabilities change over time, it is not realistic to expect to have a complete overview of them. Thus, this step is an iterative one that can be performed at different points in time and with different stakeholders. Additionally, not every potential risk is predictable. To address this, organizations should implement resilience characteristics in their EA and should use resilience strategies to guide their actions.

In our method, each risk is assessed by means of a qualitative scale, for both probability and impact [23]. For this risk assessment, we adopt the respective definitions provided in the TOGAF standard [24] which states that the probability can be assessed as *frequent, likely, occasional, seldom, or unlikely*, while the impact can be assessed as *catastrophic, critical, marginal or unlikely*. As TOGAF implies, combining these two factors would allow the risks to be assessed as *extremely high, high, moderate, or low* [24]. For example, Aldea et al.[25] show how risk analysis can be performed with the help of the Risk and Security profile for the ArchiMate language, proposed by [23]. Elements such as risk, vulnerability, threat agent, threat event, and loss event can be related to any element of the business, application, technology, and physical layers.

Organizations can choose to use any risk analysis techniques they might be familiar with. However, we do recommend following the guidelines provided by TOGAF [24] since they are in line with the goals of our method and support modeling with ArchiMate.

While the premise of resilience is for organizations to be able to deal with unexpected events, we still consider important to treat resilience also in situations in which disturbances are predictable. In the latter case, traditional risk management techniques would be useful as they create a solid basis for incorporating resilience characteristics. Furthermore, as identified in published sources [7] [8], managing vulnerabilities caused by risks is one of the characteristics of resilience. In line with this, our method builds upon risk-related concepts and extends them with resilience requirements and needs. By combining the risk analysis from Step 2 with EA modeling from Step 1, we expect EA practitioners can define better risk estimates.

C. Step 3 – Define the Alternative Solutions

This step focuses on identifying possible alternative solutions in the situation in which a disruption occurs. Specifically, this step aims at defining alternative processes, systems, data sources, and infrastructure that would assure damage control, i.e. that the impact of the disruption on the critical operations of the organization is minimal if not avoidable. Thus, the potential sources of failure should be identified, and respective alternative solutions should be defined. Plus, in situations where disruptions lead to cascading effects, a combination of solutions eeds to be considered.

As in Step 2, Step 3 leverages the Risk and Security profile for the ArchiMate language [23] to identify and define alternatives. Elements such as control objective, control measure, and security principle can be related to elements from the EA to define how the vulnerabilities should be addressed. Furthermore, for each of the risks identified in Step 2 that cannot be fully addressed with the help of control measures, several alternatives should be defined.

D. Step 4 – Define the Alternative Milestones

This step involves defining alternative milestones. It is inspired by Marella et al. [18] who state that the initial expectations on achieving a certain milestone should be revised and possible ways to mitigate the impact should be formulated. If the first milestone cannot be achieved, then we expect a compromise to be found, and an alternative target to be considered. This reasoning is in line with the premise of resilience which states that an acceptable level of performance should be restored [16].

Similar to Step 1, where we mentioned the principle of agile EA, also in Step 4 we consider it important to emphasize that not all aspects of an EA need to have alternative milestones defined. Rather, these alternative milestones should only be defined for those elements which are considered critical for the operation of the organization. This would help ensure that when an unexpected disruption occurs, it is clear what performance level is still acceptable for the organization to maintain its operations. Whenever changes to the EA are made, alternative milestones should be defined for all the elements that are affected by this change which are critical to the operation of the organization.

E. Step 5 – Integrate Resilience Characteristics in EA

The final step is where the characteristics of resilience are integrated into the design of the EA. This implies that the new EA models that are designed focus on aspects such as, diversity, efficiency, adaptability, cohesion, self-organization, robustness, learning, redundancy, rapidity, flexibility, equality, agility, vulnerability to risk, and responsiveness [7]. However, we note that not all of these resilience characteristics are easily representable in an EA model. In line with this, for our method, we choose to focus on the following three characteristics, namely *adaptability, diversity*, and *redundancy*. We elaborate on them below.

Adaptability is the ability of the EA to act in a flexible way and change in response to a disruption. When an unexpected event occurs, the EA should be able to adapt to these new circumstances and continue functioning at an acceptable level of performance. This can be done in multiple ways, such as by using alternative assets, adjusting the processes, etc. From the point of view of EA modeling, this can be represented by using the ArchiMate OR junction in combination with the Plateau concept (Fig. 2). This can signal that several alternative paths can be taken in case an unexpected event occurs. Thus, a transformation of the EA in case certain scenarios occur is modeled.

Diversity represents the option to choose from a variety of assets, vendors, etc. for elements of the EA. Thus, in terms of modeling, this means redesigning the EA to remove or reduce those bottleneck processes, actors, systems, and infrastructure that the organization currently experiences. These bottlenecks can be identified as EA elements that have many incoming and outgoing relations to other elements.

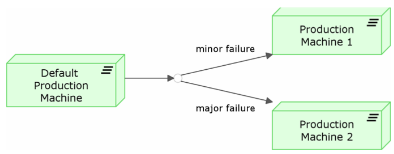

Fig. 2. Example Adaptability characteristic modeled with ArchiMate.

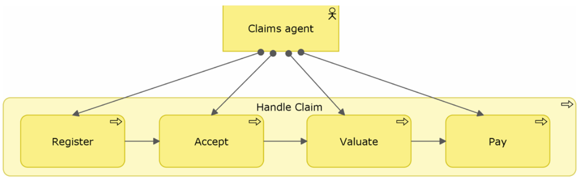

Fig. 3. Example Diversity characteristic modeled with ArchiMate.

One example of such a bottleneck is a situation in which there is only one actor able to perform several critical business processes (Fig. 3). This means that if this actor is unavailable due to a certain unexpected event, the processes cannot be executed anymore.

Redundancy is the extent to which certain components of the EA are substitutable. This can be achieved by having duplicate elements in the architecture which (partially) fulfill the same purpose. An example of redundancy that organizations use to deal with cyber-attacks and ransomware is back-ups of important data to servers in the cloud. This ensures that if the organization loses access to its primary database, a copy from the cloud can be used to ensure business continuity. In terms of ArchiMate, this can be modeled by using the AND junction (Fig. 4), which represents that both elements of the EA are contributing to another element.

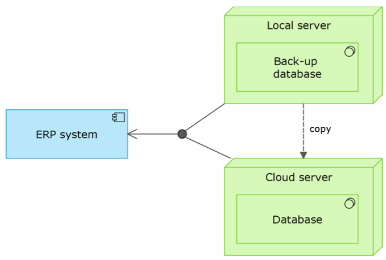

Fig. 4. Example Redundancy characteristic modeled with ArchiMate.

IV. Case Study Demonstration

Design science research methodologists (e.g. Wieringa, [29]) recommend that newly proposed methods should be first demonstrated by using case studies. This section demonstrates how we applied the EA Resilience by Design method presented in Section III, to a real-world organizational context. For this purpose, we used the research strategy called 'demonstration in a single case' as per Wieringa [28].

A. Case Description

Following Wieringa [29], we performed our case study at Nematekas, one of the largest meat production organizations in Lithuania. Founded in 1994, Nematekas is today one of the leading organizations in producing high-quality meat products. One of the recent goals of Nematekas is to improve their resilience to become better prepared for implementing new technologies and ways of working brought on by Industry 4.0.

In 2020, when analyzing their current production process, the company realized that it depends highly on the demand and on their machinery. If the demand is fluctuating, the production process needs to be able to run 24/7 for a period of time. Thus, Nematekas cannot afford to have any equipment failure to be able to ensure the demand is met.

The organization found that they had no overview of their equipment, processes, and their relations. Furthermore, there was no information about what should be done in case of disruptions caused by external events or internal failures. Due to all this, if such disruptive events occur, the production process of the organization would be severely disrupted if not completely halted. To address these issues, Nematekas has agreed to participate in our research and provide the necessary information to apply our method. To this end, several stakeholders from the organization have been interviewed and their feedback has been collected. In the following sub-sections, we detail how the steps of the method have been applied to the case of Nematekas.

B. Step 1 – Model the Enterprise Architecture

Since the organization did not have any documentation regarding their EA, we had to model it first. We used the ArchiMate language for this purpose. Since the interest of the organization is mostly on their production processes, the focus of the models is on the application, technology, and physical layers of ArchiMate. Since Nematekas is a producer of different types of meat products, each with a different process and equipment used, for this paper, we have chosen to focus on one product group, namely parboiled sausages. This allows us to go through all the steps of the method while providing a clear example of how it is applied.

The production process of the organization is required to follow the regulations set by the EU and the State Food and Veterinary Service. Thus, the organization should be able to trace any product back to the raw material and its origin. For this purpose, the organization has decided to implement the Microsoft Dynamics NAV system on its terminals. The terminals are devices that are connected to different equipment on the production floor and can be used by factory workers to control and adjust the production process. The core processes for the production of parboiled sausages are chopping, filling, heat treatment, and packing. Fig. 5 shows an excerpt of the EA model for the production process of parboiled sausages.

The company uses the Microsoft Dynamics NAV system for processing orders and managing the meet product-delivery. The production process is based on historic data of past orders which are used for forecasting demands. This information is stored on two cloud servers, namely SRVSQL and SRV-NAV, each with its own database. Backups of both databases are made each night to a local server (SRV-BKP) to avoid losing data in case of a disruption.

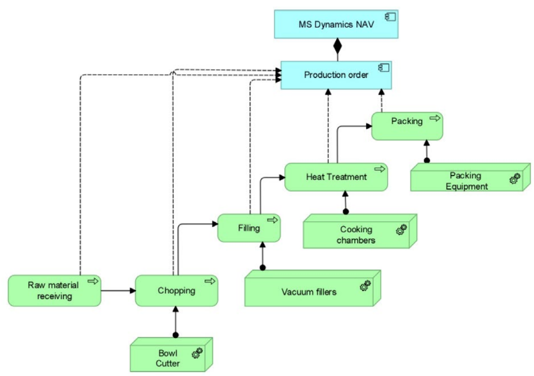

Fig. 5. Excerpt of the production process for parboiled sausages.

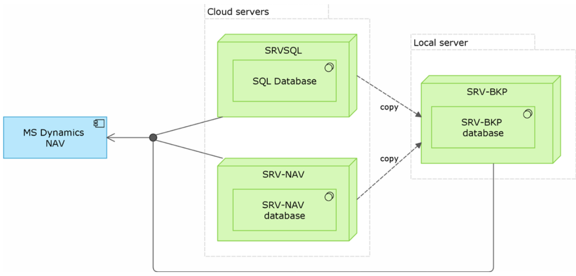

Fig. 6. Cloud databases and local backups of data for MS Dynamics NAV.

Thus, the current EA of Nematekas already covers one of the resilience characteristics, namely redundancy, even though there is a one-day data loss in case the cloud databases are affected. This could be addressed, by doing more regular backups of the data. Fig. 6 illustrates how these databases are modeled with ArchiMate.

For each of the production processes shown in Fig. 5, several types of equipment are used. For some processes, the equipment used is easily interchangeable. For example, for the chopping process, four bowl cutters are used, which have similar properties. The only difference is that one of the four cutters cannot be operated for a long period. There are also processes in which the equipment used varies significantly. This is the case of the packing process, where the machines used (Etna, Tiromat, VC999, Comet, and Veripack) have different output speeds, use different package types, and require different numbers of workers to operate.

C. *Step 2 – Identify Risks and Resilience Vulnerabilities*

Fig. 5 shows that there are five processes required to produce the sausages. Thus, if any issue occurs with the equipment in one of the processes, the whole production will be affected. For each of the steps of the production process, we analyze the equipment to determine the risk of failure. To estimate the probability and impact of the risks, interviews with the senior food technologist and the head of the mechanics department are conducted. The results of these estimates can be seen in Table I.

As mentioned before, the organization owns four bowl cutters for the chopping process. However, only three can be used constantly, while the fourth one can be used only for short periods. Thus, if one of the three main bowl cutters fails, the other two would be overloaded.

For the filling process, five vacuum fillers are used, three for linking and two for clipping. In case one of the linking machines fails, the other two can pick up the slack, while if one of the clipping machines fails, the remaining one would be overloaded.

The third production process is the heat treatment for which cooking chambers are used. The organization owns eleven cooking chambers of two types. All of the cooking chambers are relatively similar with the main difference being that two of the Stein chambers have four times more capacity than the rest.

The last production process is packing. When compared to the other processes this is more complex as it uses different types of machines with different properties. Thus, while some machines can be used interchangeably, in other situations, this would lead to a more inefficient process.

TABLE I. ESTIMATES OF THE PROBABILITY AND IMPACT OF RISKS

Process	Equipment	Probability	Impact	Risk
Packing	Etna	Low	High	Medium
Packing	Tiromat	Medium	High	Medium
Packing	VC999	High	High	High
Packing	Comet	High	Low	Medium
Packing	Veripack	High	Medium	Medium
Filling	Vacuum filler	Medium	Low	Low
Chopping	Bowl Cutter	Medium	Low	Low
Heat Treatment	Cooking Chambers	Medium	Low	Low

D. *Step 3 – Define the Alternative Solutions*

In the previous section, we highlighted the risks associated with the four major production processes for producing parboiled sausages. The purpose of Step 3 of our method is to determine for each of these processes, what types of alternatives are possible.

For the chopping process, all of the four bowl cutters have the same characteristics and can perform the same tasks, but for different lengths of time in the case of the fourth cutter. In case of a failure of a primary cutter, the fourth bowl cutter can be used temporarily to replace it.

For the filling process, some of the vacuum fillers can be reconfigured to perform either linking or clipping. Thus, this option can be used in case one of the clipping machines is malfunctioning. As mentioned before the two remaining linking machines would be able to handle the production process at a slower pace, but if only one clipping machine remains, that would not be able to handle the production at the speed of three linking machines.

For the heat treatment process, the cooking chambers are only rarely filled to capacity and they can be used interchangeably. Thus, in case one of the chambers malfunctions, there are sufficient alternatives that can be used instead.

The last production process is packing. According to the senior food technologist of the organization, 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. If Etna breaks down, VC999 is the only suitable machine for packing replacing it. In the case of disruptions where the source is Tiromat, it is possible to use Veripack, but the efficiency would suffer.

Thus, for all of the production processes, there is an alternative available either by using a backup machine, reconfiguring a machine to perform different tasks, relying on being able to use the remaining machines without overloading them, or by switching production to other machines and accepting the loss in productivity.

Other risks were also assessed, such as power outages, network outages, the water supply being cut off, etc. For all of these situations, the organization already had measures in place, such as a backup generator in case of a power outage, manual controls on all machinery and written down recipes and instructions in case of a network outage, pumping water from a well that was dug as a preventive measure, etc.

When the effects of the pandemic were felt by the organization, the biggest impact was seen in the shortage of workers due to several factors, such as a doubling of demand, employees being able to take sick leave if they had COVID-19, and the subsidies from the government for unemployed workers which were sufficient for many to stay at home and not try to search for a job. Thus, the impact of the pandemic was high, and it showed the organization that their resilience efforts in the area of infrastructure were not enough to cope with this disruption. A possible alternative in this situation would be for the organization to automate even more processes to reduce their reliance on staff availability and reduce the impact of such disruptive events in the future.

E. Step 4 – Define Alternative Milestones

Alternative milestones can be defined for two purposes. On the one hand, they can be used to determine what is still an acceptable level of performance for the organization. In the case of Nematekas, these types of milestones are applied when deciding whether or not a machine involved in the production process can be used to replace another one that has failed.

An example of this is the packing process where the machines used differ quite a lot. The only alternative for continuing the production process if the Etna machine breaks would be to replace it with the VC999 machine. However, by using the VC999 the packaging would be different than normal, the quality might differ, and at least one more person would be needed to operate it. Thus, in this case, the organization has a secondary milestone represented by this lowered productivity which is still considered as acceptable. Another example is when the sausages are packed in different packaging than normal since a substitute machine is used.

On the other hand, the alternative milestones can be used to determine the scenarios in which the execution of a certain process should be terminated or in which the use of certain systems, and infrastructure should be stopped. In the Nematekas context, below we report on two alternative milestones determining process termination. The first scenario is when due to a disruption, the quality of the produced goods is no longer according to the acceptable levels. Thus, the production process needs to be stopped until the issues can be addressed. The second milestone refers to repurposing the produced goods to cover some of the losses caused by the disruption in the process. Thus, if the meat that would normally be used for sausages is lower quality than acceptable, it can be sold as an animal by-product.

F. Step 5 – Integrate Resilience Characteristics in EA

In the previous sub-sections, we have discussed in detail the risks currently faced by the organization (Step 2) and the possible alternatives in case these risks occur (Step 3). Now we demonstrate how these alternatives can be represented in the EA of the organization. For this, we use the example of the chopping process and the packing process.

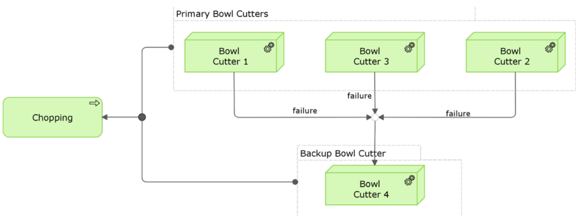

Fig. 7. Chopping process with resilience characteristics (Adaptability & Redundancy).

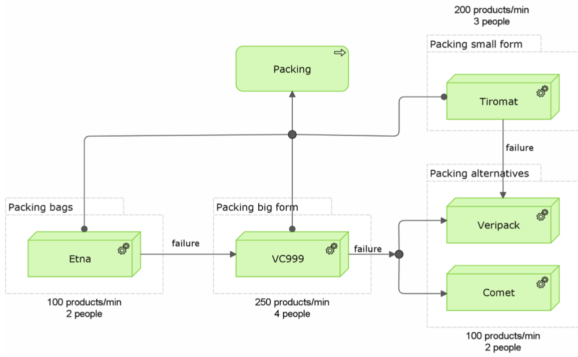

Fig. 8. Packing process with resilience characteristics (Adaptability & Diversity).

As said earlier, if one of the main bowl cutters fails, it can be temporarily replaced by the fourth one. From the point of view of the resilience characteristics, this situation represents *adaptability* and *redundance*. The chopping process can be adapted to use a different machine while still maintaining the same output, for a certain period of time. It can have redundancy in case there is a backup machine that is used only in case of a disruption, as is the case of the fourth bowl cutter. In terms of ArchiMate modeling, the adaptability of the process can be expressed by using an OR junction to relate the primary cutters to the backup cutter. Notations can be made on the relations to express the conditions under which the relation is executed. For modeling redundancy, the primary cutters and the backup cutter are related to the chopping process by means of an AND junction. This signifies that both categories of cutters can be used within the chopping process. Fig. 7 shows how these resilience characteristics can be modeled with ArchiMate.

For the packing process, the situation is more complex as there are no alternatives that are 100% replacements. Regarding the resilience characteristics, the packing process illustrates Adaptability and Diversity (see Fig. 8). Adaptability in this situation is slightly different in this process compared to the chopping process, as there are also situations in which multiple machines are used to replace one failing machine to maintain the necessary level of performance.

For *diversity*, the organization is already using machinery from different suppliers. Thus, in theory, this should increase their levels of resilience. On the other hand, the organization is using so many different types of machines, which in fact might have an adverse effect. The different ways of working with each machine combined with their varying characteristics might well cost a lot more effort in case the process needs to be adapted. Moreover, building cyber-physical systems would be more difficult, because of the interoperability with different machinery.

V. First Evaluation

Our demonstration of applying our method was followed up with our very first evaluation study [29]. To this end we set up an expert panel study [26]. As Wieringa [29] suggests, the goal of the very first evaluation is to collect quick feedback on the strong and weak sides of a method proposal and to generate potential improvementplans for the future.

TABLE II. EXPERT PANEL COMPOSITION

ID	Role	Location	Experience with EA
E1	Researcher	Lithuania	10 years of experience
E2	Researcher	Netherlands	2 years of experience
E3	Researcher	Netherlands	15 years of experience
E4	Researcher	Netherlands	5 years of experience
E5	Head of IT	Lithuania	5 years of experience

The panel included five participants. Four were researchers with experience in applying EA; some were EA consultants prior to their university careers, while other has practical experience earned in EA modelling in research projects with companies). One was the head of the IT department from Nematekas, our case study organization. Table II illustrates the roles, locations, and experience with EA of our experts.

We chose the participants based on two criteria: (1) at least 2 years of practical experience in EA; (2) participants cover a variety of roles (researcher and practitioner) and the two countries (The Netherlands and Lithuania) As it is common for very first evaluations [29]) we wanted to see if the background and the role of the expperts would influence their opinions regarding the complexity of the method and their ability to use it. We note that only one expert (E5) from the case study organization was included in this panel due to difficulties we had with the availability of participants during the COVID-19 pandemic.

The evaluation was conducted during a workshop session where the experts were first introduced to our method by means of the Nematekas results and then they were asked to provide feedback by means of a structured survey questionnaire. To design it , we have used the Unified Theory of Acceptance and Use of Technology (UTAUT) as proposed in [27]. The UTAUT was chosen because of its suitability to any design science artifact, which in our case is the method we proposed.

In the questionnaire, we included two context questions (current role in the organization, and experience with EA), and 17 statements based on the UTAUT (see Table III). The statements are grouped in five categories, as follows: performance expectancy (PE), effort expectancy (EE), facilitating conditions (FC), attitude towards using technology (ATT), and behavioral intention to use (BI). To score each statement, we used a 5-point Likert scale, with possible answers including strongly disagree (1), disagree (2), neutral (3), agree (4), and strongly agree (5).

TABLE III. OVERVIEW OF THE UTAUT STATEMENTS INCLUDED

ID	Question
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.
EE1	My interaction with the method is clear and understandable.
EE2	It would be easy for me to become skillful at using the method.
EE3	I would find the method easy to use.
EE4	Learning to use the method is easy for me.
EE5	The rewards for implementing the method are worth the time.
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/tools I use for my work.
ATT1	Using the method is a good idea.
ATT2	Working with the method is fun.
ATT3	I like working with the method.
BIU1	I intend to use the method in the next 12 months.
BIU2	I predict I would use the method in the next 12 months.
BIU3	I plan to use the method in the next 12 months.

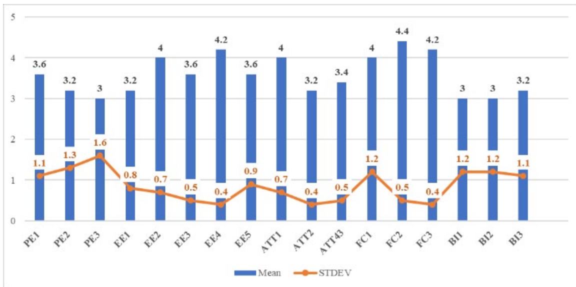

Fig. 9. Mean and Standard Deviation Summary.

Fig. 9 shows the descriptive statistics for the 17 statements we included in our survey by means of mean values and standard deviation (Sdev). The mean values for all the questions range from 3 to 4.4, which indicates that the opinions of the experts are neutral towards positive. This suggests some level of acceptance of the method.

The lowest mean scores are given to statements PE3 (*Using the method increases my productivity*), BI1 (*I intend to use the method in the next 12 months*), and BI2 (*I predict I would use the method in the next 12 months*). Considering that the lowest scores for this statement are given by two of the researchers and that the head of the IT department gives one of the highest scores, this mean value could be justified by the differences in the roles of the experts. A similar situation can be observed for the statements BI1 and B12, where the researchers provide slightly lower scores regarding their intention to use the method in the upcoming period.

The most positive mean value is given for FC2 (*I have the knowledge necessary to use the method*) which suggests that the level of knowledge the experts have on EA is sufficient for being able to use the method. This is especially encouraging as one of the experts had only 2 years of experience with EA, which suggests that our method can also be used by people who are just starting out with EA.

For the Sdev, we have seven statements that have a value above 1. A low Sdev means that the scores given by the experts are closer to the mean, while a higher Sdev indicates that the scores have a larger spread. In our case, statement PE3 has the highest Sdev, with a value of 1.6. This reinforces the interpretation that we provided regarding the mean values. A similar situation can be observed regarding the other two statements from the PE and BI categories. Another statement with a high Sdev (1.2) is FC1 (*I have the resources necessary to use the method*). The expert that provided the lowest score for this statement, provided a high score for FC2 and FC3. Furthermore, the mean value of the FC category is the highest of all categories, namely 4.2. Thus, it could be concluded that the low score given by the expert might be specific to their circumstance and perhaps not directly related to the method.

The lowest Sdev can be seen for three statements, namely EE4 (*Learning to use the method is easy for me*), ATT2 (*Working with the method is fun*), and FC3 (*The method is compatible with other systems/tools I use for my work*). The score for EE4 can be explained by the experience that the experts have with EA, which could make it easier for them to understand how to use the method. Similarly, statement FC3 could be explained by the fact that our proposed method uses the ArchiMate standard, which is familiar to the experts. Finally, the scores for ATT2 suggest that the respondents have a similar neutral opinion regarding the amount of fun when using the method.

The experts were asked to provide any additional feedback they might have that could not be addressed in the rest of the questionnaire. One aspect that was mentioned is that the resilience characteristic of *adaptability* seems to be part of *redundancy* to some extent. We argue that these two characteristics are related to each other, but that organizations can apply *adaptability* without *redundancy*. This can also be seen in the case study of Nematekas, where for the filling process, the machines can be reconfigured to perform a different task. In this situation, none of the machines are redundant or used as a backup, but rather some efficiency is sacrificed to keep the process going.

Another expert stated that *redundancy* is a very interesting and beneficial aspect for organizations to consider. However, this expert also said that some drawbacks need to be taken into account when deciding to implement this in practice, such as additional costs and dependencies to other elements of the EA. We agree with this opinion and consider that organizations should use our method as a basis for defining business cases for investments in IT and should manage these investments and make trade-offs with the help of portfolio management techniques.

One of the experts suggested us explain the difference between our method and the available risk management techniques as a way to emphasize our method's novelty. We argue that while our method is partially based on risk management techniques, many aspects differentiate it. First, it combines risk analysis with EA modeling which is not used in the popular risk management approaches. We consider this to be a crucial part, as it can help with defining better risk estimates. Second, the vulnerabilities of the organization are addressed by implementing changes in the EA according to the resilience characteristics identified in our previous study instead of following the risk management strategies. Thus, we consider that our method extends traditional risk management techniques by adding EA modeling and resilience characteristics.

Finally, the experts mentioned that the method seems promising and can be powerful if implemented correctly. The real challenge with implementing this method would be having the right competencies available in the organization, namely employees with an understanding of the big picture and the processes, data, and infrastructure. In other words, for the implementation of this method to be successful, the organization would need to have knowledgeable enterprise architects who can communicate well with other stakeholders.

VI. Conclusions and Discussion

In this paper, we have proposed a method to help organizations implement resilience in their EA design. The method builds upon early work; it combines knowledge on resilience from complementary domains, with risk analysis, and EA modeling, and is structured in a five-step process.

A. Summary of Findings and Results

We demonstrated the application of our method in a real-world case study performed at the Nematekas organization in Lithuania. Due to space limitations in this paper, we chose to focus on one technology process and have applied all the steps of the method to this process. Since this is a core process of Nematekas and is deemed by the company as a quite representative process for all other core processes in the company, we consider that including more examples would not provide new insights.

Furthermore, we used an expert panel to complete our very first evaluation. The results of this assessment indicate that our method is perceived by experts as valuable for organizations that want to design their EA with resilience in mind, as long as there is sufficient knowledge of the EA practice in the organization.

B. Limitations and Future Work

Our research has some limitations. We systematically analyzed them using the guidelines of Wieringa [28]. We discuss the limitations along with their implications for future research.

First, we built upon a systematic literature review (see [7] for complete results) with a focus on IS resilience due to the lack of papers on EA resilience. While this provided us with a solid basis, there are other domains in which resilience research is more advanced. Thus, for future research, we suggest that the search for relevant literature should be extended to other complementary domains, such as engineering, organizational science, and cybersecurity (among others).

Second, our review of the literature has revealed that there are several IS resilience strategies and characteristics that organizations can use to deal with disturbances. However, for our method, we have chosen to include only the resilience characteristics. While this can be very useful for (re-) designing the EA, the strategies could help organizations with deciding which aspects to focus on. This is in line with the feedback that we received from one of the experts regarding the Redundancy characteristic. Thus, we consider for our future work the inclusion of the resilience strategies to provide organizations with extra guidance when designing their EA models with resilience in mind.

Third, in this paper, we proposed a way to represent three resilience characteristics with the help of the ArchiMate language. However, in our previous study, we have identified 14 potential EA resilience characteristics. Thus, investigating how all 14 resilience characteristics can be modeled with ArchiMate, forms a line for future work. Furthermore, we suggest that more specific guidelines for modeling should be developed to support EA practitioners.

Finally, our method has been used in practice in the context of only one case study and evaluated by an expert panel of five people. In both our demonstration and our evaluation, our goal was not to search for universal generalizability [28] but to collect indicative observations, perceptions and experiences in the real-world context and use those as the basis for follow up empirical studies. A central validity question in such evaluations [29] is "To what extent it might be possible to have similar observations if the method is applied in similar, but different contexts?".Following the reasoning of research methodologists [28], we could think that our method could possibly be applied in a similar way to organizations that have a similar context to Nematekas. For example, in other companies in the same business sector in European countries which share organizational culture, the extent of process automation and interest in resilience and

EA. However, to get more insights into the use of our method and to improve its generalizability, we consider that more research is needed. This, therefore, forms our immediate future work.

Finally, we think that the method can be further extended to include aspects of automation, problem-solving, and comparison. For example, regarding automation, it would be interesting to design automated analyses for EA models based on the resilience patterns defined based on the resilience characteristics. This would help identify potential issues in the EA, and with the help of best practices for modelling, suggestions for improving the EAs could be provided.

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