Smart solutions for sustainability

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Smart Solutions for Sustainability: RDI for Urban and Societal Transitions Requires Cross-Sectoral Experimentation Platforms

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1 Moving Beyond Pioneering Initiatives

1.1 The Challenge of Sustainability Transitions Comes to Age

Transformative innovation was urgent a decade ago and still is today, just more so. The unsustainability crisis, mostly visible with climate changes and resource shortages, is already forcing us to reconfigure our economy and society – hopefully opening a new techno-economic cycle after 250 years of modern industrial dynamics [1]. However, this era of profound human impact on the Earth, that is, the Anthropocene, is still driven by unsustainable methods even though our thinking about it has evolved somewhat [2]. In the young twenty-first century,

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a heterogenous set of pioneering projects (seeking ways to achieve an effective transition to sustainable development) have tested the relations between innovation in the private sector and policies in the public sector. Typically, this happened inside complex, university-business-government and multi-sectoral industrial settings. Some valuable hard lessons were learned by a small set of participants, but unsurprisingly at history's scale, real systemic socioeconomic breakthroughs have not been reached yet. The question that many of us were asking a decade ago remains actual: *How to achieve those breakthroughs?* [3].

Here I take a human and technological systems (HTS) perspective, and I rely on work experiences in several countries (a) to trace some of the main historical premises of the European RDI (Research, Development, and Innovation) for smart and sustainable development and (b) to describe a science-based, practice-tested method to do so.

Human Systems Include Different Scales from Individuals to Entire Communities The largest is the whole of humanity on Earth (and in perspective, on other planets and in the outer space). While decisions ultimately rest with the individuals (based on the human rights recognized by the UN), humanity can only become sustainable as a whole, because there is a common biophysical system that sustains it: planet Earth. The unsustainability crisis is a type of problem known as "tragedy of the commons": collective destruction of a common good through individual overuses until it loses its capacity to recover (and collapses) through the nonlinear dynamics of the coupled human and natural systems (CHANS) – a category of complex dynamic systems (CDS) [4–7]. This "race to the bottom" is caused by carelessness, ignorance, and short-term thinking.

To date, we are still relying predominantly on the twentieth-century technologies, and most business models are based on neoclassic economics which considers nature to be external to economic processes, that is, our life quality still depends on the old socioeconomic premises that generated the unsustainability crisis. If we were to judge after the geopolitical-economic-environmental tensions that are piling up and spilling over around the world, the so-called perfect storm that has been looming for 10–15 years [8–10] may have just started out with a "mild shower." Back then, experts from virtually all sectors were talking about reinventing whole industries through "green business," "green jobs," and "sustainable growth," in a socially (and politically) desirable logic of sustainability and competitiveness going hand in hand. This desiderate was for a long time, and still is, reflected by the UN's Sustainable Development Goals [11–13] but remains easier said than done, by and large because of many unresolved grand issues relating to skills, technologies, markets, physical resources, institutions, and policies [14].

Conditionally positive signs can be cited. On 30 May 2022, the European Investment Bank (EIB) released a report addressing the issue of hydrogen in the energy and sustainability transitions [15]; on 14 September 2022, the European Commission (EC) proposed a new financial institution to help sustain a strong market pull matching the European technology push in hydrogen-based energy: the European Hydrogen Bank [16]. Nevertheless, since the key role of hydrogen is that of an integrator of various technologies and solutions, and because the development of hydrogen-based or hydrogen-related solutions requires systemic experimentation platforms (large-scale demonstration projects), this sector is bound (a) to integrate numerous "smart city and society" ideas and methods and (b) to reflect systemic and context complexities.

However, great potentials never remove the risk of overconfidence. Some preliminary data allow some cautious hopes that socioeconomic development may have started to decouple from environmental degradation, but the hard confirmation requires proofs of a systemic transformation – a long journey awaits us, with numerous pulls and tensions that can easily cause failure.

To succeed in the transition to climatic neutrality and overall sustainability of human activity, some necessary conditions must be met. First and foremost, we need to understand well what blocks. A good place to start is the recognition (or lack thereof) that knowledge is distributed across global networks of experts relying on unique professional experiences and embedded in local contexts (i.e., not centralized). In this sense, we know that cognitive and behavioral biases lead to project failures [17]. Most notably, the usual preference of individuals for short-term benefits is a form of long-term blindness. At the scale of society, this creates cycles of hype and disappointment which results in investment discrepancies that hurt long-term developments of technology-based enterprises, goods, and services – not a basis for "smart" solutions [18–21].

Moreover, conjunctions of biases are almost inevitable in large megaprojects, that is, "large-scale, complex ventures that typically cost US$1 billion or more, take many years to develop and build, involve multiple public and private stakeholders, are transformational, and impact millions of people" [22, 23]. But these kinds of projects are necessary in the transition to sustainability, which requires large-scale, system-level experimentation. Because megaprojects are characterized by "extreme complexity, substantial risks, long duration and extensive impact on the community, economy, technological development, and environment of the region or even the whole country" [24] and because they are "projects which transform landscapes rapidly, intentionally, and profoundly in very visible ways, and require coordinated applications of capital and state power" [25], one can convincingly argue that "looking at society through its megaprojects would reveal its ambitions, problems, as well as its future outlooks" [23]. So another major stumbling block beside short-termism is the sheer scale and complexity of the projects that are necessary for society to transform itself. Concretely, this means that if we want to avoid major mistakes, the issue of knowledge organization and management must be properly understood and addressed. For instance, one old and popular but naive idea (and not unrelated to power grabbing temptations) is that knowledge can be centralized in a person or a small group of individuals. Related to it is the cognitive and behavioral bias known as the illusion of planning (based on the illusion of perfect control) and the illusion of simple ("silver bullet") solutions to complex problems. Such biases undermine all projects. Left unaddressed, they can stump any project.

As a society, we must reach the point where the great majority of actors and stakeholder can face and understand in practical terms the reality that knowledge in general (and science itself) is (a) distributed throughout society across networks of interacting individuals and (b) parceled between many academic disciplines and areas (and between industrial fields and professional traditions), as well as between sectors of academia, business, and the government. So knowledge can only be mobilized, not "centralized." Relatedly, the myth that there is an ideal and coherent corpus of knowledge to which one can just add or take from "automatically" must be actively dispelled through pragmatic projects that target the hardest problems, that is, not by playing around with easy games that bring what appear to be more immediate and spectacular benefits but which actually aggravate the core problems.

Additionally, innovation doesn't just happen: end-value is created through hard work in complex dynamic interactions between relevant actors. Another blocker is the fact that (a) too many people outside RDI ignore the reality that scientific research is (hard but remains) just the beginning of the process of problem resolution and that (b) the amount of financial investment that is necessary to translate scientific discoveries into final products or services is about one order of magnitude larger. This might be due to a superficial understanding of science as an easy work of genius that solves everything (instead of science being the product of a long history of efforts): people seem to want to hear about that 1% genius and simply prefer to ignore the part about 99% transpiration. To be fair, there are also some myths that are popular among scientists and may create subtle frictions in RDI. One is the idea that "we (scientists) are doing the work and businesses are reaping the benefits." This comes from a combination of individual and group biases and undermines collaboration between science and the rest of the society. Still, dismissing such aspects without trying to understand their cause is equally wrong, because, as we know from industrial and organizational psychology, this would disregard conditionalities that are encoded in the respective professional cultures. Such "how we do things around here" background details (taken for granted by insiders but unseen by outsiders) tend to be ignored by everyone until catastrophic misunderstandings and surprises break in [26]. In fact, professional cultures are collective identities that reflect long-term features in the respective contexts and operations and must therefore be regarded as an integral part of the human resource. In this sense, harmless collegial jests like "engineers have built the world and economists have ruined it" (which I first heard in Romania during the 1990s when many factories were scrapped as obsolete) actually hint at the creative tension between the two principal forces driving progress at history's scales – technology push and market pull – and encapsulate the need to understand RDI as a perpetual exercise of equilibrium-finding between those forces [27].

With These Challenges in Mind, I Argue in Favor of Disciplined Experimentation Starting from the idea of "experience as horizon" [28] and taking the professional perspective of a "privileged observer contributor" [29], I describe a structured approach to managing pioneering holistic projects aiming at generating transformative innovation.

In complex multidisciplinary projects (unlike in monodisciplinary works), common denominators require dedicated efforts, often by preparatory projects. Practice

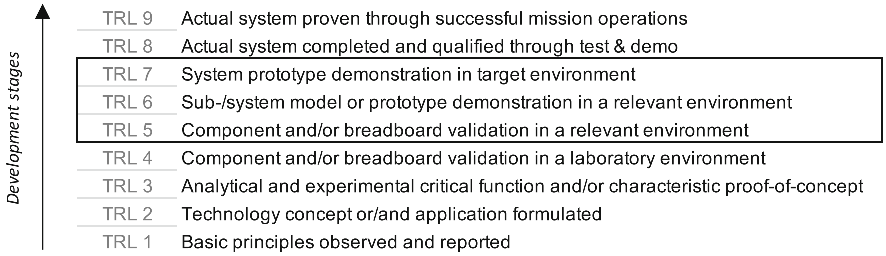

Fig. 1 Generalized list of original technology readiness levels

indicates that a project team must start from the basic idea known from the wall of the prehistoric temple of Apollo in Delphi: γνῶθι σεαυτόν (gnōthi seautón) – know thyself. Instead of undue extrapolations or overplanning toward their common goal, experts must follow scientific principles and build a shared mental representation of their work.

I propose that a logical place to start from is the technology readiness level (TRL) framework (Fig. 1) which was established by NASA in the 1970s and has become popular in industry and RDI around the world [30, 31]. Specifically, I address the main challenge that characterizes the upper half of the TRL scale: a growing need for effective experimentation at relevant system levels, especially at TRLs 5–7. To fulfill this necessity, I argue that we need to build large-scale experimentation platforms, and I describe a method: an iterative, process-oriented stepwise-integration model. In so doing, I also highlight the operational importance of distinct perspectives offered by disciplines, professions, institutions, contexts, and scales, in complex dynamic systems.

1.2 A Decades-Long Exploration of Potential Futures: Examples from Europe

About 10–20 years ago, there was a surge in pioneering science and technologies. These took the form of pilot projects studying the relations between technological innovation, business models and strategy in the private sector, and public policies – the well-known triple helix approach [32]. The Lisbon Strategy, a document adopted at the European Council in March 2000 in Lisbon (a historic city that spearhead the European Age of Discovery 600 years ago), proposed a vision for the twenty-first century, where the EU would become by 2010 "the most competitive and dynamic knowledge-based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion." This was driven by the Schumpeterian idea of transformative innovation led by science and entrepreneurship. (See [33, 34] on Joseph Schumpeter's theory about innovation and the related notions of "bioeconomy" and "ecological economics' pioneered by his student, Nicolas Georgescu-Roegen.) Although most of the technical objectives of this vision were not attained by 2010 (the economic turbulences following the 2008–2010 financial crisis did not help either), its aspirations pervaded Europe and elicited a new European spirit of experimentation which continued with “Europe 2020,” an RDI funding strategy that pursued “smart, sustainable, inclusive growth,” and the “European Green Deal” [35], a broader EU strategy focused on sustainability transitions and related crisis management. Experimentation is also explicit in the “New European Bauhaus” (NEB), a program dedicated to building public traction for sustainability transitions: “Change will not happen from one day to another. The New European Bauhaus will create the space to explore and test policy, funding and other tools for designing and building a better everyday life for all generations.” This expresses “the EU’s ambition of creating beautiful, sustainable, and inclusive places, products and ways of living ... (especially in) construction, furniture, fashion and (...) daily life” [36].

On the Upside of This EU Dynamics, a Big Wave of Bottom-Up Industry-University Initiatives Developed Across Europe Much of it was directly concerned with environmental and social issues of our society (in addition to the economic issues that were always present, especially in the aftermath of the financial crisis started in 2007–2008). Many of those initiatives also benefitted from or were elicited through the top-down funding programs by the European Commission, some of the most well-known being the Research Framework Programs FP6 (2002–2006) [37] and FP7 (2007–2013) [38], which, in order to facilitate lab-to-market processes, asked for a strong participation of small- and medium-sized enterprises (SMEs) and (since 2014) the use of TRLs in the funded research projects [31, 39–41]. They also included a type of projects called “Network of Excellence” (NoE), which saw participation from at least six countries (three EU member countries required) and the Joint Technology Initiatives (JTIs) in partnership with industry.

Another major development is the European Institute of Innovation and Technology (EIT), officially established in 2008 [42], and its first three “Knowledge and Innovation Communities” (KICs, established in 2010), namely, Climate KIC [43], InnoEnergy [44], and EIT Digital [45], which were followed more recently by similar networks for food, health, raw materials, manufacturing, and urban mobility. On behalf of the University of Versailles (UVSQ), I participated in the initial internal work organization of climate KIC, which was an opportunity to compare it with works in our own eco-innovation cluster in the Paris Region (details in Sect. 3.2).

A typical manifestation of this European innovation Zeitgeist was also the first and second European Innovation Conventions organized by the EC on 5–6 December 2011 and 10–11 March 2014 in Brussels [46]. Alongside other 2000 people, I attended each of these events, I welcomed the priority given to learning from the entrepreneurial experience coming from the USA, and I enjoyed the related technology exhibition. I also attended the World Summit of Regions for Climate, 10–11 October 2014, in Paris, France, which was focused on the involvement of cities and regions in the 2015 Paris Climate Agreement, and I witnessed intense EU-USA convergences (see also [47–49] and Sect. 3.2).

On the Downside, Such Top-Down Programs Also Had a Big Bureaucratic Burden They have been criticized for being so complicated as to hurt science itself and fundamentally undermine industrial and economic competitiveness of the EU [50]. The idea is that state actors (governments and intergovernmental organizations) can and should act as catalyzers but then let society/people take ownership and drive the process, precisely because knowledge is distributed (not centralized) and the existence of common interests is not equal to "one size fits all." Governmental overreach causes exponentially growing complications, with a double negative result: bureaucratic burden and administrative inefficiency. In democratic countries, public administration rests on (1) the fundamental principle called "the consent of the governed" which first appeared in the European cultural space during a long historical process, is adopted in the second paragraph of the US' Declaration of Independence ("... Governments are instituted among Men, deriving their just powers from the consent of the governed"), and is stated in Article 21 of the UN's 1948 Universal Declaration of Human Rights ("The will of the people shall be the basis of the authority of government") and (2) on the "whole-of-government" approach: functional coordination across public administration departments [51].

These being said, the EC did meet with professionals and collected feedback for post- FP7 improvements, for example, at roundtables organized in Brussels by Science|Business (a network of leading universities and companies [52]) in which I participated as institutional contact. The following FP, Horizon 2020, was indeed less bureaucratic than the previous FPs [53], although far from perfect. But there is yet another major issue: the very low application success rates (ca. 1/10) is unfair and represents a discouraging result-per-effort balance for many excellent-but-rejected projects. Consequently, most well-qualified applicants see EU funding as a lottery and rationally prefer to ignore it. Worse, this situation created an entire "industry" of consulting and paper-filling intermediation that (1) diverts resources away from real RDI and (2) keeps many of the best and brightest minds away – exactly when society needs RDI the most. In the vocabulary of investment economics, these funding schemes have excessive opportunity costs for the intended beneficiaries and a low/diminishing public return of investment (ROI).

In Horizon 2020, the EC also began promoting "open access" to scientific publications, which (as of October 2022) is still a promising idea and an ongoing experiment with yet-uncertain effects on how science works and how it relates to society. Interestingly, the US President has just endorsed open access for all scientific publications of research [54] – another point of convergence between the USA and the EU.

Other Initiatives Since the Year 2000 Were Funded Through National Programs Three examples have been chosen here (because I was involved in those and can testify based on my own experience): the German program FONA (short for "Forschung fur Nachhaltichkeit," that is, "research for sustainability") [55], the

French program PRES ("Pôles de Recherche et d'Enseignement Supérieur") seeking to develop large research and education clusters [56], and the Romanian CEEX ("Cercetare de Excelență") program promoting research excellence – infrastructure, people, and complex projects [57].

Numerous bilateral institutional initiatives between countries were also commonplace and boosted peer-to-peer relations, for example, the Swiss-Romanian environmental research program ESTROM, 2005–2008 [58], the Romanian-French series of conferences "University in Society" (UNISO) where the concept of "brain networking" was first proposed and debated [59–61], and the efforts by the above-mentioned German FONA program to reach out and connect with RDI actors across Europe, a process strongly energized by the conference "Sustainable Neighbourhood – from Lisbon to Leipzig through Research (L2L)" 8–10 May 2007, during the German Presidency of the European Council [62–64] in Leipzig, a symbol city for German and European reunifications, and the "Innovation Union" flagship initiative of Horizon 2020 [65].

This Tide of Enthusiasm Followed, and Has Built Upon, the Success of Previous European Arrangements and Academic Exchanges Students and teachers benefitted from the *Erasmus Program* (since 1987; *Erasmus Plus* since 2014) and the *Socrates Program* (since 1994; then *Erasmus II* between 1999 and 2007, and the *Lifelong Learning Program* since 2007), plus numerous bilateral exchange agreements. As a master student of Alexandru Ioan Cuza University (UAIC) in the historic city of Jassy (Iași), Romania, I benefited from an Erasmus studentship at the University of Groningen, the Netherlands (February–July 2000). As an undergraduate at UAIC, I received a bilateral university exchange studentship (and the support of dedicated teachers) and attended a four-week summer school at the Aristotle University of Thessaloniki, in Greece (1997). Across the EU, there are tens of thousands of such examples of personal development opportunities, which remind us that there is a grassroots dynamics of reunification of Europe after the fall of communism in Central Europe (eastern EU). It is also important to remember that this period overlapped with the emergence of the Internet as a popular medium of exchanges in the late 1990s, which catalyzed interaction between people and institutions, and generated some complex dynamics that were later on described as "brain drain" (massive emigration of the highly skilled). Internet is also how, like my entire generation, I have found research opportunities and earned my PhD at the Technical University Munich (TUM) in a German cluster focused on technology prototype developments (semiautonomous biosensors for field screening of pollutants [66]). Internet is also how my generation reconnected back across geographies: distance collaborations with home and other countries. In other words, mission-driven expert networks (like the EIT's KICs themselves) are de facto applications of "brain networking" thinking, but its advantages for universities and RDI are far from being fully used [61, 67, 68].

Since recently, the idea of networks of experts advising policy development in real-time is embodied by the European Scientific Advisory Board on Climate

Change, even though this appears to be more a compromise between the need to rely on the wider community of experts and the outdated tendency of public institutions to rely on a small number of expert advisors (in this case, only 15) [69]. At national levels, expert networking initiatives have a longer history and are closely related to RDI clusters. For example, in France, this included the establishment of numerous industrial chairs (at least compared to the previous periods), that is, public-private partnerships (PPPs) with 50:50 financial contributions that aimed at stimulating innovation and collateral research and business through crossovers between academic and business sectors. In Germany, this idea was already being used in the Fraunhofer Gesellschaft, a network of institutes covering topics from miniaturization technology to solar energy and the sociocultural aspects of bilateral cooperation between nations [70–73]. In Romania, the concept of problem solving-oriented "brain networks" was picked up by the country's Academy of Medical Sciences [74, 75] and by the Working Group for Climate Changes, an international group of 40+ scientists and administrators convened by the President of Romania to propose an integrated set of national policy measures that would use current science and technology to address current challenges (a first report of this group was launched in public debate on 8 September 2022) [76].

All these social, institutional, and cultural developments are nevertheless accompanied by the fundamental economic interest of having a united economic block (EU and EU-US partners), the development of which I had the privilege to witness at all scales (person, city, country, continent) and which partly motivated my interest in sustainable development and the management of innovation. In 1997, I first saw Euro banknote and coin designs shown in the civic center of Thessaloniki and enthusiastic Greek citizens seeing them. In 2002, TUM started paying my salary in Euros instead of Deutschmarks, and I heard German citizens worry about economy. In 2007, I saw my country Romania surfing on a tide of greenfield foreign domestic investments (FDI) that generated a powerful economic convergence with Western EU: according to Eurostat [77], its GDP in purchasing power standard (PPS) climbed from 26% of the EU average in 2000 to ca. 76% (expected) in 2022 (on average 2.3% per year, the fastest in Central Europe).

But these kinds of positive aspects call for intelligent uses of knowledge to advance private and public interests by stimulating convergent dynamics (rather than giving in to myopic fragmentation) while also protecting the progresses achieved so far.

1.3 Between Pasts and Futures

The crossovers and networking evoked here, together with the naturally interactive characters of science and business, have created a formidable potential, which, to date, remains largely unmaterialized. This has been recognized in professional conversations across Europe, including the already mentioned first European Innovation Conference – an event which undertook to address this issue at the highest policy and business level. Given the ambition of Europe to lead developments in sustainability as encapsulated in the policy goals like the European Green Deal, the transposition of research into effective solutions remains a great and growing necessity. Indeed, this takes the logic of TRL to a whole new level. Be it in Europe, North America, or elsewhere, the challenge is much more than developing a top-level spaceship technology (the original purpose of the TRL framework at NASA): it is about transforming entire socioeconomic systems.

Since decades, stakeholders and experts continue to agree that in order to deal with the complexity and challenges of profound change, individual technological advances are not enough: a systems-level approach is needed, starting with fundamental sectors like energy, infrastructure, water, and raw materials. So we talk about an already-old problem, but with more urgency and with the conditional benefit of more knowledge that has accumulated and now awaits being effectively integrated and put to use. A lingering problem is that, unlike the USA, where science finds its way easier into business, Europe appears to be stuck in a period that is characterized by an imbalance between science and business [52].

In terms of technology readiness levels, this can be described as an immense volume of work being already done at TRLs 1–5, but not nearly as much at TRLs 5–7. However, local underachievement in TRLs 1–5 can be turned around as a lower-cost environment for boosting TRLs 5–9. Such a strategy would amount to "smart specialization". (This is yet another and complementary European venue of policy experimentation, one that is integrated in the EU's reformed cohesion policy for 2014–2020 aiming at stimulating economic dynamics by local action [29, 78, 79].) This implies using local peculiarities to gain competitive advantage and thus attract resources for future "smart diversification" [80–82]. If well conceived and executed, such a TRL-based strategy (and national policy) comes as a logical (smart) solution for those EU countries that are now suffering from the effects of chronic underfunding of scientific research: any country running a stable coherent program with projects focused on TRLs 5–7 would naturally attract both private investments (domestic and foreign) and experts from their diaspora – converting brain drain into brain networking as evoked in the previous subsection [61, 67]. Within the EU, all else being equal, this competition will be won by those nations that can start with the greatest relative cost advantage and have the largest skilled diasporas (and this will be beneficial for the EU as a whole).

2 Transformative Projects Must Braid Science and Business

2.1 How to Achieve Systemic Change While Avoiding System Failures?

Unsurprisingly, actors from the sectors of energy production and distribution emerged as leaders and facilitators of the conversations between science and business, promptly warning (again, since decades) that change must be obtained in ways that do not disrupt the daily necessary system-level functions [3, 49, 83]. This means that (a) real-life operations must inform the process of development-experimentation and vice versa, and (b) ad hoc decisions that are only based on a superficial understanding of a situation (which may look familiar to specialists but are actually embedded in broader system dynamics) should not be presumed "harmless" at whole system scales (such presumptions can cause catastrophic consequences, from large-scale blackouts to various environmental, social, and economic losses, and the collapse of living standards) [4, 5, 84]. These being said, all scales of study/action are important, but ultimately the most consequential one is the scale of the project, as it collects all dynamics of interest toward a desired goal.

This is a major-but-usual challenge, because all projects tend to have latent disagreements on values and knowledge [85, 86]. One can illustrate with real life: public administration units around the world have designed and deployed a diversity of measures aiming at mitigation of and adaptation to climate change, only to realize belatedly that many of those department- or sector-driven measures were contradictory, with unexpected and mostly undesired effects that often cancel each other due to various systemic effects across scales [87]. One naturally wonders how "smart" were those solutions? In its sixth assessment report, the International Panel for Climate Change (IPCC; working group WGII, impacts, adaptation, and vulnerability, and WGIII, mitigation) points out an array of situations where mitigation and adaptation actions can be synergistic, antagonistic, or neutral to each other and to the global United Nation's Sustainable Development Goals (SDGs) [88–90]. Current assessments of effectiveness of climate change mitigation (and adaptation) are still based on the study of ex ante potentials. Because of the relative novelty of "climate actions" and the behavioral/cognitive biases summarized in the introduction (Sect. 1.1), the pressure of high expectations [91] can easily result in unwarranted and overly optimistic estimations – and usually it does [49].

The literature abounds with case studies and details, but such challenges boil down to one question: *How to achieve systemic change while avoiding system failures?* This chapter proposes an answer: through disciplined experimentation. However, the deeper question underlying it is *How to make it work (more than fail)?*

At this point, one can observe that we tend to expect that sustainable development will emerge as a new historical paradigm of human development. Still, no technology has yet emerged to be as profoundly transformative as the those that are usually thought of as defining various techno-economic paradigms or "industrial revolutions" [1, 7], and it is in fact not necessary that some particular technology comes to hallmark sustainability. Moreover, this "conspicuous absence" is not surprising for a simple reason: major events in RDI and business may not be easily detected as such while happening, and we are now living through a period of many innovations and changes. In this sense, all known historical techno-economic cycles can be understood through the lens of the theory of disruptive innovation [92, 93]. None of those revolutions was triggered by some glorious breakthroughs. Instead, certain ideas were retrospectively recognized as "very influential" ("central" or "key") – basically, just practice-driven solutions resulted from successive technical optimizations and socioeconomic changes that were dependent on an evolving context (identifiable eras).

This understanding has also been theorized in the multilevel framework of transition management [94]: new and less influential “niche” solutions (startup companies) compete for dominance, that is, a place in the “regime” of incumbents that cooperate based on a common interest to collectively determine the rules of competition (and often act to deliberately or inadvertently inhibit innovation) but also compete among themselves to become part of the quasi-immutable long-term features of the society (the general “landscape” in which everybody operates). Such metaphors serve to convey a general idea across disciplines and society but do not fulfill the operational needs of complex projects (unless they help to inspire experimentation arenas and networks) [94–96].

2.2 A Knowledge-Action Framework Model

While there is a broad agreement that new types of expertise are needed, it all starts with the ability to connect knowledge and action. The idea that modern life is embedded in a knowledge-based economy and society has become a commonplace, but achieving integration of fast-advancing knowledge (usually specialized) and connecting it with real-life action (usually holistic) remains a first-rank challenge. Figure 2 synthesizes this reality. Further, Fig. 3 places knowledge integration in the context of RDI and shows the critical role that experimentation plays along the process of development of technological solutions (products and/or services) as reflected by the TRL framework [30, 31] along the S-curve model of technology maturation [1, 92].

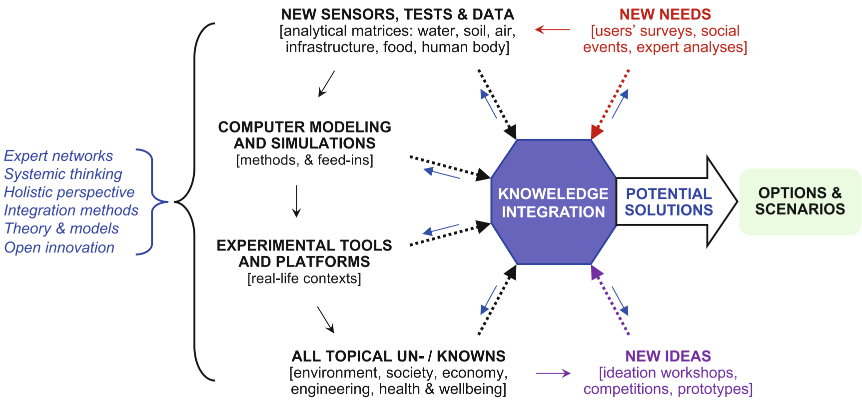

Fig. 2 General representation of the process around knowledge integration toward potential solutions as depicted by the upper TRLs and then options and scenarios for sustainable cities and societies. (Modified after [86])

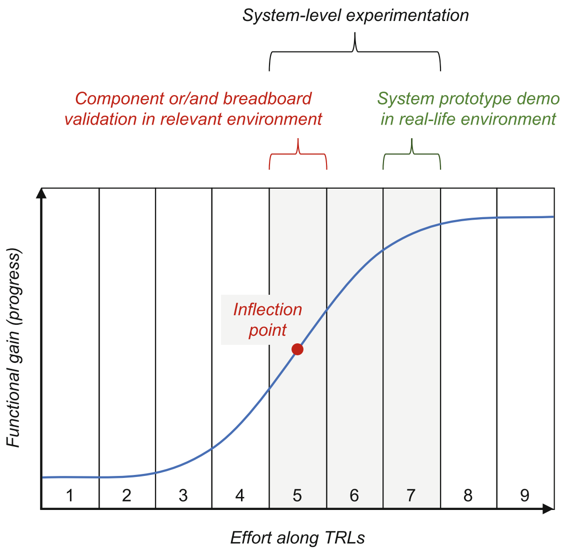

Fig. 3 The key role of systemic experimentation along the idealized S-curve model of technology maturation superimposed on the known nine technology readiness levels. The inflection point is the target of the earlier stages of development and the basis for committing resources to the later stages

In a minimal sense, experimentation only refers to the system-level experimentation captured by TRLs 5–7. Experimentation platforms are explicitly needed for this definition. In a maximal (complete) sense, experimentation involves the entire process (TRLs 1–9).

Given all difficulties related to pioneer and large projects and their root causes, from the semantic, methodologic, and historic-cultural fragmentations to the spread of expertise across contexts, I locate this discussion within the knowledge-action model called DIKAR_*process* (Fig. 4), which was developed based on experience in transdisciplinary projects and the extant literature [86], and I propose that all large and complex projects can substantially increase success rates and ROIs by following a logic of experimentation and disciplined project management as described in this model.

In a narrow sense of the term, experimentation involves only the direct generation, test, and deployment of potential solutions. In a wide sense, experimentation involves the entire in-project work process connecting scientific research and real life. This full set of roles and relations are captured here by iterative cycles within a lattice that combines the DIKAR framework in information science with the steps of problem solving in project management. Each step, depicted as a vertex ("box") in the 12 series, constitutes a "negotiation room," that is, a moment in the process when participants "sit together" to test shared understanding and agree on terminology, objectives, and methods, so that the latent disagreements evoked in Sect. 2.1 are being identified and addressed early on [85, 86] and collaboratively identify gaps, define their space of options, and articulate action scenarios. Thus, the model is a practice-borne universal project organizer, a logical tool for what has been called "fail-safe experimentation" toward sustainability [97].

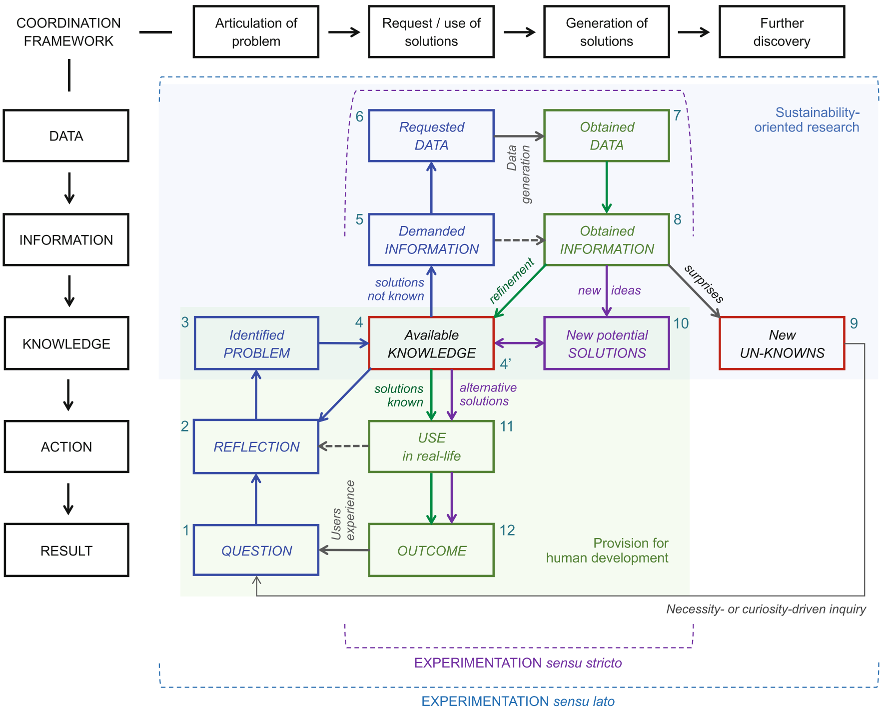

Fig. 4 Proposed understanding of experimentation (as per TRLs 5–7) within a general knowledge-action model ("DIKAR_*process*") for generating new, eco-innovative solutions. (Modified after [86])

3 Discussions

3.1 *Further Insights from the Literature on Test and Experimentation Platforms*

A particularly interesting trend observable in practice and the literature is the notion of living laboratory (or living lab), which is a user-centered research approach. This term had gained a certain notoriety, arguably under the influence of the popularity of other concepts connecting science and business, like "open innovation" and "product (or service) customization." While certain advantages are obvious, notably the stimulation of crossovers, this approach leaves some basic problems unaddressed, notably the issue of knowledge fragmentation. In fact, in fields directly related to knowledge organization itself, commercial breakthroughs were determined by inputs dealing not with the subjectivity of end users but with how knowledge is generated in knowledge communities (not the least because, in this case, end users rarely are the main contributor) [98].

The model in Fig. 4 above can help make the right distinctions by mapping these relations within the general process and thus assist in making good use of living labs: the notion of living lab is covered by the pink arrows between vertices {4′;11;12}, but the content of those relations is much more dependent on neighboring vertices (and the whole dynamics) than what that implies; for instance, user inputs are determinant for initiating the reflection process that leads to problem articulation, but an efficient articulation of the problem is only possible by mobilizing existing knowledge, and then the generation of potential solutions is based on a research cycle that, once the problem has been defined, is independent from the end user – until these alternative (potential) solutions are being tested in real life and users can say something about the outcome of old and new solutions in their life. Without the visual support (and the intrinsic logic) of the DIKAR_*process* model, this dynamic would be rather hard to grasp.

Other experiences show that political and institutional barriers tend to be obstacles to the adoption of living labs for nature-based solutions (NBS) for improving urban resilience with respect to climate changes, while knowledge brokers, various kinds of intermediaries, and cross-sectoral collaborations tend to facilitate their adoption [99]. In fact, such intermediaries can facilitate all these cross-sectoral cognitive and operational interactions and are wanted by policy makers because they are seen as boosters of eco-innovation "ecosystems," notably through functions like "knowledge creation and diffusion," "guidance of the search," "entrepreneurial experimentation," "market formation," "development of positive externalities," "legitimation," and "resource mobilization" [100]. The model above helps explain this empirical finding: intermediaries simply fulfill the function of information finding and processing by trial and error – but that does not mean that any set of intermediaries that happens to be around is efficient (or even justifiable) in terms of allocations and management of scarce resources.

In a Broad Perspective on Systemic Transitions, Cities Have a Particular Role to Play Cities have a natural capacity to connect local and global scales, because every city is simultaneously (a) embedded in its local biophysical and socioeconomic context and (b) a participant in the global network of cities from which it derives opportunities and value [3, 7, 27, 101–103]. From a system analytics perspective, a city is sufficiently large to be representative for human systems (in their complexity) but also small enough to make system-level project management possible and to allow (in projects or daily life) for a small-world effect, that is, high concentration of disparate elements coming in close contact, thus occasioning productive "shortcuts" (in the overall fluxes of people, information, and materials). This enables a city to be both a development engine for its hinterlands [104] and a unique participant in wider regional-to-global arenas [101, 105].

Especially with regard to climate and environmental changes, cities tend to demonstrate a great sense of agency and capacity to experiment, readily questioning national inertia or "one-size-fits-all" measures, because local communities are more impacted by (hence more sensitive to) situations and events occurring in their life environments and immediate hinterlands [103, 106, 107]. Universities have a particularly important role in these local dynamics, particularly in the countries from eastern half of the EU where the hopes and hardships of the transition from command to market economy overlapped a lot with the transition to sustainable development [102, 108–116].

In a nutshell, cities are "places where things happen" and represent the ideal scale for the systemic experimentation for the transition to sustainability [7, 27, 102], but they also require a conscious effort to protect that beneficial "fluid" network dynamics between cities against the rigid approaches of local/national network administrators [103]. Ignorance of complex network dynamics, or feelings of being overwhelmed, may lead administrators to inadvertently seek excessive control, which is the very antithesis of experimentation. The DIKAR_*process* model above suggests that cities are places where (through which) the full process {1; ...;12} can happen efficiently enough and thus represent a best unit for systemic analysis and action on the path toward smart and sustainable societies.

3.2 Insights from Past Projects

One Pioneering Project in Which I Participated Was Econoving This was a science-business cluster (2010–2013), aimed at developing solutions and scenarios for re-developing Versailles-Chantiers (VC), a main railway station in the City of Versailles [3, 86]. Its main challenge was the organization of interaction between universities (and research institutes) in the region of Paris (University of Versailles Saint-Quentin-en-Yvelines (UVSQ), University of Paris 11, Ecole Centrale Paris (ECP), SUPELEC), private companies (main partners, ALSTOM Grid, GDF SUEZ (now ENGIE), SNCF, SAUR, and ITALCEMENTI Group, and numerous other partners in multiple sectors, from chemical appliances to financial intermediation), and governmental agencies, that is, the so-called triple-helix configuration, for the purpose of generating eco-innovation [3, 117].

The model in Fig. 4 emerged directly from that experience, as the author hereby was the director of the Econoving cluster's graduate program *International Professional Master Program in Management of Eco-Innovation*, where academic and business experts worked alongside students, with the double goal of reimagining the railway station (and eco-city) of the future and the development of the new types of skills and expertise that are needed for generating these new solutions [27]. This master program was the driving force in developing clarity on the big picture and helping all project participants (from graduate students to senior experts) understand that true systemic solutions (a) must, indeed, be as simple as possible to be efficient but (b) must also factor-in all effects (unexpected side and network effects too), starting with ecological footprints, social acceptance/acceptability, and economic viability as a prior condition for scenarios and operationalization.

A first lesson learned by all in the Econoving cluster concerned the scope of systemic solutions: once we looked at energy consumption and costs in the main building and infrastructure of the train station itself, the issue naturally extended to include the whole city neighborhood and the city itself. It quickly became clear that the station was not "just a place where you take the train" but a point of convergence of urban socioeconomic exchanges and life, a true node of multimodal communications. Aside from technical conclusions and reports, the central benefit of the project was about a community of experts moving up the learning curve: (a) developing and testing a modus operandi and (b) a set of generalizable insights and scenarios. Now, these can also serve as a start basis for the iterative use of the framework model summarized in Fig. 4.

The first (yearlong) part of the in-cluster foresight exercise has already followed the coordination framework logic of the DIKAR_*process* above and has led to this list of conclusions about the premises of this type of projects:

- It is very difficult to collect reliable, coherent information – indeed, a worldwide known challenge.
- Trans-sectorial understanding of a city is a heavy task, due to traditional divisions between disciplines (with different vocabularies and methods).
- New types of knowledge management are needed, which requires sustained effort and learning by all, to insure a productive set of common denominators.
- The historical heritage of the City of Versailles and the broader context of the Greater Paris region represented sources of both opportunities and challenges.
- Scenario sets (and methods) can address: technology choices, social acceptability, environmental concerns, costs, and risks.
- Higher spatial scales are more important than usually thought of: a train station can only function as embedded in its city context (and many details matter).

Based on these premises and the available knowledge (both in the form of expertise available in the Econoving cluster and network and in the form of available literature and insights from other projects), the second yearlong part of the forecasting exercise established three generalizable directions for the future. In the DIKAR_*process* model, these are broad categories describing the content coded by vertices {9;10;4′;11;12}:

(a) Urban renewal: Integrative planning for radical progress in VC as key activity hub within the City of Versailles (which is also the seat of Yvelines county).
(b) Urban resilience: Smart adaptation to and mitigation of climate changes in VC as driver of urban capacity to deal with disturbances.
(c) Urban technology: Integrative (systemic) solutions for augmenting the City of Versailles as a whole to the status of all-times international hub of innovation.

In addition to valuable technical results, the cluster also generated successful developments of startups, in some cases going from TRL 1 to TRL 9. This was facilitated (in its critical demonstration phase from TRL5 to TRL7) just by the existence of this VC hub of multimodal communications as a real-world test bed for new smart solution for optimizing energy uses (in domestic, public, and industrial settings) based on the NIALM (Non-Intrusive Appliance Load Monitoring) technology. By the end of the project, we already counted a European prize–winning enterprise with a growing network of clients [118, 119]. In contexts of high energy bills, this is a useful ready-to-use solution.

At the same time, VC served as a platform that generated new questions, which were then explored (from TRL 1 up) – notably on energy flow, viability, and cost models of different technologies/products/services in the train station. The project also generated a process of building system-level models and scenarios of urban sustainability and highlighted the importance of cities as experimentation units and of the organization of knowledge in knowledge-action models that were then refined in follow-up projects.

Insights from these works converge with the broader literature on innovation management and show that experimentation plays a critical role in the development of technologies, especially at the front end of eco-innovation when "product parameters are still flexible" [120] (or, as per Fig. 4, when new ways are still "alternative solutions," that is, modifiable in interaction with the users, before becoming "known solutions"). More broadly, the idea above closes the loop with decades-old signals about the imperative of building versatility into our energy and urban systems [3, 83, 102]. Today, geopolitics show again that indulging in long-term "blindness" for the sake of short-term ease logically leads to a rude awakening. The DIKAR_*process* explains and addresses this reality and supports efficient mobilization of knowledge across "brain networks."

Another Project Provided Complementary Experience: The EIT's Climate KIC There, the main challenge was the organization of the interactions across a network of experts and institutional partners (universities/research institutes and private companies) scattered across several European countries: France, Germany, Switzerland, the Netherlands, and the UK. The "easy-to-say, hard-to-do" solution was finding operational common denominators across institutional, sectoral, and national-cultural contexts.

But a most important insight is perhaps the fact that in both Econoving and Climate KIC, the challenges of bringing partners on the same page were truly formidable at the beginning (as centrifugal forces appeared unstoppable). However, each project had an education program at the core and that proved to be the axis around which discussions kept going and the source of the first successes on which later works could gather and build. And, in both cases, the key to that success was coherent knowledge reorganization based on direct conversations between involved experts and stakeholders.

Climate KIC was also a supplementary learning opportunity at hand. My students participated in its main action: an intensive six-week graduate summer school called "the Journey!," a joint program covering at least three country contexts, fully funded by the EIT. (And I participated in planning, teaching, and management.) Its philosophy was similar to that of the Econoving master program with two differences: ours dug deeper into problems and technicalities (which included but was not limited to climate) while EIT's expanded horizons across Europe (and prioritized climate). This experience (1) enabled us new tests for relevant hypotheses, (2) obliged me to regard the multidimensional RDI space of options as a stand-alone problem to solve (which led me to develop the above model), and (3) confronted RDI dynamics in clusters-by-design vs. networks-by-design: the Econoving cluster grasped better the local community/cities, while Climate KIC was better placed for testing solutions for general use (with some conditions). This observation suggests a strategy of complementarity: initiating smart city projects by a local cluster of experts structuring a target city/problem (disciplined iterations of the model above), as a solid start basis for subsequent high-value interactions across international networks. On the contrary, generating broader (commodifiable) solutions for a smart society would require first an efficient network to distill the core specifications of a minimal product/service, and then its further development (for high market value) can benefit from the work capacity of large innovation clusters.

Also Interesting for Institutional Experimentation Is the EU's "Erasmus Mundus" Since 2004, this funding scheme provided scholarships for students in master programs involving three or more EU countries (or, since 2009, associated partner countries from around the world), with students spending at least two semesters at locations other than the institution than enrolled them. In 2011–2012, I had been solicited and I developed an initial concept based on the experience we already had at Econoving and Climate KIC, but soon I had to prioritize all resources to existing programs instead. Still, those initial works provided some insights into a growing human resource in Europe: generations of networked experts to be mobilized through disciplined experimentation [121–123]. The literature provides interesting insights on opportunities and challenges, for example, "uneasy belonging in the (student) mobility capsule" vs. the "super-mobile student" [124, 125], digital libraries [126], and smart and sustainable university campuses.

Some Other Projects Helped Me to Distill Experiences into Formal/Abstract Models Beginning with 2014, INTRAS (Institute of Innovation for Transition to Sustainability), an RDI start-up (private enterprise of public utility or "fonds de dotation," enabled by a new French policy of administrative flexibility toward innovation as inspired by classic endowment funds of American universities), focused on "big picture" modeling of the unique experience and (yet unprocessed information) from Econoving. The latter had ended in 2013, but its insights have been picked up (as intended) by SNCF and used in a new, state-led PPP of urban regeneration (2014–2019). While at INTRAS, we physically visited and we analyzed a series of urban regeneration projects in the Paris region, and we compared them with our works in Versailles, using the conceptual lenses given by the field of knowledge organization (KO) [98]. One was the experimental smart eco-district of Fort d'Issy inaugurated in 2013 (first in France; 1620 high-end apartments and common (utilities) infrastructures inside the former ruins of a military fortification abandoned after the Franco-Prussian war of 1870–1871) in Issy-les-Moulineaux near Paris and Versailles [127–129]. Another was SenseCity, an experimental research platform dedicated to the development of smart sensor networks in a university campus ("Descartes") in Marne-la-Vallée, an eastern suburb of Paris [130, 131]). In this triangle, SenseCity was the most academic and a source of technical questions linked with (a) my prior experience and the latest literature on sensor prototypes, sensor networks, and environmental analytical strategies and (b) other technical, systemic, and managerial questions from Econoving. Our basic approach was to add all those pieces together and solve the pile as an "eco-city puzzle" according to the principles of scientific modeling and knowledge organization. In it, DIKAR_*process* above first helped us to develop a set of other models (see below) and then included them as part of its knowledge vertex.

This triangle of projects helped us distill a problem solving-oriented theoretical core: success/failure is closely tied to having/lacking more explicit-but-versatile operational representations of the problem of interest. This led to the conclusion that this kind of work requires a commitment to persistent experimentation with conceptual/mathematical models being tested against ever broader experiences. For us, this resulted in a new general type of urban metabolism model called Eco-City Reference Model (ECRM), a multistep knowledge aggregator for tailoring holistic eco-city projects. This uses the systems' perspective on sustainability [7, 115, 132, 133] and a map of topics (obtained by combining empirical and literature insights with bibliometric and graph analyses) called urban sustainability nexus (USN), in which complex interdependencies between priority topics (security, demographics, buildings, climate changes, waste, health, leisure, and food) constitute a crown of issues that are gravitating around an even more central core of interdependent topics (landscape, water, energy, and transport) [7, 134–137]. Then, a daughter project (an Internet platform concept) called Interactive Knowledge Maps for Brain Networking (IKM-BN) emerged and is currently being developed for the general community of users in science, education, business, and policy [67, 68].

In terms of urban system complexity, the VC project in Versailles stayed "unbeaten": a modern multimodal transportation hub with a huge diversity of urban functions. For example, the electricity grid in Fort d'Issy eco-district included mainly residential consumption [129] while VC requirements covered industrial, commercial, and residential aspects related to the train station itself (which then served 50,000 passengers per day and growing) and the surrounding urban districts, including potentialities for onsite renewable energy sources [138, 139–141], electrical cars [142, 143], and the railway network per se [144]. By the time IssyGrid started to require technological updates, VC was in the midst of an urban renewal program that affected the entire city (e.g., it became a major hub for now-reorganized bus networks, a strong commercial and business center). By 2019, VC was the main transportation hub in the western part of the Paris region and a national eco−/smart renewal showcase for train stations and for cities.

The Formulation in Fig. 4 Was Speeded Up by Yet Another Project: ACE-ICSEN This project (2017–2020, UVSQ, CEARC) was a typical example of holistic endeavors where the number of variables of interest increases exponentially (with the number of questions asked) and quickly touches an "invisible ceiling" of feasibility. The model formulation shown in this book chapter is a direct response to the practical question "How to connect extremely different topical work packages of a complex project?" Specifically, it addressed the need for transdisciplinary methods in a so-called transversal work package (WP-TR) that was meant to link knowledge and action in three topical WPs that addressed a set of problems (characterizing the transition to sustainability) that were very different but were known to occur simultaneously: biodiversity loss at local and regional scales (WP1), health impacts of air and water pollution (WP2), and impacts of short-lived pollutants on climate change scenarios (WP3). Thus, the model is both as an example of and a means for problem structuring [85, 115, 145].

3.3 *Mapping Specific Issues and Experiences with RDI in Smart City Projects*

Here I locate project activities according to both TRL and DIKAR_*process* (Table 1) and discuss a few issues to help visualize the interactions and draw additional insights.

One Aspect Is the Social Learning That Happens Naturally Inside a Running Project This is a natural resource for formal education programs and the development of human capital in general. In the Econoving cluster, the two fortunately overlapped because (1) many teachers in the master program were also experts in the cluster's industrial component and in the train station program (all industry partners contributed teaching) and (2) all students participated directly in the cluster's train station program. The master program's module called "Integration Seminar" counted (by design and strategy) as activity in the project's Work Package WP3-Anticipation (see Sect. 3.2). Also, most students found internships with the cluster's main partners or network of collaborators. We also carried out cross-deliberations between this master program and one dedicated to architects ("Construction durable et éco-quartier"/sustainable construction and eco-districts) jointly organized by UVSQ and ENSAV (Ecole Nationale d'Architecture de Versailles). The overall experience of all participants in this pioneering project featured many issues that were known from existing expertise and literature on cultural theory (related to social learning) [149] and project management (related to cognitive and behavioral biases) [17; Sect. 1.1] but which "had to" be learned by doing, as summarized during an end-of-project meeting by one main partner (citing from memory): "it is only now, after three years, that we really learned how to work with each other."

Another Is a Fundamental Need of Strategic Data Acquisition This is true for RDI in general and for "data-driven business analytics" [150, 151] in particular. The latter is coded by the second half (vertices 7–12) of the model circuit and should be managed in the integrative context of the full model. This would help current data-driven approaches [152, 153] gain a useful sight on problems, that is, become operationally "smarter".

Concretely, the so-called knowledge discovery (inferring basic patterns from large amounts of data) was not applicable in VC because data did not exist or was not easily available. In fact, even the basic information (with any degree of

Table 1 A general taxonomy of activity types in university-business projects (PPPs), generated as a Cartesian product of technology readiness levels (TRLs) and the steps of the DIKAR_*process* model of project management

			TRLs								
			Basic science (principles)	Technology concept or application formulated	Analytical /functional proof of concept	Component validation in the laboratory	Component validation in a relevant context	Subsystem /prototype demo in relevant context	System /prototype demo in target context	System completed and qualified by test & demo	System proven through successful operation
			1	2	3	4	5	6	7	8	9
DIKAR _*process* steps	1	Question	A11	A21	A31	A41	A51, B51	A61, B61	A71, B71	B81	B91
	2	Reflection	A12	A22	A32	A42	A52, B52	A62, B62	A72, B72	B82	B92
	3	Identified problem	A13	A23	A33	A43	A53, B53	A63, B63	A73, B73	B83	B93
	4	Available knowledge	A14	A24	A34	A44	A54, B54	A64, B64	A74, B74	B84	B94
	5	Demanded information	A15	A25	A35	A45	A55, B55	A65, B65	A75, B75	B85	B95
	6	Requested data	A16	A26	A36	A46	A56, B56	A66, B66	A76, B76	B86	B96
	7	Obtained data	A17	A27	A37	A47	A57, B57	A67, B67	A77, B77	B87	B97
	8	Obtained information	A18	A28	A38	A48	A58, B58	A68, B68	A78, B78	B88	B98

	9	New unknowns	A19	A29	A39	A49	A59, B59	A69, B69	A79, B79	B89	B99
	10	New potential solutions	A110	A210	A310	A410	A510, B510	A610, B610	A710, B710	B810	B910
	4’	New/updated knowledge	A14’	A24’	A34’	A44’	A54’, B54’	A64’, B64’	A74’, B74’	B84’	B94’
	11	Use in real life	A111	A211	A311	A411	A511, B511	A611, B611	A711, B711	B811	B911
	12	Outcome (of each action)	A112	A212	A312	A412	A512, B512	A612, B612	A712, B712	B812	B912
Actions in a medium-size train station: Versailles Chantiers		*A. Academic-led activities, along these themes:* • Project writing (constitution of initial set of participants in an eco-innovation cluster/PPP: 6 universities +6 private companies); development of human capital and further networking: An international master program (fully dedicated to the management of eco-innovation – The first of the kind worldwide) as central collaboration point for the cluster; and participation in international professional networks, notably the European Institute of Technology’s Climate KIC and the elite universities-businesses network Science|Business [3, 116] • Research: Diagnosis of energy performance of the train station, including the use of and refining market solutions (new algorithms) based on NIALM technology [146, 147], energy modeling of the train station [140] and the exploration of complex engineered systems/smart grids [138, 139, 141], and the use of EV batteries plugged into the grid in 24 h patterns [142] • Development of scenarios for the redevelopment of the VC train station and its neighborhood (city district) *B. Business-led activities:* • Wide-scale real-life development of the public project for refurbishing VC and remaking the VC: Details available online, by the City of Versailles [148]									

reliability) was hard to come by (unavailable/lost original plans of the building, various later modifications, legal issues related to information sharing, and technical issues and costs of generating large new data). Consequently, the initial project objective, which was the generation of an energy model of VC based on an array of sensors (the number of which had to be predefined-budgeted in the early stages of the project), has stumbled because those sensors were too few (only 100), were later discovered to be located rather suboptimally, and were non-relocatable (all that in spite of people doing their best in the initial planning phases of the project – activities A51 to B74 in Table 1). In this situation, the foresight exercise (one among the project's work packages) redoubled efforts, gathered every bit of information available anywhere, and succeeded in providing SNCF with work options for the urban regeneration program that was carried out afterward.

This case study also illustrates the earlier-mentioned need to find the right interplay between RDI clusters and networks according to purpose: general use solutions (e.g., NIALM) and/or localities (e.g., VC). On the one hand, the aim of this foresight exercise concerned a locality: to find a best possible minimal set of realistic scenarios/potential futures for the train station in its urban context, that is, district, the City of Versailles, and the Greater Paris Region (especially within its Grand Paris program of development of communications) [154, 155], the country, and the EU. On the other hand, the purpose of the company deploying a given technology was to gain market shares anywhere, so it used the Econoving project as a platform for experimenting better solutions for meeting general market demands (e.g., monitoring/optimization of electricity consumption or a replicable train station model). The generated competing/complementary scenarios were critiqued and improved in weekly, monthly, and yearly cycles by mixed teams. Other topics included inter alia energy fluxes [139], complex engineered systems and smart microgrids [138, 139, 141], and time optimization of electrical vehicle uses [142].

The Method Also Entails some Risks to Be Accepted and Addressed as Appropriate Notably, the method requires a high-and-constant level of reflexivity and dedicated resources. By the way, the model is also relevant for robotic process automation (RPA) tools, within known limitations: task repetitiveness normally correlates inversely with project complexity and high context dependency of unsupervised/supervised choices in machine learning (ML).

The experience from the projects evoked in this book chapter suggests that some people will quickly grasp the method (especially if they have already practiced disciplined experimentation) and most will understand its logic after due explanation but will not use it unless two conditions are met (each, being potentially sufficient). Firstly, the project needs to be designed with this logic in mind from the beginning; otherwise there will be too many centrifugal "business-as-usual" forces and the project will switch on "automated pilot" (based on previous lowest common denominators). Here, I contend that given the high stakes of complex projects and the fact that the model emerged from practice, designing a project (or program or policy) with this model in mind is not too much to ask. To put it differently, the model is already distilled as a product of "human-executed RPA" so to speak. Secondly, a small team must be assigned from the start for interfacing all project participants according to the framework model described here. At a minimum, this can be just the project manager. For example, I did it in the Econoving cluster and master by resolving on the spot (thinking on the go) the paired operational requirements of Structured Problem Resolution x DIKAR (the model axes in Fig. 4), using a simple two-dimensional managerial mental model structured as a 5 × 4 matrix, that is, $Spot\ Model = \{\mathcal{M}_{i,j}\}$, $i = \{Data, Information, Knowledge, Action, Result\}$, $j = \{Problem, SolutionDemand/Use, SolutionGeneration, FurtherDiscovery\}$. But in projects above a certain size, the manager needs dedicated support to fill and manage the content of model components. This team must not add on top of existing structures (this would result in administrative conflicts and clutter); instead, it would be part of it from the beginning. Its role would not be to centralize knowledge (except for some very specific issues) but to insure workflow efficiency across relevant knowledge networks.

Retrospectively, I noticed that, in its logic, the basic mental model behind the more detailed DIKAR_*process* is convergent with the 3D Smart Grid Architecture Model (SGAM) co-developed by the European Committee for Standardization (CEN), the European Committee for Electrotechnical Standardization (CENELEC), and the European Telecommunication Standards Institute (ETSI) in response to the standardization mandate M/490 by the European Commission [156, 157]. Essentially, the DIKAR_*process* model is complementary to SGAM and informs its "interoperability dimension" (with five layers from business to physical components) and/or vice versa: SGAM can organize content details of the projects that are structured according to DIKAR_*process*, for example, to generate eco-innovation for energy transition and/or to address current energy-security-climate/sustainability challenges. Similarly, the model can help interactions between the domains of NIST smart grid concepts by the USA's National Institute of Standards and Technology [158]. In all cases, the taxonomy in Table 1 can serve as a map and operational connector for superior work efficiency and versatility.

Another Common Highlight Is the Need of Digital Systems for Efficient Operations To materialize the proposed model's potential for assuring and testing project validity and for aiding all managerial decisions, a project must not involve (substantial) "paper work". If that is not possible, my own and others' experiences suggest that the project manager(s) will soon have to choose to either "stay and fight" (if there is something worth fighting for and if winning appears to be possible) or quit (i.e., accept the sunken costs and render her/his skills and capacities available for a new and better conceived project). This also applies to public administrations: effectiveness of policies and programs for smart and sustainable society is in fact conditioned by digitalization. Otherwise, nice visions will remain costly exercises in "public relations" or worse: systematic failure will leave a trail of public distrust and social conflicts that will exacerbate crises.

The Model Can Also Help Experts Sort Out the Security-Energy-Climate Conundrum In the context of the Russia-Ukraine conflict, the European Commissioner for research and innovation launched a public debate on Horizon Europe, to see “if we are still doing the right things and if our priorities are still the relevant ones” [159]. To such purposes, DIKAR_*process* can operationally codify virtually all other concepts, approaches, and methods, starting with the multi-level model of transition management [160] and the problem of uncoordinated climate/energy/other policies between scales [87] (Sect. 2.1). In a study comparing smart city developments in Amsterdam (Netherlands), Hamburg (Germany), and Lingbo (China), Raven et al. [161] show tables which exemplify exactly the kinds of work outcomes that I envisioned for the negotiation rooms in the model. They also observe that PPPs are at the heart of meaningful urban experimentation, and cities can lead. For instance, Amsterdam adopted PPP because private funding was needed in their urban projects during the 2008–2010 financial crisis. Similarly, the unique (UNESCO) patrimony of Versailles is not an obstacle but an asset – if relevant expertise is mobilized. Cities that reinvent themselves as eco-cities [102] can play the inspirational role that Glasgow and London played in the first industrial revolution. At larger scales, the model can support, for example, the New European Interoperability Framework (EIF) seeking “seamless services and data flows” for European public administrations and their modernization through “eGovernment solutions” [162].

The Method Could Also Apply to Analyze and Reuse Results from Past Mission-Oriented Projects, for Example, those Focused on Non-/Formal Environmental Education (EE) To date, I have good feedbacks from a past project funded through the EU’s *Leonardo da Vinci Community Vocational Training Action Programme* (2006–2008), which was led from a pilot center at UAIC in Romania; involved a network of experts from historic cities in Germany, France, Spain, and other EU countries; and made important first steps toward a European Curriculum for EE and education for sustainable development (ESD) [107, 114, 163–165]). And this is just one example among intellectual resources spreading out across Europe and worldwide, which can be used and extended by cycles of expert reconnection that would also muster other RDI and education capacities [114].

4 Conclusion

The joint crises of today grew from past collective complacencies, which is yet another reason why they should not be wasted. However, competent action requires preparation. Given the overwhelming volumes of scientific outputs and heterogeneity of technological state of the art, the challenge we face is not a lack of specialized expertise but a lack of successful integration of available knowledge in novel solutions that are compatible with a sustainable development and are resource- and time-efficient. In this book chapter, I made the case that now, more than ever, we need to develop large-scale platforms for disciplined experimentation at system scales, and I proposed a method whereby any type and size of relevant professional experience called into a project can be described by 1-n iterations of graph sub-/components representing steps, paths, and cycles of the co-work process. The method relies on classifying project activities along the joint lines of project management dynamics and technology readiness levels, with the ultimate goal of obtaining the best trade-off between efficiency and versatility in any given work context (and, ideally, professional equanimity for project managers). Technically, any user of this model can exercise coding her/his own experiences (as briefly illustrated with the details shown in this book chapter) as iterative paths in the mathematical graph represented by the proposed model. Those who are familiar with category theory and graph analysis can see additional uses of the model, for example, by comparing path length and centrality of different types of activity, so as to identify gaps, prioritize tasks, and decide resource allocations or as a general framework for different other methods. This intrinsic versatility allows this model to serve as a common coder of actions and courses of action. In principle, the model also informs and can guide workflow automation and robotic process automation, via either software or users (or both, as interface).

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Protecting Organizations from Cyber Attacks: An Implemented Solution Based on CyberArk

J. M. Pinheiro and P. Carvalho

1 Introduction

As the world is becoming more and more connected, so do the threats of malicious attackers rise, attempting to gain access to information that is, and should be, confidential. These attackers focus on gaining access to privileged accounts, commonly designated as administrator accounts, and moving laterally within a company's infrastructure [11, 12, 18]. BMW (Bavarian Motor Works) is aware of these threats, and that is how this project was initiated.

Considering PAM solutions, there are many solutions available, namely CyberArk, One Identity SafeGuard, and ARCON PAM. However, since they come as a password vault for basic operating systems, they need further improvements to make them a possible choice for production work. Improvements such as creating a connection between the solution and software used by the companies, for example, an RMB (Remote Management Board). Since these improvements are an addition to the solution offered by the specified vendors, tests need to be developed to assure a working state [1, 3, 8, 17, 18, 22].

As mentioned, the way companies handle accounts is not able to withstand the attacks of malicious individuals, causing confidential information to be released to these untrusted parties, designated as a data breach. These occurrences have a very negative impact on societies' perception of the affected company, possibly reducing sales, losing market value, or even major lawsuits against them [11, 18, 19, 21]. These attacks also affect users, compromising their accounts and their

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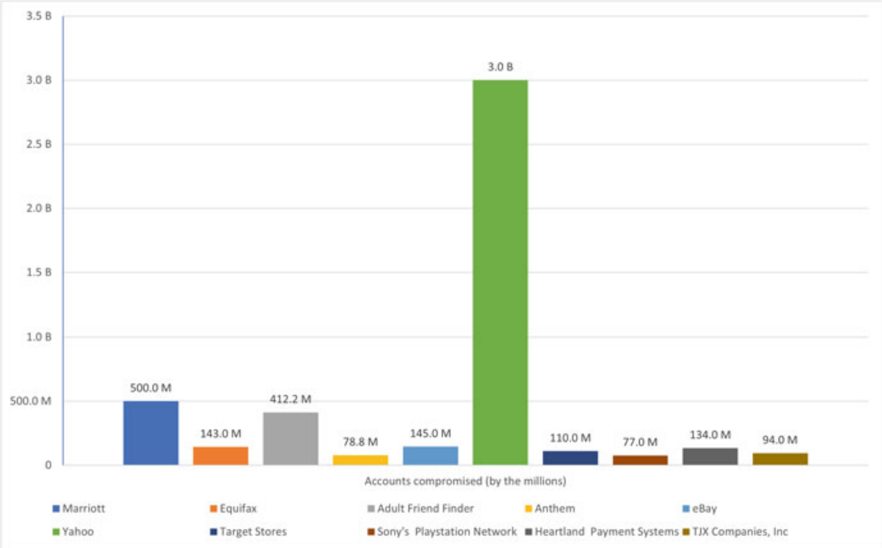

Fig. 1 Accounts compromised on the biggest data breaches of the twenty-first century [10]

personal information, as shown in Fig. 1, Accounts compromised on the biggest data breaches of the twenty-first century. After these breaches, the users, even if not affected, lose trust in these companies and decide not to use the companies' product anymore [10, 18]. EBay is one of the companies that is visible in Fig. 1, Accounts compromised on the biggest data breaches of the twenty-first century. EBay's data breach compromised the information of 146 million users, which led to the company urging users to change their passwords. As a result, eBay experienced a decrease in user activity that quarter [9, 10].

This attack was performed by using employees' log-in credentials, to gain access to rights the outsiders do not have permission to access, allowing them to move freely inside the organization's infrastructure and retrieving the customer's confidential information. The attackers had completed inside access for 229 days, which shows how dangerous and hard to track these attacks with privileged accounts are [9, 18, 19]. The financial information of the customers was securely encrypted and stored on a different network, and the breach was detected before the attackers could gain access to this information. Had those attackers gained access to this information, it would mean eBay had released 145 million customers' worth of financial information [9].

Due to these dangers, organizations are under immense pressure to remove attackers that have managed to breach their infrastructure, and "I think this pressure complicates the already considerable challenge of confidently drawing a box around what was compromised and confirming the attacker's access and influence has been eliminated, making sure they will not return." [9]. Peterson alludes to the fact that, even when a breach is detected, it is a very hard task to understand the reach of the breach, which was previously evidenced on the eBay breach, where attackers had complete access for 229 days after the breach was detected.

The purpose of this work is to transition BMW's privileged accounts into the CyberArk platform. Due to the scale of the organization, this work focuses on two specific improvements to the CyberArk platform. The first improvement that this project documents is the automation of tests for the platform: improvement that is in place to make evident the functionalities/limitations of the platform. These tests are not testing the work that was developed by the internal team but the work developed by CyberArk and should show the development team what can be leveraged later. This does not mean that development work is not tested. The opposite is very much the case since, according to the DoD (Definition of Done), development work is only accepted as complete when there are tests in place that state it works as intended. The second improvement that is realized in this project is the creation of different connection components that CyberArk does not natively support. BMW as a company uses many different technologies to manage their work, such as Windows, Oracle SQL developer, RMB's, just to name some. From the previously named technologies, only Windows is natively supported by BMW, so there is a need to create these connection components to connect to the other technologies, allowing all the BMW employees to connect to their respective workstation through CyberArk, isolating them from their privileged accounts, and as a result making a malicious attacker's job harder. To use this solution, employees need to connect to their software of use, making this a crucial improvement to the initiative, taking up most of the development teams' time [22, 23].

The automated tests are developed using java, and mainly focus on using Selenium for web-based tests, and API (Application Programming Interface) calls for API tests. The tests are fully automated, using Cucumber as the framework to automate these tests. Cucumber is supported natively by Jira and Xray, where the Gherkin, language used by Cucumber, is placed. These tests are created whenever the development team wants to test the functionality of a specific CyberArk utility. In terms of connection components, CyberArk allows developers to create and deploy universal components that can be used on the teams CyberArk environment. They also have multiple connection components available on the marketplace that do not come by default with CyberArk. The deployment of custom connection components is documented in CyberArk's documentation and requires the team to create the component itself, using AutoIt, the coding language that is advised by CyberArk, and the one the team is using currently. After this component is created, it should be placed in the components folder that exists within the PSM (Privileged Session Manager). The PSM is the server that allows CyberArk to initiate, monitor and record the privileged sessions, as well as the usage of administrative tools. When the new component is placed in its proper folder, the developer must adapt the AppLocker to tell CyberArk the new component is trusted and can be used. After the AppLocker configuration is done, now the developer needs to enter the PVWA (Password Vault Web Access–CyberArk's Web Interface) and configure CyberArk to use the newly added configuration component [22–24].

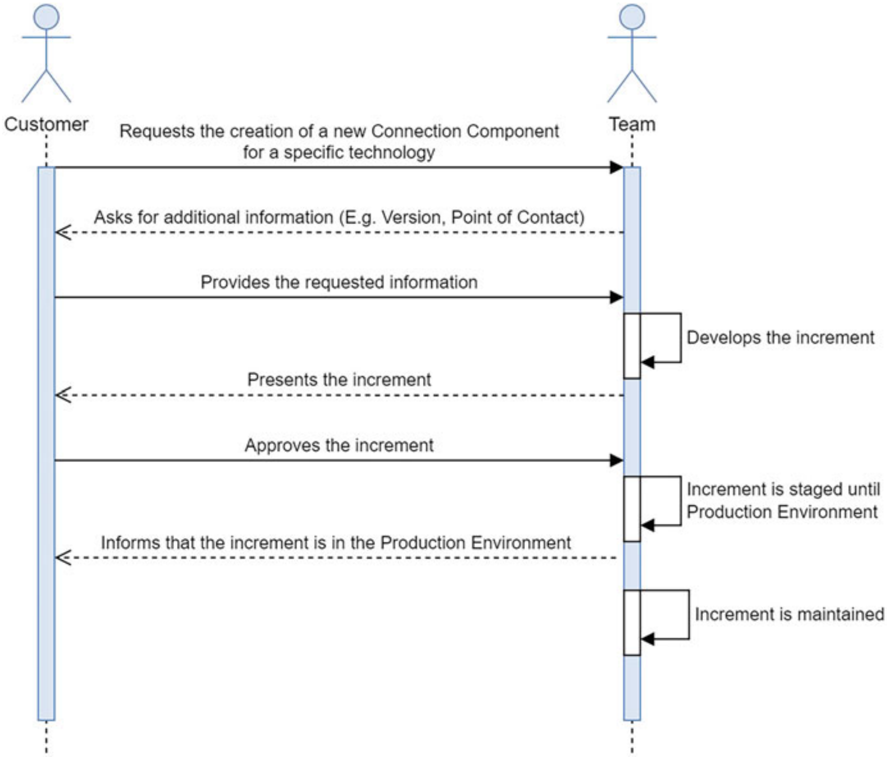

Fig. 2 Diagram of a possible request process

With this process in mind, the development team needs to create a process where BMW infrastructure team members can contact them and request the creation of these connection components. Figure 2 represents the diagram of a suggested request process, where the customer would contact the development team with information required to complete the development. Once the development is complete, the team reaches out to the customer to get the approval on the increment, staging it to the production environment afterward. Once the increment reaches the production environment, the customer is informed and the development team maintains the increment healthy.

2 State of the Art

Most of the research done in this field of security focuses on the importance of securing privileged accounts, as well as the risks involved with not properly securing those accounts. The research available on implementation solutions is very limited, especially when it comes to technical implementations and the best practices for securing these accounts. This research investigates a PAM (privileged access management) solution implemented in a corporate scenario, the benefits and difficulties of such an implementation, and the additions that were necessary for such a solution to work [12, 17, 18, 20, 21].

Protecting privileged accounts and actively responding to potential breaches have become a vital initiative for many corporations. Stolen credentials are the main avenue that attackers use when performing their attacks and breaches, and privileged accounts are the most sought-after accounts when it comes to breaching an enterprise. Compromise a system administrator and an attacker would rule over a companies' system and all connected applications and devices [15–17, 19–21].

However, privileged accounts are not limited to administration accounts. Often executives possess highly sensitive information within their own devices, and these accounts are also target for these attackers, as they would have access to confidential company secrets. These executives are often not tech-savvy, which leads to poor quality of the passwords they use, making them vulnerable to malicious attackers. Even worse, they might not realize that they are being targeted [15, 16, 18–21].

The most straight forward answer to vulnerable privileged accounts is to downgrade their permissions. However, as mentioned above, privileged accounts are much more than accounts that can cause system damage. Companies need a solution where all their secrets and privileged administration accounts are safely stored and monitored. Here is where privileged access management tools such as CyberArk and BeyondTrust are involved. These solutions add a security layer between the users and the privileged accounts that they access [13–16, 19, 20].

Both solutions offer enterprises with a mechanism to safely store privileged accounts and monitor their usage. The solutions operate in similar fashion, utilizing proxy servers as a connection point to target systems, to detach users from the targets systems, and monitoring the actions that users perform on these servers. The secrets are also stored in a secure vault server that injects the credentials when requested, however the communication between the components is where these solutions differ. BeyondTrust's components all communicate between each other, and the secret injection is done by the vault via API requests [13, 17, 21].

In contrast, CyberArk's vault is isolated and outside the domain of the enterprise, only being accessible on premise, or via a remote management board, and only able to communicate with other components via its own proprietary port. The other components themselves only communicate with the vault, as the vault is the center of all actions that occur in CyberArk, as shown in Fig. 3 [14].

Figure 4 depicts a sample connection executed by a user, and the steps performed by CyberArk to provide the protected session. Initially, the user connects to the PVWA, which is the web graphical interface where he can select which privileged account and target systems he wishes to connect to. Afterward, the user is provided with an RDP file, which allows him to establish a connection to his selected target application [24, 25].

This process is seamless to the user, as he is already connected to the selected target application; however, there are some steps behind the scenes that CyberArk

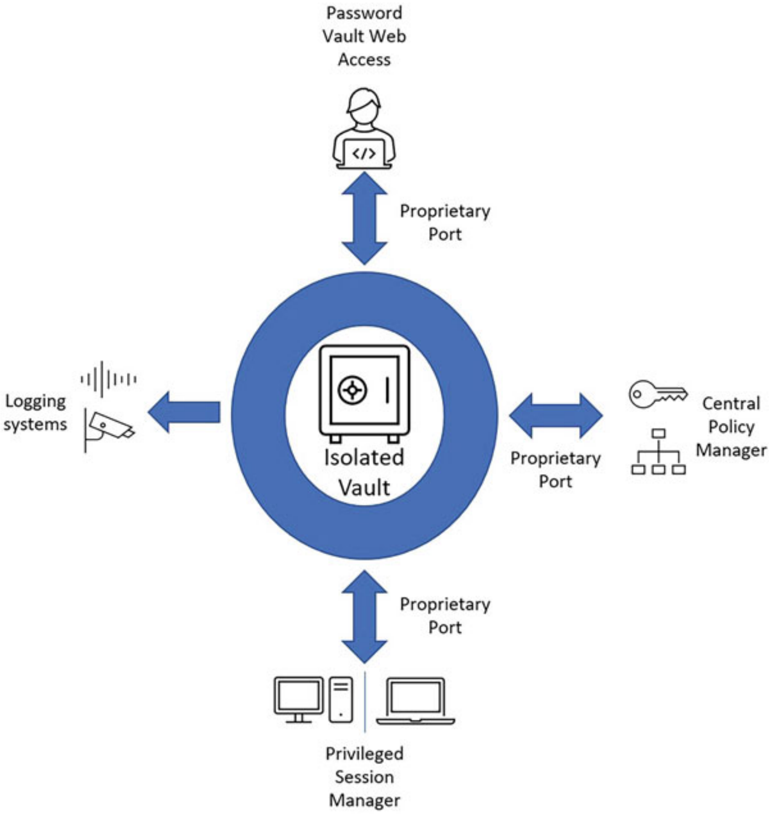

Fig. 3 CyberArk **v**ault as the center of all actions [14]

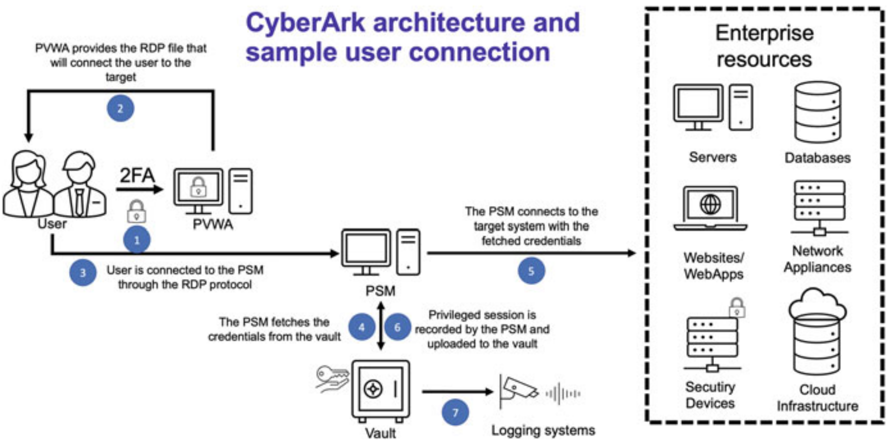

Fig. 4 CyberArk architecture and sample user connection [14]

must perform to ensure a protected session. When the user executes the RDP file in step 3, the PSM, which is the server that is running the selected application and functioning as a jump server, fetches the credential secrets from the Vault. With the credential information, the PSM is able to authenticate to the target system and provide the application process id to the Vault, ensuring that the customer only has access to the selected application and not to the entire system. All these steps are recorded by the PSM and uploaded to the Vault server, which is then integrated with BMW's proprietary monitoring solution [14, 23, 24].

This added layer of security is what caused BMW (Bavarian Motor Works) to select CyberArk as its privileged access management solution, as its features answered the companies' needs for secure usage of privileged accounts. This chapter delves into extensions developed to enhance the direct connection feature offered by CyberArk, as only a few applications are supported by the vendor.

3 Solution Description

For the purposes of this chapter, the version of CyberArk currently used by BMW is version 11.1, having the default installation alongside with the companies' rules. CyberArk itself already restricts access and power that each server component has, however having the companies GPO (Group Policy Objects) and rules restrict the components even more, making it harder for developers to perform work on these servers. Due to these issues, there is no local environment that can be used as test, which is why the test environment is used. This leads to difficulties replicating the productive environment, which causes the test environment to not behave as expected. After a feature is tested using the test environment, it will be implemented in the integration environment, which is an environment that closely resembles the production environment. In this environment, the real capabilities of the added feature can be tested, as well as the efficiency.

All the previously mentioned environments are separate. The test environment consists of servers that are only used in that environment, as is the integration and the production. The servers vary depending on the environment, with the test environment having significantly less servers at its disposal, and the production environment having most of the servers, since it is the crucial environment, and requires the highest up-time and consistency.

3.1 Existing Connection Components

Since the environments come with the base version of CyberArk installed, this also entails some connection components that CyberArk supports by default. This section presents some of these connection components, as well as their uses, and enhances the purpose of this work and why there was a business need to create more connection components for other applications. Along with presenting the connection components that are integrated by default with CyberArk, this section also explains how each connection component works and analyses of the upsides and downsides of each. These connection components are used to access the environments where the BMW employees perform their work. This asserts a higher level of security, along with tracking the actions each employee takes. It also makes it harder for outsiders to damage the company's information, since multiple steps for authentication must be performed.

SSH Protocol The first connection that CyberArk allows by default is the SSH Protocol connection. This protocol is also referred to as Secure Shell and is a method that allows secure remote login from one computer to another, protecting the communications between them with strong encryption [2]. The SSH connection allows a user to access the target server, with the protocol's dependencies, and having full access to the server, independently of the purpose the login was made with. Since the user would have one account to login, this account would be used to perform the actions the user needs. These actions cannot be tracked since the user has access to the entire server, after the server's rules are in place [4]. This solution is feasible for a user that must perform generic actions to the server itself, for example, a server administrator; however, when considering any other employee, this user does not need access to the entire server to perform his work [4].

Considering the protocol behavior, below are some upsides to the usage of the SSH Protocol connection component:

- It gives server administrators the access they need to perform their work, with the traceability the company requires.
- The tools within the server are usable, which gives users the access to their respective tools.
- Different accounts per target server allow for the application of the least privilege principle, while also minimizing lateral movement.

Some downsides to the usage of the SSH Protocol connection component are present below:

- Most users have access to tools/controls they do not require.
- Users can retrieve information that is not relevant for their work.
- Giving unrestricted access is a security breach that cannot be allowed in the company.

RDP CyberArk also has RDP as a default connection component. It works similarly to the previously mentioned SSH Protocol; however, it provides the user with a graphical interface version of the target computer. This connection is made over a network connection, allowing a user access to have total control over the target computer [7]. This connection is preferred for users such as a server administrator, since these would have access to all the required components on the target server, however, when thinking of a database user, he does not need to have access to the entire server to perform his database actions. The goal for the latter user would be to have a connection directly to the database application, and this is also the goal on the auditing side. This solution gives more traceability and removes the possibility for users to cause harm to the companies, since they only have access to the resources, they require to perform their work [4].

Considering the protocol behavior, below are some upsides to the usage of the RDP connection component:

- Gives server administrators the access they need to perform their work, with the traceability the company requires.
- Allows access to local windows administrative accounts, as a last line of defense in case all other avenues of connection get compromised.
- Different accounts per target server allow for the application of the least privilege principle, while also minimizing lateral movement.

Some downsides to the usage of the RDP connection component are present below.

- Difficult to regulate access on target systems.
- Malicious users can attempt to exploit the operating system's vulnerabilities, with the intent to move laterally in the domain.
- Giving unrestricted access to the server's software/services increases the vectors that can be exploited.
- Not possible to log inputs directly to the monitoring database.

SQL-Plus SQL-Plus is an application used by database administrators to manage BMW's database information. This application is already available by default with the current CyberArk version and is integrated in all environments [5]. SQL Plus is the application's supported Oracle database management application. This connection is the preferred solution for the initiative since it isolates the server from the application. Using this connection, the user only has access to the database he selected, and not the server where this application was started. This means that the user has access to all the tools necessary to perform his work, while not having access to any of the server's information. This is an improvement to the previous connections, the SSH and the RDP connections [5]. The SQL-Plus connection component initiates the SQL-Plus application, with the account selected in the PVWA, with the address defined in that account as the target address. This means that only one database connection can be open at a time (in the same application). Improvements to this issue are currently under discussion; however, CyberArk does not support multiple database connections at once.

Below are some upsides to the usage of the SQL-Plus connection component:

- It gives database administrators the access to the required databases.
- The tools are isolated from the server.
- Full traceability of all actions performed on the application.

Some downsides to the usage of the SQL-Plus connection component are present below:

- Only one connection can be made at a time, which changes the usual workflow for the database admins. These users are accustomed to opening connections to all the known databases and swapping addresses within one singular application.
- Not intended for complex/multi-line queries, as SQL-Plus is used for simple single line queries.

Toad Similarly, to SQL-Plus, Toad is a tool that allows its user to manage the corporations' databases. This application is also integrated by CyberArk; however, it does not work with the configurations made on BMW's servers. Due to this reason, the team had to make some changes to have this connection component operational [6]. Like the former, this method of work is the preferred solution for the initiative since it isolates the server from the application, which means the user only has access to the information present in the application and not any other internal information that does not relate to his line of duty. The Toad connection component initiates the Toad application, with the account selected in the PVWA, with the address defined in that account as the target address. This means that only one database connection can be open at a time (in the same application). Improvements to this issue are currently under discussion; however, CyberArk does not support multiple database connections at once. This connection component was changed to have a secondary RDP connection that would connect to the application. This is not the native application that the users desire; however, the connection was not working properly due to an RDP issue.

The issue was caused by a known RDP dependency, where the execution that is occurring within the RDP window stops whenever this window loses focus. This meant that when users would change to another window to perform other actions while the connection component loads, as sending an e-mail, the connection script would stop execution, since the focus was lost. This was fixed by having another RDP window encapsulate the Toad application.

Below are some upsides to the usage of the Toad connection component:

- It gives database administrators the access to the required databases.
- The tools are isolated from the server.
- Full traceability of all actions performed on the application.
- Query sheet allows for the creation of more complex queries.

Some downsides to the usage of the Toad connection component are present below.

- Only one connection can be made at a time, which changes the usual workflow for the database admins. These users are accustomed to opening connections to all the known databases and swapping addresses within one singular application.
- The connection component opens an RDP window to the application, which is not the native application that the Oracle users are accustomed to.

Table 1 Connection components current state

Product	Integrated by CyberArk	Required improvement	Developed by team
SSH	✓		
RDP	✓		
SQL-Plus	✓	✓	
Toad	✓	✓	
SQL-Dev			✓
OEM			✓
RMB			✓

3.2 Current State after Development

As mentioned on the previous section, some of the connection component had to be altered to be usable by the clients. This adaptation is the objective of this initiative and the focal point of this report.

This section presents a summary of the previous section, with a table that shows which connection components are integrated by CyberArk, which had to be updated to work on BMW's infrastructure and which had to be completely developed from scratch.

In Table 1, it is visible that even the components that were available through the base version of CyberArk encountered issues when attempting to on-board them into BMW's infrastructure. These applications required some further investigation made by the development team on possible ways to integrate them with the current environment and even improve some details on how the connection is performed. Even though this still has not forced a connection component to be created from scratch, a lot of the base process of the script had to be re-imagined. Are also illustrated, some connection components that the team developed from scratch, either because there was no product available on CyberArk or the marketplace, such as the OEM (Oracle Enterprise Manager) and the RMB, or because the request made by the client had some specific details that could not be answered by the components available, for example, SQL-Developer and RMB connection components.

4 Implementation

The team releases a working product on a two-week-based sprint rotation, which is planned just before the sprint begins. This product is based on a sprint goal, and the team follows this goal to deliver the best iteration possible. This sprint rotation also gives an overview of the developed work, which is the reason this section displays the implementation description using a sprint-by-sprint basis. Each sub-section contains information regarding the sprint's goal, along with the product(s) increment(s) that was developed during that time box. The sprint separation also

Table 2 Sprint timeline

Sprint	Start date	End date	Goal
1	4th of March	18th of March	Automate the bank auditor test
2	18th of March	1st of April	Creation of procedures that stakeholders would follow to request a connection component
3	1st of April	15th of April	Creation of a roll-out procedure Preparation for the creation of connection components
4	15th of April	29th of April	OEM connection component creation
5	29th of April	13th of May	Creation of the RMB configuration file
6	13th of May	27th of May	Creation of the RMB connection component

Fig. 5 Sprint 1 timeline

Fig. 6 Sprint 2 timeline

Fig. 7 Sprint 3 timeline

Fig. 8 Sprint 4 timeline

gives a complete view over the issues found within the development and how they were resolved (see Table 2).

After each sprint section there is a timeline graph, Figs. 5, 6, 7, 8, 9 and 10, to depict the work that was performed during that sprint.

Fig. 9 Sprint 5 timeline

Fig. 10 Sprint 6 timeline

Sprint 1 This sprint's goal was to automate manual tests found in the Jira test repository. This chapter focuses on the test that automates the verification of user permissions, namely, the bank auditor. The bank auditor is a user that only has access to specific safes, determined by the safe's name. For auditing reasons, there is a need to create tests that confirm that a bank auditor cannot access safes that do not respect their safes' naming convention. Due to this, the first step was creating the minimal requirements to implement the test. Under this category fall creating a test user that mimics a bank auditor as a CyberArk local user and rewriting the manual test as a Cucumber test using Selenium.

This test would initially log into the PVWA using the test user and verify the user only had access to safes that match the bank auditor safes' naming convention. This proved to be insufficient since the user having access to a safe does not co-relate to him having access to that safes' recordings. Due to this impediment, the test was changed to check the auditor page for the safes the auditor can access. With this approach, Selenium would need to click each audit and verify what safe it corresponds to, which is not feasible for the current scale of the project since thousands of audits would need to be checked. To counteract this issue, an investigation of CyberArk's API was initiated, which came back with possible solutions.

The API can be leveraged to return a list of safes that correspond to the audit safe the user has access to: solution that proved to be more efficient than the previously designed one. The API required an authentication token that corresponds to the user's session key, therefore the API was also used to authenticate this user. The session key was returning a JSON file, JavaScript Object Notation, without any attributes, which made it difficult to process the response dynamically. To proceed, the response was directly stored in a variable, which would contain the session key. This variable needed to be treated, since the response came with extra quotation marks that had to be removed. After the session key was properly implemented, and the API call to retrieve the recordings was complete, it was evident that the API call did not return the safe the user has access to, instead showing the safe where the recordings are stored. To complement this issue, the recordings were stored in safe that was not respecting the naming convention. All recordings were being saved to a global safe, which is the default by CyberArk, making it impossible to filter what safes the auditor has access to. Due to this issue, recording configurations had to be changed, assigning a recording safe that respects the naming convention to all bank safes. With this change, it was possible to filter what safe recordings the user has access to. After this information was altered, the test would filter all the recording safes' names and verify they only belong to the bank auditor group, by using the safe naming conventions. This allows the test to assert the user can only audit bank safes and cannot access recordings from other safes. If the previous assertion is true, then the test would pass, failing otherwise.

Sprint 2 The goal for this sprint was to create procedures the stakeholders could follow when they required a connection component to be altered or created. These procedures are described in the solution design section of this chapter; however, this section displays the methods used, alongside the investigation that took place to create the procedures. The intent of these procedures is to facilitate the interaction between the development team and the stakeholder, by reducing the amount of meetings required to start the work process. This benefits the development team by speeding up the requirement gathering process, and it also benefits the stakeholder, since the reduced traction in gathering information leads to a smoother start and development. The first target of investigation was customer support solutions, namely, automated ones, as well as the requested minimum requirements necessary to start the support process. From this investigation surged the creation of a database that contains all the current on-boarded connection components, to automate the process for the stakeholder. Furthermore, the procedures that BMW already has in place were investigated to adjust the team's needs with what the stakeholder is accustomed to, namely, to request a server, such as windows or Linux, and to request the on-boarding of a new employee. Since the stakeholders would be other BMW employees, it was considered that they are aware of BMW procedures, therefore leveraging this seemed a plausible solution. This investigation resulted in the necessity to request the project ID (Identification number) of the requester, to understand their product needs for such request. This project ID can also be used to order the requests in terms of urgency.

Lastly, the necessary requirements to upgrade or develop a connection component were investigated. For this investigation, potential stakeholders were contacted with the intent of gathering the preferred ways of contact, which became e-mail in the short term, having the self-service portal as the end goal for all future requests. With the knowledge of previous work developed on the topic of connection components, it was decided that the product version, both current and requested to update, requested version for new connection components, and a test account would need to be provided as necessary requirements for the development.

After this draft was complete, the team held a meeting to discuss the minimum required information to create/update a connection component, from which resulted the final document that can be found in the Solution Description section, Sect. 3.1 Existing Connection Components.

Another topic worked on this sprint was the setup of a Jenkins server that would run the tests developed by the team. Some barriers rose due to the server being isolated within BMW's environment, not able to download dependencies from anywhere outside this environment. This was solved by re-configuring the proxy settings found in the Linux server. Once the Jenkins was up and running, hooks with bitbucket were set up, so the tests are run automatically on every merge from pull requests, to validate the functionality of the development that was merged. Plugins necessary to run the already developed automated tests were also installed, namely, Cucumber for Jenkins. With Jenkins and Bitbucket connected, the credentials used for the tests were added to Jenkins' credential database, and the Jenkins file was edited to use these credentials as environment variables.

Test accounts for all tests were created locally in CyberArk and the necessary BMW servers, namely, Jira and Bitbucket. Afterward, the feature files for the Cucumber tests were not being stored properly, causing issues when running the tests via Jenkins. Since the feature file is dynamically downloaded from Jira whenever Jenkins starts the execution of the tests, the folder that would contain this file did not exist, since Git deletes empty folders. This was causing an issue that was not directly spotted since there are different types of feature files, the ones located in the source code that are used for development testing and the ones outside the source code that would be downloaded into the folder and are used for automated testing. A dummy file was created to prevent Git from deleting the feature files folder.

Lastly, when the Jenkins configuration was complete, it was demonstrated and explained to the entire team.

Sprint 3 Sprint 3 focused on researching procedures that have to be followed by the development team. This report details the roll-out process of connection components, the discussion about new connection components that are necessary, and the code conventions that the team follows. To create the process for connection components, roll-out, an investigation of possible ways to roll-out the connection components was initiated. After a connection component is developed, it needs to be rolled-out into the multiple existing environments, and minimum requirements need to be met to start this process. Multiple BMW procedures that were already in place were investigated to create these requirements.

After the BMW procedures were investigated, the team focused on the roll-out method that CyberArk recommends. This is found in CyberArk's documentation, documenting the process that should be followed to roll-out a created connection component onto various CyberArk components. The team adapted this documentation, using it as a skeleton for future roll-out procedures. Each connection component has to be created, tested, and documented. Part of this document guides the stakeholder on how to rollout the connection component onto the necessary environments, as well as the changes that need to be made. This document is custom made for each connection component and is part of the acceptance criteria of each connection component user story.

The team had a meeting to discuss the requirements mentioned above, resulting in the final document, which can be found in the Solution Description section, in Sect. 3.1 Existing Connection Components.

During the sprint, the team had multiple meetings with possible stakeholders that required a connection component for their solution. The first stakeholder was the OEM (Oracle Enterprise Manager) database team, which requested that the OEM was integrated with CyberArk. CyberArk's environment was already configured with all the databases found in OEM, therefore only the OEM had to be integrated. The OEM team conducted a short demo, showing what their workflow was at the time of the meeting. OEM is based on a web application; therefore, the connection component would need to open a browser and navigate to the login page to authenticate the user. This would show the user the main screen where all the databases can be found. If the user decided to authenticate into a database, he would need to click on the specific database, which would require another authentication to that database. The team refined this request after the meeting, creating multiple user stories for this issue, namely the creation of the OEM Login, a form detector to detect when the database form is visible and the authentication to the previously mentioned database, when the form detector is triggered.

Another request was made by the administration team regarding the creation of a mRemoteNG connection component. The normal process of the stakeholder's work is making multiple RDP (Remote Desktop Protocol) connections to multiple servers, for which they use the tool mRemoteNG (multi-protocol remote connections manager). A presentation of the current usage of the PAM tool was made, to which they requested the integration of the tool mentioned above, to preserve their regular flow of work. This request was also refined, leading to some spikes to understand the feasibility of adding mRemoteNG to the environment, as well as how the integration would be made. Two topics that were discussed as possible solutions were the usage of the RDP Proxy, which would only affect the URL (Uniform Resource Locators) the stakeholder would use on his RDP connection or integrating the application onto CyberArk. Both solutions required more information, since the first would have great effect on the current structure, while the latter led to some concerns with how the user would keep his personal customizations on the application. The last issue developed within this Sprint was the creation of the AutoIt code convention. This was based on the conventions suggested by the AutoIt team and was adapted to fit the team's needs. Any AutoIt code present in a pull request has to follow these conventions, and it is the team's responsibility that this is the case. The document was reviewed and presented to the team.

Lastly, the team investigated linters to integrate onto Jenkins to speed up the review process; however, no linter met the team's requirements.

Sprint 4 This sprint's goal was the creation of connection components for the stakeholders that requested them in the previous sprint. This report highlights the work developed on the OEM login connection component, as well as the issues that arose with its configuration. Lastly, this connection component had to be tested, which was the team's first Robot Framework application. Initially, the AutoIt script was developed locally, navigating to a web page, the OEM address, and inputting the credentials of the user onto the login form. After the forms are populated, the script submits and performs the authentication. Furthermore, the script must be exported to the PSM, to use CyberArk's components, so it can be used as a connection component. The DLLs (Dynamic Link Library) provided by CyberArk for connection component creation were used, retrieving the credentials from a connection request and using these for the authentication. At this point, the script was tested locally on the PSM and was working as intended. The code was then formatted to respect the team's code conventions, and the script itself was complete. With the script complete, the team followed the roll-out procedures to allow CyberArk to use this new script as a connection component. For this, the PVWA had to be configured to accommodate for these changes. The on-boarding process was followed to on-board this connection component onto the test environment. The script was compiled with administration privileges; the hardening process was executed with the executable file's hash, so it is an allowed application.

The connection component was also created in the PVWA settings and associated with the correct platform, Oracle Enterprise Manager. After these steps were followed, the user has access to the new connection component, however, the application, Internet Explorer, was not starting whenever the script was executing. After investigation of the error events, they demonstrated the user did not have permission to execute Internet Explorer. The user that runs this application on the PSM is a user called shadow user, whose password is only available to CyberArk.

From the previous conclusions, the next step was to use the admin account to reset the local shadow user's password, to verify its permissions on the PSM server. All the permissions were correct, and he was able to successfully run the AutoIt script locally. Due to these discoveries, the error would need to be the AppLocker not considering Internet Explorer an allowed application. This assumption was correct, however, the error persisted. The new errors were investigated in CyberArk's error page to no avail; therefore, the event logs were verified. The event logs displayed some errors loading DLLs when the shadow user attempted to initialize Internet Explorer. Adding these DLLs to the allowed applications in the AppLocker file, and executing the hardening process fixed the errors, allowing the connection component to be executed successfully. The Internet Explorer itself was also hardened, with minimal customization, only a single tab available, and removing the ability for the user to change the URL. With the connection component complete and entirely integrated on the test environment, the tests were the next step to finish the user story.

The robot framework test used an API call to retrieve the RDP file that would use the OEM Login connection component. This RDP file was properly obtained; however, when executing the file, the test would wait until the entire execution would end. During the execution, a prompt would appear asking if the user would want to proceed with the connection to the end point, hence blocking the execution.

Since the test was being blocked, it was not possible to click connect to proceed. Multiple robot framework keywords were tested to run the RDP file, but to no avail. A command prompt keyword was also run to start the RDP connection but with similar outcomes. Since robot framework is based on python, functions created in python can be used in robot framework as a keyword. Due to this, a python script was created to run a command that executes the RDP file. Since this script did not wait for the execution to be over, the test was not paused and the button to connect could be interacted with, but it had to be dynamic, which led to the use of image recognition libraries. Image recognition library Sikuli was installed and used to click the connect button; however, it was unsuccessful. The connection keyboard shortcut was used to connect (Alt+n), however, an image recognition library was still necessary to assert the connection component executed properly. Multiple image recognition libraries were experimented with, the final choice being the Image Horizon robot framework library, that compared screenshots to assert the result was as expected. With the integration of the library, the test was complete and assertion was successful. The integration of this library also allowed the test to be dynamic, by waiting until an image appears on the screen to execute a step, removing hard coded waits. Lastly, the complete connection component and respective tests were demonstrated to the team, and a discussion on the next required steps to complete the OEM database issue took place.

Sprint 5 The goal for sprint 5 was to initiate the roll-out process for the connection components. To reach this sprint's goal, this report presents the work developed to create the RMB connection component, namely, the configuration file that will be used by it. Due to the design the team agreed on, a singular connection component needs to dynamically authenticate a user independently of what vendor the RMB belongs to. The authentication pages vary from vendor to vendor, therefore the team decided that having a configuration file, with all the information required to perform the authentication, is the best solution. The connection component needs to travel to the target address, a web page, and needs to retrieve the vendor that page is from. With this information, the configuration file is used to retrieve the form information relative to the specific vendor. The RMB configuration file layout was discussed, with the objective being a XML (Extensible Mark-up Language) file that allows the connection component to dynamically access the username and password fields of the RMB web login form. This configuration file was developed, displaying the username and password fields for each of the RMB versions/vendors. Most of the vendors' fields could be obtained by searching for a unique id, except for iDrac version 9 that could only be obtained by using the name parameter. The name parameter used is unique for all the iDrac version 9 iterations. Once the configuration file was finished, a robot framework test was created using the Selenium library to access each RMB's endpoint. This test initially retrieves the expected element from the XML configuration file and asserts that the attributes for each vendor is correct. Afterward, the test launches a browser that navigates to the vendor's endpoint and searches for the fields, username and password, configured in the XML file. The test does this for every vendor, asserting that the configuration file is properly storing each of the RMB's login properties.

After running the tests, only the HP RMB was failing. This issue was investigated and it was discovered that Selenium could not find the login properties since they were inside a frame. The Hp node was changed to contemplate this discovery, adding information regarding this frame, allowing the test to first navigate to the frame and then search for the login attributes, making the test a success. With the test finished, it was refactored to meet the team's code convention, and later presented to the team.

With the file configuration approved and closed, the next step of the sprint was to integrate the CCP (Central Credential Provider) with the previously created OEM connection component. The latter part of the OEM connection component that performs the login to a database will need to access credentials from other accounts on-boarded onto the CyberArk environment. To do this, CyberArk possesses a feature named CCP that allows an application, in this case a connection component executing on the PSM, to request access to an account. To use this feature, the application performs an API call requesting the credentials of an account, stored in a safe, that will be processed by a specific CCP instance. The API is authenticated using the operating system's credentials; therefore, it can only be performed by a server that is within CyberArk's components.

Based on the investigation results, to test the CCP, an application would need to perform the API call. To do this, a custom connection component was created to perform this experiment. The experiment output was successful; however, the output was a file that could not be used to retrieve login credentials. After further investigating the CCP configuration on the PVWA, it was detected that there were no trusted hosts configured. This was causing the API call to return an untrusted host error. Once the host that calls the API and the servers where the CCP is configured were properly setup as trusted, the application was able to return the account's information, including the credential that was required. While working on the OEM connection component that uses the CCP application, a bug on another feature was found. The team had previously developed a script that travels to an environment, namely to a specific component, retrieving the configuration files from that server. It does this for two different environments, for example, test and integration. Most of these files are either XML or in configuration. Once these files are retrieved from both the environments, the script would initiate the comparison section, comparing each file and outputting the differences between the files. The issue occurs with the comparison of XML files. The script checks each node individually, storing the nodes' names and comparing the parameter of each node with the respective node found in the other file.

When there were duplicated parents or nodes with attributes that were different, the script would fail to confirm the difference. Below is a replication of this error:

```
File 1
<Object Name="Server 1" System="Windows"/>
<Object Name="Server 2" System="Linux"/>
File 2
<Object Name="Server 1" System="Windows1"/>
<Object Name="Server 2" System="Linux1"/>
```

This example should return that the system attribute is different between the files; however, it would not output any error, since the script would only check if the node "Object" appeared twice, and that the name attribute is the same for each object. The fix that was issued was to use the entire Xpath of the XML nodes, since they are unique to the information that they contain. This makes it evident where the differences are, and the user is able to clearly navigate to the files and perform the necessary changes.

Sprint 6 This sprint's goal was to complete the creation of the RMB connection component requested in the previous sprint. This report highlights the work developed on the webpage identifier for the connection component, as well as the issues that arose with its development. Lastly, this connection component had to be tested, which was based on the previous Robot Framework application.

Initially, the AutoIt script was developed locally, navigating to a web page, the RMB address, but was blocked by a certificate error page. To bypass this, a function was created that would check if the page were a certificate error page, by checking the text that is found on the page. If this function is triggered, the script clicks the "Proceed to the next page (not recommended)" link, bypassing the error page and entering the target web page. This is not the intended workflow; however, to complete development with the current state of the RMBs, this was the approach taken. Once the certificate error was bypassed, the login page for the vendor would open. Since there are five different vendors, HP/Lenovo/iDrac7/iDrac8/iDrac9, and the connection component was designed to be dynamic and work with any vendor, it would need to retrieve which vendor the login form belongs to. To retrieve this information, the title of the page was used. On every vendor, the title would show the vendor's name, except for Lenovo that would not have a vendor name. Since there is only one exception, this method was valid. With this approach, the page would need to be loaded to retrieve the proper title. This causes issues when looking at previous connection components, where the load times were higher than normal, due to how the proxy communicates with the target system. This was mitigated by using an AutoIt function, IELoadWait, that waits until a page is loaded. It is only a mitigation because most of the webpages for the RMBs also have JS scripts running after the page is loaded, which causes changes to occur after the loading, for example, title changes. Even though this is an issue that impacts how the script acquires the page information, and the JS scripts execution vary between vendors and connections, a listener was added to the connection component that would wait until the script reached timeout, about 60 seconds, or until the title information was populated. When this field was populated, it meant the JS script had finished executing. It also allows the script to retrieve the page's title, to acquire the vendor type, using the developed method. Up to this point, the script can open the browser, navigate to the target address, skip any certificate errors that might appear, load the login page, and retrieve the RMB vendor using the title. The issues now arise when looking at specific vendors.

Starting with HP, it is the only web page that has a frame covering the login elements. Since the login is dynamic and does not change depending on vendor, a solution would need to be found to keep the same login style for all vendors. This is still feasible since AutoIt uses objects to make calls to the Internet Explorer library, and instead of sending the browser object that does not have visibility over the login elements, the frame object can be sent, which gives the script visibility over the desired elements. The only change that had to be done was a verification of what information the previously developed config file contained. If this configuration file populated the script with information related to a frame, then the object to be sent would be the frame object, otherwise the browser object would be used to perform the login.

Following Lenovo, when the page is loaded, the server runs a JS script, which blocks the login fields. This causes a problem when attempting to set the values for the login; however, since the parameters had a state of "disabled," it was possible to halt the connection component execution until the JS script is terminated. This wait also helps all the other vendors, since it makes sure that the parameters are enabled and can be populated. Once this verification is complete, the parameters can be populated, and the login can be performed.

Considering the vendor iDrac, there are three different versions, iDrac7, iDrac8, and iDrac9. Starting with iDrac7 and iDrac8, these have the same base framework but have small intricacies, causing some minor issues that need extra attention. They function on the same base script as the previously mentioned vendors; however, iDrac8 has a longer connection time, which forced the team to increase the timeout of the execution. Apart from this minor issue, the current script responds to both iDrac7 and iDrac8 necessities. With iDrac9, there are quite a few differences. Initially, the parameters cannot be accessed through identifier, therefore the configuration file has information regarding the names of these parameters. The button is also disabled until there is input on the login fields. Normally, the script sets the value for the field, which does not count as inputting the values on these login forms. To unlock the button, the values must be written in both the username and password field. A loop was created that writes values onto these fields, until the disabled value of the button returns false, meaning the button is enabled and the login can be performed.

Similarly, to other previously developed connection components, the AutoIt script was developed locally, navigates to a web page, detects which vendor the page corresponds to, and inputs the credentials of the user onto the login forms according to the configuration file. After the forms are populated, the script would submit and perform the authentication. The local script was then configured to work via the PSM, with the necessary hardening and PVWA configurations. The script ran with minimal bugs, caused by very specific and hard to recreate circumstances. After these bugs were dealt with, the connection component was considered complete.

5 Results

At the end of every development process, the team has a procedure in place to evaluate the quality of the solution. The stakeholder's needs must be considered when evaluating the increment created, and this feedback is crucial when the product is reviewed.

There is also a company internal tool that evaluates if an increment opens a vulnerability; however, it was not mentioned in this chapter due to how CyberArk extensions are created. From a technical standpoint, CyberArk extensions are an automation of operating system calls, and the end user only has access to the exact process that the application is running on. This means that the custom code does not add any vulnerability if following the recommended standard of only giving access to the target application process.

As end users only have access to the target application, it limits the avenues of attack vectors that attackers can exploit. It is therefore of utmost importance that the applications are patched as they are the ones that can be exploited. Target servers should also be kept as isolated as possible, as to avoid lateral movements from possible attackers; therefore, it is recommended that each account only has access to one server.

Accounts should also be configured to be used exclusively, which means that only one user can use a specific account at one time. This would require more accounts per server so multiple users can work on a server at once; however, if this configuration follows the standard mentioned previously of each account only accessing one server, then the system is still secure.

Automation of platform tests, it was discontinued due to business reasons, but some tests were automated. These tests are displayed earlier in this document, and progress towards this objective assisted the team with the tests they currently create for their work, such as for the Connection Components.

The OEM connection component and the RMB connection component are both fully developed, tested, and integrated on the test environment, as well as in the process of being integrated on the other environments. They are also approved by the responsible parties. Technical information regarding these issues is present in the developed work section of this document.

During development of these objectives, some issues were found that could not be fixed. Starting with the connection components, due to the connection between the PSM and the proxy, the load times of the connection components is not consistent, which leads to using more computing power, since the script stalls until an event occurs, which is not the most efficient method of developing the script. This is a connection limitation and is in place, so the product always works. Due to its nature, this limitation will always be present.

Considering the RMB connection component, the certificate error page is currently being skipped, due to the certificates not being ready to be implemented following BMW standards, and therefore the proper workflow cannot be obtained. The connection component should not skip the certificate error page, it should stop the connection whenever the certificate is invalid. This is considered as future work for this connection component, although it will only proceed once the RMB team has the proper certificates configured, following BMW's standards.

There are also some test limitations, since end-to-end tests use graphical interface recognition technology, no movement can be made while these tests are being executed. This should not present an issue since they are run on a dedicated server, however, if this server must be updated or a windows pop-up appears, it might cause the test to fail. This is a very specific error case, and running the test again will make it have the desired outcome, be it a pass or a failure. This limitation might be revisited in the future, however, it is not currently considered in the scope of work.

With the implementation of CyberArk on BMW, and with all the increments presented on this chapter, 1500 additional teams are now using the privileged access management solution, which results in over 300,000 privileged accounts currently managed by CyberArk. All the accounts are now properly secured, following BMW password health policies and respecting German regulation in terms of financial accounts. The monitoring that CyberArk has brought to the company has also allowed BMW to pass the internal and external security audits.

6 Conclusions

The automation of tests is valuable for the development team, allowing them to understand possible weak points of the CyberArk infrastructure and how to improve these. It is also of value to the other teams in the initiative, giving them the same understanding and speeding up the testing processes.

The major contribution of this project to the company is the creation of connection components for the usage of the privileged users, keeping their accounts safe, without major changes to the environment they are accustomed to. This improvement will greatly increase the cyber security within BMW and lower the possibilities for data breaches.

During development, some issues were found. Due to the connection between the PSM and the proxy, the load times of the connection components is inconsistent, which leads to using more computing power, since the script stalls until an event occurs, which is not the most efficient method of developing the script. This is a connection limitation and is in place, so the product always works. Due to its nature, this limitation will always be present. Also, some test limitations, due to that end-to-end tests use graphical interface recognition technology; no movement can be made while these tests are being executed. If the server has to be updated or a windows pop-up appears, it might cause the test to fail. This is a very specific error case and might be revisited in the future.

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A Sustainable Framework to Manage Plastic Waste in Urban Environments Using Open Data

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1 Introduction

1.1 Motivation

Plastics are now polluting most of our urban and natural ecosystems. As stated in [1], the first evidence of plastic accumulation was found through the examination of the gut content of seabirds in the 1960s. Up until today, little progress has been made in reducing plastics but large progress in knowing the effects they have on the environment [2].

According to [3], the continuous increase of plastic waste in our cities can be harmful not only physically but also mentally, for example, with cases related to depression, anorexia, and restlessness, among others. Moreover, plastics are not usually controlled in some Eastern countries such as India and the Philippines. Thus, in India, 90% of solid waste including plastics is usually dumped in the open, but reusing plastics has been known as a positive reinforcement in order to lessen plastic waste in a community [4]. Recycling plastics through melting them and making a reusable product or using it for roads or as fuel is also a big help. However, it can lead to complications because of the incompatibility of the plastic polymers and their different melting points. There are solutions made available to help fix the problem of the accumulation of plastics. For example, as stated by [5], it is better if we throw our plastics in a landfill. On the contrary, [6] stated that landfill is the least

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