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Research methodology for industry-academic collaboration – a case study

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Abstract

When industry and academia collaborate within an applied sociotechnical research project, it generates a complex context due to different means, goals, languages, and emergent practices. The industry is interested in developing projects, maximizing profit, and satisfying its clients and customers. Academia is oriented towards performing research to understand, explore, optimize, and verify meaningful statements. Different goals, timelines, ways of working, languages, and resources create too many emergent practices and friction in the research execution. In this paper, we perform a retrospective analysis on a research project conducted over a year that focused on the current and future state in nine companies and evaluated its use of research methodologies. A finding is the need to have well-defined industry cases, and we suggest criteria for achieving this. Additionally, we see emergent practices and dynamic environments influencing the research process in industry and academic research context.

Keywords: research methodology; sociotechnical research; case study; Systems Engineering

1. Introduction

The elements in our world are connected and are dependent on each other. The complexity is higher than ever and is continuing to be more complex. Products are linked in an intertwined network of dependencies, and services are rapidly developing to satisfy their demanding customers. Fig. 1 shows an example of such an intertwined network of dependencies. The figure, i.e., Fig. 1, visualizes an elaboration of the characteristics of what Schätzet et al.[1] call CPS (Cyber Physical Systems) [1]. CPS is closely related to several concepts such as Big data and its analysis, Internet of Things (IoT), Systems of Systems (SoS), Mechatronics, and Embedded Systems. In other words, systems have cross-domain analyses. We also add the sociotechnical aspects within the additional three circles: *Human Social Organizational, Innovation Ecosystems, and Political* aspect [2].

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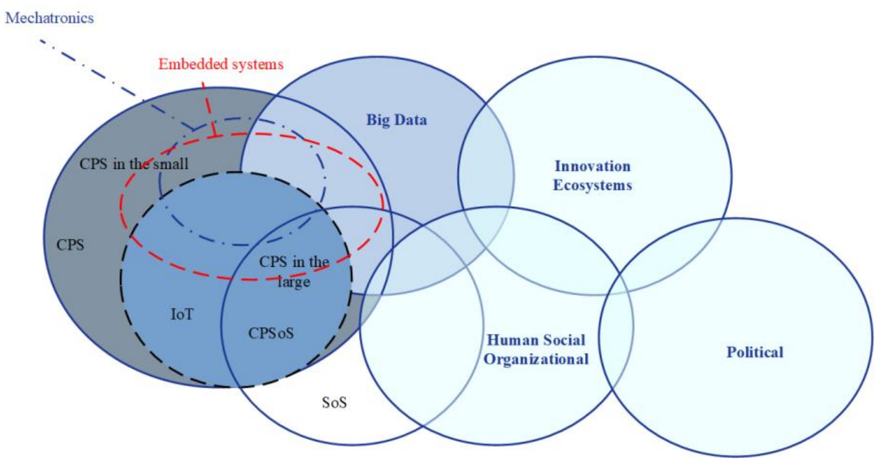

Fig. 1. Intertwined network of dependencies [1,2]

Systems are also adapting in a dynamic behavior to technical and social factors. Thus, there is a need for companies to explore new ways to maintain competitiveness. It is crucial for these companies to use the most effective methods and that these are sufficiently founded. A solution is to collaborate with academia and other companies within education and research.

One such initiative is a research project in the Norwegian high-tech industry for utilizing data in the early phase of product and service development. This research project is called “Harvesting value from Big data and Digitalization through a Human Systems-Engineering Innovation Framework” (H-SEIF 2). A research project where nine companies and two universities ensure that findings are thoroughly tested and based on research and best practices. These industries’ contexts are automation, autonomy, defense, financial technology, mapping data, maritime, subsea oil and gas, startup incubator, and innovation.

The H-SEIF 2 is a complex industry-academic research project that has various project objectives. To achieve these objectives, we need to know what research-based processes are appropriate to adapt as the H-SEIF 2 research methodology. We found the main appropriate research methods from expert input and the literature to be, but not limited to, Industry-as-Laboratory (IaL), Design Research Methodology(DRM), and Design Science Research Methodology(DSM).

This paper attempts to explain research methodologies and gain insight into the use of such methodologies in complex industry-academic research projects.

The industry is more interested in developing projects, and academia is more oriented towards research projects. Thus, when academia and industry collaborate within applied research, it generates a complex context. One of the pioneers’ frameworks that describes the different systems or projects within different contexts is the Cynefin framework.

1.1 Research project context based on Cynefin framework

The Cynefin framework is a sensemaking model[3]. This model is a decision-making framework for systems, organizations, or projects within a complex sociotechnical environment. The Cynefin model describes three types of systems-, i.e., ordered systems, complex systems, and chaotic systems. Further, the ordered system branches into simple and complicated ordered systems. There is a disordered domain in the center of the simple, complicated, complex, and chaotic contexts.

We consider the H-SEIF 2 research project as our system, and it is in a complex context regarding this model. In other words, H-SEIF2 is a project within a complex context (domain). The Cynefin framework aid in making sense

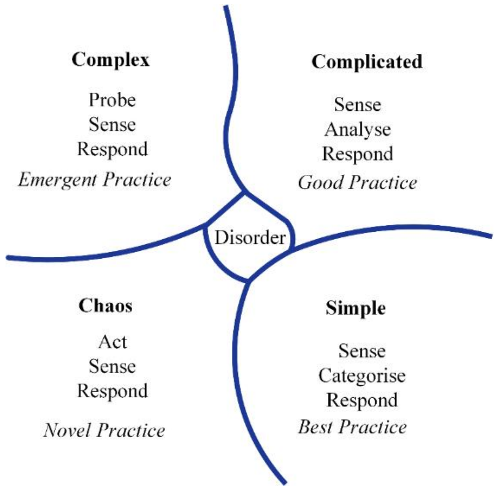

Fig. 2 The contexts of the Cynefin framework based on [3]

of the complex context and acting accordingly. Fig. 2 portrays the model that includes the following five contexts (domains):

- *Simple context, also known as "known knowns".* In this context, cause and effect relationships exist. Those relationships are understandable, repeatable, and predictable. In such a context, the system or project is self-evident for every reasonable person. The decision model is sense-categorize-respond. The simple context allows for a best practice for running a project. Good response in such a context is to watch what is coming in, match it with previously established categories, and then decide what to do.
- *Complicated context, also known as "Known unknowns"*. Cause and effect relationships exist but are not self-evident. Such relationships demand expertise. In other words, a project team needs an expert or an analytical method to solve the problems. The decision model is sense-analyze-respond. The complicated context allows for good practice.
- *Complex, also known as "Unknown unknowns".* Systems in this context have the cause and effect that are only apparent in hindsight, with the unpredictable, emergent outcome. Thus, the decision model here is probe-sense-respond. The project team needs to test and fail early within the prototypes or case studies and not the design of the case study. The project team tests the approach or methodology within a case study as its own then applies it further to other case studies when it is succeeded. Otherwise, the project team needs to test another methodology or approach. In other words, the project team needs to enhance a successful approach where the project team needs to suppress a not successful one. Complex context allows for an emergent practice.
- *Chaotic, also known as "Unknowables".* In this context, the project team cannot determine a relation between cause and effect. Thus, the aim is to retrieve the order in a project. The decision model is act-sense-respond. A project team or organization should react as quickly as possible to stabilize the situation. A chaotic context allows for a novel practice when the project team checks that this practice works.
- *Disorder*. In this domain, the situation for the project team is not clear to determine the project's context.

The boundaries between the contexts are transitions without effects except for one boundary. That is the boundary between simple and chaotic context. This border from simple to chaos is called "cliff" or "Complacent Zone". The danger within this boundary is that people start to believe that the project is in order where the actual case is that they fall over the cliff and into a crisis—applying this theory to a research project. A crisis could then refer to the failure of the research project—following that the desired research goals and objectives are not achieved.

1.2 Paper's Applied Research Framework

Applied research often starts by doing research and then converting the findings to a methodology[4]. An applied research project consisting of several industrial and academic actors will generate a complex context. The project will contain various means, goals, languages, and emergent practices. Without an appropriate structure of the research methodology, there is a danger for the project to be pushed into what the Cynefin Framework explains as a crisis.

This paper aims to identify what research methodology can be applied to a complex industry-academia research project, such as the H-SEIF 2 project, to reach its objectives and goals successfully.

The paper, therefore, has the following research questions:

- RQ1 - *What primary sociotechnical research methodologies are appropriate for Systems Engineering-focused industry-academic collaboration?*
- RQ2 - *How do these methods apply to the H-SEIF 2 research project.*

Our research approach is a retrospective analysis of a one-year current state industry study that utilized workshops, open-ended interviews, surveys, on-site observations, and analytical tools, with comparison and evaluation to the literature. We adapted the Applied Research Framework, shown in Fig. 3, as the research method of this paper[5,6]. The framework consists of the following steps:

Step 1: Shape line-of-reasoning. In this step, we express the line of reasoning following the structure of *Problem-goal-solution-rationale*. Additionally, we formulate the *research questions* more specifically based on the broad problem statement we express within the line of reasoning.

Step 2: Explore literature. We screened the literature within an informal literature review through the following sub-steps: *search* the databases, *select* the relevant articles, *read* the selected articles, and *use literature* within this paper.

Step 3: Experts' opinions. Expert's views, in this context, refer to the domain expert among the scholars within the research methods. Those scholars include academic staff, participatory scholars, and former PhD students who performed similar research projects. We *ask* experts, *interview* them informally, and include their *review* of the selected and applied research methods. In this way, we can *Identify* good, best, and emergent practices based on the experts' opinions. We conducted steps 3 and 2 as an iterative and not rigid linear sequential process. In other words, we ask the domain's expert, and then we screen the literature and vice versa. We have also conducted 2 & 3 simultaneously at some points.

Step 4: Determine the research design. We *continuously keeping notes* from the literature review and expert opinions. We organize these notes. Further, we save those notes using a common shared platform.

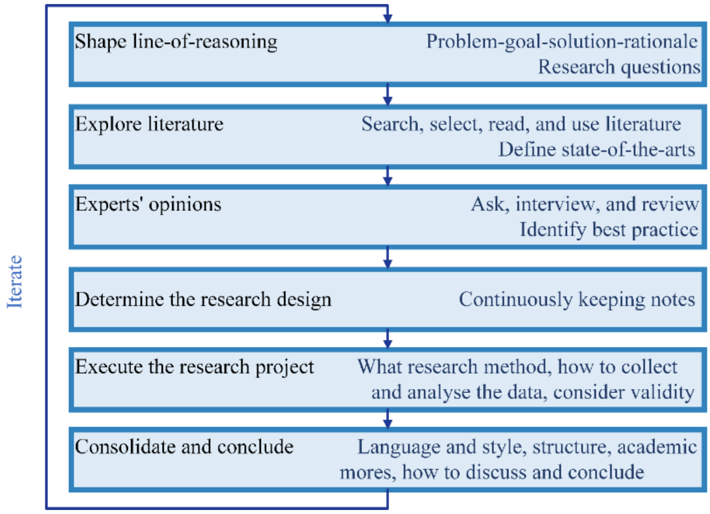

Fig. 3 Applied Research Framework modified from [5,6]

Step 5: Execute the research project. In this step, we used this process to gather relevant *research data* from the H-SEIF 2 research project, such as reviewing reports, minutes of meetings, calendars, workshop boards, and other stored information. We *analyzed* and mapped the notes, combined them into a timeline, and presented the notes as a storyboard. Additionally, the researchers compared their notes to the literature of research methods. Relevant academics *validated* the results consensual.

Step 6: Consolidate and conclude. Lastly, we review the language and style, structure, and academic writing incrementally. We send the written documents to the participatory scholars for early feedback. In this way, we aim to *discuss and conclude.*

We performed the above steps iteratively using different time boxes. For instance, we iterate on this framework first, using one hour for each box or step. Then we conducted both project and research activities. We iterate again using a more extended time boxing for each step or box until we reach a consensus view from the domain expert among scholars.

After this introduction, the paper presents the primary research methodologies, continues with a retrospective analysis of the research project. Further, the article states the findings and discussions before it concludes and suggests further work.

2. Literature of Research Methodologies

This section briefly introduces four research methodologies used in complex industry-academia research projects in a Systems Engineering (SE) context. These methodologies are Industry-as-Laboratory (IaL), Design Research Methodology (DRM), Design Science Research Methodology (DSM), and Case Study Research Methodology (CSR).

2.1 Industry-as-Laboratory (IaL)

Potts introduced Industry-as-laboratory (IaL) for conducting software engineering research[4]. Potts recognized the challenge of silos between research and actual implementation. The IaL research method suggests that the research work on a real industrial context as a test environment. The researcher should iterate and interact between the application problem domain and the research solution domain. The researchers should also formulate a hypothesis regarding applying a new method.

Further, researchers should apply this method within its real industry context. Then the researchers observe the results of this experiment or prototype and use its results to evaluate the hypothesis. The described process occurs incrementally, as Fig. 4 visualize. Muller[5] states that IaL is a suitable research methodology in SE research.

2.2 Design Research Methodology (DRM)

Blessing and Chakrabarti propose Design Search Methodology (DRM)[7]. DRM consists of four stages. These stages are *Research clarification, Descriptive Study 1 (DS1), prescriptive Study (PS), and Descriptive Study II (DS II).* Fig. 5 visualizes *these stages*, the *basic means* used for each stage, and the *main outcomes*. The bold dark blue arrows show the flow of the DRM in Fig. 5. At the same time, the dark grey arrows refer to many iterations. The DRM steps:

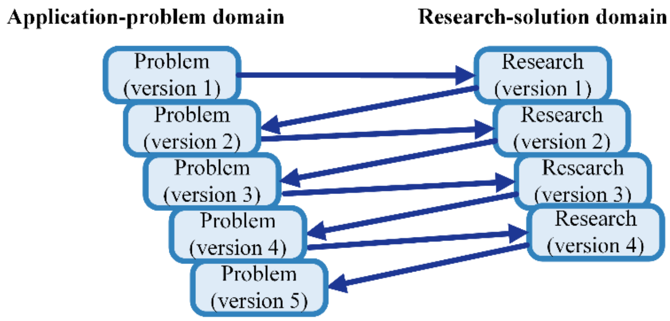

Fig. 4. Industry-as-laboratory based on[4]

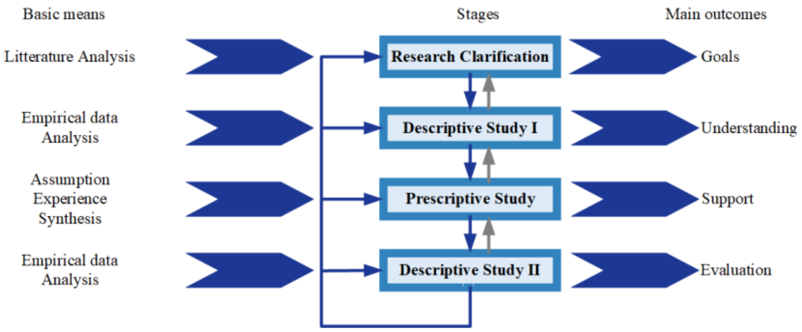

Fig. 5. Design Research Methodology (DRM) based on [7]

Research Clarification. In this step, the main outcome for the researchers is to formulate a valuable and realistic research goal. This formulation is done by searching and analyzing the literature. This analysis includes defining the factors that influence both project activities clarification and success and the factors that link both.

Descriptive Study I. The research aims at establishing a description of the current state, alongside reviewing the literature to define more factors that aid in more detailed clarification of the description. However, the researchers cannot find enough evidence in the literature, and therefore needs to interview key persons and observe practitioners within their context.

Prescriptive study. The researchers use their increasing understanding of the existing situation to validate and elaborate on the initial description of the future state. In this step, the researchers may vary some factors and understand how these factors are interrelated. For instance, one of the main factors is that a well-defined current state (problem definition) leads to fewer modifications and reduces project execution.

Descriptive Study II. In this step, the researchers investigate the impact of the support and its capability to understand the future state. Researchers select two empirical case studies to understand the actual use of the support. The first case study investigates the applicability of the software or prototype, whereas the second examines the usefulness.

2.3 *Case Study Research Methodology*

Case study research (CSR) is a research methodology[8]. *Defining a case* is the first of the three steps in designing case studies. The other two are *selecting a case study design* and *using theory in design work*. Fig. 6 shows a two-by-two matrix describing four different case study designs. These four different case study designs are: *multiple-case study holistic, multiple-case study embedded (include several Embedded Unit of Analysis (EUA), Fig. 6 visualizes EUA 1 & 2), single-case study holistic, and single-case study embedded*. Fig. 6 also portrays the fuzzy boundary between a case study and its context by the dashed line. There are various data collection sources, also called sources of evidence, in doing case studies. These sources include observations including participant and direct observation, interviews, and physical artifacts.

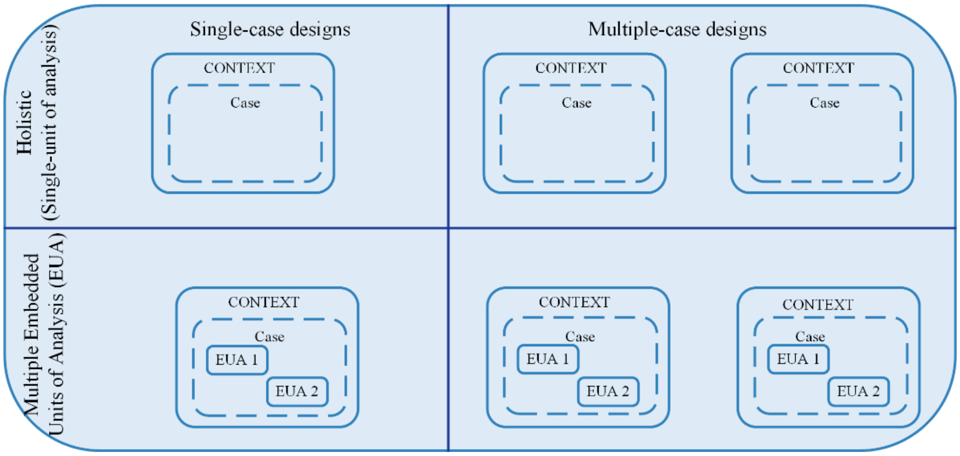

Fig. 6. Basic types for case studies based on [8]

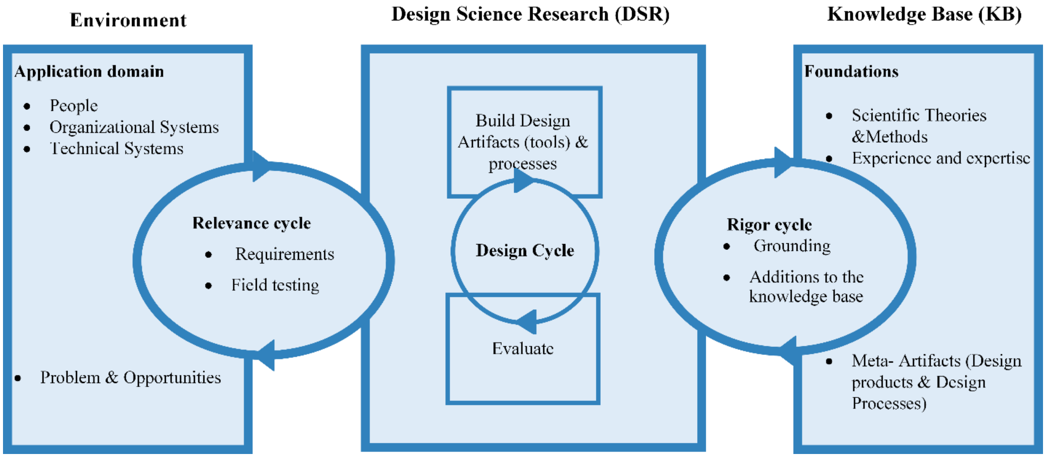

Fig. 7. Design science research methodology (DSM) based on [9]

2.4 Design Science Research Methodology

Design science research methodology (DSM) motivates to improve the application environment by introducing and implementing artifacts[9]. Here artifacts can mean things that occur naturally and things that are created including tools, process, or methodology. The three pillars of DSM consist of the *Environment, Design Science Research (DSR), and Knowledge Base (KB)*. The environment is the immediate application context. DSR is where the researchers perform design cycle iterations with KB and environment support. The KB is the foundation that supports the research through state-of-the-art literature and technology. A key part of DSM is the iterations and reflections practices in its research cycles, i.e., *relevance cycle, design cycle and rigor cycle* between the three pillars, as shown in Fig. 7. The *design cycle* that is central cycle for DSM solves problems in the environment domain by introducing, developing, or creating new artifacts based on knowledge and new design and tests them within its context.

An example is when a manufacturer struggle with the quality of its production, a new process (artifact) is introduced, but that process has only been tested in another context. The essence is to test it in its actual environment to determine its value. Additional iterations need to be done until the desired goal is achieved[10]. Scribante et al.[11] state that DSM is appropriate for complex sociotechnical systems[11].

3. A retrospective view of the H-SEIF 2 Research Methodology

This section describes each research stage executed in the H-SEIF 2 research project's first year. Fig. 8 visualizes a conceptualization of the research project. We had five research phases that included two to three project activities. We used various data collection methods throughout the project, such as meetings, interviews, workshops, literature reviews, surveys, and observations. We realized the need to update our research methodology during execution, highlighted as light red circles in the figure. Even though Fig. 8 presents the timeline as a rigid linear sequential timeline, there were, in reality, many iterations back and forth within the phases and activities. The activities had a close relation to the industry and their cases. For a detailed analysis of the cross-case studies, see[12] (Langen T, Falk K, Mansouri M. System Thinking for Big Data in Early Product Development - An Industry Study, unpublished data, December 2021), and a detailed case study, see [13] (Ali H. B., Mansouri M, & Muller G. Applying Systems Thinking for Early Validation of a Case Study Definition: An Automated Parking System, unpublished data, March 2022).

3.1 Organizing and Planning – The Research Plan

The H-SEIF 2 research project followed the H-SEIF (1) research project. It has the same academic partners but went from 4 to 9 industrial actors. A common denominator for the partners is their interest in SE. The first H-SEIF project investigated how to get empathy in technology. The H-SEIF 2 project extends this towards big data in innovation. *Organizing and Planning* constitute the first phase of the H-SEIF 2 research project with these steps:

1a. *Industry Consortium Establishment*: The partners agreed to joint research.

1b. *Research proposal and Funding*: The consortium established the proposal and achieved funding. The planned research methodology was to use IaL (Industry-as-Laboratory), emphasizing interviews and observations. In addition to the co-creation.

1c. *Project Start*: All partners met and discussed with kick-off meetings.

3.2 Current State Company

The second research phase had the purpose of understanding the problems and current state in each of the individual partner companies. This *Current State* phase included:

2a. *Industry Pre-Case Definition:* The project researchers arranged one-to-one meetings with all industry partners to pre-define an appropriate case study. The researchers agreed with each other on some criteria for well-defined case studies. These criteria include that the case studies: should be a part of an ongoing project within the industry partner, should be aligned with the overall research objectives, and should be a vital issue within the industry partners and have allocated the needed resources to collaborate with academia. We realized that DRM (Design Research Methodology) is well suited for our research in this step. This realization is based on literature review screening, expert domain opinions, and research nature. The key driver of the research nature is the need to connect theory with the case studies. This connection is also known as case-study design.

2b. *Industry Case Definition:* This step has its foundation from the findings from the previous step. The researchers met and prepared for a one-to-one online workshop with key persons for each proposed case study from the industry

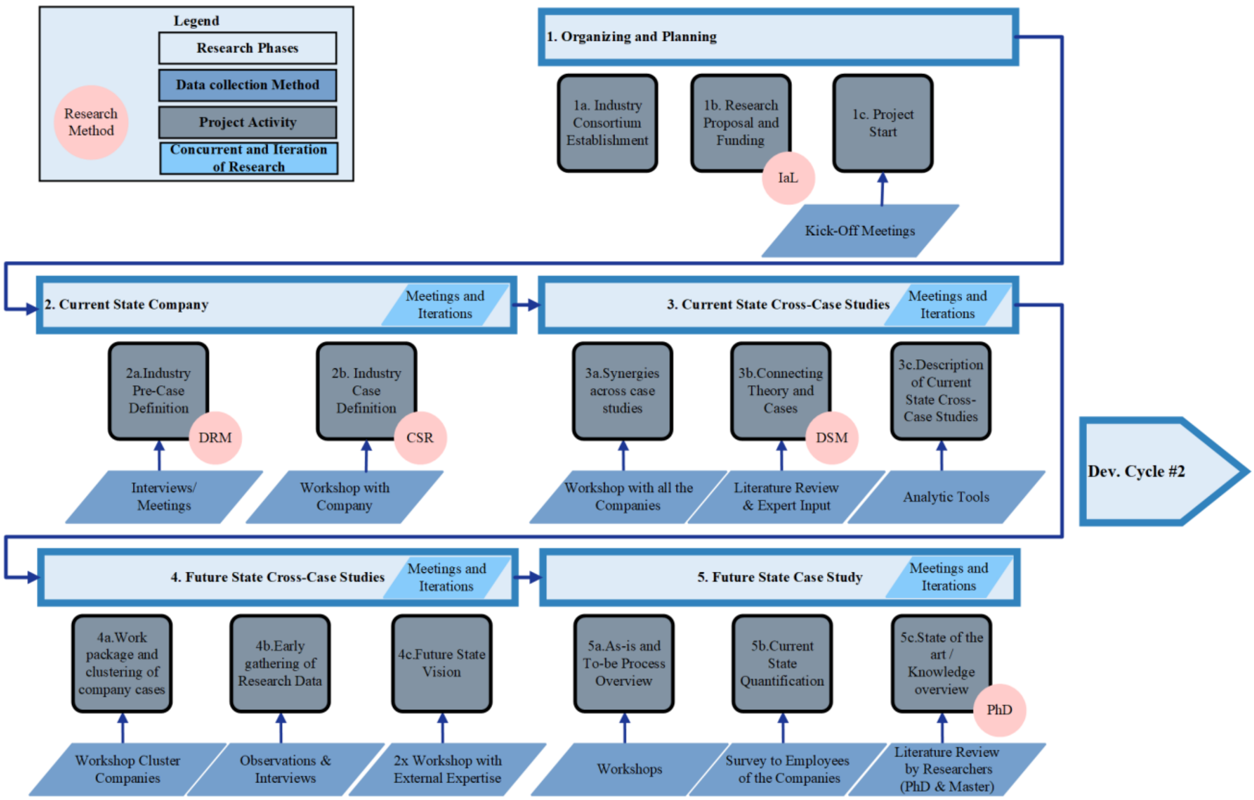

Fig. 8. A retrospective view of the H-SEIF 2 Research Methodology

partners. Some of the industry partners had several proposals for appropriate case studies. The researchers used digital interactive platforms such as Microsoft Teams, Zoom, and Miro. They structured the drawing boards using the SE (Systems Engineering), and ST (Systems Thinking) approaches, including their tools [14]. These tools included Stakeholder analysis, context analysis, visual canvas, and others. In this step, we added one more research method to our research method toolbox, i.e., Case Study Research (CSR). We needed to look closer at CSR to define a case, select a case study design, and use theory in design work. Yin[8] calls these three steps for designing case studies. We believe we have embedded multiple case studies (ref. Fig. 6)

3.3 Current State Cross-Case Studies

In the third research phase, we defined synergies across the case studies. Then we connected theory and case studies before describing the current state. This phase included:

3a. *Synergies across case studies:* Researchers attempted to identify synergies across the defined and selected case studies from several industry partners. Therefore, the researchers conducted workshops with all the companies. We used digital interactive platforms, mainly Miro. We had joint and separate sessions with two up to three industry partners (cohort). The researchers discussed the industry partners that constitute a cohort in advance, where they believe each cohort had synergy among each of their case studies. For instance, one cohort included a Company's case regarding Condition-Based Maintenance (CBM) implementation for their System-of-Interest (SOI). The other company within the same cohort had already implemented CBM and had a long experience implementing it. Thus, these two companies could discuss lessons learned and synergies across their case studies within their session together.

3b. *Connecting Theory and Cases*: In this step, the researchers aimed to connect the state-of-the-art literature with the current state of the different case studies. For instance, the researchers zoomed in at each case study's context and proposed a design for the needed artifacts tools within its context. Thus, we recognized a need to look and add one more research method to our research methods toolbox. i.e., DSM (Design Science Methodology).

3c. *Description of Current State Cross-Case Studies*: An emergent need from the academics was to analyze the previous steps' findings to understand how all the cases were connected and dig deeper into understanding the problem domain of each case study and its analysis units. Additionally, to validate the case study design early and generate a common understanding from academia and industry partners. We applied ST (Systems Thinking) and its tools through all the case studies and dug deeper into one of the cases. We created a context diagram to identify the stakeholders, systems, and environments and created CATWOE analytic tools to understand and communicate the purpose of the H-SEIF 2 research project. Understanding the problem domain of one of the case studies as our world view aid in more awareness of possible synergies across the case studies using H-SEF2 as our perspective.
See[12] (Langen T, Falk K, Mansouri M. System Thinking for Big Data in Early Product Development - An Industry Study, unpublished data, December 2021) for all case studies definitions, and see [13] (Ali H. B., Mansouri M, & Muller G. Applying Systems Thinking for Early Validation of a Case Study Definition: An Automated Parking System, unpublished data, March 2022) for more in-depth analysis of one of the case studies.

3.4 Future State Cross-Case Studies

The former phase revolved around finding the need and desired future as a collective. The project researchers used a top-down approach to find a vision and invest in future narrowed-down research. This *Future State Cross-Case Studies* phase included the following steps:

4a. *Work package and clustering of company cases*: Researchers clustered the case studies based on the synergy findings from the previous steps. These clusters were allocated to the project researchers. Project researchers include two PhD research fellows, one post-doc, and participatory scholars. We refer to the latter as project researchers or researchers in the text. Further, the project researchers generated master and bachelor theses under these different clusters. Each cluster included two up to three case studies.

4b. *Early gathering of Research Data:* This step was an activity for generating more tangible research data from the various cases. The primary means were visitations that led to on-site, direct and participant observations, workshops, dialogs, and open-ended, informal, and semi-structured interviews. Additionally, some companies delivered data from their products and systems for other researchers to analyze. This stage worked as verification to investigate potentials related to the stated H-SEIF 2 research project questions.

4c. Future State Vision: This step was conducted collectively over two workshops, and a third party was hosting these workshops. The external expertise (third party) had competence from systems-oriented design and gave us a neutral and fresh approach. The results were a common collective vision to motivate the H-SEIF 2 partners and grasp similarities that triggered further collaboration desires. The third party came up with the same researchers' results regarding the clusters and their case studies. This finding indicates that the third party's results validate the researchers' conclusions and findings.

3.5 Future State Case Study

The fifth phase focused on the research by isolating each company case. We did this by isolating the context to increase control by moving to laboratory settings. This *Future State Case Study* phase included the following steps:

5a. As-is and To-be Process Overview: This step enclosed mainly workshops with each company. The goal was to focus on the narrowed-down context and see both the current as-is situation and the future to-be vision.

5b. Current State Quantification: Researchers based the current state quantification on a more extensive survey issued to the partners' employees to answer questions related to the H-SEIF 2 research project goals. The project researchers used the results to get an insight into each of the companies and compare old and new results. This stage was misplaced because it took time gathering inputs and opinions from relevant people and getting employees to answer.

5c. State of the art / Knowledge overview: This step shapes the last activity within the first year of the research project. Here we took a step back and viewed the research executed in H-SEIF 2 and evaluated it to other research methodologies that operate in a similar context. Thus, we asked the research question (RQ 2), "*How do these methods apply to the H-SEIF 2 research project*". This research question resulted in the PhD research methodology that we present under the Finding and Discussion section (ref. 4.4) in this paper.

The above phases and steps constituted what we call *Development Cycle*. Development Cycle number 2 is the next main iteration in H-SEIF 2. All the phases and their steps are conducted in an iterative process even though Fig. 8 shows it as linear and rigid sequential phases and steps. Fig. 9 demonstrates our methodology for the development cycle as to how the iterations happened on a conceptual level from H-SEIF 2 perspective. The iterations at H-SEIF-2 level occurred according to the grey lines visualized in Fig. 9 where the bold blue arrows depict each project activity itself.

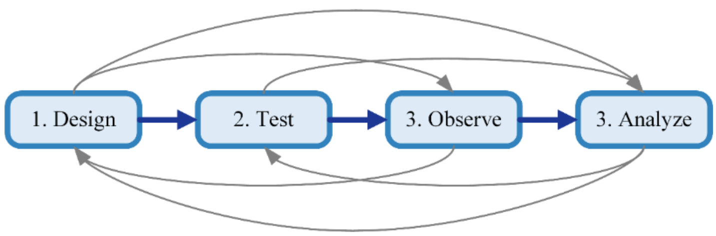

Fig. 9. The approach of conducting the project activities

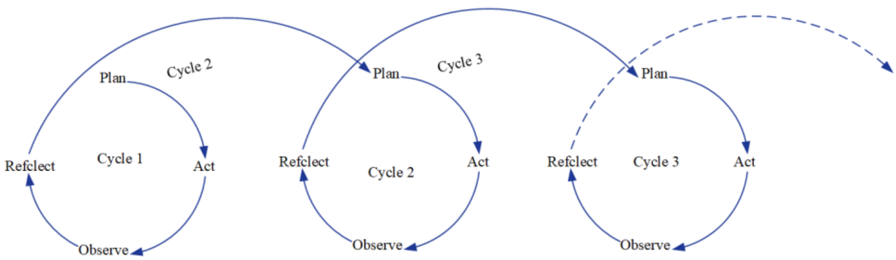

Fig. 10. Action research cycle: Plan, Act, Observe and Reflect

However, Fig. 9 is similar to Kurt Lewin's model. This model is an action-reflection cycle of planning, acting, observing, and reflecting. We adapt this model within our action research process. Fig. 10 visualize this model. We first *Plan* what to do, then we *Act* by executing the plan and collecting the pieces of evidence. Further, we *Observe* by monitoring, recording, and taking notes. Ultimately, we *Reflect* on what has occurred to improve further [15–17].

We also adopt Kolb's learning model for reflection [18,19]. We perform the action research cycle through several iterations. We mainly plan for at least three iterations. However, we believe that Lewin's model focuses more on the social aspect, especially "Act" and "Reflect", while Fig. 9 focuses more on the technical aspect. In our research, we investigate sociotechnical systems.

4. Findings and Discussion

In this section, we present our findings with discussions. These findings are the *Importance of Well-Defined Case Studies*, the *Emergent Practices and Dynamic Environments in industry and academic research context, Comparison of research methodologies,* and *Our research methodology* that we plan to adapt further.

We elaborate on our perspective on the findings and our research activities.

4.1 Importance of Well-Defined Case Studies

We observe that the several research methods have common aspects even though they use different terms for the same element. For instance, IaL, DRM, and CSR emphasize the problem definition, also called case study definitions.

The H-SEIF 2 research project used most of the first year to define the case studies (*Current State*) and increase the understanding of the different case studies with their contexts. Proper definitions of case studies might be one of the main factors that lead to research project success, meaning executing within the allocated time. Thus, selecting and defining appropriate case studies in an industry-academic research context is essential. However, some evolution of the case study definitions is expected and necessary.

Finding synergies across the case studies is one of the primary needs within research to increase the finding's verification and validation. Analyzing the case studies to investigate synergies between them and their context had led to the further development of the pre-defined cases. Researchers have conducted several iterations during these evolutions internally and externally, i.e., researchers and key persons from the industry partners.

We characterize a well-defined case study when it has synergy with the other cases in the research project while also fulfilling the criteria mentioned in subsection 3.2 2a.

4.2 Emergent Practices and Dynamic Environments in industry and academic research context

Academia is more oriented towards research and observing as-is situations, whereas the industry is more oriented towards developing projects and maximizing profit. The industry is more immediate on design and solutions, while academia has to use more time on understanding, exploring, and verifying results. In other words, academia and industry have different interests, contexts, guidelines, and work practices.

The different perspectives from academia and industry resulted in chaos regarding performing the project activities at H-SEIF 2 level. Fig. 9 depicts this chaos of conducting these activities as the light grey arrows indicate. However, each project activity itself went as the bold blue arrows indicate. Also, Fig. 9 shows how the researchers approach performing the different phases and steps in section 3, and it includes the following steps:

1. *Design.* Design of the different project activities within H-SEIF 2.
2. *Test.* Researchers test the design of the different activities within the previous step. This test included feedback and comments from the industry partners and project management. For instance, the participants give feedback after executing the workshop. Additionally, the researchers ask the participants to suggest topics for further workshops.
3. *Observe*. The researchers observe the activities and take notes.

4. *Analyze*. The researchers analyze the activities and establish notes, discussion, and brainstorming. For instance, the researchers conducted a ZIP analysis for the project activities. Z stands for zoom, I stands for innovation, and P stands for problem [20].

We think that all research methodologies and their models describe what we should do within a real-world context. However, the real world is never as simplistic as in theory. The research methodologies mentioned in the literature section highlight the importance of iterations, which we observed being done in H-SEIF 2. Thought, the iterations are not always practiced as a rigid sequential loop. Sometimes it is messy and jumps between the research activities back and forth in an unorganized fashion, as shown in Fig. 9. These processes and activities lead to emergent practices.

Emergent practice results from social interactions, individual capabilities, various needs, and practices between industry and academia. Additionally, we had dynamically changing environments, such as change of project prioritization and key employees moving to other positions.

Therefore, we define H-SEIF 2 to be in a complex context. The research needs individuals with different backgrounds to develop tools, processes, or methodology to reach the project objectives within such a context. Including different researchers with different backgrounds in such a context is brilliant and has already given promising milestones to achieve the project objectives. However, we believe that we started within the *complicated* context regarding the Cynefin framework. This complicated context occurred within the first phase under section 3, also 3.1 - *Organizing and Planning* the research Plan. Further, we tried to push towards *simple* in some phases and steps to apply best practices. Then from *simple* to *complex,* further to *chaos* context, and back to the *complex*. One of the key drivers for this push between the different contexts was a lack of resources. Later, we got extra resources which pushed us back to a *complex* context. Within this context, the momentum is highly dependent on the key persons within the research project and their dynamics.

4.3 Comparison of research methodologies

Table 1 shows a comparison of the above research methodologies- IaL (Industry-as-laboratory), DRM (Design Research Methodology), CSR (Case Study Reached), and DSM (Design Science Research methodology). We compare these research methodologies regarding the following criteria: *Abstract level*, *Specific focus*, and O*verall goal*.

Table 1. Comparison of Research Methodologies.

Research Methodology	Industry-as-Laboratory	Design Research Methodology (DRM)	Case Study Research (CSR)	Design Science Research Methodology (DSM)
Abstract level	Meta²	Meta³	Meta²	Meta²
Specific Focus	Action research with incremental understanding and exploring of the problem domain and solution domain	Whole research design, using at least two case studies	Case study design: define, select design, use theory in design.	Application environment and artifacts (tools)
Overall Goal	Connecting research: what, why with an application from industry: how to	Verification of research results using two case studies	Case study and its context and nature: embedded or holistic	Designing and developing artifacts (tools) to connect application domain and knowledge base

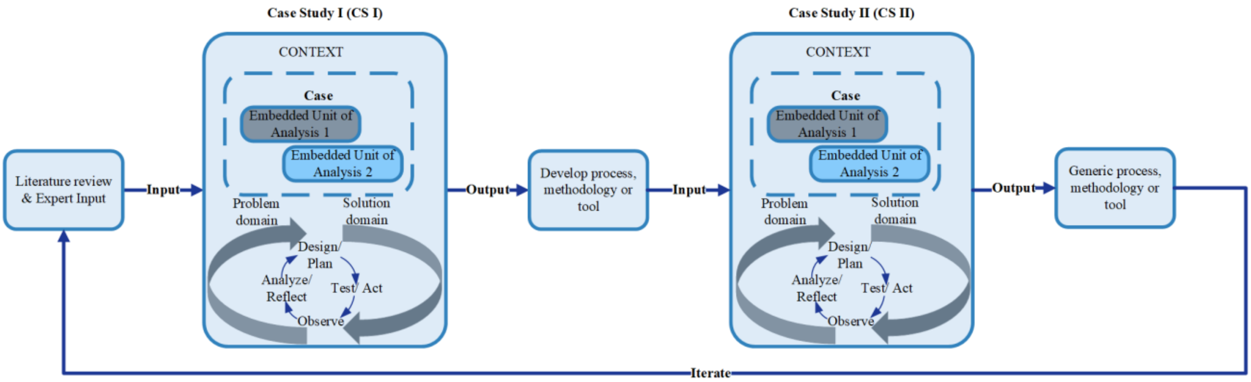

Fig. 11. PhD research methodology within H-SEIF2 research project

The *abstract level*, also known as the meta-direction, indicates the level of the worlds of the practitioners and researchers. Muller gives an example of different meta-levels, $Meta^0$- the bottom line for the product creation, $Meta^1$-enabling architecting method, $Meta^2$- proactive research of the architecting method, and $Meta^3$- scientific foundation-method to research architecting method [21]. We consider DSM, CSR and IaL as $Meta^2$-level research methodologies as we apply these methodologies for each case study. Where we conside DRM as $Meta^3$- level research methodology as we apply it for two case studies or more in parallel to identify synergies across case studies. The other two criteria are: *Specific focus*- the main specific focus for each research method, and *Overall Goal* is the generic emphasizing aim within each research method. We could also include more criteria such as commonalities as we realized that the mentioned research methodologies emphasize the problem's well-definition or the case study. However, we believe that we included the most relevant criteria related to our research's context.

4.4 PhD research methodology within H-SEIF 2 research project

The first two authors of this paper are PhD research fellows. For these authors, it is essential to follow a research methodology for their PhD. Each author focuses on two case studies from the nine industry partners. Fig. 11 shows our planned research methodology further inspired by the mentioned research methodologies in section 2.

We start with a literature review and expert input. The literature review focuses on the main and secondary research questions for the PhD and one case study. The results from both literature review and expert input are input for a case study I. In Case study I (CS I), we conduct ST (Systems Thinking) and its tools to analyze and well-define the case study. The case study includes several embedded units of analysis. We apply several iterations from the problem domain to the solution domain, applying our planned adapted action research cycle: *Design/Plan, Test/Act, Observe and Analyze/ Reflect*. These iterations from the problem domain to the solution domain are inspired by the IaL (industry-as-laboratory) research method. Since we investigate sociotechnical systems within our research, we need to adapt both our research's technical and social aspects. We cover the technical aspects by *Design, Test, Observe and Analyze*. Where we cover the social aspects by *Act* and *Reflect.*

Further, we develop a process, methodology, or tool (output) based on these iterations. We apply this output to a similar case study with joint embedded unit analysis in CS II with CS I. Using this joint unit analysis to CS II is inspired by the DRM (Design Research Methodology) research method. We apply our approach again: *Design/Plan, Test/Act, Observe and Analyze/Reflect* as we did to Case study I. We aim in this stage to come up with a generic process, methodology, or tool that applies to similar emended unit analyses for different case studies. However, we pay attention to the context within each case study. This context and its boundary included embedded unit analysis is inspired by CSR (Case Study Research) method. After developing a generic process, methodology or tool, we iterate the whole process again until we verify and validate the results. We perform these iterations within several time boxing and several development abstract level of artifacts (tools, prototypes, process, or methodology). We may also include more than two case studies if we get enough resources in terms of the case definitions scope and time for doing PhD within the planned project time execution. The development of artifacts (tool, process, or methodology) is inspired by

DSM (Design Science Research Methodology). We believe that we included the most relevant and essential aspects from the different research methodologies into our PhD research methodology. These aspects result from conducting our analysis to H-SEIF2 cross studies, alongside with more in-depth analysis to one case study. Additionally, to understand and realize our research's context as we executed the first year of the research project.

5. Conclusions

This study has tried to identify which research methodologies can be applied to complex industry-academia research to reach its research objectives and goals. The paper shows a one-year retrospective view of a sociotechnical research project, H-SEIF 2, that operates in a complex industry-academic context. We evaluated the H-SEIF 2 practices to the primary research methodologies of similar research.

The most used sociotechnical research methodologies appropriate for industry-academic collaboration, focusing on SE (Systems Engineering), seem to be: IaL (Industry as Laboratory), DRM (Design Research Methodology), CSR (Case Study Research Methodology), and DSM (Design Science Research Methodology).

These research methodologies were applied and adapted to the H-SEIF 2 research project. Applying these methodologies resulted in the following findings:

(1) *Importance of Well-Defined Case Studies.* Criteria for a well-defined case study: expressing a well-defined problem definition for the case study and validating it with the company, the case study should be part of an ongoing project that the company prioritizes and have enough resources, the case study should be aligned with the overall research project objectives. Additionally, it is essential to think of synergies between the case studies when defining each case study for itself.

(2) Emergent Practices and Dynamic Environments in industry and academic research context. The dynamic environment of the research project is a result of that academia and industry have different contexts, interests, and work practices. The different perspectives from academia and industry resulted in deviation regarding performing the project activities at the research project level. While the controlled case environment and activities are performed according to the technical iteration process of *design, test, observe,* and *analyze*. We believe that this deviation is a result of the naturally dynamic environment of the project. We also observe that we plan to follow a specific research methodology in theory. However, we may deviate from the research methodology in the real world.

(3) Comparison of research methodologies
We compared the applied research methodologies briefly. However, we may need to compare them in more detail.

(4) PhD (H-SEIF 2) research methodology
We came up with our PhD research methodology as part of the H-SEIF 2 research methodology based on the mentioned applied research methods that we plan to adapt further. We emphasize that this methodology is a living research methodology, which can be evolved and updated.

Our recommendation is to investigate suitable research methodologies early within research. However, be aware that the steps might not be followed as stated in theory, thus be creative, flexible, and adaptive. We suggest using the Applied Research Framework to define and investigate the suitable research methodologies for a research project.

In future research, we will be conducting the next development cycles of the research project and evaluating the overall research and its sub-research activities. We also aim to compare the different research methodologies in more depth and compare them to the H-SEIF 2 research project activities. This comparison can result in lessons learned for similar research projects.

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